National Defence Défense nationale

Maritime Engineering Journal

82

Since 1982

Canada's Naval Technical Forum

March 2017

SPECIAL EDITION

Halifax-Class Modernization / Frigate Life Extension Project

In this Issue:

- HCM/FELEX Backgrounder
- Behind-the-scenes: Project Perspectives and Lessons Learned
- Valuable Industry Insights

Canada

New Sea Legs for Canada's Navy Frigates

HMCS *Montréal* (FFH-336) in mid-life refit at Irving Shipbuilding's Halifax Shipyard

Director General Maritime Equipment Program Management

Commodore Simon Page, OMM, CD

Maritime Engineering Journal

(Established 1982)
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Commodore's Corner

Project Perspectives

Industry Insights

A rejuvenated HMCS *Calgary* during successful trials off the West Coast in 2013.

Photo by DND

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Commodore's Corner

By Commodore Simon Page, OMM, CD
Director General Maritime Equipment Program Management

Teamwork, Trust and Respect Redefined

It is with great pleasure that I write a few lines of introduction for this special edition of our *Maritime Engineering Journal* about the Halifax-Class Modernization / Frigate Life Extension (HCM/FELEX) project. Thinking ahead about what my remarks might focus on, I recalled something that someone said recently to the shipyard workers who were involved in this complex and hugely successful project, and I knew then what it was I wanted to share with all of you.

Indeed, it was during an HCM/FELEX media event celebrating the last of the 12 mid-life refit work periods in Halifax that Brian Carter, President of Seaspan Shipyards, remarked to the assembled Irving Shipbuilding Inc. workers: "I don't know you personally, but I know what you do and how well you do it." To my mind these words captured the essence of the execution and success of the HCM/FELEX project by encompassing, in a very intimate manner, so many of the principles that have become essential to the successful delivery of today's complex equipment projects. Values such as respect, trust, teamwork, and interacting in good faith come across very clearly in Mr. Carter's words, and emphasize a modern approach toward project vision that is critical for success.

The HCM/FELEX project was a lesson learned for all of us about how teamwork begins by building trust and respect, and then creates its own energy and relationships to deliver great results. The values embodied in Mr. Carter's statement need to be fully embraced at all levels of organizations as a way to bond individuals into teams, and it was this that allowed us to manage the complex and intense environment of HCM/FELEX so successfully.

People are defined by many things, but for those of us who serve in the Royal Canadian Navy, or who ply our expertise within one of the RCN's support organizations in government or industry, it is the vessels and projects we work on during our careers that will define our generation. For those of us who can now identify as members of the "HCM/FELEX generation," I am quite certain that the lessons we learned about teamwork, trust, and respect will redefine our thinking about the way we approach and execute the challenging and complex naval projects of the future.

I hope you enjoy reading this special issue, and somehow connect in your own way to the success of HCM/FELEX – a defining project of our generation.

A First for the Maritime Engineering Journal

On behalf of the editorial and production teams, we are excited to bring you this special edition of the *Journal* – the first of its kind in the publication's 35-year history.

How especially poignant it is, this being Canada's 150th year of Confederation, that we have focused on the singularly spectacular success of the project to modernize the Royal Canadian Navy's *Halifax*-class Canadian patrol frigates, some 25 years after their own successful introduction to the fleet in the 1990s. These ships have in the past, and will continue for many years, to provide exemplary service in bringing security and prosperity to our wonderful nation as the RCN meets (and exceeds) the ongoing needs of the Government of Canada in a world full of change.

This special edition is meant to explore and document the tremendous effort undertaken over so many years by countless dedicated and hard-working public servants, Canadian Armed Forces personnel, and industry partners to return the Navy's principal combat vessels to operational effectiveness. It is the sincere hope of all who contributed material for this issue that their insights might, in time, help shape future projects and endeavours toward equally successful outcomes.

For the instant, please enjoy your magazine, along with our best wishes for the year ahead.

— ***Captain Dave Benoit, RCN, Senior Editor***

#Teamwork

I am very appreciative of what Commodore Page and his team have done to develop, for the first time ever, a special edition of the *Maritime Engineering Journal*, and to dedicate it to the Halifax-Class Modernization effort. This modernization is a testament to the exceptional leadership, outstanding teamwork, and extraordinary professionalism of all those involved over the life of the project. "All" in this context refers to industry, other government departments, Defence, and the Royal Canadian Navy (RCN). I am extremely proud of the success that this project represents, not only because it finished on budget and on time, but more importantly because of the tremendous capability it will provide to the bright, hard-charging, dedicated men and women who serve their country at sea to make a difference at home and abroad on behalf of Canada and Canadians.

The success of these upgrades has been demonstrated on exercises such as Rim of the Pacific 16, Trident Juncture, and in operations in support of our NATO commitments. I think the true measure of the success of this modernization is the fact that the Royal New Zealand Navy will be sending their frigates to Canada to receive a similar modernization package, and that other navies are also looking toward Canada to modernize their warships.

In closing, I would like to congratulate the impressive team of professionals at Director General Maritime Equipment Program Management, and the RCN's naval technical support community more broadly, for their pivotal roles in enabling a truly made-in-Canada success story. BRAVO ZULU!

Yours Aye,
Vice-Admiral Ron Lloyd

HCM/FELEX: An important Chapter in Canada's Naval Technical History

Welcome to this special edition of the *Maritime Engineering Journal*. The idea for pulling together the story of the Royal Canadian Navy's successful frigate modernization/life-extension program came from Lt(N) David Irvine, a former Combat Systems Officer with the HCM/FELEX project management office (PMO) at National Defence Headquarters in Gatineau, Québec. As the project draws ever closer to completion, we feel his initiative to capture this important chapter in Canada's naval technical history before most of the players dispersed was both timely and long-sighted. Thanks to his own considerable effort, and to that of the other people and organizations who came forward to share their insights, there now exists a remarkable behind-the-scenes record of one of the Navy's most complex technical undertakings.

The articles that follow are meant to provide a narrative of the principal challenges, approaches to problem-solving, and lessons learned that were key to ensuring the success of the project. There are definite themes that span across the articles: collaborative problem-solving, focusing on system level performance outcomes, and hard work and perseverance to ensure that the right outcomes were achieved. One has to remember that when implementation started eight years ago, many of these were new, untested, and groundbreaking initiatives for their time. HCM marshalled in new approaches for managing requirements, working collaboratively with industry partners, and employing governance to help clear the path for issues that could impede progress. It benefited from clear and unreserved support at every level in the Assistant Deputy Minister (Materiel) and RCN chains, and when necessary those senior-level relationships had a positive influence on activities that were important to stakeholders within industry and government.

Equally important were the professionalism and dedication of each member of the PMO staff and the extended teams in Halifax and Esquimalt, and in ADM(Mat). This was hard work, and required passion and often very long days to execute the reviews, meetings, trials and complex discussions that were at the foundation of the work. We collectively "upped" our game in terms of our technical and project management expertise over the past eight years, and many individuals, including Lt(N) Irvine, have already moved on to employ that knowledge to the benefit of other naval projects.

Project Manager Dave Monahan

Finally, I would be remiss if I did not say a few words about the extraordinary contributions of my two predecessors. Successful projects don't happen just by accident. One of the biggest determinants for successful project outcomes is how well they are set up at the start. Paul Hines was responsible for obtaining project approval and for establishing the initial enablers, such as the governance, that were key to managing the risks anticipated for the implementation phase. His vision and leadership left an enduring and positive influence on everything that followed.

As we know all too well, no plan survives first contact with reality, and Geoff Simpson's leadership, personal approach, and decisiveness were absolutely key to ensuring the project's successful outcome. To be able to quickly rally industry, and the RCN and ADM(Mat) organizations around his strategies for issue resolution was an extraordinary endeavour. The plan changed significantly over time, and he inspired the confidence and support of the leadership and project teams necessary to make the undertaking a success.

In closing, enjoy the articles; don't be afraid to ping on those who have experienced HCM, and I hope this inspires the next wave of leaders for the projects that are coming next.

— Dave Monahan
Project Manager – HCM/FELEX

Technology and Teamwork – Keys to Sucess

Geoff Simpson (right) with Paul Hines in 2010.

As HMCS *Toronto*, the last of 12 frigates, completed her mid-life refit last fall, it was hard not to reflect upon the last several years of the Halifax-Class Modernization program and determine the keys of success. The HCM project will be characterized by its complexity both in terms of technology, and of the breadth of stakeholders in industry, government, and the Department of National Defence (DND).

Dan Ross, Assistant Deputy Minister of Materiel from 2007 to 2013, considered the undertaking to be the most complex, high-risk project of its day. With more than 60 industrial partners, multiple unaligned complex contracts, two coasts with two cultures, and an eager customer with an ambitious delivery requirement, the need for an executable plan was paramount. Executing the plan while managing the complex schedules, goals, and budgets would be critical for success.

Certainly, the professionalism of all teams – DND, Public Works and Government Services Canada, Lockheed Martin Canada, Seaspan, Irving Shipbuilding Inc., Fleetway, and others – provided the necessary positive foundation for the project, but launching it the right way with the establishment of project structures with a governance framework in place would prove to be key to the project's outcome.

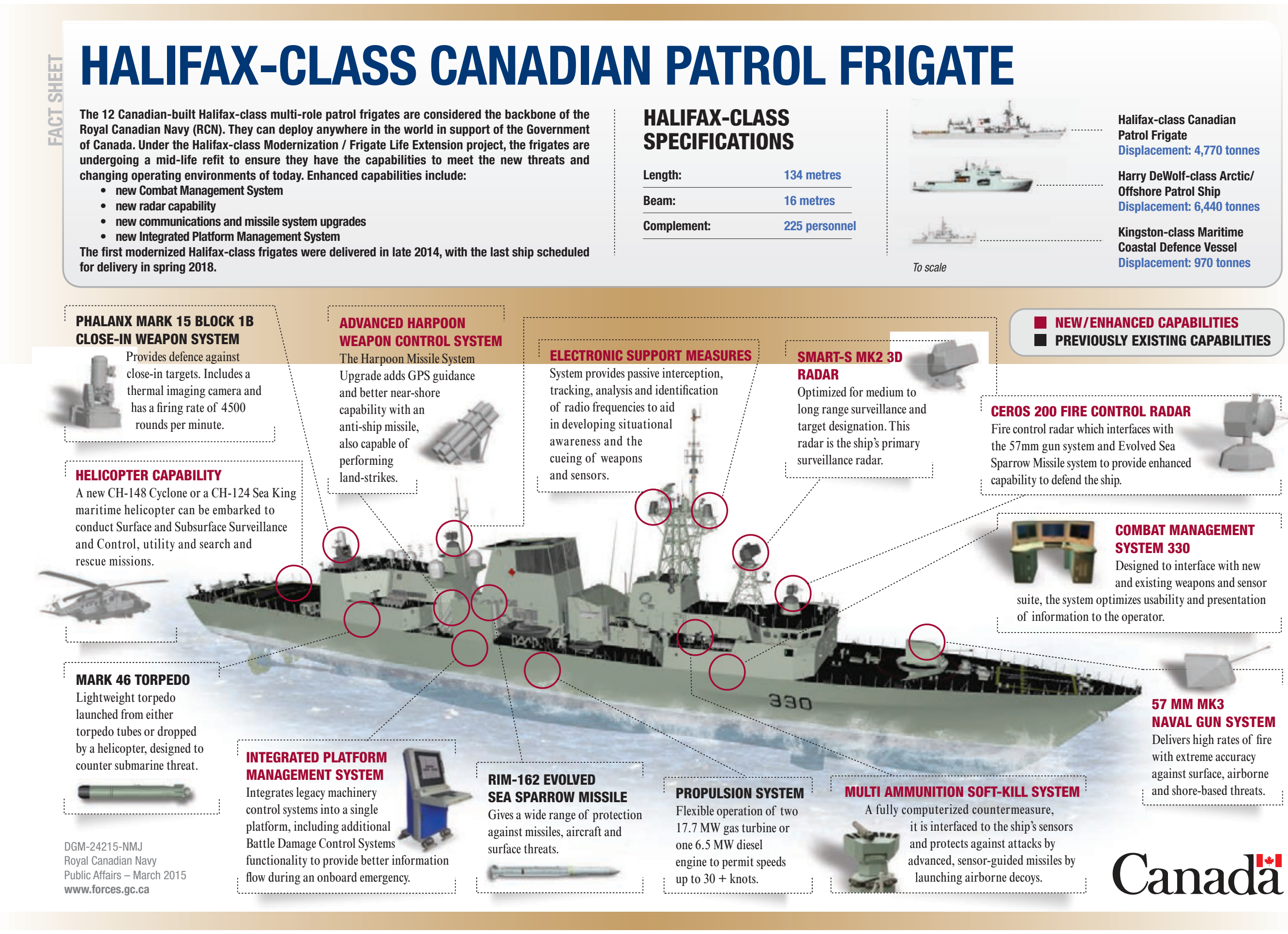
Paul Hines, the first HCM project manager, was instrumental in developing and implementing our governance, in addition to shifting how DND communicated with industry. Early in the project's life he initiated industry working groups designed both to understand industry's ability to deliver on the mid-life refits, and to improve upon the efficiency of the procurement process to achieve the first scheduled refit of the first ship in 2010. He changed how we communicated with industry, and in so doing created critical relationships that were instrumental in solving problems and aligning organizations to a common goal. He changed the formula for success, from the use of a collaborative process to the creation of a Committee of Sponsors comprised of government and industry leadership.

As we reintroduce HMCS *Toronto* back into the Navy's fleet, it is important that we remember all those who made this possible, and in particular Paul Hines. Paul passed on in 2011, but his legacy will be forever aligned to the success of the Halifax-Class Modernization project.

— Geoff Simpson
Former Project Manager – HCM

Backgrounder – HCM/FELEX

Backgrounder by the Department of National Defence and the Canadian Armed Forces



The 12 *Halifax*-class frigates, commissioned between 1992 and 1996, form the backbone of the Royal Canadian Navy (RCN). The ships were originally designed for anti-submarine and anti-surface warfare, primarily in the open ocean environment.

The role of the *Halifax* class has changed. Current and evolving maritime threats are faster, stealthier, more maneuverable, and shifting from the open ocean to the near-shore environment. The littoral environment poses challenges to sensor and weapon systems due to higher traffic density and proximity to shore-based threats. In addition, ships now face asymmetrical threats, such as attacks from smaller, more manoeuvrable vessels that were not envisaged at the time of the ships' design.

Innovations in procedures and tactics have enabled the frigates to operate effectively in the new threat environment, despite equipment limitations. However, sensor and weapon enhancements were needed in order to enhance the ships' ability to deal with these new threats into the future.

The HCM/FELEX project managed both the modernization of the combat systems, and a planned mid-life ship refit program to ensure the frigates remain effective throughout their service life. This work encompassed modernization of the ship's platform, including ship systems upgrades, and acquisition and installation of new capabilities such as enhanced radar, new electronic warfare system, upgraded communications and missiles integrated into a new Combat Management System.

Industrial cooperation and global export opportunities

The HCM overall program included more than 30 companies that worked together closely with the Government of Canada to deliver a first-class capability, on time and on budget. This program was a highly complex and collaborative effort between the Department of National Defence (DND), the RCN, and Canadian shipbuilding industry partners, and has delivered robust economic benefits to Canada.

Multiple competitive processes were put in place to select various contractors through open, fair, and transparent procurement processes for this complex work package. In March 2008, Irving Shipbuilding Inc.'s Halifax Shipyards on the East Coast and Seapsan's Victoria Shipyards on the West Coast were selected to conduct the refit work on the fleet. In November 2008, Lockheed Martin Canada was selected and awarded a contract for the Combat System Integration (CSI) work.

The modernized frigates will serve the RCN for years to come. The overall management and success of the program has proven to be a partnership model for future shipbuilding projects, and has been recognized internationally. For example, DND assisted the New Zealand Ministry of Defence with their decision to upgrade the combat systems on their ANZAC-class ships.

DND provided valuable information to New Zealand on the Combat Management System, installed as part the HCM/FELEX program, and shared our modernization experiences to date. This global export opportunity is the result of the close collaboration between DND and industry.

Project breakdown

The Halifax-Class Modernization/Frigate Life Extension project and other separately-funded projects within the HCM program have brought enhanced capabilities to the ships, which are required to meet the new threats and changing operating environments. These include:

Halifax-Class Modernization/Frigate Life Extension

- New Combat Management System;
- New radar suite;
- Interrogator Friend or Foe (IFF) Mode S/5;
- Internal communications system upgrade;
- Harpoon surface-to-surface missile system upgrade; and
- Electronic warfare system upgrade;

Other HCM projects

- Long-range infrared search and track system (SIRIUS);
- Modification to the BOFORS 57mm naval gun;
- Replacement of the Shield II missile decoy countermeasures system;
- Replacement of the integrated machinery control system (IMCS); and
- Replacement of the navigation radars.

Many maintenance and sustainment activities, and projects, strive to maintain equipment at current levels of capability through the execution of intense preventive, corrective, and unique mid-life maintenance activities.

Several follow-on, stand-alone contracts have been let outside the Halifax-Class Modernization/Frigate Life Extension project to complete other needed upgrades, such as accommodation for the Cyclone Maritime Helicopter, and the new Military Satellite Communication System.

Conclusion

Planning, preparation, and coordination of the HCM/FELEX project began in 2002. The first modernization refit began in September 2010 with HMCS *Halifax,* and each refit period was expected to take approximately 18 months, with the testing and trials expected to take approximately an additional nine to 12 months. The final ship upgrade and corresponding sea trials are expected to be completed in the 2018 time frame.

There remain further maritime capability projects that will complement HCM. These include the operationalization of the *Victoria*-class submarines; the integration of the Cyclone CH-148 helicopters; the modernization of the Aurora long-range patrol aircraft; and the purchase of Arctic Offshore Patrol Ships, Joint Support Ships, and Canadian Surface Combatants.

HCM: A Successful Program

By Cdr Steve Whitehurst
Systems Engineering Manager – PMO HCM/FELEX

As the *Halifax*-Class Modernization program and HCM/Frigate Life Extension (HCM/FELEX) project are in their final stages, we can declare success. This is not to say they were without challenges, or that the final outcome exactly matched what was envisioned at the outset, but it is important to consider the factors that enabled this positive outcome. This article will provide background on the HCM program, highlight key challenges, describe the decisions, approaches and innovations that paved the way to success, and discuss some of the significant capability improvements that HCM delivered (and will yet deliver) to the Royal Canadian Navy.

This special edition of the *Journal* has several articles on topics related to HCM discussed by the subject matter experts who led these specific capability areas to success. The HCM/FELEX Project Management Office (PMO) team took ownership of many issues outside of the direct scope of the program in order to address schedule and performance risks that could impact HCM's overall success. Whether a direct project deliverable or not, the professionalism and enthusiasm with which members of the PMO team managed these technical challenges was impressive. The pride that these professionals have for their successes and for the capability delivered directly to the Navy is evident in the articles they have written.

HCM Background: Initial Challenges

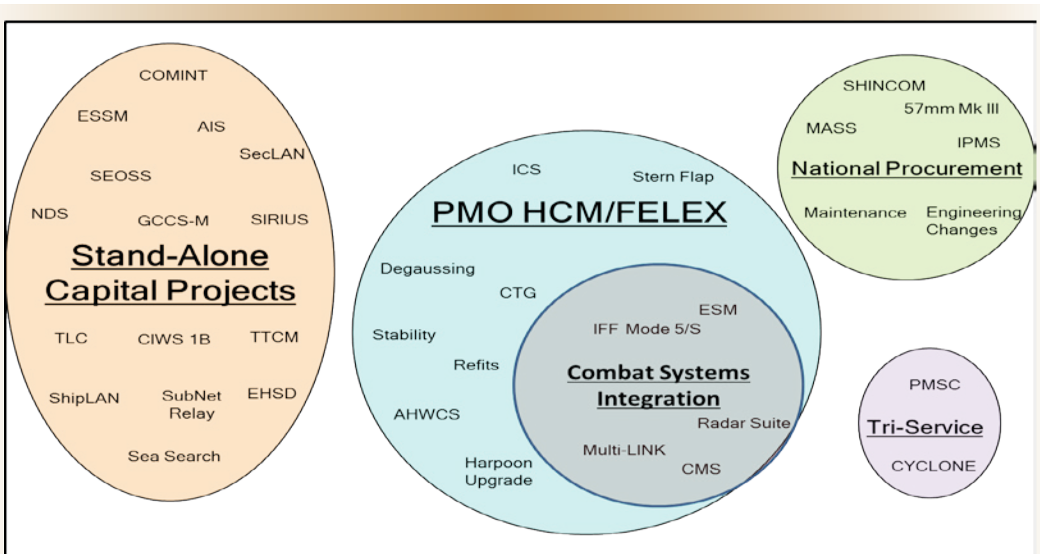
In its simplest form, the goal of HCM was to modernize the *Halifax*-class combat systems while simultaneously coordinating the planned mid-life maintenance period for each ship. As these maintenance and modernization periods were longer than normal docking work periods, a deliberate approach to planning the inclusion of significant engineering changes such as the Integrated Platform Management System and many others was also implemented.

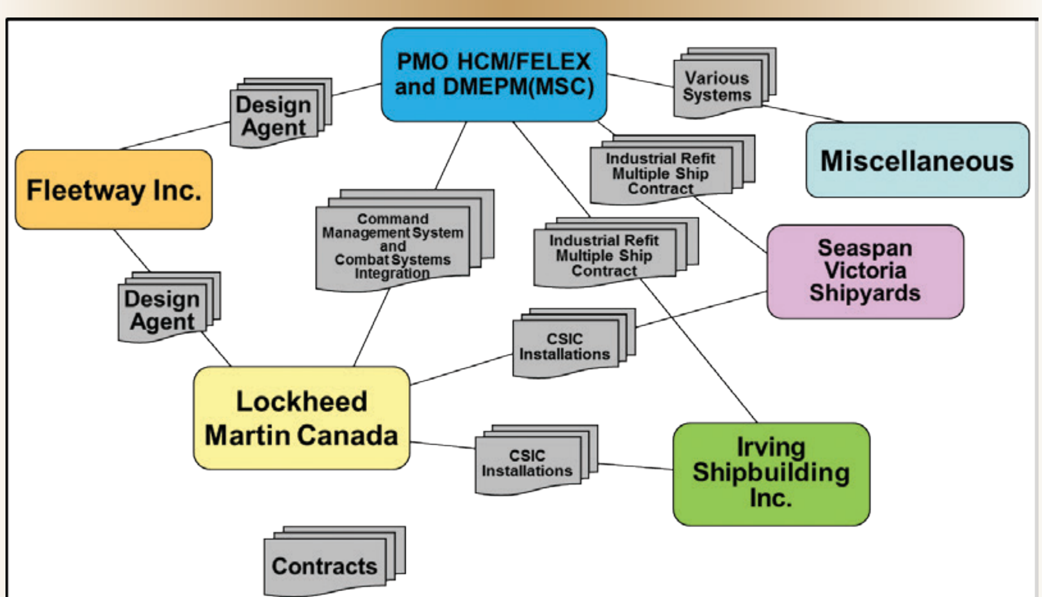
Although this article is not meant to provide the complete history of HCM, it is important to highlight some of the initial conditions and limitations that were established at the outset of the implementation phase. While this article will focus on the combat systems integration (CSI) contract, which is a large group of engineering changes within the overall HCM program, it should be noted that the program operates in an environment of complex relationships with industry established via a network of contracts between various stakeholders with competing priorities. Of note are the competing priorities placed upon the shipyards and the design agent that are being asked to satisfy two customers simultaneously – DND in the form of the PMO, as well as Lockheed Martin Canada, the combat systems integrator.

Specifically, for the combat systems integration (CSI) contract, in project management terms, all three sides of the triangle (scope, schedule, and cost) presented significant risk as HCM entered implementation. With regard to scope, there was a relatively late decision to change the approach from a traditional contract with thousands of requirements and a prescriptive statement of work (SOW) to more of a performance-based contract. Although the number of requirements was reduced and a statement of objectives created, a prescriptive SOW was retained, and the time provided to the team was insufficient to completely transform the contract documentation. The result was pseudo-performance requirements that resulted in a high degree of ambiguity for both the contractor and the PMO. However, the CSI Performance Specification (CSIPS) established the functional capabilities that were required. Contract management became objective-based where the objectives were defined by a series of milestones based on the performance specification and prescriptive SOW. This approach was incentive-based, similar to performance-based contracts. The milestones incentivized the contractor to achieve scope and schedule objectives.

As for the schedule, there were limitations placed on the program from the outset. As the program began to take shape, it was realized that delays to the schedule would push the refits too far beyond the mid-life time frame of the *Halifax* class. In addition, any delays would result in a reduction in the number of platforms available to the

HCM Program Scope





Contractual Relationships

Navy for force employment purposes. For these reasons, HCM was required to emphasize the importance of remaining on schedule. Each ship was limited in the amount of time available for modernization activities, and the overall program was required to maintain its planned end date. The development and implementation phases were therefore constrained, and extending the program was never an option when issues arose. This tight schedule prevented a lead ship approach from being considered in order to mitigate the scope risk discussed above. Finally, due to the competitive bid approach, the fixed-price contract, and the significant development work required, there was risk that the contractor would be encouraged to minimize efforts where possible, and that they would be faced with a significant challenge to deliver on all requirements.

The Path to Success

It was the early recognition of these initial conditions that resulted in the PMO implementing specific governance initiatives aimed at overcoming these challenges. The primary goal was to ensure that the contractor saw the benefits of collaboration. A simple step taken in this direction was the alignment of milestone payments with the priority outcomes. Open communication at the top levels permitted this alignment as well as the possibility of continuously readjusting the payments as required to keep the contractor's focus aligned with DND's priorities.

Another important change, which permitted the open communication discussed above, and which was the foundation for the collaborative working environment, was a governance structure focused on relational contract management. Although there remained the standard working relationships between subject matter experts and at each of the management levels, an even higher level of governance was established to set the collaborative tone for the overall integrated team. Initially leading with a few "industry days," the governance with industry partners became more formalized with the Canada Industry Integrated Project Team (CI IPT) meetings and the eventual addition of the Committee of Sponsors (CoS). The CoS was comprised of ADM (Mat), the Commander of the Royal Canadian Navy, an assistant deputy minister from Public Services and Procurement Canada (formerly PWGSC), and the presidents of the primary contract companies (CSI and shipyards). A significant accomplishment of this body was the agreement on a common vision that committed each organization to focus on the overall success of the HCM program, thereby creating a team approach that is leveraged to this day.

A key realization during the early stages of implementation was that incremental delivery of capability was essential. The contractor's initial intention was to deliver the complete solution with the first ship using a single software build, and First Article Acceptance (FAA) being verified and declared based on the first testing cycle. Due to the complexity of the program, this approach would have been unfocused, and likely to fail. Not only would this present a significant challenge to the contractor with respect to the scope being delivered in a single software build, but it would have been a substantial task for the DND test and trials team to verify all of the requirements in a shortened period of time.

Additionally, this delivery approach allowed for no margin of error. In the event that the initial build failed to achieve its aim, the program would have been forced to delay the declaration of FAA. Also, certain software design decisions would have had to have been made to meet schedule timelines. These decisions could have made the recovery of a failed build difficult and costly, which in turn would have led to delayed milestone payments to the contractor, negative media coverage, and potentially additional management oversight.

Instead, a build-a-little/test-a-little approach was taken where FAA would not occur until several ships had been delivered. At the highest level, software delivery was divided into phases that provided increased operational capability with each step. At first, situational awareness was the focus. Then efforts turned to tactical operations, and finally tactical execution. As the system gradually increased in capability and complexity, the testing program evolved with various missile firing events with amplified sophistication. As the program was approaching the significant contract milestone of FAA, the contractor and the PMO maintained focus on operational capability and delivering a system that was acceptable for operational use. In order to achieve FAA, the contractor was required to meet an established level of capability. The remaining deliverables would be scheduled for delivery in advance of Final Operating Capability (FOC).

This software delivery approach allowed for focused development and testing. In addition, by implementing this incremental delivery approach, milestone payments could be aligned to each delivery, thereby removing some cash flow risk from the contractor.

Although DND's relationship with the contractor was important, it was not the only affiliation that was essential to program success. The program's relationship with its customer, the RCN, is also notable. There are several levels of oversight provided by various flag officers within the Navy, up to and including the Commander of the RCN as part of the Committee of Sponsors. It was the close relationship with and dedicated involvement of the project director (PD) and his staff that ensured the RCN oversight was well managed. The benefits here were threefold. First, by having such a strong and committed PD team, the PMO and contractor were able to benefit from having immediate feedback from the eventual customer on a wide range of issues. This ensured that the overall team maintained focus on priority areas and avoided wasted effort on less important issues. In addition, there was less effort required on behalf of the PMO with respect to meeting the needs of RCN oversight as the PD was a trusted agent of the RCN senior leadership. Finally, PD involvement in the verification allowed a double sign-off to take place. Both the PMO and the PD concurrently accepted the verification results and reduced PMO work in requirement verification.

Another factor that contributed to the collaborative working relationship between the contractor and the PMO was the establishment of DND on-site managers (OSM). On each coast, a small OSM team was able to develop a strong working relationship with the contractor. This provided an important communication link between the contractor and the PMO as well as the Formations. The OSM teams were often able to assist the contractor by identifying the challenges impeding their progress, and by finding ways to remove these obstacles.

Perhaps the most important lesson that can be learned from the HCM experience with regard to complex project management is the ability to compromise. With such a long-term complex program, a DND focus on the black and white words of the contract would have likely resulted in several negative outcomes. First, DND would lose any flexibility to achieve more results in key areas. While there was a contract in place, it was not the first point of reference when challenges were encountered. Rather, teams focused on what was right for the program and where changes were required. The contract was enabled to cover those decisions. By refocusing the work and evolving the contract to align it to the most significant elements of the undertaking, the project was able to deliver on time and on budget. Second, in areas where the initial requirements were poorly written or vague, DND would have quickly found itself at an impasse with the contractor if both parties were inflexible. In order to execute an effective ability to compromise, HCM ensured that a process was in place for rapid issue escalation, thereby providing resolution and feedback to the contractor in a timely manner rather than keeping them waiting for a decision, which would only have resulted in schedule delays.

Although HCM has recently declared FAA, there is some final scope yet to be delivered. Several derived requirements are being explored – enhancements that will be focused on delivering added capability to the RCN such as infrared cameras, laser range-finders, uninterruptable power supplies, and additional training. In addition, effort is ongoing to equip the fleet maintenance facilities with the necessary tools, documentation and training to support the new CSIC systems. Finally, the PMO will ensure that a significant quantity of spares is acquired in order to ensure the systems are well supported in the near to medium term. While the program moves toward FOC and project closeout, it is important to ensure that a smooth transition occurs with the in-service support teams. Information and knowledge transfers will take place to ensure that support for these new systems will continue seamlessly as HCM comes to an end.

The results speak for themselves: a complex program delivered on time and within budget. While there is still much to do before HCM can close its books, it is time to declare success. Although it is understood that the decisions and approaches taken by the PMO enhanced the program's likelihood to achieve success, it must be noted that it is people who make the difference. In this case, the credit goes to the broader community of stakeholders that all played a role in influencing the results.

Within DND, the support and commitment of senior leadership, the issue resolution skills and collaborative approach of the coastal Formations (including MARLANT, MARPAC, Directorate of New Capability Insertion, the Fleet Maintenance Facilities, Base Logistics, and HCM/FELEX CSI on-site management team, and Multi-Ship Contract detachment teams), and the dedication and responsiveness of supporting agencies such as the Directorate of Naval Combat Systems, Directorate of Naval Platform Systems, Canadian Forces Naval Operations School, Canadian Forces Naval Engineering School, Sea Training (A), Sea Training (P), Directorate of Maritime Management and Support, Naval Personnel Training Group, Directorate of Military Careers, Canadian Forces Maritime Warfare Centre, Naval EW Centre, Naval Engineering Test Establishment, Quality Engineering Test Establishment, and Defence Research and Development Canada, all played key roles in this success.

Finally, I would like to acknowledge and thank Dave Monahan, Paul Daniel, and Henry Eng for providing me with a historical perspective of the early days of HCM, thereby allowing me to include some of these details herein.

Halifax-Class Modernization – Where did it begin?

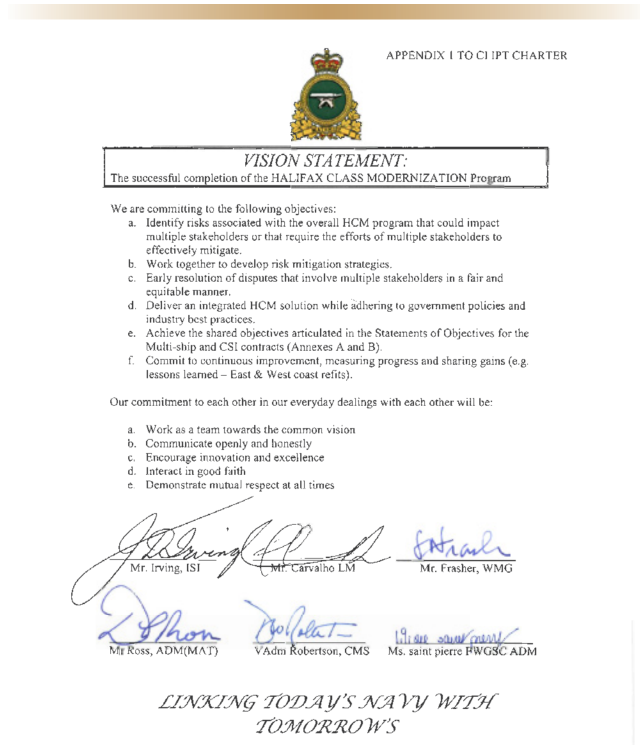
By David Brenner – former *Halifax*-class Naval Requirements Manager, PMO HCM/FELEX Integrated Schedule Manager, and Integrated Test & Trial Manager and by Paul Daniel – former PMO HCM/FELEX Ship Management Office Engineering Manager

Early Days and Options Analysis

The 12 *Halifax*-class ships were commissioned between 1992 and 1996 and became the "workhorses" of the Royal Canadian Navy over the ensuing years. As part of the overall concept for the class, there was recognition that a mid-life upgrade would be needed to ensure that equipment obsolescence and evolving threat environments could be addressed. With a planned lifespan of 30 years, the mid-life time frame was 15 years after delivery and commenced in 2007. In fact, the planning to address this mid-life upgrade was started quite early with the identification of the *Halifax*-class Systems Upgrade Project in March 1993. This project's objectives were to:

a. rejuvenate aging systems with credible and capable equipment to meet Canada's present and future needs;
b. exploit the results of Canadian research and development; and
c. provide long-term corporate and industrial benefits for Canadian industry.

A mix of significant engineering changes, and maintenance activities, was acknowledged as being necessary to address the mid-life objectives for the class. In recognition of the risk exposure associated with execution of the upgrade program, the Frigate Life Extension Project (Project FELEX), approved in 2002, would be responsible for the overall design integration, coordination, and implementation, while managing on all aspects of risk and issues. In addition, the various capability change objectives were articulated in a non-project Statement of Requirements approved in 2003 as the *Halifax*-Class Modernization (HCM) program.



APPENDIX I TO CI IPT CHARTER

VISION STATEMENT:
The successful completion of the HALIFAX CLASS MODERNIZATION Program

We are committing to the following objectives:

a. Identify risks associated with the overall HCM program that could impact multiple stakeholders or that require the efforts of multiple stakeholders to effectively mitigate.
b. Work together to develop risk mitigation strategies.
c. Early resolution of disputes that involve multiple stakeholders in a fair and equitable manner.
d. Deliver an integrated HCM solution while adhering to government policies and industry best practices.
e. Achieve the shared objectives articulated in the Statements of Objectives for the Multi-ship and CSI contracts (Annexes A and B).
f. Commit to continuous improvement, measuring progress and sharing gains (e.g. lessons learned – East & West coast refits).

Our commitment to each other in our everyday dealings with each other will be:

a. Work as a team towards the common vision
b. Communicate openly and honestly
c. Encourage innovation and excellence
d. Interact in good faith
e. Demonstrate mutual respect at all times

Mr. Irving, ISI — Mr. Carvalho LM — Mr. Frasher, WMG

Mr Ross, ADM(MAT) — VAdm Robertson, CMS — Ms. saint pierre FWGSC ADM

LINKING TODAY'S NAVY WITH TOMORROW'S

Definition Phase

In 2006-2007 a risk assessment conducted by the project leader identified a number of significant risks associated with the execution of individually managed capability insertion projects. First, since each of the stand-alone projects was proceeding individually through its own development and approval process, they would not all be ready for implementation within the same time frame. Furthermore, the interdependencies of the individual projects from an integration point of view (for both hardware and software) brought complexities and risks that were well beyond the mandate of the individual projects themselves. In the same vein, the impact of the implementation of all of the change activity for the HCM drove a set of derived requirements at the platform level. Design integration in areas such as the mast and operations room, as well as impacts to ship margins for weight and stability, electrical power distribution, and chilled water meant that a much more coordinated and holistic approach was needed to manage the risks.

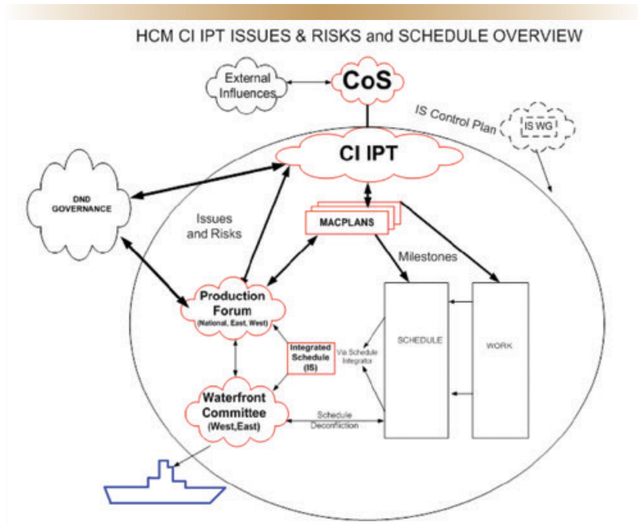
Thus, in 2007 the HCM/FELEX project was approved with the overall mandate to coordinate, manage risk, and implement HCM. Five large projects: the *Halifax*-class Modernized Command and Control System Project; the Radar Upgrade Project; the Identification Friend or Foe Project; the Multi-Link Project, and the Electronic Support Measures Replacement Project were combined into a single bundled requirement. In recognition of the new scope, Project Management Office (PMO) FELEX was reorganized into a larger project, PMO HCM/FELEX. In order to accomplish this mandate, the new project was given the task of putting in place a single combat system integration (CSI) contract, as well as shipyard contracts to install the engineering changes and conduct the needed maintenance activities.

Concurrent with the definition work, communication with industry was started in late 2004. Between 2005 and 2007 a series of focused Industry and Canada "Industry Day" working groups were held to support information sharing and development of the procurement requirement. The goal was to establish the framework behind the relationships that would be needed to ensure smooth running of the various components of the modernization program. During this period a common vision and language were created collaboratively among the working group participants that would be inserted into the eventual contracts to support the future governance objectives. At contract signing, all participants committed to the Canada-Industry Integrated Project Team Charter and Vision document.

What became known as the Multi-Ship implementation shipyard Contracts (MSC) were awarded in March 2008 to Irving Shipbuilding on the East Coast, and Victoria Shipyards (Seaspan) on the West Coast. In November 2008, Lockheed Martin Canada was awarded the combat system integration contract, and the modernization program commenced implementation.

Implementation Phase and the Emergence of Governance as a Key Enabler

At the highest level of the Canada-Industry governance, a Committee of Sponsors (CoS) was established to provide leadership and overall coordination of key program objectives. The CoS was co-chaired by Commander RCN and ADM(Mat) and attended by chief executive officers (CEOs), or their representatives, of the principal industry partners involved in the HCM program. The CoS received an overall appreciation of the program status, endorsed the various Canada-Industry risk mitigation efforts, and provided the leadership within their respective organizations to enact these measures. Subordinate to this governance was the Canada Industry Integrated Project Team (CI IPT) comprised of senior leadership and project managers from government and industry, as well as senior military participants representing the project sponsor organization (see diagram). Early in the life of the CI IPT governance, this body was challenged to solve a major issue – the dual accountability of HCM work: those elements of scope managed by ADM(Mat); and those under the responsibility of the combat systems integration contractor Lockheed Martin Canada.



Serial Workflow

The CSI contract awarded to Lockheed Martin Canada included responsibility to implement, with a shipyard of their choice, the combat system upgrades. Thus, ADM(Mat) would execute the maintenance and non-CSI engineering changes under the MSC contract, then transfer custody of the ship to LM Canada who would execute the CSI work, potentially at a different shipyard, and then complete acceptance trials with the PMO, after which the ship would be returned to the Navy. These serial shipyard activities were estimated to require 12 months, six months, and 12 months respectively. Once it became apparent that LM Canada had chosen the same shipyards for their work, the opportunity to further compress the schedule was identified under a combined ADM(Mat) and LM Canada contracted refit with the shipyards.

Thus, in July of 2009, the PMO and industry counterparts locked themselves into a room and, armed with markers and sticky notes, filled the walls with what would ultimately become known as the "Macro-Plan" or MACPLAN for how the work would be sequenced over a 14-month period. The MACPLAN was ultimately endorsed by the CI IPT and at the Committee of Sponsors, and formed the keystone planning document for the modernization program. It also identified the need for the governance body to coordinate the execution of the blended workflow plan. Since those initial days, this governance was employed to address key issues and risks that were impacting the HCM program. As you will read throughout this special edition of the *Journal*, in almost every case it was the governance and foundational vision that were key to overcoming the challenges.

Requirements Writing and HCM/FELEX: "Begin with the end in mind"

By LCdr Amit Bagga
Combat Systems Test and Trials Coordinator – Halifax-Class Modernization Project

Approaching requirements writing with the "end in mind" captures the need to always maintain at the forefront the inevitable compliance phase of a project and the product acceptance process. A holistic view toward requirement writing permits us to leverage performance specification concepts and incentive-based contracting, and fosters positive defence-industry work relationships. This proverb also refers to the absolute need for requirements – and the path to their fulfilment is to always refer back to the people, and the respective processes they underwent to achieve the intended real-world operational capabilities.

As the HCM/FELEX project prepared to embark on the great challenge of achieving the First Article Acceptance (FAA) milestone in the fall of 2015, this philosophy was paramount in that it enabled what was an immensely successful industry-defence partnership exercise: The joint examination of over 900 requirements, and a review of a substantial amount of objective evidence data with only a few months to correctly bring them to closure. It is necessary to affirm that most program and requirement compliance challenges are surmountable with effective industry-defence liaison, and this article will describe the various HCM/FELEX challenges, successes, and lessons learned related to the FAA acceptance process, and the path to requirement compliance.

The Path to FAA

For HCM/FELEX, First Article Acceptance represented design acceptance, and the completion of an extensive volume of test and trial activities and objective evidence deliverables, all amassed and categorized as per their linkages to the requirements. The accumulation of data from six ships' worth of trial reports and design documents was impressive, yet daunting from a review and acceptance perspective. Added to this mix was a significant amount of operational data gathered from years' worth of missile exercises, air-defence exercises, operational capability checks, and deployment feedback, all of which were invaluable in demonstrating our readiness to achieve the critical FAA milestone.

Evolution of requirements writing in relationship managed contract

The primary challenge in commencing the requirement acceptance process is relating it to the available objective evidence. To do so, one must first establish a comprehensive understanding of the requirements first principles, specifically their original intent as derived from the Statement of Requirements (SOR), the High Level Mandatory Requirements (HLMRs), and the broader context of end-to-end baseline performance and design. In assessing the requirement against available objective evidence, one not only refers to original design intent, but also to these first principles to re-establish whether the requirement had been properly assembled and referenced given the challenges of proving compliance in the live environment. According to the Vice Chief of the Defence Staff directive on requirements first principles, they must be traceable, attainable, verifiable and complete. Moreover, they need to be visionary, and leverage to the greatest possible extent the technology forecasts of the best design concepts. At the same time, requirements must have direct and unambiguous links to operational needs, and be grounded in what is achievable, being mindful of the risk to cost and schedule overruns.

For HCM/FELEX, the challenge of managing the Combat System Integration Performance Specification (CSIPS) was represented by the momentous task of initially synthesizing and consolidating upward of 10,000 requirements. Dedicated focus groups eventually brought this number down to a more manageable, but still substantial, 3680 requirements. With the tall order of requirements writing in mind, the natural tendency is to progressively increase the number of requirements as the complexity of technology evolves, offering enhanced performance. At the outset this would appear to have the intended result, but it inevitably becomes quite challenging when taking into consideration the need for clear original design intent, and managing the ever-critical linkages back to the SOR. Furthermore, no matter how unambiguous a "shall, will or must" statement is written, the imperfect reality of implementation will inevitably result in deviations. Whether these challenges are real or perceived, they ultimately stress the importance of industry-defence partnerships and the need for innovative thinking by both parties, particularly in the areas where system performance has evolved from the time of the Critical Design Review. This was the case leading up to HCM/FELEX FAA, where numerous compliance impasses were jointly discussed in the context of original intent and the reality of implementation. Innovative and flexible approaches were developed to segment and categorize observations that enabled the teams involved to remain focused on capabilities, and address the pertinent gaps via a capability focused CF-1148 Report of Inspection list. Project requirements are, after all, only contractual tools for interpreting, developing, and implementing performance baselines, not the end result in themselves.

Achieving Timely Critical Capabilities

In a highly complex software integration project utilizing commercial off-the-shelf (COTS) equipment, the spiral developmental process becomes a relative necessity. Within this new reality, achieving a configuration-managed product baseline can require numerous iterations and regression testing to attain and validate critical design steps. Under tight complexity and operational constraints, the iterative project can become burdened by the contractual formality of factory acceptance tests (FATs), harbour acceptance trials (HATs), and sea acceptance trials (SATs). Naturally, these formal activities need to proceed on time such that milestones can be achieved on schedule, so how then does an iterative project demonstrate the requisite performance in formal activities while capabilities are still being developed? While in the midst of RCN preparations for the first modernized frigate, and while addressing decision points to send the remaining ships into mid-life refit, the trial teams developed an innovative framework of system capability assessments based on the CFCD 129 Naval Readiness and Sustainment Policy. Together with the creation of operational capability checks, many partially achieved functionalities and features were synthesized into rudimentary capabilities that could be readily understood and employed by the fleet.

The need for the HCM/FELEX operational capability checks was readily apparent within the complex framework of ship integration, and by the need to validate end-to-end performance. This became particularly salient when considering that the requirements for the detect-to-engage sequence were the result of hundreds of requirements coming together seamlessly and simultaneously. This reality along with the experiences gained to understand, interpret, verify and assess capabilities in a more direct and operational way was also a principal strategy leading up to FAA. At this advanced juncture our acceptance process had matured, and requirements assessments were more about real-world scenarios, operator feedback, and the cumulative effective of requirements, rather than the individual clauses that represented them. In this way, it was not abnormal for lower-level requirements to be deemed divergent from a higher capability that had already been proven. This was a key lesson learned from the formality of early contract deliverables and the mechanical process of conducting FATs, HATs and SATs. The pragmatic approach of system capability assessments toward requirements and acceptance management would ring true for a project of any size at any point in its acceptance process.

The machinery control room (MCR) on board HMCS *Ville de Québec* prior to refit.

The Criticality of Critical Design Review

A notable challenge with progressing requirement acceptance is understanding the effects of change management. Using an extensive process of waivers and deviations, engineering change requests, and contract change proposals, it can be easy to get drawn down into individual system assessments and contractual terminologies without really relating things back to original design intent, the engineering trade-offs presented, and their respective operational effects.

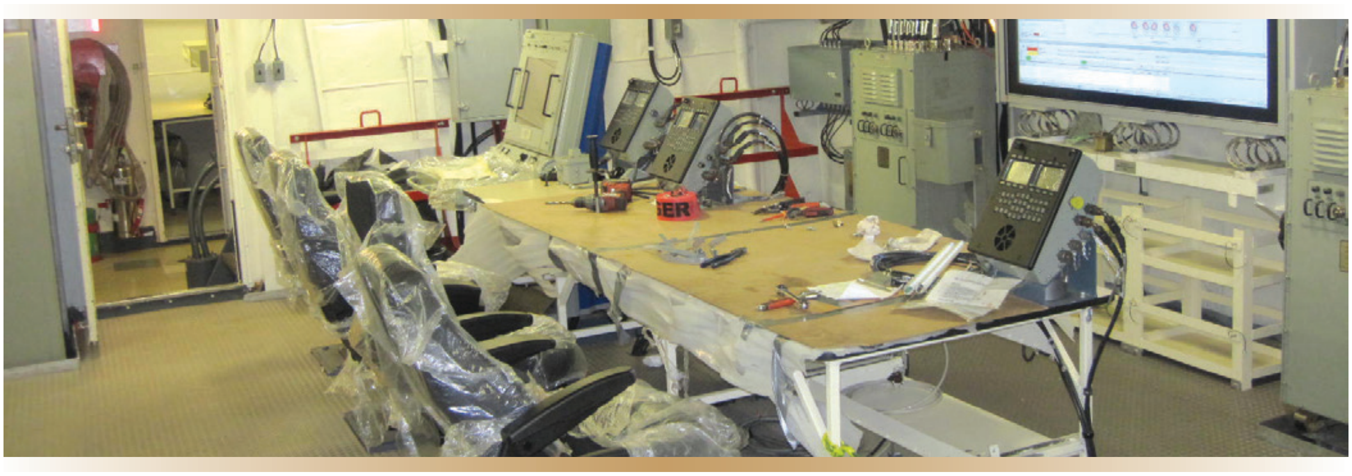
Beginning with the end in mind also refers to the absolute primacy of Critical Design Review, and its ongoing importance throughout development, trials, and compliance assessments. The importance of understanding requirements in the context of these initial decisions is most essential since, from this point on, implementation constraints and limitations will continuously affect the form, fit and function of the systems, and ultimately their acceptance. No doubt the far-reaching effects of Critical Design Review are difficult to foresee at the time, but they remain especially relevant, particularly for second-order effects of complex system integration as seen in such areas as environmental engineering, materials usage, HVAC, and equipment transportation requirements. Going down a particular design and technology path brings with it unintentional trade-offs, and these need to be investigated and understood from an operational and engineering standpoint before design decisions are made.

Requirements in View of Validation Limitations

To validate our requirements at the more extreme ends of the envelope, and reduce ship risk and loading, many requirements were validated at the Land Based Test Site. Within the context of the synthetic environment, and the high fidelity necessary for the validation of end-to-end performance, we inevitably came across limitations due to the confines of testing under lab conditions. Likewise, testing in the live environment was also constrained given practicality margins. These constraints could have led to testing deviations that could have resulted in costly investigations, and in the need for extrapolation arguments to the requirement's compliance argument reflective of the more extreme conditions present in operational theatre. The situation was equally true for requirements that affected COTS equipment, given that quoted military standards might not apply, and mismatches might exist between testing standards, OEM specs, and anticipated outcomes based on operational experience. Beginning with the end in mind instilled in us the awareness to develop requirements in a way that enables their assessment within the practical limitations of the synthetic and live environments, while leveraging alternative validation modes including modelling wherever possible.

The HCM Statement of Requirement

When it comes to requirements in performance-based contracts, we are cognizant of the need to describe capabilities and requirements while refraining from addressing the solution in the steps leading to the Request for Proposals



The same space in HMCS *Charlottetown* following refit.

process. This concept remains vital from the requirements acceptance and closeout perspective. During the acceptance process leading up to the initial operating capability (IOC) and FAA milestones, it was always important to keep in mind the high-level, end-to-end performance and mission capabilities, as opposed to attaining specific solutions or design characteristics. This was particularly relevant given that a complete mapping of product requirements for the SOR was never fully achieved. Subjectivity ultimately results in more debates and adds complexity during compliance assessments. Satisfaction arguments related to the requirements need to be specific as to intent, such that judgment calls can be made within the spectrum of reasonable applicability to available objective evidence.

Within this context, the process of capability attainment and SOR achievement was particularly acute when completing design and testing at the Land Based Test Site. While the value of the site was essential to HCM, and will certainly pave the way for future platform acceptance activities, it is important to remember that the limitations of simulators, stimulators and emulators in comparison to the highly complex and integrated environment of a modern combat management system. Program managers and directors must therefore be cognizant of synthetic environment limitations and the need for additional operational checks to gauge success against the SOR. For HCM, the conduct of more than 10 operational capability checks, and various deployments supported "as built" knowledge of the product's form, fit and function.

Conclusion

Requirement writing is a truly difficult undertaking. It is an art of generating capability by forecasting future threats (both technically and geopolitically) and using a mixture of science, engineering and, at times, gut instincts. Once developed, the change control and compliance assessments must always remain focused on the operational capabilities they are aimed to achieve, staying mindful of the real-world environment and long-term sustainment. In our HCM/FELEX project, attention to the timely achievement of operational capabilities was prevalent throughout the program, and by virtue of it being a 'no-fail mission,' it inherently created the momentum to propel the acceptance process to fulfillment. The iterative process, while frustrating from a purist perspective, enabled periodic operational checks that brought new insights to the requirements.

No matter how many individual requirements a project has, the ability to routinely and regularly ascertain the achievement of real-world capabilities throughout the program is essential to closing the gaps and reaching project success. In our project, this was achieved by the effective use of such tools as the system capability assessments, operational capability checks, and novel compliance status categories that enabled a dynamic and forward-thinking acceptance process. Furthermore, the ability to understand the original requirement intent via well-articulated satisfaction arguments was paramount, especially for a program like HCM FELEX that can span many years, and where HR transitions can affect continuity. Finally, in a performance-based program with strong industry-defence partnerships and a large amount of complex integration requirements, the trials program must remain flexible as a means to end, rather than as an end in itself. It is, after all, the operational capability that is being sought, and it is this that should be encouraged over the need to simply meet contractual obligations.

Integrated Logistic Support – Critical Through-life Support

By LCdr Rob Waller – CSO-6 ILS Systems Engineer PMO HCM / FELEX

Whether you aware of it, as engineers and members of the RCN, you rely on integrated logistic support (ILS) on a daily basis. ILS is one of the least understood areas of project management, less sexy than procurement, installation, or testing, but is critical to through-life support and transition to in-service. By its very nature it crosses all boundaries, and as such connects with all aspects of a system or project.

Within the HCM/FELEX project, managing all of the ILS deliverables (spares, planned maintenance routines, Canadian Forces Technical Orders, test equipment, maintenance strategy, obsolescence, and transition) requires several subject matter experts working full time with many external stakeholders with the end goal of providing the maximum operational availability to the RCN in supporting Canada's mandated missions. Much like oversight, ILS can sometimes feel like herding cats.

Given its monstrous scope, I will only discuss a few interesting elements. In this article I will speak to the Maintenance Requirements Review (MRR) process, as well as managing Combat System Integration Components (CSIC) sparing levels, and the challenge of keeping the bins filled.

When the Combat System Integration Design and Build (CSI DAB) contract was awarded in 2008, the DGMEPM-supported maintenance strategy for HCM/FELEX and other HCM engineering changes was to move toward a "first-line to third-line" strategy. In 2009, during an HCM oversight committee governance meeting the deputy chief of staff for HCM briefed the concerns of the fleet maintenance facilities (FMFs) that the maintenance strategy did not include them as a strategic enabler for providing through-life maintenance support for the *Halifax* class, and thus represented a risk to operations whenever surge requirements arose. It was decided that this concern was valid, and the MRR was created as a process whereby the PMO would work in concert with the FMFs and the Directorate of Naval Combat Systems (DNCS) to determine what second-line capabilities could be completed by the FMFs rather than an in-service support contractor, and would represent a positive cost benefit over the life of the system when juxtaposed with the initial procurement costs.

An MRR governance structure was formed soon after with key members being from the Combat Systems Office, DNCS and the FMFs on both coasts. An MRR steering committee at the section head level would discuss the findings and proposals for each CSIC system, while the MRR oversight committee would be the director-level approving body for the MRR options before implementation could proceed.

The first step in the MRR process was to understand what second-line capabilities existed for the different systems. This was achieved through site visits to the individual OEM facilities for the different CSIC systems where the equipment, tools, and training were understood, and what scope would be feasible within FMF's existing skillsets. Once the site visit was finished, a detailed report was submitted by the OEM, outlining different options for FMF second-line support, including the associated costs, training, and material requirements. From these findings a business case was produced for review and approval by the oversight committee, based on recommendations made by the steering committee as the most cost-effective solution and/or representing a coastal strategic capability desired by the RCN. In most cases, the options being approved represented test equipment that allowed No Fault Found

(NFF) testing. In a first-to-third-line maintenance strategy, all defective parts are shipped to the OEM for repair or replacement. Based on the onboard training and testing capability, approximately 10 percent to 30 percent of the material that is returned to the OEM isn't damaged, and is quickly "repaired." In these cases the customer is charged, regardless. Having a second-line able to identify NFF cases would avoid these charges.

As of the release of this special edition of the *Journal*, two of the nine MRR solutions have been fully implemented (i.e. equipment installed, initial training completed, documentation and spares delivered), with the aim of completing as much as the remainder as possible prior to HCM/FELEX full operational capability (FOC). Much like the hybrid approach being pursued by the naval in-service support initiative, the net result of the MRR is a shared responsibility between the in-service support contractor (ISSC) and FMF that provides an overall cost savings to Canada, effective employment of our strategic enablers – that is, the FMFs – and shortening the troubleshooting "OODA loop" decision cycle that translates into a more technically available warship.

Another ILS challenge that has impacted a majority of HCM and RCN stakeholders is the initial sparing strategy for the combat systems integration (CSI), and how those initial assumptions led to difficulties over the past three years in making sufficient material available for supporting operations. The original concept for procurement of initial spares was to err on the side of caution and buy a smaller quantity of spares such that failure data could be gathered over the two years leading up to in-service support, and a more accurate Logistic Support Analysis Report (LSAR) could ensure the correct number and type of spares material be procured. The primary intent was to minimize cases of buying material that would sit on a shelf for 20 years and never be used. While the concept works in principle, it was identified early after contract award that the amount of material that DND asked LMC to deliver would be insufficient. A collaborative discussion between PMO, DNCS and LMC occurred in 2013 to assess what the delta should be between what is needed to support operations, and what was already scheduled to be delivered.

At the time, other parallel ILS issues made it challenging to identify the scope of what was needed. Specifically, large-scale cataloguing efforts required in the Defence Resource Management Information System (DRMIS) once material was delivered made it very difficult to know for certain what material the RCN held. Once the list of material was identified, a series of contractual vehicles was pursued to obtain the parts as quickly as possible. Depending on the CSIC system, standing offers, existing DNCS contracts with OEMs, new sole-source contracts, and competitive bids were used. Because of the complexity, long lead times, and the normal procurement processing challenges, several contracts took longer than expected to be let, causing delivery schedules to extend out to late 2017. As operational transition occurred on the first four ships in 2014, the year-long CSIC warranty started, and while material was returned for repair or replacement, only a small number of operational spares (made up primarily of the shipboard spares for future ships) was available to support operations.

During this time it became apparent that some material was failing at a rate greater than the OEM identified as the mean time between failures. Also, additional spares required for deployers was not factored into the original procurement, and delays in in-service support contracts being set up all contributed to the challenge of supporting the fleet. Due to the cumulative problem space, collaborative communication between the ships, PMO, N37s, the high-priority request (HPR) cells, and Base Logistics mitigated the issue where possible, but also led to an increase in material transfer requests from other ships (TRANREQs) to support operations. In some cases LMC provided their own material intended for mid-life refit installations in order to support the RCN's operations. An unintended benefit from this struggle was a reassessment (as a technical community) in articulating operational impact, and a more holistic approach by ships' heads of departments (HODs) in understanding that regaining technical capability sometimes comes at a cost to other units – either materially or through FMF production support – and striving for 100-percent technical readiness is not always the best solution for the fleet.

As the remaining in-service support contracts will not be available until 2019, additional measures are required to keep the stock levels replenished. A second operational imperative spares procurement is now underway to do just that. Through the conduct of recent sparing analyses using real failure data, forecasted requirements have been fine-tuned to reflect what is needed to support operations for the next three years. As well, this procurement is able to resolve past material issues, and create the correct baseline for material support.

The ins and outs of integrated logistic support will continue to be a challenging subject for engineers, but given the significance of ILS in delivering technical capability, its lessons are well worth learning.

Cyber Security and the Halifax-Class Modernization (HCM)

By LCdr Jennifer Waywell – IT Security, Combat Systems Office, PMO HCM/FELEX

Cyber Security: How is it relevant to Naval Engineering?

Computers are everywhere in homes and workplaces, and they are susceptible to virtual and physical attack. In the Canadian Armed Forces, there are strict regulations to ensure the security of information technology assets such as desktop computers and national networks, but how are warships protected from cyber attack?

Cyber security is the protection of information systems from threats to confidentiality, integrity, and availability.[1] Examples of these types of attacks are the theft of information, the unauthorized modification of a system or its data, and denial-of-service attacks on a system. With the advent of the 'internet of things' – the network of everyday objects such as household appliances, vehicles, phones, and buildings that are embedded with electronics and connected to the Internet – cyber security is becoming an everyday concern.[2]

In addition, cyber attacks on industrial control systems are becoming more frequent and more sophisticated.[3] These attacks are directed at networked control systems such as those in industrial plants, and may be used to disrupt service and threaten public safety (causing, for instance, power outages, fires, or train derailments). In the naval context, imagine a remote hacker who takes control of shipboard control systems, and who uses this access to take control of the ship's combat or marine systems. The attacker could then steal classified data, cause physical damage to shipboard materiel, deny access to critical systems, or use the systems to accomplish enemy goals (such as firing weapons, changing engine movements, or shutting down critical power or cooling).

Many nations have developed significant information warfare capabilities, and have the ability to conduct large-scale orchestrated cyber offensives in order to meet national objectives.[4] Information warfare is not only a

1. *Overview of IT Security Risk Management: A Lifecycle Approach (ITSG 33)*, Communications Security Establishment Canada, 1 November 2012.
2. Chris Clearfield, "Rethinking Security for the Internet of Things", *Harvard Business Review*, 26 June 2013.
3. Jim Finkle, "U.S. official sees more cyber attacks on industrial control systems," Reuters, 13 January 2016, at http://www.reuters.com/article/us-usa-cybersecurity-infrastructure-idUSKCN0UR2CX20160113.
4. Jonathan Racicot, "The Past, Present and Future of Chinese Cyber Operations", *Canadian Military Journal*, Vol. 14, No. 3, Summer 2014.

concern during naval operations; vulnerabilities can be exploited in the supply chain, during repair and overhaul, during ship refits, and in the disposal phase. Cyber security is therefore an important consideration for naval materiel throughout its lifecycle.

HCM/FELEX Information Technology Security (ITSEC) Challenges

Before HCM, the *Halifax*-class frigates followed information security procedures for the shipboard networks: ShipLAN (Shipboard Local Area Network) and the classified networks. These security procedures included Assistant Deputy Minister (Information Management) (ADM(IM)) Certification and Accreditation (C&A). The command and control system was comprised of specialized military equipment designed and configured only for this purpose, as were the majority of the weapon and sensor systems and their interfaces. These systems were managed in accordance with naval policies and naval engineering policies (such as weapons certification and configuration management), but they were not subject to the information security policies applied to information technology (IT) equipment.

The modernized *Halifax*-class frigate has undergone significant upgrades to the combat suite. Many components of shipboard systems are now commercial-off-the-shelf (COTS), which can increase their vulnerability to attack. The CMS-330 combat management system is largely comprised of COTS equipment, as are many components of the weapon and sensor systems, and many of the interfaces use standard commercial network protocols. It became apparent early on in the project that the new combat suite would have many of the features of an information system, and that information system security was going to be a significant concern for the HCM/FELEX project.

In November 2012, the Communications Security Establishment published IT Security Risk Management: A Lifecycle Approach (ITSG 33).[5] This document and the process it describes superseded the previous C&A policies with a more comprehensive approach to IT security – one that is intended to be applied through the equipment lifecycle. The portion of the IT security risk management process that replaced C&A is called Security Assessment and Authorization (SA&A), and involves a thorough

assessment of the security risks of the system. If the assessed security risks are accepted by the operational authority, then an authority to operate (ATO) is granted for the system, allowing it to be used in operations. Detailed guidance on how to implement the SA&A process in the Department of National Defence (DND) was not published until March 2014.[6] By this time, the ITSEC team in the Project Management Office (PMO) HCM/FELEX was already forging ahead to achieve ATO for the first high-readiness deployment of a post-HCM frigate in the fall of 2014 (HMCS *Fredericton*).

HCM/FELEX ITSEC Accomplishments

HCM/FELEX was the first major capital project in DND to implement the SA&A process, and the implementation began while the process was still in development. To guide this process an oversight committee was stood up with members from the Directorate General Maritime Equipment Program Management (DGMEPM), the Royal Canadian Navy (RCN), and the Directorate Information Management Security (DIM Secur) in ADM(IM). This facilitated the achievement of tight deadlines with very limited human resources.

The SA&A process had been devised with a typical shore-based computer network infrastructure in mind; HCM/FELEX applied the SA&A process to the combat suite on a warship. This introduced a layer of technical and operational complexity, and added elements to the

5. ITSG 33.

6. *Security Assessment and Authorization Guideline 2014*, ADM(IM)/DIM Secur, Version 1, March 2014.

analysis that were outside the expertise of the analysts and assessors in DIM Secur, who normally work with enterprise systems, not combat systems. HCM/FELEX is now an example of the application of information security principles to a platform IT system, something which the RCN and the Assistant Deputy Minister (Materiel) (ADM(Mat)) had not done before.

Several hundred security control mechanisms were reviewed in the course of the security assessment for CMS-330 and its subsystems. This required a review of many policies: materiel management, information management, personnel security, and physical security. This work led to the creation of new policies (for instance, changes in cellphone use on board ship), and to changes to existing policies (such as procedures for visitors to ships). The security assessment also required a review of technical security controls, both software- and hardware-related. To accomplish this, a thorough study was conducted of the CMS-330 and all the systems with which it interfaces.

The granting of HMCS *Fredericton*'s ATO in December 2014 was a significant achievement, one that had only been made possible by the considerable efforts, over 14 months, of a small and dedicated team from PMO HCM/FELEX, Directorate Naval Requirements (DNR), Directorate Naval Combat Systems (DNCS), Directorate Naval Information Management Requirements (DNIMR) and DIM Secur. Over the following six months, the team continued to refine this work to obtain ATOs for successive ships, and in September 2015, a class-wide ATO was granted for the CMS-330 and the combat suite in *Halifax*-class ships. Significant challenges had been overcome to achieve this milestone, and it was a major success for HCM/FELEX and the RCN.

How is Cyber Security managed for the *Halifax* Class?

Cyber security in the *Halifax* class is enforced by a combination of controls: hardware and software design features, standard operating procedures, shipboard security policies, and the security classification of equipment and data. These controls mitigate the security risk. The residual risk of this set of controls will change through the remaining lifetime of the *Halifax* class with changes to equipment, procedures, and policies. Monitoring of the aggregate cyber security risk for CMS-330 and its subsystems will be conducted by the system authority and the operational authority, and will be used to inform decision-makers on cyber security impacts.

The Future for Cyber Security and Naval Engineering

HCM/FELEX has paved the way for the assessment and authorization of platform IT systems, but ITSG 33 is a process for applying information security considerations to equipment throughout its entire lifecycle. Future projects will need to consider cyber security from the very beginning, ensuring that appropriate security controls are incorporated into project plans, and that they are implemented, tested, and monitored. This is systems security engineering: a systems engineering approach for identifying vulnerabilities and mitigating security risks.[7] Systems security engineering is becoming an important part of how projects and systems are managed in DGMEPM and in ADM(Mat).

Cyber security is relevant to the naval engineering community. On board ship, it is enforced through the application of policy such as physical security, equipment classification, and configuration management. For project managers and lifecycle managers, there are additional concerns such as supply chain security, contract security, development of the security profile for ATO, and maintenance of the risk register for the lifetime of the equipment. As the cyber threat becomes more significant, the management of Systems Security risk will only become more important to the practice of naval engineering.

7. "Security Engineering," from *Guide to the Systems Engineering Body of Knowledge*, accessed 24 March 2016 at http://sebokwiki.org/wiki/Security_Engineering.

Operational Capability Checks: *A crucial, but unforeseen, element of the HCM tests and trials program*

By Lt(N) David Irvine – CSEO HMCS *Charlottetown*

Since the latter part of 2011, I have been fortunate to work within the *Halifax*-Class Modernization (HCM) world in one capacity or another. My first exposure dates to my time at Fleet Maintenance Facility Cape Scott while preparing for the arrival of the modernized frigates, and attending initial training at the Maritime Advanced Training and Test Site (MATTS) facility in Dartmouth, NS. This was soon followed by an Assistant Head of Department tour on board HMCS *Halifax*, a three-year posting to PMO HCM/FELEX as both a systems and tests and trials engineer, and finally my current role as the Combat Sytems Engineering Officer of a post-mid-life refit ship – HMCS *Charlottetown*.

Of all my experiences within HCM, one of my most fulfilling roles was providing engineering support during operational capability checks (OCCs), and participating in the behind-the-scenes working group headed by the Directorate of Naval Requirements (DNR) representatives. From my perspective, the shrewd insertion of ad hoc OCCs during the program to overcome operational challenges and risks is an important story to share with the greater naval community. Undeniably, the OCC process was crucial in facilitating the deployment of HCM ships and, thus, a key contributor to the overall success of the project, even though it was an unforeseen requirement.

Upon my arrival at PMO HCM/FELEX, the project was going through a very noticeable transition; that is, attention from a tests and trials perspective had evolved to include the planning and execution of significantly more complex, integrated warfare trials, with each trial set culminating in the conduct of a multiwarfare event. In HCM terms, this meant we were preparing for the first Level 6 and 7 warfare trials on board HMCS *Halifax*. As a newly posted-in project officer, this shift in focus was both exciting and somewhat uncharted, differing significantly from my predecessor's role, a common occurrence within the Naval Technical Officer world. I quickly learned that the modernization of *Halifax*-class ships could not be performed in isolation. These weren't simply project ships, they were operational ships as well. Progressing both the project and operational programs in parallel would be no simple undertaking despite it having been considered at

length throughout the planning process. More to the point, it wouldn't be without gaps or arisings. Administratively speaking, the HCM trials process and the governance therein would become a particularly effective means of validating requirements and generating post-test analysis action items and subprocesses (e.g., system problem reports for tracking and resolution); nonetheless, HCM trials results on their own weren't an adequate metric for the operational suitability of any given version of the combat management system (CMS) and its accompanying subsystems.

Without question, more was needed in terms of validating core combat capabilities, and assessing safety risks beyond what the acceptance trials could convey for implementation of a given combat systems integration component (CSIC). It was concluded that some form of delta testing or assessment would be necessary to overcome this deficiency, and prepare for the live-fire testing and beyond. But whatever the solution was, it had to allow for more flexibility and investigation outside of a contractor's trial script, which understandably focused on acceptance versus operational readiness. But how could this be done amid an active program? Would the contractor support this late change?

By the spring of 2013, performance issues and the lack of a finished CMS product, coupled with an ever-increasing risk to schedule, forced PMO HCM/FELEX and DNR to formally revise the tests and trials plan of the day, and risk-mitigate any further schedule pressure on project milestones. Although systematic and comprehensive, HCM acceptance trials were lacking when it came to operational readiness derivatives. With eventual buy-in from all parties, and enough contractual flexibility to support and fund its addition, the key complement to the existing program would become the addition of OCCs to address the above challenges. In layman's terms, OCCs were a series of RCN-led (i.e., DNR), project staff-supported, operational readiness assessments that arose out of necessity, leveraging existing testing methods, but were never anticipated contractually.

The OCC concept encompassed a realistic and operationally-oriented verification process that was rooted in an obvious priority scheme, allowing the RCN to establish a clearer understanding of the readiness of a given candidate CMS version. Based on a deliberate software development approach, OCCs would require the contractor to go through a rigorous phased software development and testing scheme; not dissimilar to methods that have long been used by DND agencies. This injection of additional testing, however, would complement the existing trials program, but be more operationally focused in assessments and takeaways, allowing DNR and PMO HCM/FELEX to advise the RCN accordingly.

Initially branded (a bit misleadingly) as "freeplay," the first OCC took place at Lockheed Martin Canada's Land Based Test Site (LBTS) during the summer of 2013 with upward of 50 personnel supporting its conduct. Another 10 or so OCCs would follow, with the last occurring on board HMCS *Charlottetown* in the fall of 2015 in support of HMCS *Fredericton*'s deployment, and the latest software release. Although scheduling and HR challenges were often limiting factors, the ideal OCC plan comprised several phases, including contractor software regression testing, initial verification testing ashore, and at-sea validation assessments of candidate software using realistic warfare scenarios as a way of stressing the CSIC configuration. Contrary to the site acceptance tests, DND staff served as trial lead and director, while the prime contractor subject matter experts (SMEs) supported and observed. This was a significant role reversal between contractor and customer in terms of trial execution, but one that proved particularly effective given the intent of the operational capability checks, and the accessibility of contractor SMEs throughout. This allowed the OCC team to focus on the predetermined serial priorities, while the contractor team could provide support and clarify queries and concerns as they arose in-situ. In doing so the contractor could reduce "false positives," and increase observation accuracy with the aid of data collection and analysis tools, and an onsite presence. Upon completion, the teams would jointly produce a trial log in support of follow-up activities, and a formal back-and-forth would ensue in line with existing closure processes.

The ability to prioritize and home in on problem areas within a phased approach was a central theme of OCCs, and one that should not be understated. More specifically, this ability to "poke and assess" specific concerns was instrumental to the program's success – an option that simply didn't exist within formal acceptance trials (and understandably so). Another benefit of the OCC process was the irreplaceable exposure a ship's company received to the CMS software, with subject matter experts readily accessible. Moreover, it was groundwork that would pay dividends within follow-on activities relating to the tiered readiness program. In the end, the increased stress and complexity of OCCs clearly exposed issues that would otherwise have gone unobserved. In fact, OCCs continued to produce lists of unacceptable performance observations up until the last serial, and many of these issues were witnessed only within OCC-based activities.

Going forward, and where applicable, it is highly recommended that OCCs continue to be used as an operational complement to acceptance trials, paralleling the latest framework within related naval orders for software release and development. The inclusion of OCCs as a key phase within an effective tests and trials program, both contractually and in practice, would be of great benefit to future projects of similar scope and complexity.

I would like to thank Cdr Scott Godin and Len Terpstra for their historical insights into the OCC program. Thanks also to those directly responsible for my continued involvement in the OCC program – Cdr Steve Whitehurst, Cdr Rob Gray, and LCdr Dany Normandeau. Further, I am grateful for the mentorship and collaborative approach of my DNR counterparts, LCdr Matt Low, LCdr Mark O'Donohue, LCdr Monty Friend, and Kristina Ducas (LCdr retired).

HCM Multi-link Capability Insertion

By Steve Whiting – PMO HCM/FELEX Operational Requirements Analyst

The HCM/FELEX project brought together five new technologies as part of the overall Combat System Integration Components (CSIC), including perhaps one of the most flexible tools in terms of information sharing and situational awareness – a multi-link tactical data link (TDL) system.

Link: Noun or a Verb?

To the non-initiated, tactical data links are the means through which ships, aircraft, and land units exchange tactical data (targets, own position, engagements, etc.) over the air via UHF/SHF and EHF SATCOM. Datalinks have evolved since their inception during the Cold War, with technologies expanding to include anti-jam, time division multiple access (TDMA), and frequency-hopping features.

The most basic of the TDLs (Link-11) is comprised of a number of units that are referred to as nodes, and are required to maintain communications with an overall net control station (NCS) running the network. The NCS polls the units in the net in turn, gathering their data, and subsequently produces the overall tactical picture for all to share. This link utilizes UHF/HF and UHF MILSATCOM to exchange its data. If for any reason the NCS experiences a technical or communications problem the tactical data link is lost, and all this vital information along with it.

Next is the workhorse of TDLs, Link-16. This link is commonly denoted as nodeless, where each participant is assigned time slots within a network, and this network will function regardless of the participation of any particular unit. The closest thing to a node (NCS) here is the net time reference that is needed to synchronize the network, and facilitate other units to join and enter the network. After the network has been established it can operate for hours without another net time reference.[1] The shortfall of Link-16 is its place in the radio frequency spectrum. As it lives in the 960-1215 MHz range, it shares signals with other civilian and military communications systems, and therefore must have those frequencies physically notched out (utilizing a band-pass filter). The result is that this frequency band restricts Link-16 to line-of-sight operations. To mitigate this shortfall, Link-16 can also operate over TCP/IP (transmission control protocol/internet protocol) using a protocol called JRE (joint range extension). Through encryption of both messages and transmissions,

1. Understanding Link 16, Logicon 1994

allocation of segmented networks, and the ability to stack networks on top of one another, the growth of this technological breakthrough (Link-16) has permitted more and more units (and countries) to share higher fidelity situational clarity.

The newest player in the TDL game is Link-22. Introduced as the NATO Improved Link Eleven (NILE), this link is compatible with the Link-16 message types. Positional fidelity, however, provides a beyond-line-of-sight capability. The premise behind Link-22 is to utilize existing Link-11 radios and commercial off-the-shelf computers, and to reduce overall human-machine interaction. At its very basic form, Link-22 consists of a super network with as few as two units talking to one another. At its most complex, a maximum of 125 units could be communicating within eight NILE networks. In order for units to exploit this beyond-line-of-sight capability, Link-22 employs fixed-frequency HF in the 2 MHz to 30 MHz range. Similar to Link-16, Link-22 is nodeless and uses distributed protocols, so it has no single point of failure.[2]

Link in the RCN

The Royal Canadian Navy has utilized tactical datalinks (11 and 14) since the early 1980s, with a predominance of Link-11 to the present day. TDMA-based Link-16 was introduced in the Tribal-class destroyers in the mid-90s to address the shortfalls of Link-11. Unfortunately, the RCN discovered that this new technology would not seamlessly assimilate with the Tribal-class combat management system, forcing this tool into a stovepipe configuration, and subsequently pigeon-holing the user community to a very select few.

Jumping ahead to 2004, the RCN through consultation with many of its allies and coalition partner navies adopted a radical and untried philosophy: to combine and synergize all tactical datalinks regardless of the RF medium (i.e. UHF, HF, and SHF), and to “normalize” them into one seamless picture for the user. The RCN would thereby be able to participate in any TDL environment. Along with this far-reaching equipment came the need to revamp how the users would understand and employ this complex toolset.

Normalizing all the old and new TDLs was necessary so that the new frigate CMS-330 combat management system would not care which link network was feeding it information. The CMS would always present the data received in a common format for the user. The need to normalize was also important from a configuration management outlook, and instead of having three or four stovepipe links with each talking to the CMS at once, the answer presented itself in the guise of single translator called the Data Link Processing System (DLPS). Each of the TDLs on board the ship reports its information to the DLPS in its own specific language and format, and the DLPS in turn looks after forwarding this data to the CMS in the language it understands.

This new technological and philosophical change for the RCN has garnered the attention of our allies and partner navies, particularly the RAN, RNZN, RN and DEU, all of whom are eager to conduct tests and trials with the new HCM ships at the earliest opportunity. On the RCN home front, the HCM multi-link capability viewpoint was immediately adopted, and adapted to address the future TDL requirements of the Joint Support Ship and Canadian Surface Combatant platforms.

Along with other navies, the HCM multi-link capability has attracted the interests of the defence industry communities, both in Canada and abroad. The successes and lessons observed have been regularly briefed to industry partners through trade show forums and Industry Day opportunities. These interactions have provided the opportunity to educate both industry and end-users in the challenges faced by users, and the technological advances that industry can demonstrate or expand upon to meet these challenges.

The HCM ability to “plug and play” into any TDL network nationally and internationally is being proven almost on a daily basis, and with every ship deployment. This capability is expanding our technological initiatives, and proving our advancements in this data-sharing capability. None of this could have been possible without the strong collaborative efforts between the RCN users, industry partners, and the PMO who met often to resolve issues in an effort to deliver on schedule the most robust product possible.

2. Understanding Voice+Data Link Networking, Northrop Grumman 2013

Commander Task Group Habitability – Executing Innovation and Ingenuity in a Constrained Space

By LCdr Rob Waller – CSO-6 ILS Systems Engineer PMO HCM / FELEX

LCdr Mike Wood demonstrates the challenges of shipboard accommodations.

As the Canadian Surface Combatant (CSC) Project moves toward implementation, a key criterion being assessed for selection of a design reference point is accommodation. While the original Statement of Requirement (SOR) called for 255 core crew and mission personnel, it is now widely accepted that the available hull designs cannot accommodate this number. The RCN and PMO are going through a detailed analysis of assessing what operational impacts are felt when you start shaving down the number of personnel in the Watch and Station Bill. This is an interesting exercise, and represents the opposite approach experienced under the HCM/FELEX project via the Commander Task Group (CTG) habitability engineering change (EC), where the expectation was to provide additional bunking within an existing finite space for whenever the CTG was embarked.As the HCM/FELEX engineering change project manager (ECPM) from June 2009 to December 2010, I was responsible for taking the approved option for adding 19 additional bunks on board, and finalizing the specification in time for HMCS *Halifax*'s mid-life refit. As I also worked with New Capability Insertion (West) for three years after that, I was no stranger to hearing individual complaints about the fruits of my, my forebears', and my successors' labours. The intent of this article is to provide some insight into the challenge of implementing an HCM EC that has an emotional link due to it directly affecting a sailor's quality of life at sea, and the true challenges of providing innovation and ingenuity in a constrained space.

CTG habitability is one of three HCM/FELEX-funded ECs that were managed outside of the Combat System Integration contract. It directly supports the requirement for the first four ships to be CTG-capable to bridge the gap between the divestment of the *Iroquois*-class destroyers, and the delivery of the Area Air Defence/CTG variant of the CSC. Not to be confused with the Directorate of Naval Platform Systems habitability ECs that modified the office spaces, and installed additional heads and washplaces, CTG habitability covers additional accommodation for 19 personnel throughout the ship, an extra command chair and multi-function workstation in the operations room, and a CTG briefing space in the after sonar instrument space (Aft SIS).

As with every EC, it all traced back to the operational requirement. Once the SOR was produced, an Options Analysis phase spanning a year took place where Fleetway Inc. and DMSS 2 analyzed eight possible options that created bunks "out of thin air." Proposals ranged from taking away mess common areas, converting equipment rooms into accommodation spaces, creating new spaces abaft the main mast, enclosing the hangar mezzanines, and rearranging mess layouts without modifying bulkheads to fit a few more bunks. After a detailed review and acceptance process throughout DGMEPM, a final design was chosen that represents five major alterations to meet the command intent:

a. Because of the curvature of the hull, raising part of the deck in 2 Mess allows an increased footprint to add three extra bunks;
b. Amalgamating 7 and 8 Mess, and completely redesigning the layout to add six bunks;
c. Adding a third bunk and locker storage in Cabins 1, 3 and 5 to gain three bunks;
d. Modifying 10 Mess to change it from a 12-person mess into two six-person messes to allow for the eventual displacement of officers and senior NCMs when task group staff are embarked; and
e. Creating a six-person mess, and a two-person office space within the footprint of General Stores No. 2.

[While not requiring any modification, the 19th CTG staff bunk is achieved using the second bunk in the coxswain's cabin.]

While the complexity of the scope of work was immense – the specification was broken into four parts and filled an entire banker's box – the additional challenge of this EC was the level of integration with other ECs, and the coordination required with ECPMs who were implementing in parallel. New messdecks required new lighting and SHINCOM terminals. Adding connectivity to the Aft SIS briefing space relied on agreements with SecLAN to provide Thin Client (computer) drops, and redesigning the metal table was required to create a section that folds down so as not to impinge on the Nixie torpedo decoy system maintenance envelope. Absconding valuable space from General Stores No. 2 required the purchase of additional Vidmar storage cabinets that could be placed on top of existing cabinets to come as close to a zero-loss solution as possible. Finally, putting more people in spaces not originally designed for them had a second-order effect in the need to re-evaluate the HVAC balancing and orifice plate adjustments to ensure the air cycling met safety and human factors standards (several ECs contributed to this issue, and still need to be completed before Full Operational Capability).

While the end solution isn't perfect, I sincerely believe that the execution of the original requirement was done with the goal of benefitting sailors. There are two main complaints I hear most often. The first is related to the "Alley of Death" in 7 Mess where it takes some creative coordination during action stations when 12 people have to exit their bunks and don action gear in a very narrow space. While it is awkward, a Sea Training casualty exercise proved it is possible to extricate someone, and the design does not contravene any safety regulations (the requirement for mess main passageways is 0.9 metres wide, and secondary passageways is 0.7 metres wide). The second complaint concerns the cramped confines of the third (top) bunk in the three cabins. While we have done the best we can to manage the addition of these much-needed bunks, I fear that the close proximity to a deckhead will continue to be an unavoidable reality of shipboard life for a few people.

In the end, an ECPM's job is to deliver on the requirements directed by the operational community. With some clever engineering, this can be considered an overall success, complete with Internet café and large-screen display for movie watching when CTG staff or Sea Training aren't embarked. For anyone who's ever been relegated to a cot behind a cabinet in Communications Control Equipment Room No. 3 on a deployment, or been forced to hot bunk for any period of time during workups, a slight reduction in headroom is a small price to pay.

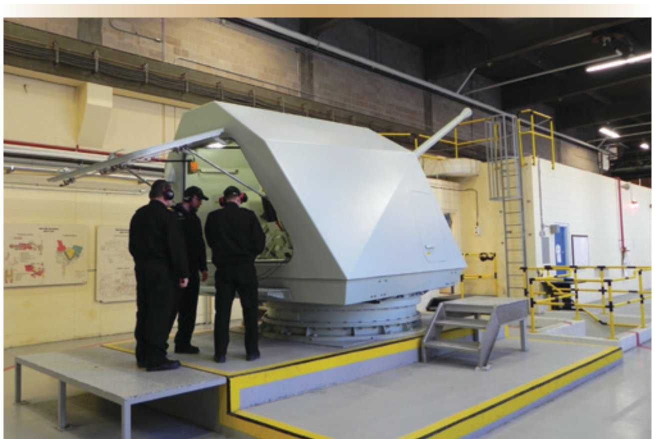
Security Considerations for Trainers and Shore Facilities

By LCdr Robert Houghton – Training, Trainers and Shore Facilities Manager

The modernization of the Canadian Patrol Frigate leverages some of the most technically sophisticated capabilities within the defence industry. Although Department of National Defence (DND) is impacted by regulations imposed on information technology, there is a wealth of experience within the Royal Canadian Navy (RCN) in managing accreditation processes. What many people might often overlook is the correlation of two other security concerns – namely, sensitive discussion areas and secure storage areas. Security policy is designed not only to protect vulnerabilities of electronic assets, but to ensure the proper safeguarding of physical assets and classified material. This article discusses how all three facets of the security policy affect the technical solutions of trainers and shore facilities.

Information technology (IT) has created its share of challenges in the world of security. While not a comprehensive list, there are a number of practical considerations when identifying IT requirements in a facility. First, the nature of the IT project should be clearly identified. Is the implementation to be a total refresh (i.e. new), or an incremental upgrade? Will the project be outsourced to a private contractor, or managed by DND personnel? Second, it is important to understand the level of complexity that is required. Is the system legacy? Is it classified? Will cloud technology be leveraged? Will the system interface with an existing network, or will it be stand-alone? Each of these questions is eventually weighed against product and process assurances; however, a crucial step in the process is the concept phase where a security control profile is used to document controls in the context of business activities, relevant threats to the information, and potential impacts of the technical implementation. To complete the profile, a security approach identifies the selection of controls, as well as a validation and verification process. This assessment provides initial assurance, and shapes other infrastructure requirements.

Initial Assurance Requirements (IAR) provide a basis for understanding the security control profile in the context of a threat assessment and the type of information to be safeguarded. Simply put, the security strategy must be addressed throughout the planning process, with key physical factors being the function of the facility and its security zoning. As an example, a classified stand-alone system may require enhanced security measures to account for open storage of network servers. Depending on the classification level and the physical location of the facility, the solution may potentially vary from a communications closet to an access-controlled secure storage room. More importantly, a clear understanding of the security layers is necessary, particularly the remaining vulnerabilities as layers are removed. Questions to be considered could include: What type of physical security zone is adequate for my facility? What separation do I need from the public zone – or alternatively, where is the reception zone? What process has been established to control access between these zones? When modifying the use of facility, it should be recognized that security is established through a



combination of design and process. National Defence Security Orders and Directives, or simply NDSODs, offer policy guidance to implementers of secure facilities. Chapter Five of NDSODs is an excellent source of information; however, it is important not to underestimate the advice of experts in this field.

For example, an engineer might question the necessity of examining security zones. After all, the heat load and electrical calculations provide the mathematical basis for determining how much power and cooling the space requires. But what if you need to consider acoustical attenuation? Imagine if there were potential for the facility to be used for sensitive discussions. How would this impact the engineering solution? The simple answer is that a sensitive discussion area (SDA) requirement affects every engineering solution.

Physical security standards, not unlike building codes, have established parameters for building walls and ceilings, but how an electrical conduit or mechanical plenum – benign elements on their own – are introduced into a space can affect a room's acoustical performance. They therefore become extremely relevant when creating an SDA. Granted such facilities have been constructed in the past without difficulty, but the requirements for an SDA must be identified at the onset. Sounds simple, right? Yes, until requirements are combined. What if you need to build an SDA that allows for open storage of classified equipment? As an example, most engineers recognize that sound typically travels more effectively as material density increases. In a shipboard application, the sound path would ideally be interrupted through the use of isolation modules such as shock mounts. In a building, the principle is similar – isolate rooms by interrupting the sound path through a combination of varied-density material.

So how does this all tie together? Electrical and mechanical loads, acoustic performance, security zones ... it seems somewhat overwhelming. Truth be told, it *can* be if the right stakeholders are not introduced into your project early. The first step is to identify whether the desired capability needs to be protected, and if so to what extent. The second, and perhaps the most important step, is to consider system security throughout the engineering process. There is now a growing niche for systems security engineering, driven through the proliferation of technology. Organizations such as the National Institute of Standards and Technology deal extensively in cyberspace security; however, it is essential not to forget the basics: physical security.

So what about Trainers and Shore Facilities?

The initial approach in developing or enhancing a shore facility is to determine its purpose and what is being protected. The type of technology, and the sensitivity of discussions will shape security requirements, and these can be documented in the IAR to set the required security control profile.

The next step would be to identify the stakeholders required to develop the solution. This is crucial, as introducing design changes to effect newly identified security requirements late in the process becomes difficult to manage and will inevitably affect project cost and schedule. Projects would be well-advised to establish a project charter, or terms of reference, with expertise being intra-departmental so that the project manager has formal acknowledgement of stakeholder involvement. More importantly, variances in individual processes can be identified up front.

Finally, project objectives must be explicit within the terms of reference. While perhaps intuitive, objectives should not be confused with requirements, although one objective is to meet the requirements. A fundamental component is for stakeholders to agree to a design concept as a starting point. As review processes unfold, the design will be reconciled against requirements and a detailed design produced. The most important piece of the design puzzle is to consider security throughout the entire life of the project.

Training Requirements, Coordination, and Challenges Associated with the Combat System Integration Design and Build Contract (CSI DAB)

By CPO2 Martin Cashin, MMM, CD
PMO HCM/FELEX CSI DAB Training Coordinator

The *Halifax*-Class Modernization/Frigate Life Extension (HCM/FELEX) Combat System Integration (CSI) Design and Build (DAB) contract identifies specific elements of the *Halifax*-class combat suite that will be upgraded.[1] Parallel to this contract is the installation of more than a hundred engineering changes (ECs), each with different EC project managers, which were also implemented during the mid-life refit. This article will focus on the training requirements, coordination, and challenges associated with the CSI DAB contract.

Requirements

Since the CSI DAB contract was performance based, specific equipment was unknown, or yet to be designed, when the contract was awarded. A training needs analysis was therefore unable to be completed by the RCN or Director General Major Project Delivery (Land & Sea) on equipment that had yet to be procured and integrated.

Built into the statement of work for the CSI DAB contract was a requirement for the prime contractor to develop an Instructional Requirements Analysis Report (ILS-002)[2] using procedures described in Volume 3 of the Canadian Forces Individual Training and Education System (CFITES) Policy Manuals (A-P9-050-000/PT-003). In order to better prepare Lockheed Martin (LM) Canada to develop the training requirements, PMO HCM/FELEX tasked various naval training establishments to review occupational specifications (i.e. ex-job-based specifications) for NCS Eng, MARS, Combat Operators (Sea), Naval Electronics Technicians, and Naval Weapons Technicians. This resulted in a list of task statements that were provided to LM Canada for all trades and positions required for manipulating the new command and control system, and/or maintaining the new combat system equipment.

LM Canada completed its analysis, and subsequently produced the Instructional Requirements Analysis Report in 2010, which was reviewed by the Navy's project and training establishments. The amendments produced a second version that was the basis of the training plan.

Coordination

In order to ensure training contractual requirements were effectively managed, the Personnel and Training Working Group (P&T WG) was established under the authority of the CSI DAB Statement of Work.[3] The P&T WG was co-chaired by the training lead from LM Canada and the training manager at PMO HCM/FELEX. More importantly, key naval stakeholders were provided associate membership from the following organizations: Project Director (Directorate of Naval Requirements), the coastal N1 organizations, all naval training establishments, D MAR PERS 3, D MIL C2, and DMTE 2 (now Naval Personnel Training Group 3).

This working group created the governance structure for the PMO, contractor, and RCN to advance project goals while providing the structure to address any arising that

1. Halifax Class Modernization / Frigate Life Extension Combat Systems Integration Design and Build Statement of Work, Rev 10.2, 12 September 2008. Para 1.1
2. Op. Cit. para 6.1.2.2
3. Op. CIt. Para 6.1.1.2

surfaced throughout the life of the project. The P&T WG commenced three months after the contract award, and was held quarterly, or as frequently as required.

Challenges

The location of the contractor-owned training facility was in Halifax, but not within the boundaries of Canadian Forces Base Halifax. Its location was convenient for software testing and trials of CMS-330 and associated equipment; however, there were minor logistical challenges with its location in order to adequately support those students not from the geographical area. Additional transportation and feeding arrangements were required, which slightly inflated training costs as a result. Key stakeholders at CFB Halifax and Directorate of Naval Logistics were engaged to ensure logistical and accommodations costing was kept to a minimum while ensuring all students not from the Halifax area were adequately taken care of.

The HR plan did not reflect the requirement to have DND personnel embedded at the contractor's facility in order to perform regulating office duties. Consequently, the project required sourcing two military personnel for the duration of the project to assist LM Canada in liaising between the contractor, the project office in Ottawa, and the course-loading authority now located on the West Coast. PMO utilized the Canadian Forces Task, Plans and Operations (CFTPO) system in order to source a chief petty officer (CPO2) and a petty officer (PO2) to staff a pseudo-divisional cell to ensure that the requirements of sailors and public servants completing inital cadre training were met. Furthermore this regulating office worked to maintain a high course-loading volume so that the maximum number of personnel could benefit from the training. Having the training occur on the opposite coast than the course loading authority, the regulating office was able to quickly backfill seats if they became available based on NPTG-provided standby lists.

Another condition of training at a contractor facility is the requirement for all DND personnel to have a Visit Clearance Request (VCR). This is a requirement directed by CFAO 20-5 and industry requirements as directed by Public Services and Procurement Canada – Canadian Industrial Security Division. This required more than 8000 VCRs to be applied for, annually renewed, and managed throughout the life of the project. This was a major undertaking by project staff, as well as by every unit security supervisor for all DND personnel that required access to the contractor facility.

Assessment

What is the lesson learned for future projects? Had this facility been constructed on the real property of CFB Esquimalt or CFB Halifax, these logistical issues and additional travel costs would not have been a concern. The logistical issues from a training perspective are relatively minor in value; however, at some point between First Article Acceptance and Full Operational Capability, the remaining trainers at Lockheed Martin's Maritime Advance Training and Test Site (MATTS) facility will need to be transitioned to naval training establishments, which will reduce the availability of trainers for steady-state training and the ability to update the CMS-330 combat management system if required. Had the trainers been originally built on DND properties, the training black-out associated with this transition would not be an issue, nor would the requirement for visit clearance requests have been as large an undertaking. Personnel would have still required to be verified as holding a valid security clearance; however the process would have been totally controlled by DND if the facility were under DND control.

Conclusion

This discussion has explored some of the issues surrounding training at a contractor-owned facility. Historically, most training for the RCN has occurred within DND-owned facilities. The current security tempo of the Government of Canada, coupled with the recent release of National Defence Security Orders and Directives, provided some not-so-fair-winds and following seas in order to have sailors adequately trained on the modernized HCM platforms, but the course was navigable thanks to a large amount of ingenuity and willingness by all training stakeholders to get the job completed. Whenever possible, consideration should be given to having training delivered in DND facilities, but when this is not possible, then the second- and third-order effects pertaining to security, logistics, and human resources must be considered.

A Common Reference Point for Post-HCM Ships

By LCdr Dany Normandeau (PMO HCM FELEX CSO 2-4), and Spencer Collins (Naval Engineering Test Establishment)

Like many of the legacy combat systems, the sensors introduced as part of the Halifax-Class Modernization have the ability to compensate, in software, for their position with respect to a chosen reference point. Combat systems can also account for a variety of other bias correction values obtained through trials, such as pitch, roll, elevation, range, and bearing bias. These values allow the systems to correct for physical bias, and provide settings specific to the class or the ship itself.

The problem at hand is that not all systems use the same point of reference, or even the same coordinate system. Getting every system to use a common reference has been a challenge even before HCM, but the introduction of sensor bias within the new CMS-330 combat management system (CMS) renewed interest in the single common reference point for all combat systems.

Any combat systems engineer, weapons engineering technician, or experienced operator will know that the ability to aim the gun correctly, or to merge the track from two sensors, is dependent on the use of common references. As a target approaches the ship there are increasing parallax issues and range/bearing differences (Figure 1) that, if not compensated for, will result in the inability to merge tracks from various sensors, or to point the gun correctly.

A ship's common reference point for combat systems is called the own-ship reference point (OSRP). For *Halifax*-class ships that have completed mid-life refit (MLR), the OSRP will be a fixed point (see Figures 2 and 3) based on a calculated estimate of the centre of gravity of a post-MLR ship in a loading state that would be typical mid-deployment – in essence, not fully loaded (in the deep departure state), nor empty (in the light arrival state). The OSRP is the same for all *Halifax*-class ships, has fixed values in three axes, is now documented in a Canadian Forces Technical Publication, and does not move with load[1].

1. For modern combat systems, this common reference point is typically centred on the main radar or the centre of gravity of the ship at a known load state. The advantage of the latter is that this point can also be used for navigation, as the ship's centre of rotation is essentially the same as the centre of gravity.

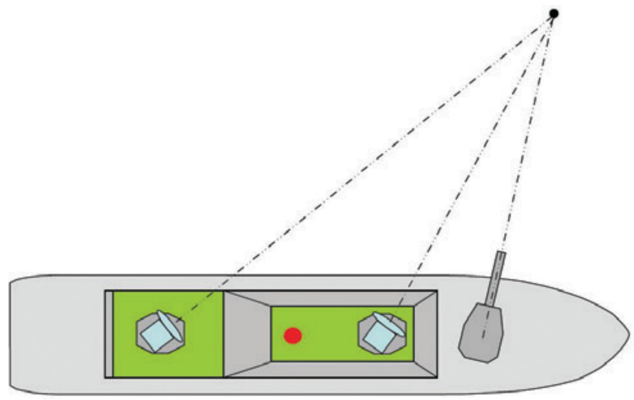


Figure 1. Parallax increases as targets get closer

Interestingly, through the survey of a ship on each coast, and comparison with other surveys, Fleet Maintenance Facility Engineering was able to develop a class average positional reference (within five cm) for all radars[2]. The parallax values give the X, Y and Z values from the sensor and gun to the ship's OSRP. These values are entered into either the subsystem or the CMS as appropriate.

The CMS-330 design features some automated functions to ensure all range, bearing, and elevation errors between sensors relative to a reference sensor (normally a fire-control system) are removed. This function depends heavily on the assumption that all sensors are reporting target position with respect to the OSRP. The combat systems alignment verification trials accomplish this important task.

The OSRP change is not without some road bumps. Early on, it was discovered that one of the sensors, the SG-180 radar, had no offset to OSRP (an error of approximately 21 metres longitudinally). The discovery triggered a change in the CMS-330 software, as well as several tests, to ensure the OSRP offset correction function was working correctly.

Several key systems such as the inertial navigation system, the Mk-48 guided missile vertical launch system, and the Phalanx close-in weapon system have biases that compensate for the fact they are not located right at the OSRP. Several of those systems had offsets that were very close to the new post-MLR ORSP, but investigation revealed that most did not reference the same point previously.

Changing the reference point even by a few centimetres can require some serious effort depending on the system. As an example, the positional adaptation tables for the missiles have to be reprogrammed, and simulations executed to ensure the missiles do not hit any ship structures.

In conclusion, the coordination of all the individual system offsets to OSRP has to be done in a systematic way. Fortunately, the engineering change process captures and coordinates these changes for all affected systems. Publishing the new OSRP will ensure that all weapons and sensors will report targets from a common point in space (the OSRP) and will make the *Halifax*-class weapons performance more accurate and lethal.

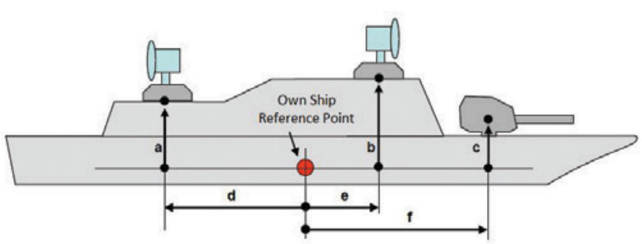


Figure 2. Own Ship Reference Point

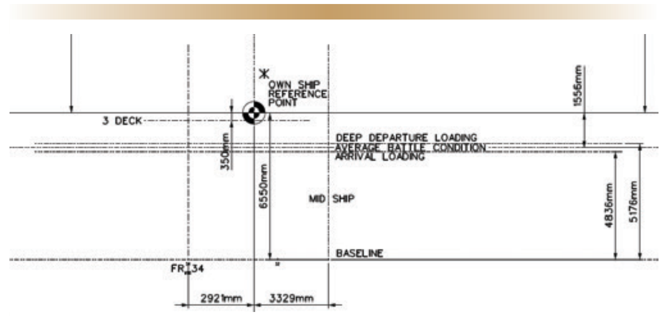


Figure 3. Own Ship Reference Point Close-up

2. Results can be found on drawing Own Ship's Reference Point (Halifax Class Average) W-15011. Original reference provided in embedded PDF object should source document be required.

Industry Insights:
Lockheed Martin Canada Perspectives

[***Editor's note:*** The major industry partners involved in HCM/FELEX were invited to offer their own insights and views regarding key aspects of the project.]

Governance

The Halifax-Class Modernization (HCM) project embraced a governance structure that operated on multiple levels providing project guidance throughout the life of the project. The levels, ranging from an executive committee down to working level groups, provided stakeholders a formal vehicle by which to report and obtain status, exchange ideas on challenges and solutions, and to agree upon adjustments and course corrections. The governance structure allowed the different governance levels to operate somewhat autonomously, taking appropriate decisions and actions within their own authority level, but also ensured that the actions and decisions at any one level flowed seamlessly into the other levels. The governance structure resulted in authority being delegated to the lowest level. This empowered stakeholders to make the best decisions possible for the overall good of the project based upon the broadest range of the most recent information available.

The Committee of Sponsors (CoS) represented the executive level governance with executive membership from DND, Public Services and Procurement (PSP) Canada, Irving Shipbuilding Inc. (ISI), Seaspan, Fleetway, and Lockheed Martin Canada meeting once every four to eight months depending on the stage of the project. The CoS Charter bound each member to work openly and fairly with each other in a spirit of cooperation to influence a positive outcome for the overall project. The CoS would make broad course correction decisions with the blessing of all stakeholders.

The ***Canada*** Industry Integrated Project Team (CI IPT) was a tri-annual conference style event that ran from 2009 to 2015. The event was managed at the senior program manager level and brought various DND and PSP stakeholders together with primary industry stakeholders on the project. The event typically spanned three to five days with multiple breakout groups to optimize accomplishments. The CI IPT addressed all major project activities including technical issues, schedule challenges, contractual matters, and logistical issues. The CI IPT event typically provided valuable status and reporting used for the CoS. Major benefits of the CI IPT were:

- Establishing and strengthening relationships for the life of the project
- Sharing of information at all levels
- Working through key challenges in breakout groups.

The East and West Coast production forums, represented by DND and industry, were empowered to resolve local challenges for each of the ships undergoing the refit program. The production forums operated on a weekly basis to address routine business and challenges, but reported in through the National Production Forum, which was an oversight and authority body within the CI IPT construct.

The lowest level formal governance structure was the working group whose composition typically consisted of DND and Lockheed Martin representatives, but other stakeholders were engaged as required to achieve progress. The working groups typically determined what actions and activities were required, within the confines of the contract, to develop the products and deliveries to meet the end customer's objectives. For example, the Trainers and Training Working Group met on a regular basis to shape the training agendas and the training products needed to conduct initial cadre training and longer term regenerative training. Working groups reported up through the program management chain and typically funnelled into CI IPT activities.

The lessons resulting from the modernization governance experience were that the program structure and associated processes had to embody clear communication channels, and empower project stakeholders to resolve issues at all levels.

Engineering Change (EC) Specifications

Development and management of engineering changes (ECs) on the HCM project presented a challenge due to the program's aggressive schedule. To reduce costs and risk, Lockheed Martin Canada used a Lockheed Martin USA ship design team that had recent and relevant experience working on the US Navy's Littoral Combat Ship design. In conjunction with Fleetway (***Canada***'s *Halifax*-class Design Agent), the HCM design modifications could be transformed into 17 Combat System ECs (nine strip-outs and eight installations) to support the shipyard refit activities. However, the process and standard of the ECs were developed to fit within the existing operating practices of the Royal Canadian Navy. This allowed the project team to leverage existing Canadian know-how, resources, and implementation activities to reduce risk and schedule impact.

To develop the ECs, the Lockheed Martin ship design team worked closely with the Lockheed Martin Canada Combat System Integration Component (CSIC) team to identify, develop, and collect the necessary information from the various equipment vendors. The process commenced with Lockheed Martin Canada establishing formal specifications for the budgets and margins associated with each subsystem to ensure that products developed by vendors would fit within the overall envelopes available in the final ship product. Vendors were required to take these budgets and margins into account when designing their subsystems. This Vendor Furnished Information (VFI) included the ship interface requirements, interconnection cables, connectors, electrical requirements, cooling requirements, environmental characteristics, and the physical characteristics of each subsystem's equipment.

The positioning of the equipment was the result of multiple design studies including human-machine interface for operation and maintenance. The tools employed supported the development of initial layouts of the above- and below-deck equipment. The mast was assessed for technical performance including detection range, antenna fields of view, interequipment electromagnetic interference, and radar and thermal signatures. Three-dimensional views of the mast and the combat system spaces were created to support stakeholder walkthroughs prior to the final configuration approvals.

The schedule imposed the largest challenge in preparing the ECs for the first ship's arrival in the shipyard. The shipyard required the ECs six months or more in advance of a ship entering the yard in order to procure long lead material and develop a production plan. The design agent required the VFI atleast 12 months in advance of finalizing the EC design, and many of the vendors needed a year or more to produce the VFI required. Since the contract was signed in November 2008, and the first ship entered the yard in September 2010, the schedule was compressed out of the gate before any new challenges arose.

To address the schedule challenges, Lockheed Martin took several mitigation actions to minimize schedule impact, including:

- Obtaining VFI during the pre-contract stage to the maximum extent possible
- Embedding the design agent's staff onsite at Lockheed Martin to achieve quick turnaround of changes and to address any shipyard concerns on the ECs
- Standardizing vendor items (such as cable and connector type) to reduce the learning curve for the design team
- Conducting a "Kaizen" improvement on the EC development process to drive out unnecessary activities
- Establishing extensive metrics to measure and understand EC progress
- As required, when VFI was not readily available, use Lockheed Martin's extensive industry knowledge base to develop preliminary ECs to allow shipyard planning to commence.

All ships need configuration changes for multiple reasons, and therefore additional ECs are required on a ship-by-ship basis. Lockheed Martin Canada set up a Redline/Change Management program early in the refit program to support the program management of multiple stakeholder inputs. A weekly change control board was initiated to ensure the changes were assessed by multiple stakeholders for impacts across the installation of ECs.

Although being built upon an older model, the ship ECs were effective in identifying the standard documented processes to be used in the refit, and the specific equipment part references. For future programs there is a potential to employ new shipbuilding digital information models to produce EC type design. However, the risk mitigation techniques used on HCM, such as obtaining VFI pre-contract, can still be employed to address the challenges that will surely arise in a complex shipbuilding project.

Lead Ship

The *Halifax*-Class Modernization was planned with a two-year period of design activities prior to the 12 ships entering mid-life refit. Following an extensive two-year (plus) preparation that resulted in a proposal being delivered to ***Canada*** in June 2008, LM Canada accepted the contract to design the Combat System Upgrade. To reach a price and performance that met ***Canada***'s objective for a firm, fixed-price based contract was a challenge. The contract contained fairly standard contract terms and conditions, a high-level Statement of Work (SOW), and a Combat System Integration Performance Specification (CSIPS) for a price of $1.282B Canadian dollars. The refit schedule was based on a 10-year fleet plan, with HMCS *Halifax* (Ship 1) entering the shipyard for refit in 2010.

Traditionally, in US ship build and refit programs, a lead ship is designated to manage the developmental risk on the project. The design and production problems and challenges that arise are resolved on the lead ship to create solutions that can be applied to follow-on production activities. Typically, production does not stabilize until Ship 3 to Ship 6.

The HCM contractual construct provided the option to test the performance of the upgraded combat system over the first five ships to meet the accepted design baseline. Any back-fit changes required to any ship due to shortcomings discovered during testing on any other ship were the responsibility of the contractor. In effect, the concept of having a lead ship on which to validate design, resolve issues, update the production baseline, and adjust price simply did not exist.

During the proposal development between 2006 and 2008, it was apparent that there were challenges in producing a final configuration without a lead ship. To mitigate this challenge, Lockheed Martin Canada developed a plan to maximize performance on the first refitted ship, thereby reducing risk with follow-on ships. This approach drove many planning decisions, including selecting the same shipyards to conduct the refits as those selected by ***Canada*** for the Multi Ship Contract, and using ***Canada***'s design agent, Fleetway International, to create the engineering changes required by the shipyards. One of the early major decisions was to take advantage of existing designs when possible to minimize potential rework.

LM Canada planned a land-based test site (LBTS) to be constructed in the Dartmouth area of Nova Scotia that would support the validation of the combat system design prior to setting to work on the first refitted ship. The LBTS would utilize the 13th shipset of equipment destined for the Combat System Training Centre, and provide an integration environment with realistic sensor performance. The power was designed to match the three-phase supplies on the ships, and shipboard type cables would be used to closely replicate the shipboard design. Critical ship equipment interfacing with the combat system was selected, along with the design for the test scenario generator used in the combat system training devices and simulated equipment models. A rooftop platform was planned that would allow the installation of all selected sensors (2D, 3D and navigation radars, Identification Friend or Foe (IFF), electronic support measures (ESM), and fire-control radars), such that they could radiate and detect real-world air targets in the local area.

Following contract award, the first LM Canada ship plan created a challenging program that led to system engineering activities that were essential to mitigate the risk of customer stakeholders having different expectations of the delivered products. The System Requirements Review, Subsystem (equipment) Source Selection and the Preliminary Design Review (PDR) all needed to be held within the first year of the contract to maintain the schedule.

The design reviews, coupled with working groups across the program for the combat system upgrade, were designed to cover all the contract deliverables. These included the ship combat system (including its performance, electrical, mechanical, and software details, and its ability to support interactions with the ships operational and maintenance crew), a land-based test site, training for the ships' crews and shore establishment support resources, the combat system training devices themselves, support products (including naval electronic system test range equipment identified by ***Canada***), predicted system failures and effects, operation and maintenance manuals, special tools and test equipment, spares, and configuration data sets.

With no lead ship and the short time span between contract award in 2008 and the refit in 2010, emphasis was placed on installing the selected sensors on the ship's hull. The ship design engineering team, located at the Lockheed Martin facility in Moorestown, New Jersey, under the guidance of the LM Canada technical director, and working with Fleetway International within the HCM CSI Ship Design Integrated Product Team (IPT), were pivotal in developing the above-deck and below-deck equipment layout, and transforming this into the technical data package that could be used by Fleetway to create the combat system engineering change packages. In parallel with the ship design, LM Canada was verifying the performance through specialty reports, including overall weight reports, centre of gravity calculations, electrical loads, cooling water requirements, etc.

From the outset, the configuration of the legacy ships entering the refit was a risk, and a mitigation strategy was developed where a pre-refit survey was conducted on board that used scanning lasers to take digital measurements of the ship spaces. The intent was to provide the best baseline possible for developing the installation ECs. During the pre-refit surveys, limitations including the effect of the lagging and the amount of equipment in the spaces made it difficult to conduct the surveys. In general, many spaces were cleared out during the equipment removal activities.

The ship ECs were split into 17 major ECs – seven for the removal of legacy equipment, and 10 for the installation of the new sensors. The ECs were focused on complete subsystems that provided a picture of all the changes required to allow a subsystem to operate. This included the material list, and the hull, mechanical, electrical, and combat system diagrams. To support the extraction of work within spaces on the ship, a cross-reference matrix was provided to map the system-based ECs to the onboard compartments.

At PDR, ***Canada*** identified concerns about the performance of the 2D radar proposed to meet the new combat system requirements. Working with LM Canada and the original equipment manufacturer (OEM) for the 2D Radar, an agreement was reached at the follow-on ***Canada*** Industry Integrated Product Team conference week in October 2010. This resulted in changes to the equipment fit that required further changes to be incorporated in the below-deck combat space. LM Canada, working with the OEM, was able to redesign the below-deck spaces.

The Critical Design Review (CDR) for the combat system was held one year after the PDR in Montreal in the summer of 2010 as the major event prior to the ships entering refit. This review once again presented the status of the design of all items related to the combat system integration contract. A set of actions resulted from the reviews that were planned to be worked through with the LM Canada Integrated Product Teams.

In 2010 LM Canada established a shipyard office with personnel located in office space rented from ISI. The purpose of the collocation of staff was to facilitate timely and efficient resolution of problems so that immediate baseline changes could be employed for the following ships.

Shortly after the combat system CDR in 2010, the baseline set of ECs was delivered to the shipyards to meet their requirement to have this six or more months ahead of the refit. With the delivery of the first baseline production, planning could begin in earnest by ISI. The materials specified in the ECs could now be sourced. Thus began a number of activities to find suitable sources for the specialty steel required for the combat system installation. This included ordering mill runs for a number of materials, sourcing specialty steel components from various industries, and locating local suppliers for the material listed in the ECs.

To mitigate the time delays resulting from design changes driven by configuration differences on each platform, LM Canada had design agent resources working alongside LM Canada in the office located at ISI. This specific activity was to work through defect advice notices from the shipyard by analyzing the design issues on the deck plates, and providing a change that would rectify the issue.

Changes discovered in the installation and testing process resulted in many changes with suppliers. At the onset of the project, Lockheed Martin had recognized that suppliers' reaction would be crucial in getting issues resolved quickly before they impacted follow-on platforms. Lockheed Martin intentionally invested in building relationships with all key suppliers.

Although the baseline used on the first ship required changes, it did form a solid basis as a production design that allowed LM Canada to achieve success without a lead ship.

Cable Management

Lockheed Martin Canada considered cable management to be one of the cornerstones of the refit and, as a result, conducted early surveys, backed by a strong configuration management culture, that was critical to understanding the existing and new cable installations.

Early in the modernization project, ***Canada*** recognized the potential negative impact cable management could have on the life of the project. ***Canada*** took mitigation steps to get cable management under control so that any impact would be minimized. One of the earlier activities was the institution of a cable management plan (CMP), within which all stakeholders' cables, including Lockheed Martin Canada's, were integrated into a cohesive, consistent plan.

The CMP effort was challenged due to several pre-existing factors, including:

- Lack of a detailed baseline configuration for the existing ships' cables, transits, and cableways
- Lack of Canadian industry's and ***Canada***'s expertise in dealing with recent large-scale projects
- Premature or lack of vendor-furnished information on new cable requirements
- An invalid assumption that modern technology would decrease the overall number of cables (and hence resulting transits and cableways) required throughout the ship
- The need to reuse a large number of legacy cables
- The use of legacy permanent cable/transit packing materials not intended to facilitate non-destructive cable removal and reuse
- The need to separate red (classified) and black (non-classified) cables

Given the pre-existing factors, a decision was made to pursue a path to electronically automate the cable design through a proven toolset such that efficient adjustments could be made as the project progressed. Although not predictable from the onset, the toolset soon proved inadequate for the task at hand mainly due to the existing cable configuration not being fully available.

The exercise, however, did produce the data banks required to facilitate an alternate process that relied more heavily on human interaction. A cable specification standard and process was established whereby the available cable information could be readily transformed into production cable sheets. The cable production sheets required manual review from various stakeholders, but as more and more sheets were produced, the quality and production rate steadily increased. In conjunction with prioritizing the order of ship production work and providing onsite design experts, the CMP activities could keep pace with ship production activities thereby minimizing the overall impact to the schedule.

Despite the progress, cable management remained a key focus for management until well into the refit schedule. Several initiatives to monitor and improve cable management continued until up to and including Ship 7. These included:

- Providing reels of cable versus cut cables so that deckplate adjustments could be made
- Measuring the cable routes prior to cutting the cables for installation to prevent cables being too short or excessive wastage
- Instituting a strong quality control program to identify cable damage during the pull process

- Synchronizing cable pulling with other platform work during the refit to ensure that cables were not damaged from heavy industrial work still being completed in compartments
- Coordinating the pulling, connectorization and testing of cables with other ship refit work to optimize productivity.

The volume and complexity of cables for HCM had the potential to derail the entire project. The cooperation among stakeholders and the drive for success allowed the teams to effectively manage cables such that the refit schedules remained overall on track.

HCM Material Management – A Combat System Integration (CSI) Perspective

Ship Installation Material List

The Consolidated List of Material (CLM) in the Lockheed Martin Canada combat system design specified the material items required for the HCM CSI Project. The CLM was built by Fleetway International from the raw materials in each of the design drawings contained in the seven removal and 11 installation engineering change (EC) packages. The list included:

- 786 line items removed from the ships
- 585 line items returned to ***Canada*** directly
- 201 line items stored for reuse.

The installation ECs included 3680 line items: 2773 to be supplied by the shipyard, and 907 by LM Canada, the client. This was for each of the 12 ships.

Material Delivery Schedule

From the outset of the proposal, Lockheed Martin Canada's objective in working with each of the combat systems equipment suppliers was to have the first ship's equipment delivered by the time the ship entered refit as the benchmark. With any large program, the open and focused communication among all stakeholders is critical in making design decisions to meet the customer requirements and balancing these decisions with the need to deliver the equipment to meet the refit schedules. A good material management approach is required to achieve this balance.

Material Management

All CSI equipment was essentially installed in the refit at the shipyards and material management was critical to support efficient working, i.e. right materials for the refit work. The risk of shipyard work potentially being held up due to late material from Lockheed Martin Canada and its suppliers was a key driver in many Lockheed Martin Canada's decisions. Lockheed Martin Canada's scope under the HCM contract also included taking custody of the ship legacy equipment when the ships entered the refit, and then dispositioning the equipment to be either reused, returned to ***Canada***, or scrapped.

Collocated Offices at Both Shipyards

One of the many mitigations to the material supply risk was that Lockheed Martin Canada located a team of skilled resources in rented offices at both shipyards for the duration of the refit contract. These resources were former Royal Canadian Navy and Lockheed Martin Canada support resources alongside subcontractor resources from Fleetway International and L3 ESS, the key sensor support specialist. These resources were selected based on their experience working on the legacy ship configurations, and also on the activities taking place at the shipyards. Both offices were initially managed by Lockheed Martin resources from the USA that had experience on the AEGIS program.

Both offices were provided with capabilities to efficiently communicate with any team on the CSI program including:

- the ship design product team that delivered the ship engineering changes;
- the CSI subsystems teams working with their manufacturers to deliver complex equipment and spares, and handle frames, to the Halifax region;
- the refit material warehousing and transport team; and
- the schedule management team within Lockheed Martin, ***Canada***, and the shipyards.

Through regular meetings, shared desktop technology, electronic data management, printing and scanning capabilities, and an IP phone system, efficient virtual communications could be maintained. As with any human experience, working on any new equipment is a key skill development activity. Lockheed Martin Canada budgeted time for the West Coast resources at the land-based test site located on the East Coast, and at the lead shipyard on the East Coast, prior to the first ship, HMCS *Calgary*, entering the West Coast shipyard in 2011.

Material Delivery Risks

Material delivery risks came from many areas and included items such as changing customer requirements, incorrect design or handling of information, missing legacy ship baseline information, manufacturing quality issues, delivery delays, misplacing material, material damage during transportation, installation material handling damage, material exposed to inclement weather, unexpected performance issues arising during installation, and set-to-work activities that could lead to early consumption of spares.

Material Delivery Plan

Lockheed Martin Canada made a conscious decision to retain control of the CSI material until it was required for shipyard production activities with a just-in-time delivery philosophy. This allowed complex material supply decisions to be made within Lockheed Martin Canada in support of the ship refit schedule, and also the follow-on equipment set-to-work, harbour trials, and sea trials conducted when the refitted ships were returned to ***Canada***'s naval base and fleet maintenance facilities (FMFs).

Logistically, Lockheed Martin Canada's own equipment for the CMS-330 and the major subsystem equipment was planned to be delivered to a central warehouse in the Halifax, Nova Scotia area. Due to limited warehousing options on the West Coast near Esquimalt, British Columbia, Lockheed Martin Canada decided that the material required for the five West Coast ships would be held on the East Coast, and then shipped across the country just in time to support their West Coast refits. A limited size warehouse was rented through Victoria Shipyard Ltd (VSL) to receive the equipment and hold it prior to being requested for installation during the refit.

Halifax Transfer International (HTI) in Burnside, Nova Scotia was selected in 2010 by Lockheed Martin Canada to store the HCM CSI material. Our material management resources located at HTI directed warehouse personnel to store or pull equipment required to support either East Coast or West Coast shipyard activities.

First Equipment Delivery – Land Based Test Site (LBTS)

As a fundamental element of mitigating the equipment installed performance, LM Canada planned an LBTS at the Lockheed Martin Canada office in Dartmouth, Nova Scotia. This LBTS facility gave us the ability to operate the combat system as an integrated system on land ahead of the ship refit activities. The LBTS supported both live test targets and simulated environment to exercise the overall system functionality. The objective was to verify the combat system performance against the original customer requirements, and provide an efficient fault isolation environment for the many engineers, and test resources that would bring the system together.

The site was constructed using the same cable configurations as in the ships so as to allow design issues to surface early, and develop changes quickly ahead of the ship set-to-work and trial activities. The sensor platform designed for the LBTS was based on the ship refit designs, and modified to meet the commercial building codes and the operation requirements within a city environment.

The LBTS proved to be an efficient development and test lab for the combat system, including the combat management system. Manufacturers' field service representatives conducted training of the in-country Lockheed Martin Canada and contractor resources that would carry out the installation of the equipment on follow-on ships.

Legacy Equipment Removal

Lockheed Martin Canada developed a tagging system using the data from the Consolidated List of Materials for the CSI's seven removal ECs. The tags were based on ***Canada***'s 942A tags, supplemented with computer-generated labels that included the part name, EC number, and CLM item number if the part was to be retained, returned, or scrapped, and a bar code suitable for use with a handheld scanner. The tags are familiar to ***Canada***'s personnel and were pre-printed prior to a ship's arrival. Each tag was attached by the Lockheed Martin Canada shipyard onsite team, and if there were leftover tags it indicated that either the part was not delivered with the ship, or it could not be found and this would be resolved through discussions with the local ***Canada*** project office representative. The tags also proved useful for tracking parts as they were removed and directed at the jetty to be transported either to the Lockheed Martin Canada warehouse in Burnside or Esquimalt, to ***Canada***'s returned equipment storage warehouse, or to a scrap bin at the shipyard.

New CSI Material Delivery

Certain material challenges presented themselves during the refits. LM Canada worked closely with ISI and VSL buyers to locate sources of the specialty steel required in military platform designs identified as client-furnished material in the ECs. The experienced shipyard buyers were able to locate specialty steel from various locations, including procuring complete steel mill runs (80 tonnes) of the required thicknesses of steel plates. The plates were procured in one batch for the whole program, primed, and stored with specialty firms that had the handling equipment suitable to move and store the plates.

Other specialty industry materials were also required, such as the pole masts that were fabricated from specialty steel pipes used in the oil industry. These were located in Texas and transported to both shipyards in Halifax and Esquimalt.

Some economically difficult material to acquire, due to limited need and minimum-buy quantities, was offered by ***Canada*** from their stock used to maintain the fleet. These included the T-bars used to reinforce the deck plates under the weight of the combat system equipment racks, for example. Other limited quantities of shaped specialty steel for the mast structure was also supplied to Lockheed Martin Canada by ***Canada***.

Notable material delivery experiences from the refit program included, in 2012, a 3D radar being transported by a Lockheed Martin Canada freight company from the Halifax port under a low bridge suffered damage to its integrated Identification Friend or Foe (IFF) antenna mounted on the top of the main rotating sensor array. The complete radar antenna assembly had to be returned to the manufacturer, Thales, in Europe for repair and retesting. Lockheed Martin Canada worked closely with Thales who adapted their production schedule to accommodate LM/DND, and ISI was able to re-sequence the antenna delivery destined for the follow-on ship to maintain HMCS *Fredericton*'s refit.

Other experiences on large programs were late ordering of parts due to volume. The shortage was identified as late, and the challenge then became expediting the delivery with the various manufacturers. One notable example was the complex Switching Automatic Bus Transfer (SABT) devices procured from L3 Power Paragon in California. Fortunately, with the large production quantities for the US Navy, the L3 project manager was able to work with his other customers to re-sequence the production line and support the HCM refit schedule. From this there were issues with identification plates, but it allowed the HCM refits to maintain the overall program schedule.

Tags used to identify parts being removed from legacy ships

Quality issues that are found over time do occur on large contracts. An example included a batch of waveguides that were noted to have paint peeling prematurely after their installation. Following a root cause analysis with the supplier, the waveguides had to be removed from the ship and returned for repainting. This did require a rework schedule to be developed, including all the follow-on delivered stock in the Lockheed Martin Canada warehouse. The vendor was supportive, and the refit schedule was able to be maintained with a lot of extra work from the material management team.

Some problems can be quite small and require detailed investigation. Early in the program, on HMCS *Winnipeg*, a trend was noted in failures on the LCD displays used in the CMS-330 consoles. In this case multiple issues were observed where the screen image would separate, or a colour would be lost. The root cause was isolated by a Lockheed Martin Canada technician measuring the resistance of an internal multiple strand cable and its connector shell crimps. These measurements indicated a problem with the crimp connections, and a detailed investigation with the manufacturer concluded that a crimping machine in the display component supplier had not been set correctly by an operator. The recovery actions were to replace all internal connection cables in the delivered displays. Lockheed Martin Canada, working with the manufacturer at our own cost, had over 600 cables remade and conducted a retrofit program in Canada to rework all the delivered displays, and those in stock for the completion of the contract.

Symptoms may arise that indicate that a sensor is not performing. The initial instinct is that a delivered component has failed, but upon investigation water is noted dripping from cable connectors attached to equipment inside the ship. In this case the water was impacting the electrical

Lessons learned

Some lessons learned that will benefit future programs include:

- ***Shipyard material management*** is critical to support efficient work, with the right materials used in support of work.
- ***Maintaining material control*** for as long as possible to ensure access to additional material to overcome schedule pressures.
- ***A collocated stakeholder's materials management depot*** would be ideal at the shipyard. Competitive lease rates are always a challenge.
- Using strong ***integrated material management processes*** by all stakeholders.
- Using modern ***non-proprietary tools*** to allow quick understanding of materials state
  - SAP - Inventory Control/RFID technology
  - Bar Coding
  - Controlled Goods Process Education and Management
  - Materials call-out process
- ***Pay attention to small fittings*** such as pressure gauges, and specialty power supplies, etc., that are specified by subsystem suppliers, but designed in the ECs and procured by the shipyard or the systems integrator. These are generally found at the last minute and require special attention to maintain the production schedules.
- Cables – Generally, long lead expertise from the Lockheed Martin Corporation in the USA was instrumental in managing and sourcing the cables and connectors required for the refit. ***Dedicated resources for cable procurement*** are recommended.
- ***New equipment damage*** – Shipboard electronics are heavy, and installed in relatively tight spaces. Damage happens, so don't be upset. Isolate the root cause, find solutions to prevent it from happening again, but most of all be flexible. Additional material is helpful to mitigate the production schedule.
- ***Quality issues, either design-related or production steps missed, are likely at the root cause of failures occurring early in the installation phase.*** Pay attention to replacement part requests, don't jump to conclusions, and maintain an open environment that allows the team to participate in root cause isolation, work with the designer/OEM to find a solution, and provide feedback to OEMs on the performance. Share your experience through as many resources as possible.

signal performance creating the initial symptoms. This investigation identified the root cause to be the communication of installation instructions on critical interfaces, notably cable penetrations. The resulting repairs required the cables to be removed and replaced at a large cost. Lockheed Martin Canada worked with the shipyard to agree on a new process to prevent this from reoccurring on follow-on ships. Cables from follow-on ships could be used, and the consumed volume had to be reordered in time to support the production of the last ships.

Complex Material Issues – Premature Failures

Premature failures can arise during testing on the first ship. One example was the premature failures noted in the 3D radar. LM Canada working diligently with Thales was able to isolate the root cause after face-to-face meetings. In these situations, business dynamics can prevent information being made available to support these root cause analyses. For this particular problem, it was found that a critical component had three versions in the HCM-supplied material, each with increased reliability. Lockheed Martin Canada, together with Thales' Netherlands project manager and technical team, worked through the root cause analysis of the failed items and included data provided by Lockheed Martin Canada from the trials program and results from the 3D radar's operation on multiple ships. Thales stepped up to their commitment and agreed to update all the supplied items to the third version of the product. An upgrade program was set up to return the items directly from ***Canada*** to the actual part manufacturer located in the USA. The reliability of the 3D radar has now reached a level that is in line with its specified performance.

Other instances of observed performance problems during installation included cables with core diameters that were slightly higher than the connector pin barrel in the connectors. The experienced Lockheed Martin USA connectorization team contracted by Lockheed Martin Canada had procedures that did not allow the peeling back of any conductors in a cable core to make the cable fit into the pin barrel; in this case, approximately the diameter of a single strand of the core. Due to production schedule pressures the cable core was butted against the connector pin and soldered. Over time, this joint failed due to cable flexing that eventually caused symptoms to appear on the fire-control directors. Technicians conducting repairs found it difficult to return the equipment to a working condition. During this period, parts were being replaced and returned for repair with above-normal frequency. After another investigation, the root cause was isolated and an engineering change request had to be created to add a larger pin placed in series that had a barrel diameter sufficient to cover the cable core. The pin was then inserted into the existing connector pin and soldered. This new joint provided the performance required to ensure a reliable in-service performance.

Other instances of complex systems issues successfully resolved were when the 3D radar on HMCS *Halifax* and then HMCS *Montreal* started vibrating during operational use causing significant noise in the commanding officer's cabin. The radars were being turned off during sleep periods. Lockheed Martin Canada technicians worked with Thales, the OEM, and the ship's crew to investigate potential causes. Through open communication between all parties, and experimentation using additional tensioning bungees to change the resonant frequency of the frame, the root cause was confirmed as a mechanical resonance being excited following very slight wear in the radar's structural absorbing frame joints. Lockheed Martin Canada's in-country resources are working openly with Thales specialists in Europe. Thales initiated and installed improved software settings, shifting the radar's servo drive overall excitation frequency away from the resonant frequency of the mechanical structure. The modified servo constants were successfully tested on newly refitted ships that were conducting operations in different weather conditions. This was another example of international open communications with mutually trusting relationships that resulted in a technical solution found quickly to achieve the required installed performance on the ships.

In Summary

The above examples are a selection of the HCM program's material supply experiences that were a direct result of an open, trusting relationship between among all parties.

This effort involved, at times, long working hours and time away from home at sea, working with suppliers on the phone, sending emails, exchanging data, visiting ships and supplier facilities to find the root cause of problems, and developing solutions, all with the aim of delivering a system to ***Canada*** that will perform for years to come.

Industry Insights:

Perspectives on HCM/FELEX from Irving Shipbuilding Inc.

Stakeholder Governance

Most aspects of ship refit/repair projects like the mid-life refits (MLRs) for the Frigate Equipment Life Extension (FELEX) are complex. The differences between ship configurations, state of repair, inclusion/exclusion of specifications, and location of original build all result in each ship having a different set of challenges. Some ships required more structural and steel repairs than others due to the different maintenance conditions, while other ships received new capability upgrades midway through the program. All of these factors in a program as complex as FELEX mean that inevitably all parties involved will have to identify, communicate, research, and implement solutions to each and every challenge.

While each contributing organization was well equipped to deal with the challenges individually, the FELEX governance structure was key to ensuring that all levels of each organization effectively approached each challenge in an open and collaborative environment. Each organization within all levels of the governance structure brought a unique set of skills to the table to ensure that only the best solutions to the challenges were implemented. From the Committee of Sponsors down to the face-to-face meetings within the production environment, the governance structure allowed for all participants to provide essential input to ensure success.

The working relationships that were formed as a result of the governance structure are worth noting. While this arrangement ensured effective communications in a more formal manner, the day-to-day contact between and among all partners while working through issues and challenges formed a very proactive and collaborative environment. This fostered a close working relationship across partnerships that could not have been anticipated at the outset of the program. As an example, prior to the FELEX program the interaction between the Irving Shipbuilding production workforce and the Fleet Maintenance Facility (FMF) production workforce was essentially nonexistent; but during work on the last few ships of the program, it was commonplace to see both workforces functioning side-by-side both at Irving Shipbuilding's Halifax Shipyard, and at the adjacent FMF. This is considered to be a success story in itself.

No Lead Ship

Entering the production phase of the MLRs without a lead ship strategy presented challenges that Irving Shipbuilding had to overcome to ensure a successful *Halifax*-Class Modernization (HCM) and FELEX programs. Several measures were implemented to address the challenges that this created.

Irving Shipbuilding took a proactive approach to defining specification criteria – working with the Department of National Defence (DND) and Lockheed Martin Canada (LMC) to provide clear specification parameters and definition with achievable/measureable results. A number of areas were impacted, and Irving Shipbuilding developed new processes to react to the outcomes of this challenge. A stringent document control process was implemented that allowed for the processing and effective dissemination of changes and updates to the engineering specifications. A FELEX-specific SharePoint site was created to host all updated specification-related information, including drawings and reference materials. The new process involved the insertion of hyperlinks embedded within each parent specification that would link to updates.

The hyperlinks were embedded on any page (for both specifications and drawings) where a revision or modification existed. Tablets were issued to supervisors and planners for use in the field to ensure that the front line had mobile access to the latest revisions of specifications and drawings. Infrastructure was installed throughout the ship to provide WiFi access to mobile interface with SharePoint. This resulted in the front line having one source of information that included all current contracted information. The infrastructure put in place to support this one new process resulted in enabling the Irving Shipbuilding FELEX program to expand the use of mobile access to support other processes such as work pack access, ordering material, and approving requisitions.

Each MLR project provided an opportunity for improvement through the implementation of lessons learned. Specification maturity increased with the completion of each MLR, allowing for more consistent conduct of ship repair, schedule attainment, and quality of workmanship in each MLR ship delivered.

Cable Management

The removal and installation of cables formed a significant portion of the HCM/FELEX program, and substantial effort was put into this area to ensure success. Irving Shipbuilding worked with all parties involved in cable management for the FELEX program to validate cable information received from DND and Lockheed Martin Canada.

A frigate's bridge before and after refit. Substantial effort was put into the removal and installation of cables to ensure success.

Validation of the cable state for each ship was achieved by conducting a second cable survey after the ship arrived at Irving Shipbuilding for refit. Once validated, Irving Shipbuilding created a database from individual specifications, identifying managed and unmanaged cables, and implementing a cable tagging/flagging process for enhanced identification in the field. This resulted in less rework, more efficient installation of new cable, and minimal wasted cable.

Irving Shipbuilding also created transit packing lists and other tools to help prevent overprescribing of cable transits. Welding procedures were reviewed with DND, and clarification was requested from the original equipment manufacturer (OEM). This resulted in the implementation of updated welding procedures, and the utilization of a jig obtained from the OEM. A more robust oversight was introduced, increasing Irving Shipbuilding surveillance of the welding process from fit-up to post-weld. Packing of transits evolved and improved throughout the program as more training from the OEM was provided, better techniques were identified, and the experience levels of the workforce increased. This resulted in better cable completion, meeting or exceeding tolerances in fit-up.

Throughout the implementation of cable management for FELEX, a close collaborative relationship was developed between Irving Shipbuilding, DND and LMC in resolving cable issues. This resulted in better cable removal and installation as demonstrated in reports generated specifically to measure the success of cable management (such as Cable Pull, Transit Packing, and Termination reports).

Material Management

Irving Shipbuilding was reliant on DND to supply restricted materials as government-supplied material (GSM), and also dependent on Lockheed Martin Canada for materials related to the Combat Systems Integration (CSI) portion of FELEX. In some cases this caused delays in delivery of material to Irving Shipbuilding. Due to the age of the frigates, substitute contractor-furnished material (CFM) for legacy systems and equipment had to be sourced and approved by DND, causing challenges and risks to the material state of each ship. Deviations were inevitable in a number of instances when acceptable substitute material could not be sourced.

Irving Shipbuilding played a lead role in mitigating and efficiently managing material for the FELEX program. Key decisions made to conduct bulk buys for steel and cable proved very effective for the overall program, providing

easier and quicker access to material when needed. Management of bulk buys and expanding the minimum order quantity allowed for cost savings.

Irving Shipbuilding further implemented daily tracking and expediting of high-priority materials. Availability of material for use on FELEX was improved by providing easier access to the material by warehousing it in closer proximity to the production area. Flow of material from DND/LMC to Irving Shipbuilding's material management team to the field improved throughout the program as lessons were learned and implemented. Irving Shipbuilding implemented, enforced adherence to, and conducted continuous improvement of its shipping/receiving processes so that control of the vast amount of material was maintained to acceptable levels. In a production environment such as ship repair there are some instances when material, even after proper shipping process is followed, is damaged during installation. A Request for Material Replacement (RMR) process was developed and implemented for any material that was damaged during installation, so as to track and ultimately minimize the time needed to identify, source, and receive replacement material.

Irving Shipbuilding's ownership of the management of materials purchased by Irving Shipbuilding, and supplied by both customers (DND and LMC) for the FELEX program, improved the ability of the project teams to complete the refit work in a timely manner.

Industry Insights:
Victoria Shipyards Co. Ltd.

Introduction

Victoria Shipyards Co. Ltd. (VSL) was proud to be part of the *Halifax*-Class Modernization and Frigate Life Extension (HCM/FELEX) refit program on the West Coast. While VSL experienced many challenges, there were also numerous successes, culminating with the on-time delivery of all West Coast Canadian Patrol Frigates back to the Royal Canadian Navy after each of their mid-life refits.

Some of the major achievements were recognized by the cooperative approach that all stakeholders took in realizing that we had to succeed equally. Having the West Coast Detachment, Lockheed Martin Canada (LMC), Fleet Maintenance Facility (FMF), and Victoria Shipyards management teams collocated in one building was a major factor that contributed to our collective success. This allowed for effective communication, problem-solving, and timely resolution to daily issues that arose.

Another area that greatly assisted the program was continuity of personnel. This stability within the program allowed the working relationships to improve as the program progressed. These team members were able to gain invaluable experience and implement lessons learned on subsequent vessels.

Numerous lessons learned were recognized and applied by all departments throughout the five-year program. Some of the highlights include:

- Consolidating work packages into one collective schedule, allowing for maximum productivity within a 12-month mid-life refit (MLR);
- Consolidating all engineering change (EC) compartment work scope to avoid duplication of trade activity, including lead abatement, strip-out, hot work, and production activities;

- Changing the operations room after bulkhead removal route to allow for earlier transit and cable installation;
- Improving the ultra-high-pressure process for above-waterline preparation through a new production procedures and customer inspection process;
- Changing the process for overboard discharges to allow for more effective inspection and identification of required repairs; and
- Successful strategic partnerships between the RCN, Lockheed Martin Canada, FMF, and VSL.

HCM/FELEX Program Manager Randy Little stated that VSL was proud to be a part of this multi-faceted team on a program that, while very challenging, provided steady work for a significantly sizable workforce over the past five years. Randy further stated that this program is a testament to the professionalism of all departments at VSL in completing this program safely, efficiently, and with the highest regard for protecting our environment.

Stakeholder Governance

Stakeholder governance was an important aspect to the success of the HCM/FELEX program. The governance consisted of the Committee of Sponsors, Canada-Industry Integrated Project Team (CI IPT), production forums, and waterfront committees. The governance allowed for issues involving multiple stakeholders to be resolved in a fair and equitable manner at the appropriate level. Issues that could be resolved at the deckplate level were handled at that level, and only elevated if necessary. This approach ensured that senior levels were only engaged when required to deal with more complex issues involving multiple stakeholders that could not be resolved at the lower levels.

A unique component of the HCM/FELEX program was the Strategic Partnering Plan with all of the major stakeholders. The plan outlined the procedures, protocols, and mechanisms that allowed all stakeholders to work on the ship during the core period when the vessel was in the VSL facility. This plan also allowed VSL to conduct its work before and after the core period while the frigates were in in the naval dockyard. This agreement was reached to ensure that the maximum amount of work could be conducted in the minimum amount of time, and with a minimum of conflict.

The Strategic Partnering Plan allowed for de-confliction of pre- and post-MLR work for VSL and FMF. During the pre-MLR, VSL commenced strip-out of combat and machinery control systems while the vessels were still in the naval dockyard. This work was critical in VSL's ability to maintain the schedule throughout the MLR. The FMF also had the ability to carry out work while the vessels were under VSL's control on a non-interference basis. One example of this was FMF's ability to set to work and conduct generator trials in the Esquimalt Graving Dock facilities. This ensured that all vessels could be transferred back to the naval yard at the end of the MLR with power being supplied to critical systems.

The HCM program governance team was an integral component to VSL's successes achieved while executing work throughout the HCM/FELEX program.

Material Management

VSL experienced many challenges while sourcing materials on HMCS *Calgary*, the first CPF to undergo an MLR at Victoria Shipyards. While preparing the estimate and sourcing materials, it came to light that there was a potential for negative impacts to *Calgary*'s critical path.

Of particular concern was the availability of specialty items at a reasonable price. During the bid preparation, VSL identified gaps through a question and answer process, and requested that some specialty items be converted from contractor-furnished material (CFM) to government-furnished material (GSM). The RCN conveyed they also could not supply some of this material in time to meet schedule requirements.

These specialty items included, but were not limited to, the following items:

- Specialty steel
- Electrical cabling
- EMI gaskets
- Electrical conduit
- Electrical transits packing and associated supplies

To mitigate the potential material issues, the following actions were taken: ***Specialty Steel*** – This was identified early on as one of the major issues affecting the schedule. VSL obtained agreement from LMC to source mill runs of specialty steel through a local supplier. With this vendor we established vendor management inventory parameters that included off-site storage, delivery, and stock reporting. This process ensured steel was available as required for LMC and RCN work, and only a minimum of steel plate was remaining after job completion. This remaining material was returned to the RCN for use on subsequent projects.

Electrical Cabling – Due to complex shipboard requirements, manufacturing lead times, and the limited number of qualified vendors, cable sourcing was identified as one of the high-risk areas on VSL's risk register. Similar to how the steel issues were resolved, VSL collaborated with LMC and RCN in identifying and consolidating the cable requirements for the entire vessel, including all RCN and LMC engineering changes. This information was used to leverage volume buying with preferred vendors who were selected to assist with management of cable stock, along with cutting and storing.

The collaborative relationship that was developed during the program served as an opportunity for sharing material resources as required between LMC and RCN work. This initiative removed traditional constraints that could otherwise have had a serious impact to the overall program schedule.

Engineering Changes

Prior to the first MLR vessel, VSL had many years of experience working with the RCN in executing docking work periods, which included Particularized Maintenance Repair Specifications (PMRS), as well as engineering changes. However, VSL had not previously experienced the sheer number of ECs received for the mid-life refits, from both the RCN and LMC. In addition, the scope of the ECs impacted all areas of the vessel; many spaces had numerous EC installations occurring simultaneously.

During the first MLR, on HMCS *Calgary*, VSL experienced several challenges while carrying out installation work for the numerous ECs. Work packages were not specific to each compartment, which caused some confusion and created follow-up rework due to interference issues. There was also a learning curve required for all supervisors to clearly understand the process for identifying issues with the specifications and materials.

- To deal with the issues from the first vessel, the following improvements were developed:Training sessions given to supervisors were enhanced to better address emerging issues; and new work packages were developed for compartments with multiple EC installations. The packages contained all specifications that were applicable to that space, as well as photos of the strip-outs and installations from previous vessels. The packages were clearly marked for reference only to ensure that workers used the current specification for strip-out and install, and did not rely solely on information from the previous vessel.

Work flow and quality improved throughout the program due to time, experience, and working through the learning curve. Information being provided to LMC and the RCN from the VSL supervisors improved to describe identified deficiencies, and the quality of work instructions received from the customers also realized improvements.

Control of red-line drawing changes also improved as the program progressed. VSL received an unprecedented amount of changes during the MLRs, and it was important to ensure all changes were incorporated correctly. Databases were developed to track and monitor progress of changes. Quality control was essential to ensuring all work was completed, and completed correctly. To assist in this function a quality control checklist was developed and implemented. This checklist was controlled by each trade that carried out the QC inspections. Upon completion of the trade conducting their own QC, an inspection was called to allow the customers to witness. This ensured the responsible trade group was accountable for the accuracy and completion of the work.

The success achieved on the EC implementation could not have been accomplished without the full cooperation received from LMC and the HCM/FELEX Detachment. Quick responses to technical questions, local decisions, along with innovative solutions were key success factors.

Cable Management

The initial cable management plan received for HMCS *Calgary* provided several challenges for VSL. The late receipt of the plan along with numerous inconsistencies and lack of tracking proved to be problematic. Weekly meetings were held on-site with the RCN and LMC to assist in identification and resolution of various issues. As issues emerged, it was necessary to do a risk assessment on the cable run to determine whether to proceed with the run when discrepancies were noted with the route.

By the arrival of the second vessel, many improvements had been recognized not only in the management plan but through lessons learned during execution of the work. Better tracking tools were implemented to allow for real-time tracking of runs and progress. On the second vessel, VSL's strategy consisted of commencing the cable pull in the aft areas of the vessel. Doing so allowed all the hot work to be completed in the forward section prior to introducing any cable into that area. This permitted early start of cable pulling, while reducing the risk of cable damage during hot work in the forward sections of the vessel. In addition, the location of the bulkhead removal route cut-out between the operations room and Radar Room 2 was changed to allow earlier access to this area to commence the cable pull.

Since LMC was responsible for termination of the cabling, they required immediate access to compartments during the MLR. In collaboration with LMC, it was agreed that the cable pull sequence would be done by compartment, versus by individual EC. This allowed some spaces to be completed to a stage where they could be turned over to LMC earlier in the refit for connectorization.

Additional shop-floor efficiencies included using tags on cable hangers to identify routes, colour-coding cables with tape to identify cables that were being removed and ones that were to be coiled back, and which EC they belonged to. The use of placards was also implemented at each transit location. Placards identified and tracked each cable that was to pass through the transit to allow progress to be monitored. The electricians themselves also gained valuable knowledge as the program progressed, better understanding the complex cabling requirements such as cable separation, identification, and bend radii.

The key to the success of the cable management plan required that all stakeholders understand the need to work collaboratively to investigate and resolve issues quickly and professionally.

Conclusion

The collaborative approach taken by all stakeholders for the HCM/FELEX program ensured success at all levels. Victoria Shipyards was very proud to have played an instrumental role in the overall achievements of the program, and looks forward to providing continuing support to Canada's West Coast naval fleet for many years to come.