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Special Feature: Under the microscope

Canadian Defence Research into the Effect of Coatings on the Integrity of Nickel Aluminum Bronze (NAB)

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Canada

MOTHER CANADA
REMEMBERING THE SACRIFICE
OF CANADIANS, 1914-1918

Canadians from all walks of life answered the call in the First World War

A century ago, at the 11th hour of the 11th day of the 11th month in 1918, the ironically labelled "War to End All Wars" was over.

When the grim tally was taken after hostilities ceased, the First World War had resulted in more than 40 million casualties – including about 20 million deaths. Roughly half the deaths were military personnel, the rest civilians who were at the wrong place at the wrong time in history.

Roughly 620,000 Canadians enlisted with the Canadian Expeditionary Force (CEF) during the war. Of these men and women, close to 60,000 died in action. The fledgling Royal Canadian Navy (RCN) – created just four years before the outbreak of the war – reported 150 deaths from all causes. No accurate record exists for Canadians who volunteered for service in the Royal Navy or British Army. Some 1400 Canadians died while serving with the British Flying Services.

Of the 172,000 Canadians wounded in "The Great War," many returned home broken in body and spirit. The small British colony of Newfoundland sustained about 1300 killed and several thousand wounded. And, of course, millions of Canadians played their part by keeping the home fires burning.

— Tom Douglas

Inset image reproduced with the kind permission of: Lieutenant Commander Norman Wilkinson , O.B.E., Canada's Answer, CWM 19710261-0791, Beaverbrook Collection of War Art, Canadian War Museum.

Photo courtesy The Vimy Foundation

Director General
Maritime Equipment Program Management

Commodore
Christopher Earl, CD

Maritime Engineering Journal

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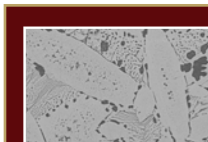

Scanning electron microscope image of nickel aluminum bronze. Special feature begins on page 5.

(Photo courtesy Defence Research and Development Canada (DRDC) Atlantic.)

Current and past issues of the *Journal* are available online at the website of the Canadian Naval Technical History Association – www.cntha.ca

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COMMODORE'S CORNER

"It's a marathon, not a sprint"

By Commodore Christopher Earl, CD

As I have progressed through my career there have been various highlights that, at the time, seemed relatively insignificant. At some point – sometimes years later – they became poignant memories that form the essence of who I am. We all have these experiences that define us as individuals, our recollections of service to the nation that ultimately allow each of us to contribute a degree of wisdom and knowledge to the daily working of the Royal Canadian Navy (RCN).

While the recollections among all of us may take different shapes and forms, the Naval Technical branch is truly blessed with a cohort of several thousand men and women whose job it is to solve problems, find innovative solutions, and move acquisition and sustainment projects forward so that the RCN remains Ready to Help, Ready to Lead, and Ready to Fight. When you consider that *Harry DeWolf*, our first Arctic and Offshore Patrol Ship, was launched in September and will enter service next year; that steel was cut on the new Joint Support Ship in June; that the MV *Asterix* is now available and providing important support to deployed Canadian naval units; and that a preferred bidder for the Canadian Surface Combatant design has been announced, the future looks bright indeed.

As if that weren't enough, our branch continues to support and modernize numerous marine systems in the *Halifax*-class frigates, even as we embark on an ambitious and important *Victoria*-class modernization project, and continues to support the aging maritime coastal defence vessels. Every day, we ensure that everything else our navy needs to function (i.e. small boats, auxiliaries, weapons, radars, oily water separators, and so on) is safe, reliable, and readily available. When you stand back and look at the enormity of what is being accomplished, it is truly impressive – and the professionalism and commitment of our branch to 'get it done' is absolutely outstanding. No matter what role you play, your efforts toward our overall success are important.

The volume of our task can at times be all-consuming, and from personal experience I fully appreciate that there are times when the pile of work seems to consistently grow, rather than diminish. There always seems to be more to be done, and if we aren't careful about how we manage the workload, our professional development and personal lives can suffer at the expense of fleet readiness – which brings me full circle to those highlights and memories I was speaking about.

Photo by OS A. Proulx, Canadian Forces Support Unit (Ottawa), Imaging Services

Mr. Patrick Finn, Assistant Deputy Minister (Materiel), presided over the change of appointment ceremony on June 1, 2018 as Commodore Simon Page (left) turned over the DGMEPM position to incoming Commodore Christopher Earl (right).

About a decade ago, RAdm (Ret'd) Richard Greenwood – who was a commodore serving as DGMEPM at the time – made a comment that seems so pertinent today. He reminded me that success is measured by our branch's ability to continuously move issues and challenges forward, but warned that once we resolved one item, there would always be another to take its place. Naval technical work is all about maintaining momentum and pace, he said, and since it is people who ultimately preserve that momentum, it is worth bearing in mind that, "It's a marathon, not a sprint."

RAdm Greenwood's words of wisdom have stuck with me to this day, and when all is said and done, my ask of each of you in turn is simple: Take care of yourself, take care of your family, enjoy your work, and continue to provide your exceptional level of support to our navy going forward.

FORUM

Communitech Innovation Base Camp

By A/SLt Abbigail Cowbrough

From July 9 to 13, 17 members of the Royal Canadian Navy consisting of Naval Technical Officers (NTOs) from acting sub-lieutenant to commander, and non-commissioned members (NCMs) in the Marine Technician and Weapons Engineering Technician occupations from leading seaman to chief petty officer second class, participated in a Communitech Innovation Base Camp in Kitchener-Waterloo, Ontario at the invitation of the Royal Canadian Air Force Aerospace Warfare Centre. Communitech is an organization that helps companies learn methods, build tools, and create a mindset that allows them to validate opportunities for innovation.

The impetus for the Communitech base camp was a Unit Morale Profile survey conducted for the Naval Technical Officer (NTO) occupations in late 2017, which identified a number of issues impacting the job satisfaction of NTOs. Chief among these issues was a concern expressed by seagoing heads of departments (HODs) about the heavy workloads, which has ramifications not only for the HODs, but the entire seagoing engineering department. The Naval Engineering Council was briefed on these results in May 2018, and directed that HOD workload concerns be examined in more detail. The Communitech base camp was then identified as an innovative means to carry out this task.

The first three days of the camp focused on the problem of *why* HODs are overworked, and once root causes were identified, phone calls were made to 15 different HODs, both current and past, across Canada. The HODs validated or invalidated all identified root causes, and were very enthusiastic about the work that was being conducted.

The process of understanding the root causes of HOD concerns involved hundreds of sticky notes and ideas, both good and bad. The team focused on three main issues that affect seagoing HODs; namely: lack of work-life balance which was partly attributed to gaps in the training system and sometimes unrealistic job expectations; lack of time to meet diverse training requirements; and a reduced level of technical readiness in some platforms caused by a shortage of experienced personnel, lack of spare parts, and insufficient competence in working with the Defence Resource Management Information System (DRMIS).

Multiple tactics were used by the two Communitech coordinators to guide the team in reaching these three root causes, focusing first on broad ideas that were narrowed down as our time at the base camp concluded. We created long time lines that represented an NTO's life from Phase VI trainee to HOD, noting the minute tasks that are required of a HOD while preparing for and during their HOD tour.

A group of RCN officers and NCMs participate in one of the exercises to determine root causes of the problem of overwork faced by heads of department at sea.

Capt(N) Sheppard being briefed by LS Cheryl Gouthro and team.

Generally, HODs spend much of their time teaching or mentoring their AHOD and Phase VI trainees, with one HOD stating they had conducted 35 qualification boards in two years. A single board or practice board for the final qualification board can take up to four hours. The overall workload comes down to the time spent on training, and to the tasks that cannot be delegated. As a result, the HODs are working an average 16 to 18 hours a day at sea, and 10 to 12 hours a day when the ship is alongside. The HODs who said they did not feel overwhelmed said they had "great divisional support," with "NCMs and AHODs who were capable at their jobs."

On day four of the base camp, three solutions were theorized. The first solution consists of having people complete their Phase VI and AHOD training packages prior to joining a ship so that their time at sea can be better utilized consolidating the qualification and gaining actual work experience. A reduced training workload would alleviate stress for the HOD, and allow more delegation of tasks. The second solution consists of developing a shore team to assist the departments on workflow management. The third, to have a HOD mentorship program that would allow HODs to converse with more senior members. Each solution was presented to a different HOD who expressed feedback on its viability in the fleet.

Two of the most important lessons we learned were: "failure is learning," and "run with a prototype." Failure allows us to invalidate ideas and solutions that do not positively impact the problem. This process ensures we move forward and focus time and resources on real solutions. One way to validate an idea is to present a prototype solution to the customer, the HODs. This allows feedback from the customer to explore the impact of the proposed solution. In terms of prototypes, create a simple top-level solution and see how to implement it. It may or may not work, but it is better to have an idea of its implementation earlier on in the process than to have a finished product that does not solve the problem. It was much more beneficial for the group to create a solution and present it to the HODs and receive feedback in the same week, than to wait months for their comments.

On the final day, MEPM Chief of Staff Capt(N) Mark Sheppard visited us from Ottawa and was briefed on the work we had done at Communitech. After having recently completed an innovation workshop himself, he was familiar with, and very open-minded to the innovation techniques that Communitech had taught everyone.

Communitech was a great experience and provided an open and welcoming space for naval personnel of all ranks. Having a mix of junior and senior officers and NCMs brought forth a wide range of ideas and insights that would not have otherwise been explored. It was a full week of learning across all ranks that facilitated two immediate improvements. The first was a decision implemented on both coasts to permit designated shore-based HOD-qualified officers to assist their seagoing colleagues by signing-off on the OJPR requirements of trainees. The second was an agreement to reduce reporting requirements for shipborne HODs by eliminating the requirement for the Periodic Engineering Letter – formal direction of this decision will be promulgated shortly.

A second workshop was recently conducted at Communitech to further refine options that had been identified in the first workshop. The results of this work will be presented this fall to the Naval Engineering Council, which is committed to facilitating the resolution of issues raised in relation to HOD workload.

The NTO HOD job at sea always has been, and always will be demanding. The Communitech work has allowed for a validated understanding of where the demands are too high and what can be done to reduce those demands while still providing world-class naval warfare engineering on operations. The naval technical branch is fully committed to better understanding the HOD workload issue and will not hesitate to take decisive action to ensure that the experience is a rewarding and pivotal career point for all.

A/SLt Abbigail Cowbrough (front centre in the group photo on page 3) is a Marine Systems Engineer graduate of the Royal Military College of Canada, and is working for the Fleet Technical Authority at Fleet Maintenance Facility Cape Scott in Halifax while awaiting the start of her applications training. Currently, she is progressing initiatives for NTO retention and credibility, and was one of the members that attended the innovation lab at Communitech.

SPECIAL FEATURE

Canadian Defence Research into the Effect of Coatings on the Integrity of Nickel Aluminum Bronze (NAB)

Editorial introduction: Thanks to its excellent corrosion-resistant properties, nickel aluminum bronze is used in a number of marine applications, notably ships' propellers. However, depending on whether cathodic protection is operating or not, NAB responds in interesting ways when surfaced with a coating of epoxy or an antifouling compound to reduce biofouling.

Despite having her research into these effects cut short by the closure last March of Dockyard Laboratory Pacific (DLP) – an Esquimalt-based adjunct of Defence Research and Development Canada (DRDC) Atlantic – Defence Scientist **Trisha Huber** was able to draw certain conclusions that should be of great interest to naval engineers and materials scientists everywhere. The *Maritime Engineering Journal* is extremely pleased to be able to present this summary of Dr. Huber's findings.

Part 1: The Effect of Coatings on NAB[1]

By Trisha Huber, Brad Noren, Vincent Drover and Heather Smiley

Nickel aluminum bronze (NAB) exhibits excellent corrosion resistance and is used for many marine components, including propellers. When NAB is cathodically protected, biofouling of NAB can be significant (Figure 1),[2] although coating NAB can help to mitigate this issue. Recent studies on the effect of the coating on NAB have been performed at the Dockyard Lab Pacific, at CFB Esquimalt. In the absence of cathodic protection, NAB is known to undergo crevice corrosion.[3] While propellers are usually cathodically protected, there may be instances of inadequate cathodic protection (i.e. cathodic protection system turned off, or water ingress under a coating[4]). The studies summarized here focus on the progression of crevice corrosion under a coating in the absence of cathodic protection.

Specimens of NAB were coated with either marine epoxy (primer of permanent coating system) or copper-ablative antifouling (temporary coating) – Figure 2 – followed by immersion in seawater for 18 months. Cross-sections of the specimens were cut and examined periodically (three, six, 12, and 18 months) for the onset of crevice corrosion.

Photo credit: S. McLaughlin, DRDC – Atlantic Research Centre.

Figure 1. A fouled propeller of a vessel that sat alongside for 18 months in Victoria, BC. The extensive biofouling required removal by mechanical means, increasing the risk of propeller damage.

1. This work was originally presented in a DRDC Scientific Report (DRDC-RDDC-2018-R154) in August 2018.
2. When cathodically protected, the natural biofouling resistance is suppressed, thus the NAB is sometimes coated to mitigate marine biofouling.
3. Crevice corrosion can occur wherever an area of the substrate is covered by another material (crevice-former) and a thin film of liquid exists between the substrate and the material. The crevice former can be a coating, biofouling, or other material, including calcareous deposits, which are formed by the precipitation of calcium carbonate and magnesium hydroxide in seawater under alkaline conditions; the alkaline conditions are created by hydroxide production resulting from cathodic protection.
4. Cursory modelling performed at Defence Science and Technology Group (DSTG), Australia, indicates that the protective potential diminishes under a disbonded coating, resulting in areas which may be inadequately cathodically protected.

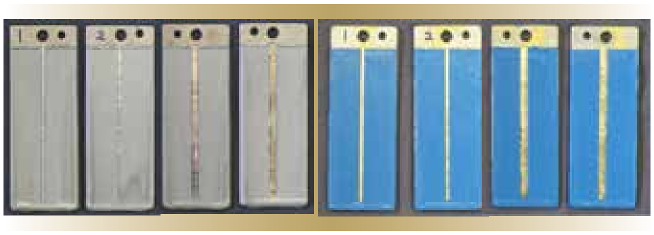


Figure 2. Front and back of epoxy-coated (left) and antifouling-coated (right) specimens after an intentional defect had been milled on both sides, and prior to immersion.

Figure 3. Note the rough surface of the epoxy specimen (left) resulting from the grit blasting, in contrast to the smooth surface of the antifouling specimen (right). Scale bars are 50 µm.

Figure 4. Epoxy (top L/R) and antifouling (bottom) specimens exhibiting evidence of tarnishing as well as blue-green copper-based and red-brown iron-based corrosion products.

Examination of the cross-sections of the epoxy-coated specimens revealed some damage due to the surface preparation of the NAB; whereas, the antifouling-coated specimens that were given minimal surface preparation remained undamaged, and still quite smooth. (Figure 3).

After three months of immersion, blue-green copper-based and red-brown iron-based corrosion products were observed (Figure 4). After 18 months of immersion, the epoxy-coated specimens exhibited significant blistering, indicating water ingress (Figure 5).

A major difference in undercutting (corrosion under the coating) was observed between the antifouling-coated specimens, and the epoxy-coated specimens. The epoxy-coated specimens exhibited substantial undercutting, and more advanced crevice corrosion,[5] whereas the antifouling-coated specimens demonstrated very little undercutting, and very slight crevice corrosion.

Crevice corrosion is difficult to detect at its outset, so the epoxy-coated specimens were etched with silver nitrate to emphasize early signs of this process. After etching, corrosion-containing areas appear a bit chewed up, as shown in Figure 6. The extent of corrosion under the coating was measured for all epoxy-coated specimens, and reported as a function of crevice location, as labelled in Figure 7. From the Table 1 summary of the measured extent of corrosion for each specimen, by crevice location and time of immersion, it is clear that the extent of corrosion varies significantly across all four crevice locations. While the rate of crevice corrosion depends on many factors, including crevice geometry, it is apparent that once crevice corrosion begins, it can proceed at a rate of approximately one cm per year under the epoxy.[6]

The main take-home message from these studies is that NAB immersed in seawater should not be coated with a barrier coating (marine epoxy) if cathodic protection will not be employed. If biofouling mitigation is important in the absence of cathodic protection, then a temporary coating of copper-ablative antifouling will serve the purpose well.

5. Crevice corrosion in NAB is selective phase corrosion (SPC) where initially one phase of the NAB (alpha) undergoes corrosion, but later, within the crevice, the conditions change such that different phases undergo corrosion, and the initial corroded phase no longer corrodes.
6. The progression of crevice corrosion was noted on epoxy-coated specimens that were not cathodically protected. No crevice corrosion was noted on specimens that were cathodically protected, although the intent of the experiment was to monitor the specimens for 5 years. Closure of the Dockyard Lab concluded the experiments prematurely.

Acknowledgements

The authors gratefully acknowledge helpful discussions and technical support from Yueping Wang, Kumar Sadayappan (Natural Resources Canada (NRCan)), Wayne Neil and Kate Dylejko (Defence Science and Technology Group (DSTG)), Chris Bayley, Joel Higgins, and Alexandra McLeod.

References

1. I. Richardson, Guide to Nickel Aluminum Bronze for Engineers, Copper Development Association Publication No. 222, ed. C. Powell, January 2016.
2. J.A. Wharton, R.C. Barik, G. Kear, R.J.K. Wood, K.R. Stokes, F.C. Walsh, "The corrosion of nickel-aluminum bronze in seawater", Corrosion Science 47 (2005) 3336-3367.
3. J.A. Wharton and K.R. Stokes, "The influence of nickel-aluminum bronze microstructure and crevice solution on the initiation of crevice corrosion", Electrochimica Acta, 2008, 53, 2463-2473.
4. T.A. Huber and Y. Wang, "The Effect of Propeller Coating on Cathodic Protection Current Demand: Sea Trial and Modelling Studies", Corrosion, 2012, 68, 441-448.
5. Procedures for First Level Nickel Aluminium Bronze Castings, Ministry of Defence Standard 02-872 Part 3 Revalidation, Issue 1, 2Dec2002, Section 3 Etching and Examination for Corrosion, p. 14.

Figure 5. Epoxy specimens after 18 months of immersion, showing significant blistering at numerous locations.

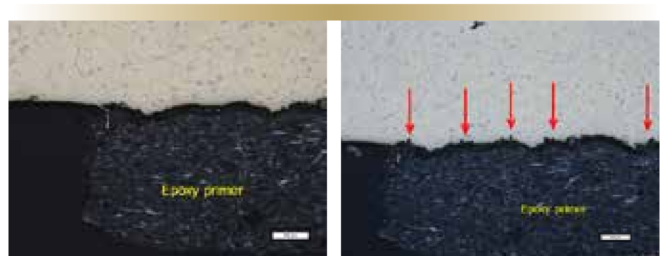


Figure 6. Crevice location 1c after three months of immersion: Photo at right shows the effect of etching with silver nitrate in emphasizing areas exhibiting crevice corrosion (red arrows). Scale bars are 50 μm.

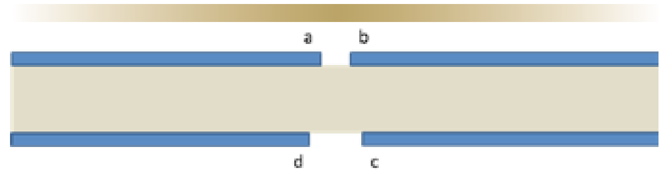


Figure 7. Diagram showing labelled crevices.

Table 1: Extent of Crevice Corrosion for Epoxy Specimens, by Crevice Location

SPECIMEN	MEASURE OF UNDERCUTTING (IN MM)			
	a	b	c	d
3-MONTH EPOXY – 1	0	0	2.5	0
3-MONTH EPOXY – 2	0	0	2.75	0
6-MONTH EPOXY – 1	5.3	0	7.3	0
6-MONTH EPOXY – 2	0	0	6.8	0
12-MONTH EPOXY – 1	6	11.5	> 6.2[1]	5.1
12-MONTH EPOXY – 2	0	0	10.9	0
18-MONTH EPOXY – 1	0	> 12.1[1]	5.7	14.8
18-MONTH EPOXY – 2	0	0	13.5[2]	0

[1] Beyond this depth, the coating was missing, thus undercutting extended farther than measured.
[2] The specimen had been cut for mounting, and the undercutting was right to the edge, thus actually extended farther than measured.

Part 2: Mitigating Propeller Biofouling with a Temporary Antifouling Coating

By Trisha Huber, Brad Noren, Vincent Drover and Heather Smiley

Abstract

The effect of copper-ablative antifouling on cathodically-protected nickel aluminum bronze (NAB) coated specimens was investigated. Specimens were immersed for 18 months in low-flowing seawater, under cathodic protection, and assessed periodically (at three, six, 12, and 18 months); the assessment included the removal of a small cross-section for microscopic examination. Changes in the coating itself, as well as the surfaces of the NAB were monitored as a function of time. The onset of copper conversion was noted by the three-month mark, and continued to increase with time. Furthermore, electrodeposition of copper, originating from the coating, onto exposed NAB was also noted by the 18-month mark.

Introduction

Nickel aluminum bronze, commonly used for propellers, is a complex copper-based alloy typically containing 6-13% aluminum (Al), up to 7% iron (Fe) and 7% nickel (Ni), and up to 1.5% manganese (Mn), by weight [1]. The Al, Fe, and Ni improve the strength and corrosion resistance, and the Mn enhances strength and imparts oxidation resistance [1, 2]. The alloying elements are not uniformly distributed through the copper base, but exist in varying quantities within different phases of the microstructure. The microstructure can be controlled, to a degree, through composition, fabrication conditions (temperature), and subsequent heat treatment [1]. The prevalence and distribution of each phase has a significant impact on the overall properties of the alloy.

Figure 1 shows a scanning electron microscope image of NAB, denoting the various phases. The α-phase is comprised mostly of copper and aluminum, and appears light in colour. The intermetallic κ-phases are rich in Ni, Al, and Fe, and appear darker. The κ_{I} - phase is typically large irregular-shaped globules, and the κ_{II} - phase is typically the smaller irregular-shaped globules, or rosettes. The κ_{III} – phase exists as lamellar-shaped, or globular (degraded lamellar) precipitates in the eutectoid region, and the κ_{IV} – phase exists as small particles distributed throughout the α-phase [1, 2].

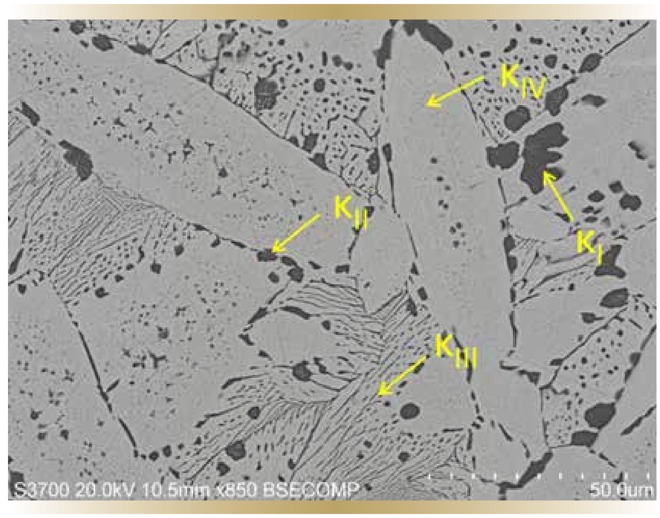


Figure 1. Scanning electron microscope image of NAB showing the Cu-rich a phase and the different intermetallic κ-phases, denoted by yellow arrows.

Corrosion of NAB

Although NAB exhibits high resistance to general corrosion, attributable to the formation of a duplex oxide film (comprised of copper (I) oxide (Cu_2O) and alumina (Al_2O_3)), it is susceptible to pitting, galvanic corrosion, and crevice corrosion [1]. Corrosion of NAB can be mitigated through cathodic protection (CP). NAB propellers that are electrically connected to the ship's hull, via shaft grounding systems, should be protected by the ship's CP system (either sacrificial anodes, or an impressed current cathodic protection (ICCP) system). In the absence of a CP system, inadvertent propeller protection may also occur via galvanic coupling to the steel hull, to the detriment of the hull.

Propeller Biofouling Mitigation

Although NAB exhibits resistance to biofouling as a result of the formation of copper ions created by slow dissolution of NAB in seawater [1], suppression of the formation of copper ions, via cathodic protection, diminishes NAB's natural biofouling resistance. This is a serious issue for vessels which sit alongside for extended periods of time. Figure 1 of Part 1 shows a propeller from a naval vessel that sat alongside for 18 months. The biofouling is significant and covers all surfaces of the propeller. Mechanical means was necessary to remove the biofouling, ultimately risking damage to the propeller.

In order to mitigate biofouling on vessels destined to sit alongside for extended periods, the propellers can be coated, either with a permanent coating system or a temporary antifouling coating. The intent of the permanent coating would be to provide biofouling mitigation, drag reduction, and optimize the hull potential [3], for the life of the propellers (or at least until the next docking work period). The intent of the temporary coating would be to provide biofouling mitigation until the ship is in active service, at which point the coating will slowly wear away when the ship becomes more active.

Here we report highlights of observations noted during an experiment in which cathodically-protected antifouling-coated NAB specimens were immersed in seawater for 18 months. Periodic assessment was performed at three, six, 12, and 18 months of immersion, and involved photographing, as well sectioning the specimens for microscopic examination.

Experimental

Specimens of NAB machined from an old propeller were cut into small rectangular pieces, approximately 4” long x 1.5” wide x 1/8” thick (i.e. 10 x 3.8 x .3 cm). Elemental analysis of the cast NAB, determined by inductively coupled plasma-mass spectrometry (ICP-MS) identified the NAB to be UNS C95800: 9.6% aluminum, 4.9% nickel, 4.5% iron, 1.7% manganese, and the remainder copper.

Surface preparation comprised abrasion by hand with 400-grit emery paper, intended to roughen up the surface for enhanced adhesion, but not significantly alter the NAB surface profile. After an ethanol wipe, the copper-ablative antifouling coating was applied by brush, in two coats, yielding a dry film thickness (DFT) of approximately 250 μm. The coating contained up to 50% by weight copper (I) oxide, and up to 10% by weight copper (II) oxide. Once the coating had fully dried, an intentional breach in the coating was introduced by milling a lengthwise slot on each side of the specimen, completely through to the NAB surface. On one side, arbitrarily designated the front, the slot was 2 mm wide, whereas the slot was 5 mm wide on the back (Figure 2).

Figure 2. Front (left) and back (right) of antifouling-coated specimens after intentional defects had been milled on both sides: 2mm on front, and 5 mm on back.

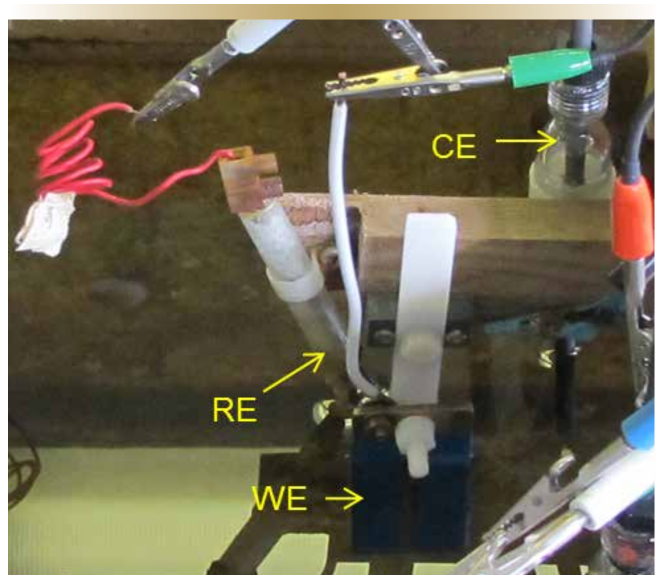


Figure 3. Close-up of an immersed specimen, showing relative location of specimen (working electrode, WE), reference electrode (RE), and graphite counter electrode (CE).

The specimens were immersed in seawater (pumped from a small bay near Esquimalt Harbour) and connected to a Gamry Reference 600 potentiostat, operated in potentiostatic mode (-850 mV vs. Ag/AgCl), with a graphite counter electrode, and an Ag/AgCl reference electrode (Figure 3). For much of the 18 months, the seawater within the system was flowing; however, for maintenance periods (approximately one week out of every month), the system was not flowing. During these periods, the seawater was aerated to ensure that the conditions were not completely stagnant.

The specimens were removed from the seawater at three, six, 12, and 18 months of immersion for visual examination, and for removal of a small cross-sectional piece from the bottom of each specimen for microscopic examination using an Olympus GX71 Inverted Metallurgical Microscope. Samples sectioned from the specimens were mounted in cold mount epoxy and polished to 0.05 microns (μm) with alumina paste and cloth media. The cut edge of each parent specimen was repaired with epoxy coating and re-immersed in the seawater tank.

Results and Discussion

These experiments were designed to replicate conditions in which cathodically-protected propellers are temporarily coated with an antifouling coating. The copper-ablative antifouling is a controlled depletion polymer containing a significant quantity of copper oxides (25-50% by weight copper (I) oxide and 1.0-10% copper (II) oxide) which function as the biocide. Seawater ingress results in dissolution of the copper oxide, causing slow release of copper ions from the surface of the coating. With time, the outermost region of the coating becomes depleted in biocide – this is known as the leached layer. While alongside, the leached layer increases in thickness, impeding the diffusion of biocide to the surface. However, the coating matrix is designed to ablate as the ship moves, essentially rejuvenating the coating, and allowing biocide to be released again.

Figure 4 shows the protected specimens after 18 months of immersion. Although the exposed NAB would be expected to maintain a bright, shiny appearance, consistent with being cathodically protected, the specimens exhibited darkening at exposed NAB, which became progressively darker with time. A viable explanation of the NAB darkening with the antifouling specimens is that the leached biocidal copper ions undergo electrodeposition onto the exposed NAB regions. This phenomenon has been observed previously,[1] when antifouling-coated NAB was immersed in a large beaker of seawater and cathodically protected; copper was observed on the surface of the NAB, and did not arise from selective phase corrosion (SPC).

Copper Conversion and Electrodeposition

Under conditions of cathodic protection, copper oxide in electrical contact with the substrate can be reduced to metallic copper. This process is known as copper conversion and was first noted on ships' hulls in the 1960s [4]. Copper conversion can arise when the copper oxide-containing antifouling coating is not electrically isolated from the cathodically protected hull, such as when the primer is too thin or contains voids, or when the antifouling is applied directly to the cathodically protected substrate.

Figure 4. Front (left) and back (right) of cathodically-protected antifouling specimens after 18 months.

This phenomenon was noted in these experiments as early as the three-month mark, and the degree of copper conversion was found to roughly increase as a function of time (Figure 5). These regions are either adjacent to the score line, or at the edge of the specimen where the coating is thinner.

In addition to copper conversion within the coating, reduction of the leached biocidal copper ions onto the surface (electrodeposition) can also occur. This phenomenon was noted on protected antifouling specimens after 18 months of immersion (Figure 6). This process clearly modifies the surface of the substrate, and is likely detrimental to a propeller surface, as it could impact drag and noise.

Conclusions

The copper ablative antifouling coating was found to undergo copper conversion in thin areas, or those adjacent to a breach in the coating. In addition, the undesirable electrodeposition of copper onto the surface of the NAB was observed, increasing its roughness. This could presumably cause issues with drag and noise. The application of a copper-based antifouling coating could be a viable means of mitigating biofouling for a short period (less than 12 months), however, its long-term use on cathodically protected NAB is not recommended.

1. Unpublished results.

Acknowledgements

The authors gratefully acknowledge helpful discussions and technical support from Yueping Wang, Kumar Sadayappan (Natural Resources Canada (NRCan)), Wayne Neil and Kate Dylejko (Defence Science and Technology Group (DSTG)), Chris Bayley, Joel Higgins, and Alexandra McLeod.

About the Authors

Lead author **Trisha Huber** received her PhD in Chemistry from Queen's University in 1994, and has been employed within the Government of Canada's defence research community since 2001. As a Defence Scientist with DRDC, she has worked on various aspects of marine coatings, with recent focus on the incorporation of self-healing technologies into coatings (primarily above water) for the purpose of mitigating corrosion. Following the closure of Dockyard Laboratory Pacific in March, Dr. Huber began transitioning from being a materials scientist to an operational researcher with DRDC's Centre for Operational Research and Analysis, where she said she looks forward to continuing to support the Royal Canadian Navy (RCN).

Brad Noren is currently an environmental technologist with Fleet Maintenance Facility Cape Breton, but was working as a chemical technologist with Dockyard Laboratory Pacific during this study into the effects of coatings on NAB. Analytical chemist **Vincent Drover** and research technologist **Heather Smiley** from DRDC Atlantic in Halifax were brought in to assist with finishing up the experimental aspects of the study at DLP.

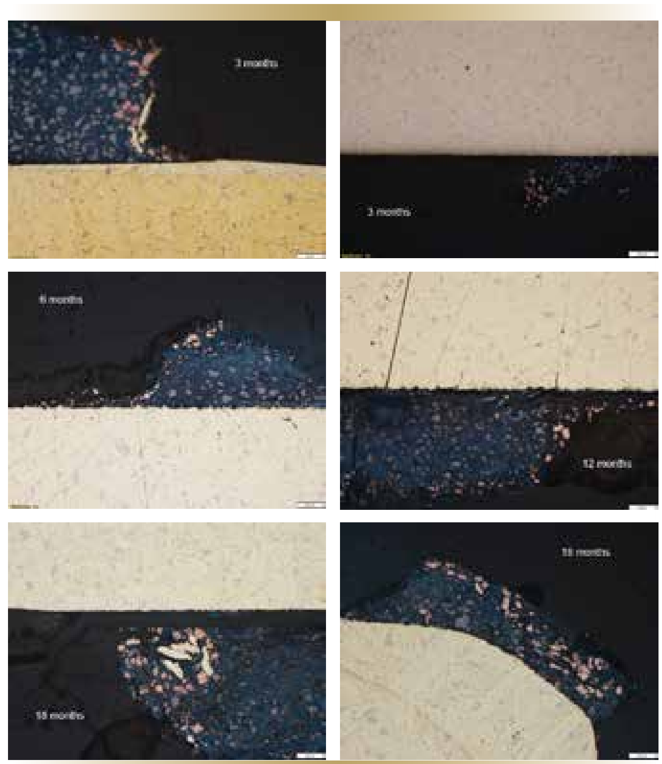


Figure 5. Images of protected antifouling-coated specimens showing evidence of copper conversion as early as three months, and roughly increasing in degree as a function of time (top – three months, middle – six and 12 months, lower – 18 months). Copper conversion refers to the process by which the copper oxide particles in the antifouling coating undergo reduction to metallic copper as a result of the cathodic protection current. Areas most susceptible to copper conversion are areas where the coating is very thin, such as at corners (lower right), and areas adjacent to a breach in the coating (all other images). Scale bars are 50 µm.

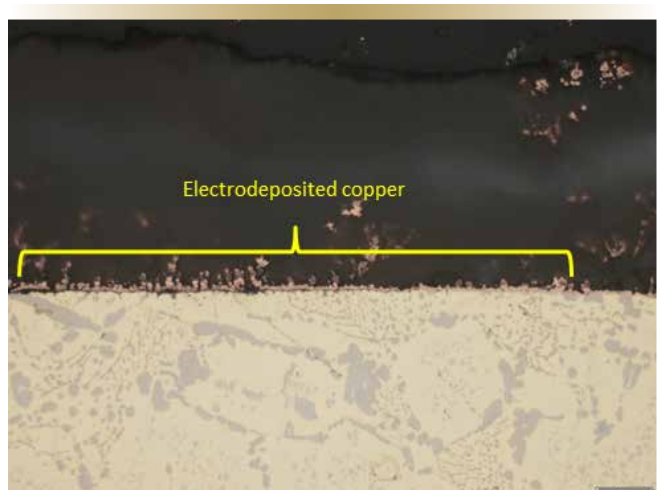


Figure 6. Copper deposition visible on exposed area of NAB after 18 months of immersion. Scale bar is 20 µm.

References

1. I. Richardson, Guide to Nickel Aluminum Bronze for Engineers, Copper Development Association Publication No. 222, ed. C. Powell, January 2016.
2. J.A. Wharton, R.C. Barik, G. Kear, R.J.K. Wood, K.R. Stokes, F.C. Walsh, "The corrosion of nickel-aluminum bronze in seawater", Corrosion Science 47 (2005) 3336-3367.
3. T.A. Huber and Y. Wang, "The Effect of Propeller Coating on Cathodic Protection Current Demand: Sea Trial and Modelling Studies", Corrosion, 2012, 68, 441-448.
4. W.A. Anderton, "Cathodic reduction of cuprous oxide in vinyl antifouling paints", J. Oil Col. Chem. Ass'n.

Materials Science Support to the Royal Canadian Navy

By Gary Fisher

For as long as people have used water-borne vessels, there has been a need for marine materials science. Whether that science is conducted by simple observation and trial-and-error, or by using modern sophisticated instrumentation, its purpose is to answer three basic questions:

- Are we using the right materials?
- How do we protect these materials from damage?
- How do we repair any damage to the materials?

The RCN has long recognized the need for materials science support. During the Second World War, for instance, the Navy employed scientists on the West Coast to support Pacific operations, which led to the establishment of the Defence Research Board (DRB) in 1947 to ensure the availability of defence science support to the Canadian Armed Forces during times of war and peace. The DRB – known today as Defence Research and Development Canada (DRDC) – established a number of centres across the country, including the Esquimalt-based Pacific Naval Laboratory (PNL) in 1948. This later became Defence Research Establishment Pacific (DREP) – forerunner to Dockyard Laboratory Pacific.

Materials science research was an early fixture of PNL operations, beginning with work into cathodic protection of vessel hulls in 1950. Through the years, defence materials research on the West Coast yielded a number of significant achievements, including:

- Elucidation of the underpinning science, and development of the basic design, of an impressed-current cathodic protection (ICCP) system that is still in use preventing hull corrosion on naval and commercial vessels around the world;

- Development of aluminum vinyl anti-corrosion paints that are resistant to delamination (or disbondment) effects caused by cathodic protection – instrumental in the adoption of ICCP;
- Introduction and development of radiography to assess vessel weld and hull integrity;
- Development, through component failure investigations, of a thorough understanding of metal failure and fracture. This led to DREP scientists publishing the text, "Why Metals Fail," which was a standard text in many Canadian university curricula for years; and
- Development of the Ferroscan™ to facilitate analysis of metallic debris worn from lubricated contacting metallic component surfaces.

With Canadian industry and academia taking on an increasing percentage of work involving marine materials science, the Department of National Defence decided in March of this year to close DRDC's Dockyard Laboratory Pacific, and consolidate all future projects through DRDC Atlantic in Halifax.

Gary Fisher is the Section Head of Dockyard Laboratory Pacific, a section of DRDC Atlantic located in Esquimalt, British Columbia.

Submissions to the *Journal*

The *Journal* welcomes unclassified submissions in English or French. To avoid duplication of effort and ensure suitability of subject matter, contributors are asked to first contact the production editor. Contact information may be found on page 1. Letters are always welcome, but only signed correspondence will be considered for publication.

FEATURE ARTICLE

Wideband Global SATCOM and its Integration into the Royal Canadian Navy

By Lt(N) Kevin Hunt

Images courtesy Harris Corporation except where noted.

Introduction

Canadian naval assets are now connecting to America's newest satellite communications constellation in order to meet strategic communications requirements. Installation of the satellite communications antenna on board ships throughout both the Atlantic and Pacific fleets is currently underway to increase redundancy of reliable, high-speed connectivity at sea. This article will outline the WGS system, its installation on board the *Iroquois*-class destroyer HMCS *Athabaskan* (paid off from RCN service in 2017) and its on-going integration into the remaining surface combatants and non-combatants.

Photo credit: RCN

WGS Background

The Wideband Global SATCOM (WGS) system is a military satellite communications network owned by the United States Department of Defense (US DoD). Its role is to provide worldwide users with 24-hour continuous high-speed cross-band (two-way X-band and Ka-band) satellite communication services. The satellite constellation was meant to raise the communication capacity of the US military, augmenting both the aging Defense Satellite Communications System (DSCS) and Global Broadcast System. This new SATCOM capability was eventually extended to its allies in exchange for the funding of system upgrades.

The contract for building the original three WGS satellites was awarded to Boeing Satellite Systems in January 2002, who began construction on their pre-existing BSS-702HP satellite platform. The contract covered the three satellites, the associated ground control, engineering support, and all necessary training. The first satellite, WGS-1, was launched in 2007 and became operational in April 2008. Launches of WGS-2 and WGS-3 both followed in 2009, and together with WGS-1, provided worldwide coverage. In 2012, the US DoD contracted Boeing to increase the system's bandwidth, thus initiating the process of constructing follow-on Block II satellite platforms which would include a number of upgrades. Satellites WGS-4 and onwards incorporated a radio frequency bypass capability for unmanned aerial vehicle connectivity, whose intelligence gathering and surveillance needs call for heightened data rates.

While just three equally-spaced satellites in geostationary orbit can provide worldwide coverage along the equator, seven additional Block II satellites would increase bandwidth and build redundancy into the network. At the time of this writing, the constellation consists of nine orbiting platforms, with Boeing on contract to deliver a tenth and final satellite in 2018.

Buying into WGS

In 2007, the Australian government funded the construction of both the constellation's sixth satellite and the accompanying ground infrastructure at a cost of US$822.7 million, in exchange for their military's access to the entire WGS system. Australia's involvement in the WGS program opened the door for additional international partners. The funding of the constellation's ninth satellite was an international partnership, involving Canada, Denmark, Luxemburg, the Netherlands and New Zealand. The individual financial contribution of the partner nations is proportional to their military's bandwidth access.

Canada's 2012 partnership with the US DoD for WGS bandwidth came as part of the $452 million Mercury Global Project; $340 million of which funded the development of the ninth satellite platform. The remaining finances subsidized the construction of the necessary ground stations and deployable terminals. With Boeing as the prime contractor, Canada's contribution included the return of US$240 million to Canada in the form of domestic employment. Of the five international partners with the US DoD, Canada made the largest financial contribution in exchange for, like Australia, access to the entire WGS system. The bandwidth leasing partnership with the US is the most cost-effective method of achieving our strategic military SATCOM requirement, as opposed to developing and operating an exclusively Canadian SATCOM constellation with worldwide coverage. The incorporation of the WGS system into the Navy's surface fleet enables a high-speed exchange of data with headquarters and vice versa.

Until the WGS deal, the Canadian Armed Forces (CAF) was purchasing bandwidth from commercial satellite companies as needed at an approximate cost of $25 million per year – a price which was expected to continuously increase over the coming decades. In light of growing cyber-security threats around the world, transitioning to a secured, government-controlled satellite system was in tune with the secure nature of military communications. While the participation in the WGS system is the most cost-effective option for Canada's SATCOM needs, the bandwidth readily accessible in certain geographic regions is never guaranteed. Furthermore, the US DoD can terminate the Royal Canadian Navy's (RCN) connectivity at any time for their own operational purposes.

Canada gained access to the WGS constellation in 2012, using interim ground terminals. The Memorandum of Understanding with the US included reserved frequencies for military communications until 2031. Incorporating the network capabilities with expeditionary military forces around the globe was immediate, including assets from Operation Impact in the Middle East and Operation Reassurance in Europe.

The partly Canadian-funded satellite, WGS-9, launched from Cape Canaveral on 18 March 2017 with DND representatives in attendance. Continuous improvements in the payload as the program progressed made WGS-9 "among the most capable military communication satellites on orbit," according to Rico Attanasio, the executive director of Boeing's Defence and Civil Satellite Programs.

The WGS System

The WGS constellation offers 4.875GHz of instantaneous switchable bandwidth, with the Block I satellites (WGS-1, WGS-2, and WGS-3) providing between 2.1 to 3.6 Gbps of data transmission rates depending on modulation and ground terminal configuration. The high data throughput meets the requirement of the modern C4ISR data exchange requirements for military command, control, support, and information management. The data transfer rate of the original three satellites exceeded that of the legacy DSCS satellites by a factor of ten. The Block II (WGS-4, WGS-5, WGS-6, and WGS-7) and Modified Block II satellites (WGS-8 and WGS-9) boast a data throughput of 6 Gbps and 11 Gbps, respectively.

Like all SATCOM systems, the WGS system is divided into three segments: the space segment, the control segment and the terminal segment.

The space segment is the satellites themselves, built on Boeing's BSS-702HP platform. Two extendable solar arrays feed two Lithium-Ion batteries to provide the needed 11 Kilowatts (end-of-life power) while an electrical propulsion system of four axial thrusters and four radial thrusters execute all station-keeping manoeuvres. The bus's high-power configuration is a necessity in meeting the payload's power demand and precise antenna pointing. Tested components and redundancies push the satellite's expected on-orbit lifetime to 15 years.

At an orbital altitude of approximately 35,800 kilometers, the satellites' orbital velocity matches the Earth's rotational period. The satellite thus appears motionless in the sky, at a fixed position relative to a ground-based antenna. The satellites execute daily burns, totalling 30 minutes, to maintain their 0.01° orbital positioning relative to the Earth. With the satellites appearing motionless relative to the Earth's surface, a stationary ground terminal can maintain connectivity without active tracking. From geostationary orbit, the satellite's field of view (FOV) covers the Earth between 65° North and 65° South. Flexible coverage areas are achieved via each satellite's nineteen independent coverage beams: eight steerable and shape-able X-band transmit and receive phased array antennas; 10 high-gain Ka-band steerable dish antennas; and a single wide-beam X-band antenna covering the entire visible Earth. Users of either frequency band can be connected anywhere within the satellite's FOV, with coverage beams able to change in near-real-time via ground command.

The high communications capacity of the WGS constellation is due to digitally channelized transponders, which handle the conversion of uplink signals into data prior to downlink. Boeing's new Generation-6 channelizer circuit technology isolates both uplinked X- and Ka-band signals into approximately 1,900 routable subchannels. The channelizer maximizes operational flexibility by converting X-band signals into Ka-band and vice versa, thus yielding a 90-percent increase in bandwidth compared to the previous satellites. The same channelizer also executes automatic network control and enables both broadcast and multicast services. Modified Block II satellites thus delivered nearly double the available bandwidth of earlier WGS satellites.

In terms of security, the satellites handle both unclassified and encrypted data, while also segregating each nations' data passed over the network. Boeing recently completed a fleet-wide software upgrade for anti-jam capabilities courtesy of the Space Systems Resiliency Upgrade. Information management techniques now bolster the satellites' protection from both intentional and unintentional electronic threats, in addition to geolocation of hostile signals. Furthermore, the newest upgrade has satellites applying low forward-error correction, channel interleaving and frequency-hopping spread spectrum to make the signals more resilient to hostile activity.

The control segment, headed by the 4th Space Operations Squadron in Colorado, continuously monitors satellite payload and station-keeping manoeuvres. Management of the network's usage is via secure Army-run Wideband Satellite Operations Centers (WSOC) located around the world. Each WSOC controls the operation of up to three WGS satellites. Tracking and control, in addition to command uplinks, are achieved through ground equipment contracted from ITT Industries and Raytheon. Telemetry data relayed to the ground via either X- or Ka-band transmissions includes orbit degradation and correction information.

Finally, the terminal segment is the various mobile military units, including naval, ground and air assets including unmanned drones. The Mercury Global Project included funding for the construction of seven anchor stations at three sites which provide the connectivity between the WGS constellation and the existing CAF communications network. The anchor stations, which consist of antennas and their associated ground infrastructure, are located throughout Canada. In 2014, General Dynamics Canada was awarded the $59.1 million contract for their construction, as well as a second contract for in-service support. As for the user, $15 million of the original investment was allocated to acquire different types of portable terminals for deployed units, including ones small enough to be carried by a soldier on the battlefield. Communications between these small terminals and the constellation is only achievable with the satellite's high-gain Ka-band antennas.

The antenna selected for the RCN is the AN/USC-69 SATCOM terminal built by Harris Corporation (Figure 1). The antenna is an engineering feat in itself, able to continuously track both geostationary and non-geostationary satellites from on board a ship in conditions up to Sea State 6. Dual-band capable, the antenna has long been used by American naval assets to access the DSCS and WGS satellites. The antenna is equipped with its own inertial measurement unit to track and compensate for pitch and roll, and thus only requires a ship's heading input. The system is capable of storing two blockage profiles, where the ship's superstructure blocks the antenna's line of sight to the satellite and to protect sensitive equipment.

Installation and Integration into the RCN

The Harris Corporation provided the RCN with the military commercial off-the-shelf terminals that would provide surface combatants and non-combatants with the global Internet Protocol via the WGS system. The *Halifax*-class frigates *Regina*, *Ottawa*, *Toronto* and *St John's* were equipped with the first such systems (AN/USC-69(V3)) under the Short Term Satellite Communications Upgrade (STSCU) Project. *Toronto* and *St John's* used the WGS system for their participation in Operation Reassurance in 2012 and 2013, respectively. The communications suite on board *Athabaskan* was mission-fitted with the AN/USC-69(V3) terminal within a two-week time period in January 2016. The limited bandwidth with fleet broadband and only one operational SHF antenna called for the system's installation just in time for the ship's sail to US Naval Station Mayport in Jacksonville, Florida for TGEX 2-16. The system includes an antenna with a protective radome (Figure 2) on the hangar top (*Halifax* class), after pilotage (*Kingston*-class maritime coastal defence vessels), and bridge top (*Athabaskan*), an LP air connection to provide 1 psi of positive pressure to the radome, a control cabinet and a PC-based remote-control station for control and monitoring. A direct feed from an inertial navigation system provides the ship's heading. To ensure proper configuration, the antenna base must fall within 0.5° of the ship's master datum for pitch and roll, and be aligned within a tenth of a degree of the ship's heading. Such precision calls for custom builds by above-water engineering. The ship's infrastructure, including the cabling and patch panel, limit the system's throughput capability. Between 2016 and 2017, *Athabaskan* averaged in the vicinity of 1.3-1.8 Mbps, where the *Halifax* class experiences an average 3 Mbps throughput. However, the high-speed internet accessibility didn't come without technical difficulties.

Initial Problems

The last-minute installation of the system on board *Athabaskan* in 2016, coupled with the ship's anticipated decommissioning, resulted in limited support in terms of radio-frequency (RF) safety and system operations. The ship was never intended to host such a system, and while although the starboard Separate Tracking & Illumination Radar (STIR) platform was vacant at the time, the antenna was often wooded due to surrounding fixtures and the mast's proximity. An antenna is considered wooded if its line-of-sight with the satellite is obstructed. The mast alone yielded 40° of wooded tracks at 20° satellite elevation – tracks which the ops room officers and bridge watchkeepers did their best to avoid throughout our exercises. If the satellite elevation dropped below 20°, the proximity of the two OE-82 UHF SATCOM antennas expanded the angle of wooded headings to a total of 56°. If wooded due to manoeuvres, the system was consistent in coming back online.

The Quality Engineering Test Establishment's (QETE) initial RF survey limited access to the bridge top, gun deck, and forecastle forward of the breakwater as areas out of bounds when radiating, restricting ship and helicopter operations. With *Athabaskan* being the only ship of its kind with the system, QETE developed blockage profiles around the ship's structure. While a 10° blockage profile inhibited radiation of the forecastle for safety reasons, it restricted continuous connectivity with the WGS-3 satellite which sits at 18° elevation in Halifax Harbour. A 10° elevation limit caused continuous connectivity losses while sailing in any noticeable sea state. *Athabaskan*'s short work period in the summer of 2016 afforded QETE the chance to conduct another survey, which resulted in an optional 0° blockage profile and less restrictive maximum exposure levels (MELs). At transmit powers below 4 Watts, there is a zero-metre MEL. Exercising in the vicinity of Naval Station Mayport, the new 0° blockage profile enabled continuous connectivity since the same satellite was now held at only 12° above the horizon. With only the one antenna, the ship's position alongside Mayport and surrounding ships' masts determined if we'd have connectivity.

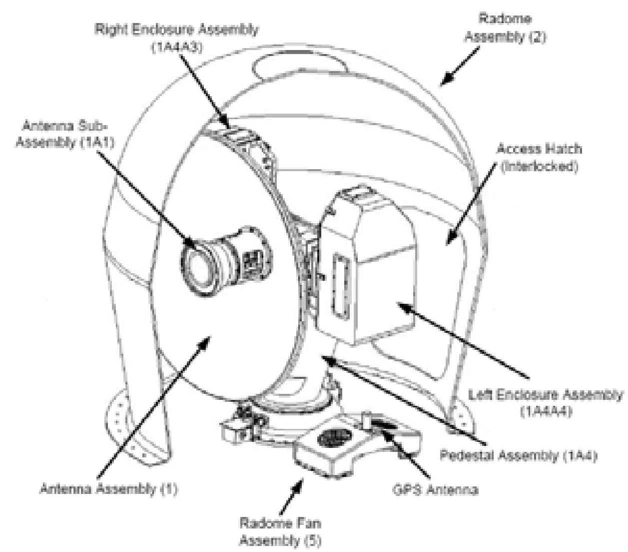


Figure 2. The Harris antenna protected within the radome.

Orbiting over Brazil at 52° West, the WGS-5 satellite did present a higher target in the sky, but technical difficulties on the WGS-side prevented continuous connectivity. *Athabaskan*'s system was proven correct and the ship reconnected to WGS-3 on the transit home.

Being the first and only *Iroquois*-class ship to use the system, there were immediate issues which required investigation. The combination of moist air originating from the LP air system and an improper radome door seal led to the build-up of ice on the antenna's bearings in cold weather. Ice particles prevented the fine adjustments needed to maintain connectivity on a continuously moving platform. Despite the door's clasps being firmly shut, the issue could only be rectified by proceeding to a warmer climate. In addition, continuous losses in connectivity were caused by faulty soldering on a number of connectors on both the antenna and control cabinet, which required replacement. The modem also periodically displayed faults which would require a system reboot.

Mastering the system and developing the necessary safety and operating procedures was an on-the-job training act for *Athabaskan*'s combat systems engineering department. Two possible blockage profiles (one limited at 10° elevation and the other limited at 0°) required two distinct sets of positive control checklists.

Other problems encountered were beyond the crew's control. The weather on station as well as the conditions at the anchor station were both factors in the system's connectivity. *Athabaskan* transmitted and received in the X-band, while all transmissions between the satellite and the ground station were in the Ka-band. The latter is susceptible to atmospheric absorption, and so the WGS-3 downlink to the anchor station at the Naval Armament Depot in Dartmouth, Nova Scotia was affected on more than one occasion. Furthermore, the satellite's low elevation on the horizon amplified the connectivity issues due to atmospheric interference.

As with other SATCOM systems, maintaining connectivity in higher sea states and at higher ship speeds is problematic. Also, the nature of the geostationary orbit means that the WGS satellites are not accessible in the extreme North or South. Proceeding to higher latitude past 74°, the satellite simply dips below the horizon and therefore falls out of sight.

Lessons Learned and the Future

In 2015, the RCN received ministerial approval under the Maritime Satellite Communications Upgrade (MSCU) Project to provide permanent WGS SATCOM capability, with the same terminals (AN/USC-69(V3)) providing the same capability. The MSCU system will be installed in all *Halifax*- and *Kingston*-class ships.

At the time of this writing, *Vancouver* and *Glace* Bay have also been fitted, with the remaining installations due to be complete by 2021. The *Resolve*-class auxiliary oiler replenishment vessel *Asterix* is also due to be fitted with the system, with Canada signed onto WGS access until 2031. On board the *Halifax* class, the system will augment the services already provided by the Navy Multi-band Terminals (NMT) and fleet broadband.

In the frigates, with the antenna installed on the hangar top, the antenna is not shadowed as much as it was on board *Athabaskan*. While it has an approximately 245-degree unobstructed line of sight (Figure 3), only having the one antenna yields a particular set of bearings where the antenna is wooded. Having two antennas, like the *Iroquois*-class SHF and *Halifax*-class NMT, enables continuous connectivity regardless of ship's heading.

Current installations under the MSCU Project are not supported by an uninterrupted power supply (UPS). The travelling wave tube, which amplifies the outgoing signal,

Photo credit: RCN

Figure 3. The AN/USC-69 SATCOM antenna (grey radome) has a nearly 245-degree unobstructed line of sight from its position on a frigate's hangar top.

needs approximately five minutes to cool down, while the computer also needs time to properly shut down. While any sudden loss of power can degrade the system's components, uncontrolled re-establishment of system power can cause failures. A UPS integrated into the *Halifax*-class MSCU would prevent gradual degradation of the system.

Safety-wise, all future installations of the system will be complemented by a simple three-way switch to facilitate positive control. A low-power option, where the system continues to radiate below 4 Watts, would facilitate man aloft procedures due to a zero-metre MEL. Instead of continuously shutting down the system, the switch will also facilitate helicopter operations while maintaining connectivity, albeit at a reduced bandwidth.

The US DoD has already commenced discussions regarding their next generation of satellite communications. The Pentagon hopes to enhance its space-based assets by stimulating international cooperation, and thus, Canada was among nations invited to the Analysis of Alternatives to review requirements and options.

Conclusion

With a cumulative price tag of over US$3.7 billion, the WGS constellation is the largest international military space project. While it succeeded in its purpose to elevate the American military's communication capacity around the world, it simultaneously solidified the interoperability of American forces with their allies on the newest battle frontier.

Continued on next page

Acknowledgements

I would like to acknowledge LCdr Dominic Dupuis, PO1 Chris Oldham, Charlie Falldien, William Kennedy and the staff at DNCS 2-3 who contributed their technical expertise to the completion of this article.

Lt(N) Kevin Hunt is a Naval Combat Systems Engineering Officer. He completed his Phase VI and A/CSEO tours on board HMCS Athabaskan, *one of the first few surface combatants to install and extensively operate the AN/USC-69(V3) system. He holds a Master's degree in Space Science with research in satellite communications.*

References

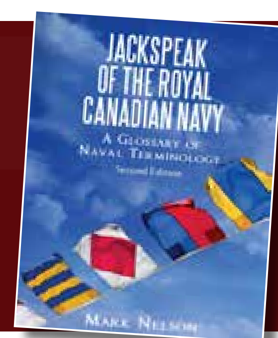
- Aerospace Technology. (2018). Wideband Global SATCOM Satellite. Retrieved from http://www.aerospace-technology.com/projects/wgs-satellite/
- De Selding, P.B. (2016, November 10). Canada says Military SATCOM Negotiations with US are much Improved. Retrieved from http://spacenews.com/canada-says-military-satcom-negotiations-with-u-s-are-much-improved/
- General Dynamics. (2014, November 13). General Dynamics to Design, Build and Support Anchor Stations for Canada's Mercury Global Project. Retrieved from https://gd-ms.ca/news/general-dynamics-to-design-build-and-support-anchor-stations-for-canada%E2%80%99s-mercury-global-project.html
- Government of Canada. (2012, January 17). Canada's Participation in the Wideband Global Satellite Communications System. Retrieved from http://www.forces.gc.ca/en/news/article.page?doc=canada-rsquo-s-participation-in-the-wideband-global-satellite-communications-system/hgq87xyn
- Government of Canada. (2015, July 21). Single Antenna SATCOM Terminals. Retrieved from https://buyandsell.gc.ca/procurement-data/tender-notice/PW-QF-103-25241
- Henry, C. (2016, May 5). Boeing, Air Force Discuss WGS Improvements. Retrieved from http://www.satellitetoday.com/regional/2016/05/05/boeing-air-force-discuss-wgs-improvements/
- Ray, J. (2017, March 19). Internationally-Backed Military Satellite Successfully Launched atop Delta 4 Rocket. Retrieved from https://spaceflightnow.com/2017/03/19/internationally-backed-military-satellite-successfully-launched-atop-delta-4-rocket/
- Spaceflight 101. (2018). WGS – Wideband Global SATCOM. Retrieved from http://spaceflight101.com/spacecraft/wgs-wideband-global-satcom/

Book Review: Jackspeak of the Royal Canadian Navy: A Glossary of Naval Terminology – Second Edition

Reviewed by Tom Douglas – Associate Editor *Maritime Engineering Journal*

Dundurn Press (info@dundurn.com)

ISBN 978-1-45974-279-6 [Paperback $19.99]; 184 pp; bibliography



To many authors, one clear measure of success is an invitation from their publisher to produce a second, larger edition of their work. CPO 1 (Ret.) Mark Nelson's original book of naval slang – picked up in his 26-year career with the RCN – was reissued in October. The new version of *Jackspeak* contains about 400 additional expressions.

Did you know that a "280 lady" is a sailor who served mostly in the DDH 280 (Iroquois) class? Or that "pig boats" were ships of the Porte class that opened and closed the anti-submarine nets protecting harbours, and were later converted to Naval Reserve training vessels?

The author points out that navy slang can confuse a new recruit: "For example, there is more than one way to refer to a lazy person, as they can be called a skiver or a skate – or can be described as swinging the lead. The same goes for sleeping arrangements, as a sailor might sleep in a pit, cart, or rack, but only occasionally a bunk."

Nelson – a great name for a sailor – has fun with expressions coined for his historical namesake: "You'll find Nelson's balls up top on the bridge, and Nelson's blood down below in the mess."

FEATURE ARTICLE

Buy Cyber-Secure: Improving Cybersecurity of Procured Combat Systems*

By Commander Jay Thor Turner

[*Adapted from the author's 2016 Canadian Forces College directed research project which includes complete bibliographical references and citations.]

The world is constantly changing and evolving, which implies that the threat landscape is following suit. In order to improve cybersecurity of acquired systems, DND and the CAF must educate its workforce, including key decision-makers, and develop a holistic cybersecurity program that integrates risk management with sound requirements engineering and system security engineering (SSE), both internally and in industry.

The CAF's effort to keep pace economically with technological advancement and to maintain the technological fighting edge has resulted in systems that are based on commercial-off-the-shelf (COTS) hardware and software, and along with these come new vulnerabilities and increased attack surfaces. Additionally, the drive to interconnect every system and to have access to vast amounts of data in order to make better and faster decisions also increases the CAF's exposure to threats. Employing advanced technology has become a double-edged sword requiring the CAF to focus on ensuring the systems it uses are both effective and defensible in cyberspace.

As the CAF embraces the available advanced technology in its pursuit of improving and modernizing its capabilities, without proper management and engineering it is exposed to ever-increasing risks with respect to software and software-centric systems. In the global arms race, modern military platforms and systems continuously increase in complexity and cost, and the price of maintaining the competitive technological edge over potential adversaries substantially increases as a result. Over the past several decades these stresses have inspired a number of changes in how the military procures its advanced military systems. One of the key changes is the focus on procuring COTS based systems as opposed to military specification (Mil Spec) based systems. This change is readily apparent when comparing the original build of the *Halifax*-class frigates with the most recent HCM/FELEX mid-life refit and modernization project. [A Halifax Class case study is contained in the author's full project thesis. – **Editor**]

The *Statement on Canadian Defence Policy* in 1992 specified that defence procurement should "avoid unique Canadian solutions that require expensive and risky research, development or modification of existing equipment." This was followed up in the *1994 National Defence: Budget Impact* where it was stated that "in its acquisition strategy, the Department … will emphasize the purchase of equipment 'off the shelf', the use of commercial standard technologies, and unless absolutely necessary, the avoidance of military modifications." Finally, the 1994 Defence White Paper stated,

> [t]he Department will increase the procurement of off-the-shelf commercial technology which meets essential military specifications and standards. Full military specifications or uniquely Canadian modifications will be adopted only where these are shown to be absolutely essential.

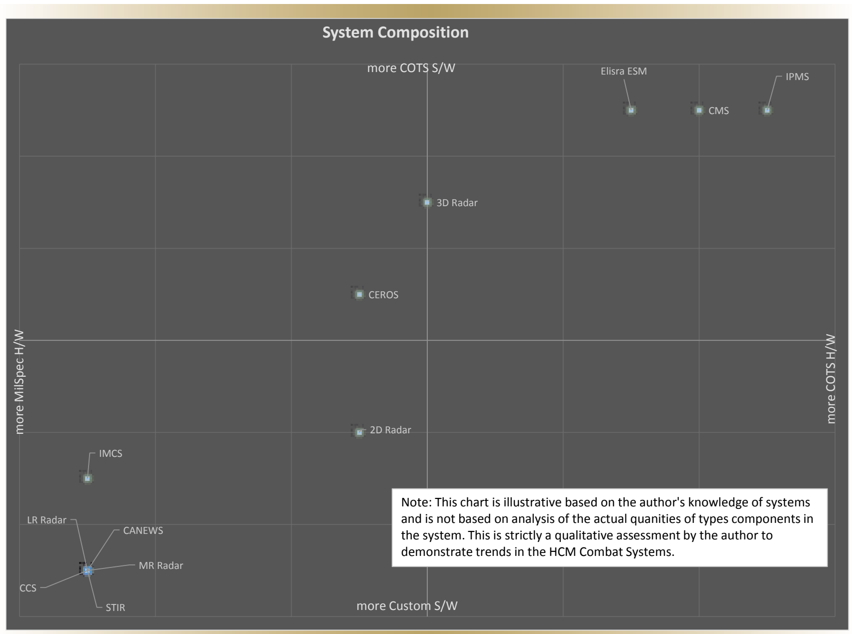
The Growing Threat in Cyberspace

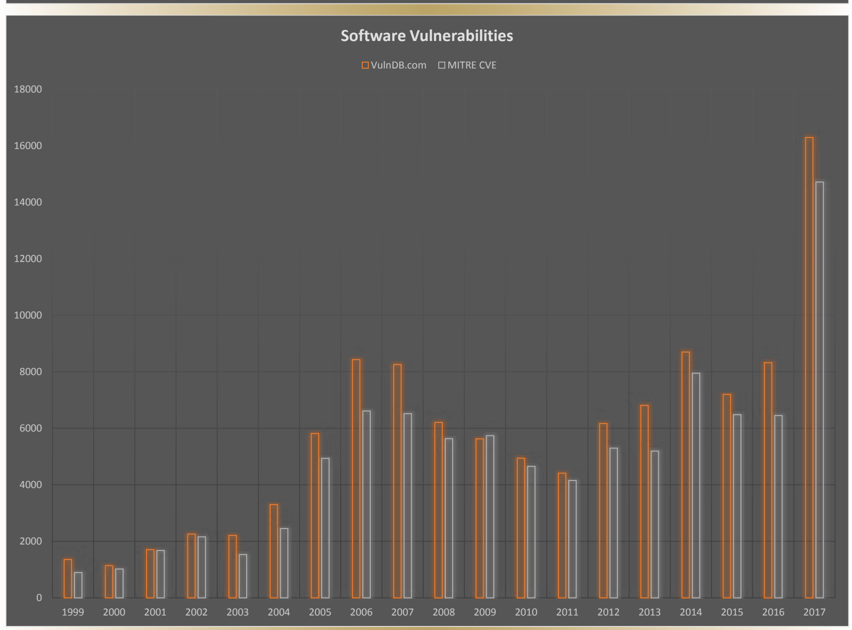
Although increased reliance on COTS technology provides distinct advantages in a number of areas, it has some undesired effects, namely exposure to a broader set of cyber threats. The COTS software and hardware components used in modern systems are present in a wide variety of industrial, commercial or personal use systems and products, which changes the landscape for would-be attackers. Most of these COTS components are accessible for testing, experimentation or examination, thus allowing potential attackers to design and develop effective cyber attacks. For example, according to a 2016 PricewaterhouseCoopers survey, the number of detected security incidents increased by 38 percent in 2015 in all industries, while they grew by 137 percent in public sector organizations.

Many forms of cyber attack rely on the exploitation of flaws and vulnerabilities in software or firmware that can be attacked over a network or the Internet with malicious software (malware). Some malware is analogous to a fire-and-forget weapon, and is able to autonomously navigate computer networks and systems, leveraging vulnerabilities to self-propagate, escalate privilege, and deliver specific payloads. The payload of the malware might vary depending on the desired effect of the attack, but could range from providing persistent access to a system or network (e.g. Backdoors or Remote Administration Tool/Trojan), to overloading the system (i.e. Denial of Service), to altering the operation of a machine controlled by a computer. In any of these cases, malware presents a clear danger and real risk to military operations by affecting combat systems and platforms.

Both industry and the CAF must take action to manage cyber risks in modern combat and platform systems. Without appropriate action, CAF systems may be left indefensible and/or wide open to cyber-attack, leaving military cyber-defenders at a distinct disadvantage. Although there are many approaches to managing this risk, a long-purported approach is to build security into the system.

The CAF is in the process of recapitalizing its naval fleet, as well as planning for the procurement of a new fighter aircraft and the Joint Unmanned Surveillance and Targeting Acquisition System (JUSTAS). These new ships, aircraft and other systems will be more interconnected via computer networks and be made up of more COTS hardware and software than ever before. Given the complexity of these "systems of systems," retrofitting them to add security after they are delivered would very likely be unaffordable and unfeasible for DND to manage. Additionally, attempting to manage or control any residual risks associated with the security of these systems, given the growing cyber threat, could be a significant undertaking. Defending these systems would also prove to be extremely challenging for CAF cyber-defenders who are still early in the development of that capability, which has thus far been solely focused around traditional computer systems and networks.





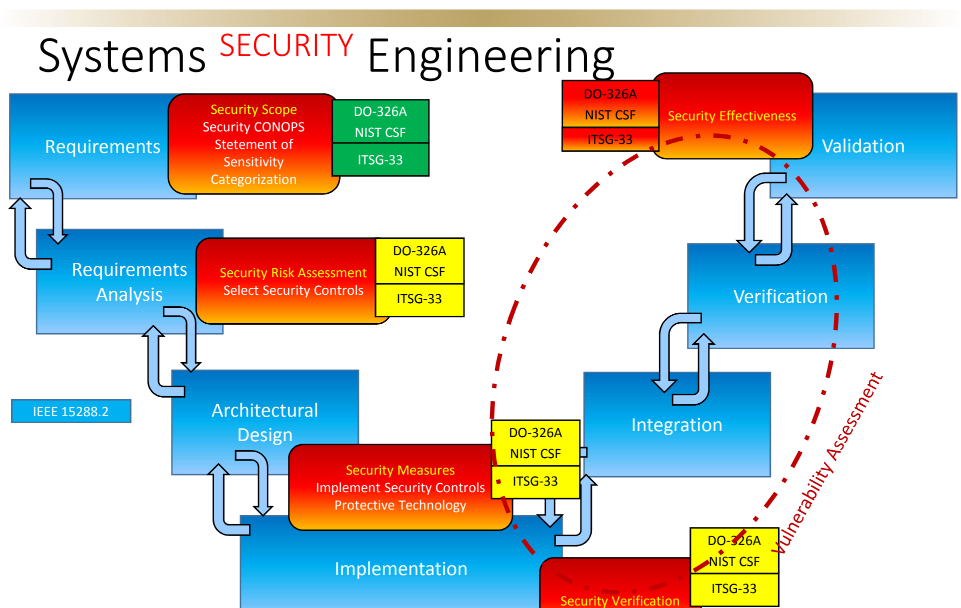
A New Approach to System Cybersecurity

Based on these looming challenges, DND and the CAF must adapt their approach to acquiring systems such that cybersecurity is a key consideration and is designed into systems, validated and verified throughout the development, implementation and on final delivery. DND and the CAF must educate the workforce. While the situation improved over time, the HCM/FELEX project demonstrated in its early stages some of the issues that can occur when decision-makers are not adequately informed of the risks they are accepting with respect to cybersecurity. The personnel informing the decision-makers, and the decision-makers themselves, must be educated appropriately in order to effectively manage cybersecurity. This education must be fluid and updated regularly as technology and cybersecurity risks evolve. Simply updating policies will not be effective when the workforce is not properly educated to implement those new policies.

Beyond general education with respect to cybersecurity, two key subject areas must be addressed – system security engineering (SSE), and requirements engineering. As RAND Corporation researchers looking at improving cybersecurity of USAF weapon systems pointed out, project staff must "understand both system security engineering and the mindset and tactics of adversaries determined to attack through cyberspace." Additionally, project staff, system engineers and system life-cycle managers must be keenly aware of SSE considerations. Finally, personnel in ADM(Mat), as well as operational requirements developers, must be formally educated in requirements engineering specific to the subject of *security* requirements engineering. The cost of not addressing issues with requirements up front is far too high to accept in the operations and maintenance phase of a system's life cycle.

DND and the CAF must improve in requirements engineering, and in order to support this it will require relevant and current cybersecurity policies and standards. In order to keep pace with the rapid developments in cyberspace, these policies and standards need to be flexible and adaptable. This may require significant effort and resources to keep current with the state of cyber-threats, so DND and the CAF may need to look externally for these policies (i.e. to the expertise and experience of external consultants) and standards, or focus on process and principles like SSE to develop cyber-secure solutions. Based on these standards and policies, requirements must be grounded in reality and have reasonable feasibility of being successfully delivered when the system is implemented. Again, education and subject matter expertise will be required to support this, but it will avoid challenges as seen with HCM/FELEX such as the declassification of hardware or implementation of cross-domain solutions. Additionally, the problem of generating requirements that were based on broad policies without performing the necessary analysis would be avoided. Sound general requirements and security requirements engineering go hand-in-hand with SSE, and represent high-payoff investments.

The RAND Corporation researchers also stated that requirements specific enough to be placed into a contract and operationally tested were unlikely to be successful. Major capital projects will still have contracts and requirements documents, but it will take a combination of sound security requirements and SSE to succeed on the cybersecurity front. The key challenge, presently, is how to ensure the contractor embraces SSE in their process. One method would be to demand compliance with an appropriately tailored standard such as *ISO/IEC 15288:2015 Systems and Software Engineering – System Lifecycle Processes* supplemented by *NIST SP 800-160 – Systems Security Engineering: Considerations for a Multidisciplinary Approach in the*



Credit: Cdr Marc Lanouette and Mr. Steve Sterling

Engineering of Trustworthy Secure Systems. Beyond demanding compliance, auditing may also be required to ensure that as schedule and resource pressure increase, best-practices or standard processes are not shed. DND and the CAF need to invest heavily in SSE, as well as investigate methods to ensure that it is used by contractors so as to enable security to be designed into systems.

As can be seen, there are a number of issues that need to be addressed. The rapid pace of change in this field requires a robust support framework as well as agility. A formalized cybersecurity program like the US Navy's Cybersafe would do a number of things to manage the risks in this domain. First, it would create an institutional culture where cybersecurity is everyone's responsibility. This aspect is further supported by properly educating the workforce so that all personnel have some understanding of cybersecurity. Second, it would focus and prioritize efforts to survivability first, and then mission assurance, which fits well with the RCN's *float, move, fight* damage control doctrine. Through this cybersecurity lens a broader mission perspective would be taken of critical points of failure between systems. A program like Cybersafe would bring SSE and risk management frameworks (RMFs) to the view that the cybersecurity problem space includes people, process and technology. The challenge of cybersecurity will not be solved with one single method or one perspective, but through a holistic view of system security. In DND's specific case this will require review and improvement to its own IT security RMF, and a determination of the adaptations that will be required to synchronize these with the acquisition process. DND and the CAF must develop a broad cybersecurity program focused on managing the specific risks with respect to acquisition of platform and combat systems.

In summary, it is recommended that DND and the CAF:

- educate the whole workforce in cybersecurity;
- formally educate requirements engineering for project staff and operational requirements developers;
- invest heavily in SSE, specifically through education, as well as investigate methods to ensure that it is used by contractors, such as auditing, so as to enable security to be designed into systems; and
- develop a holistic cybersecurity program for acquisition that includes an improved risk management framework and fully integrates SSE.

Conclusions

The challenge of procuring cybersecure and cyber-resilient systems is manageable. In order to improve cybersecurity of acquired systems, DND and the CAF must educate its workforce, including key decision-makers, and develop a holistic cybersecurity program that integrates sound requirements engineering, system security engineering, internally and in industry, and risk management. The cyber domain is a complex and rapidly changing environment where only adaptability and sound first principles will enable success. The days of security by obscurity have passed. The increasing complexity and use of COTS technology in modern software-centric combat and platform systems continue to expand the avenues of attack through this new domain.

There are many approaches to address this growing problem, but no single or static approach is likely to succeed. The problem must be addressed at the core of the system, or systems, by integrating cyber-resilience and cybersecurity as inherent qualities into their design so as to avoid the failings of past procurements where security was either an after-thought, or initially misguided. Education, awareness and a broad view of the problem space, which includes the mission and the adversary's perspective, are required to succeed in defending some of Canada's most critical systems in cyberspace. Based on the analysis presented in this research it is clear that action must be taken to ensure DND and the CAF's combat and platform systems are defensible from an inevitable cyber-attack in the future. Through preparation and education, DND and the CAF can prevent a cyber-attack from wreaking havoc on our mission critical systems.

Cdr Turner is the Senior Security and Integrated Data Environment Manager of the Canadian Surface Combatant Project in Ottawa.

Reference:

Buy Cyber-Secure: Improving Cybersecurity of Procured Combat Systems, LCdr Jay Thor Turner, PR 500 Directed Research Project, Canadian Forces College JCSP 42, Toronto, ON, 9 May 2016.

NEWS BRIEFS

U.S. Meritorious Service Medal – LCdr Brennan Blanchfield – DGMPD (Sea)

June 15, 2018 – RAdm Art McDonald presents **LCdr Brennan Blanchfield** with the U.S. Meritorious Service Medal for his outstanding service as the *Arleigh Burke*-class destroyer (DDG-51 Class) Aegis Production Officer from July 2014 through July 2017 as Supervisor of Shipbuilding Conversion and Repair, in Pascagoula, Mississippi. LCdr Blanchfield was recognized by the United States Armed Forces for his tremendous leadership of a multi-disciplinary team of more than 20 members in the supervision of production activities for the construction of six DDG-51 class ships. His tireless efforts resulted in the successful achievement of numerous critical milestones, including the successful execution of DDG-113's two-part builder trials and live-firing testing. His contributions across the border have brought great credit to himself and the Canadian Armed Forces.

Photo by CPO2 Duane (Sunny) Gall

LCdr Blanchfield is currently the Production Officer for the Joint Support Ship Project with PMO JSS Detachment Vancouver.

— Courtesy ADM(Mat) MATFLASH

Newfoundland Escort Force commemorative bell unveiled in St. John's, NL

The last of three ship's bells commissioned to commemorate the Allied naval and merchant sailors and air personnel who lost their lives while maintaining vital supply lines between North America and Europe during the Second World War was presented to Newfoundland and Labrador Lt.-Gov. Judy Foote on Sept. 11.

The unveiling at Government House in St. John's marked the culmination of a 13-year project to connect the port cities of St. John's, NL, Halifax, NS and Londonderry, Northern Ireland – waypoints for wartime convoys under the protection of their naval escorts. The Newfoundland Escort Force bell was gifted to the province of Newfoundland and Labrador by the Londonderry branch of the Royal Naval Association, represented by chairman **Robert Buchanan** with other members and their spouses.

In addition to local dignitaries, also in attendance were **Cdr Corey Bursey**, representing the Canadian High Commission in London; project coordinator **LCdr (ret.) Pat Jessup** – PR chair of the non-profit Canadian Naval Memorial Trust responsible for the preservation of the wartime corvette HMCS *Sackville* berthed in Halifax; *Sackville* CO **Cdr (ret.) Jim Reddy**; 95-year-old wartime bomber pilot **Arthur Barrett** of St. John's; representatives of the Crow's Nest Officers' Club in St. John's, and other trustees who had contributed to this touching memorial project.

Photo Courtesy of LCdr (ret.) Pat Jessup

Unveiling the Newfoundland Escort Force commemorative bell at Government House in St. John's, NL are: Robert Buchanan (left), Jim Reddy, Lt.-Gov. Judy Foote, and wartime bomber pilot Arthur Barrett.

The first bell, named to commemorate North Atlantic Convoys, was installed at St. Brendan's Church at CFB Halifax in 2005, and the second bell, named in honour of the famous "Newfie-Derry Run," was installed in Londonderry in 2007.

PRESERVING CANADA'S NAVAL TECHNICAL HERITAGE

CNTHA NEWS

Canadian Naval Technical History Association

With a little help…

By Tony Thatcher

Since 1992, the CNTHA has been going strong as a volunteer organization of mainly retirees working in support of the Directorate of History and Heritage (DHH) in Canada's Department of National Defence. DHH has an ongoing project to capture and preserve our country's naval technical history, and the CNTHA is pleased to be able to contribute to this in a meaningful way through our ongoing Oral History Project.

Over the years we have captured many amazing "behind-the-scenes" insights from people who in their day worked the front lines of some of the Royal Canadian Navy's most interesting technical achievements over the past 60 or more years. For the most part, the detailed information we have been able to capture about the circumstances and decision-making associated with the RCN's ship and equipment programs, and the defence industrial base supporting them, might well have been lost.

What's interesting is that our sailors at sea today are working with equipment and systems that have in many cases evolved directly from the work done by the Canadian men and women who blazed new inroads in all areas of naval technology in decades past. These talented people didn't simply embrace innovation, they made it their own in everything they did. And so it continues with the military and civilian members of Canada's defence team today.

The CNTHA has been very fortunate in documenting and preserving many aspects of the RCN's technical history for DHH and the benefit of future researchers. It's one of the best ways we know of celebrating this country's significant achievements in the naval technical arts, and we enjoy being able to share this information through our website. Today, more than 25 years into our effort, we are pleased to say that we enjoy an extraordinary level of support from the office of the Director General Maritime Equipment Program Management.

Where we could use a little help from all of our friends now is in ensuring that the volunteer work we do on behalf of all Canadians can continue. To this end, we are seeking a couple of new members – deputies, in fact – who could soon take over the reins of the CNTHA's Oral History Project and the maintenance of our website. These tasks require a fair degree of attention, no question, but the work is rewarding in that the important oral and written lessons of Canada's naval technical programs will continue to be preserved for generations to come.

We look forward to hearing from you.

CNTHA News
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