IDEaS Corrosion Detection in Ships Sandbox: Technologies Demonstrated and Next Steps

Shona R. McLaughlin
Innovation for Defence Excellence and Security
Defence Research and Development Canada
60 Moodie Drive
Ottawa, Ontario, K1A 0K2
CANADA

Shona.McLaughlin@forces.gc.ca

ABSTRACT

In the spring of 2022, the Canadian Department of National Defence's (DND) Innovation for Defence Excellence and Security (IDEaS) Program held a month-long Sandbox event for a Corrosion Detection in Ships challenge. The challenge to the Non-Destructive Examination (NDE) and Innovation communities was to demonstrate technologies of varying maturities that could detect and assess corrosion behind surface coatings such as paint, insulation, tiles, and seamless decking onboard Royal Canadian Navy (RCN) platforms. Participating Innovators were given the opportunity to demonstrate their solutions in two modalities: i) under ideal conditions on large test panels representing various elements of the ship such as hull, decking, and piping, and ii) under real-world conditions on an operational RCN vessel. Department of National Defence and the Canadian Armed Forces (DND/CAF) subject matter experts provided feedback on each solution. The broader aim of the Sandbox was to inform DND and the RCN of currently available and mature as well as emerging and unconventional NDE technologies that would enable them to rapidly and reliably detect and assess corrosion on the RCN platforms without reliance on human visual inspection or removal of equipment or coatings. The Sandbox showed that unconventional and emerging inspection technologies such as drones with imaging technologies including optical and thermal and AI for rapid visual inspection are becoming mature enough to start implementing. This paper will discuss the Sandbox event, conventional and emerging technologies demonstrated, lessons learned, and areas of future work for the development of novel approaches to corrosion detection in ships.

Keywords: corrosion inspection, innovation, artificial intelligence, machine learning, drones.

1.0 INTRODUCTION

The Innovation for Defence Excellence and Security (IDEaS) program was launched by Canada's Department of National Defence (DND) in 2018. The IDEaS program was developed to provide mechanisms that allow DND to better access technology development and innovation, and to leverage Canada's Innovation community to address tough challenges posed by the Department of National Defence and the Canadian Armed Forces (DND/CAF).

The IDEaS program has five elements to foster innovation over a range of solution maturity levels from initial concept, all the way up to proven solutions: Innovation Networks, Competitive Projects, Contests, Sandboxes, and Test Drives. The purpose of the Sandbox element is to give participating companies (Innovators) the opportunity to test and demonstrate how their solutions address published challenges in a structured environment provided by DND/CAF, with scenarios developed by subject matter experts (SMEs) and potential end-users.

During the Sandbox, Innovators receive on-site feedback from the DND/CAF technical SMEs and end-user SMEs. This provides the necessary context for Innovators to refine and develop their prototypes both during and after the Sandbox. Sandboxes also allow end-users to learn about the "state of the possible" and about upcoming less mature solutions to the challenge, potentially influencing future DND/CAF acquisition decisions.

Participation in Sandboxes is by application in response to a posted challenge with a call for applications. The applications are reviewed and scored by a committee of scientific and military or end-user SMEs, and top scoring solutions are invited to participate. There is also a mechanism by which "strategic picks" can be invited, i.e., applications which may not have scored as high, but are a technology that is sufficiently innovative and different from the others that the DND/CAF would like to know more about. This enables the demonstration of a broader number of ways to address the problem, and different aspects of the problem.

The Sandboxes are run at no cost for the Innovator to use the DND-provided Sandbox facility, but participating Innovators do not receive any financial incentives to participate or develop their solutions. Instead, a portion of travel, shipping, and other costs incurred related to attending the sandbox are reimbursed by the IDEaS program. (IDEaS, 2023a).

2.0 CORROSION DETECTION IN SHIPS (CDIS) SANDBOX CALL FOR APPLICATIONS

The call for applications for the Sandbox was launched in November 2021, and the Sandbox was held in April and May 2022. The challenge statement was:

> *How might we detect and assess corrosion behind surface coatings (such as paint, insulation, tiles, seamless decking …) onboard Royal Canadian Navy (RCN) platforms in order to reduce corrosion's operational impact and improve the effectiveness of scheduled and unscheduled maintenance?*
>
> *The end-state outcome of this challenge is to implement a functional solution for rapidly and easily detecting and informing the operators and engineers of all corrosion in a vessel while it is in operational use in a non-destructive manner that does not rely on human visual inspection or the removal of equipment. That information can then be used for unscheduled but required repairs, and planning for major work* (IDEaS, 2023b).

There were three types of corrosion defined by the Sandbox:

- **General corrosion**: defined as areas of continuous corrosion, or patches of corrosion in a common area.
- **Pitting corrosion**: defined as individual localized cavities of corrosion in a surface.
- **Crevice corrosion**: defined as corrosion between adjoining materials, such mounting pads, the deck, and connecting bolts.

Innovators were invited to apply with inspection technologies that demonstrated detection capability on one or more corrosion types in a dry environment. Additionally, there was a desire to evaluate underwater inspection methods to detect any of the three corrosion types.

At the time of application, solutions needed to be at Solution Readiness Level (SRL) of 5 or higher. This means "basic solution components are integrated and tested" (IDEaS, 2023c). SRL 5 was chosen to ensure that solutions were mature enough and ready for demonstration and testing in the simulated environment of the Sandbox (IDEaS, 2023a).

The IDEaS program received 19 applications in response to the call. Many of the applications were from companies whose primary applications were in fields other than naval or marine vessels, i.e., inspection of oil and gas pipelines, and fixed infrastructure (bridges, tanks). The applications received were broadly categorized based on whether they were conventional vs. unconventional/ or emerging approaches, the sensor technology type, and the sensor platform (Table 1). In some cases, a conventional technology was incorporated onto an unconventional or emerging platform, and the overall approach was categorized as unconventional or emerging. Some of the applications included multiple technologies and platforms integrated into a single solution, such as combining Artificial Intelligence / Machine Learning (AI/ML), optical imaging, ultrasonic testing, and drones.

Table 1: Technologies and approaches from the applications to participate in the Sandbox.

Approach	Technology	Sensor Platform	Demonstrated at Sandbox?
Conventional	Eddy Current (EC), Pulsed Eddy Current (PEC)	Handheld / Push-Broom Robotic (dry)	Y
	Magnetic Flux Leakage (MFL)	Handheld / Push-Broom	Y
	Ultrasound (UT), Phased Array (PAUT)	Handheld / Push-Broom Fixed Sensor	Y
	Visual Inspection	Human inspection	N
Unconventional or Emerging	Acoustic Imaging	Handheld / Push-Broom	N
	Artificial Intelligence (AI) / Machine Learning (ML) / Deep Learning (DL)	Software with sensors on: Drone (aerial) Tripod or Cart	Y
	Capacitance Imaging	Handheld / Push-Broom	Y
	Electrochemical Methods	Fixed Sensor	N
	Environmental Sensors (e.g., Time of Wetness)	Fixed Sensor	N
	Hyperspectral Imaging	Tripod or Cart	Y
	Impulse Excitation	Handheld / Push-Broom Robotic (dry) Robotic (underwater)	Y
	Optical Imaging	Drone (aerial)	Y
	Passive Magnetic Field detection	Handheld / Push-broom	Y
	Thermal Imaging	Drone (aerial)	Y
	Thermography	Tripod-mounted + Handheld heating element	Y
	Transient EC	Handheld / Push-Broom	N
	Ultrasound (UT)	Drone (aerial)	Y

Nine Innovators were invited to participate in the Sandbox, representing a mix of conventional and unconventional approaches to corrosion detection, and a range of maturities from SRL 5 to SRL 9 (proven or commercial solutions) (IDEaS, 2023c).

3.0 SANDBOX STRUCTURE

The Sandbox was held over four weeks at the Centre for Ocean Ventures and Entrepreneurship (COVE) facility in Dartmouth, Nova Scotia, Canada. Each Innovator was given up to 5 days of time, which included demonstrating their solutions under ideal conditions on engineered test panels with known defects, and also demonstrating the solutions under real-world conditions on a Canadian Coast Guard (CCG) ship (CCGS Hudson), a Royal Canadian Navy (RCN) ship (HMCS Goose Bay and HMCS Glace Bay), and/or a smaller dive boat (Dominion Diving – Roadway Vessel).

3.1 Test Panels

Six engineered test panels were designed by DND's Naval Engineering Test Establishment, and fabricated by an external contractor, to be representative of different areas of the naval ships:

- Dry Hull with the underwater and above water paint scheme used on RCN vessels (Figure 1)
- Wet Hull with the underwater paint scheme used on RCN vessels (Figure 2)
- Deck with seamless decking, quarry tile, and machine mounts (Figure 3)
- Deck with non-skid coating, machine mounts, bolts, and kick pipes (Figure 4)
- Fuel Oil Transport Piping (Steel), with flanges, valves, and elbows, painted (Figure 5)
- Seawater Piping (CuNi) with flanges, valves, and elbows, painted and wrapped in 1" thick insulation (Figure 6)

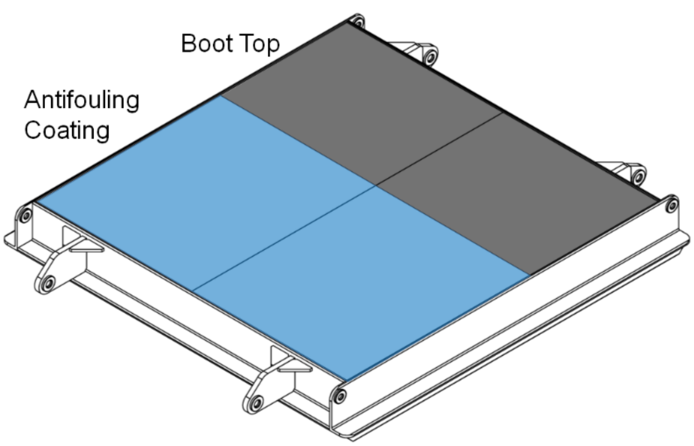
Flaws representing the three types of corrosion in the challenge were introduced into the hull and deck panels and the pipes by machining areas of thinning. These areas were on the back side of the hull panels, so that they were not visible under the paint, the front/top surface of the decking panels where they were covered by seamless or non-skid coatings, or quarry tiles, and on the inner surfaces of the pipes.

General corrosion (large areas of wastage) was introduced as circular flaws with diameters of 6 in (15.25 cm) and 12 in (30.48 cm), and material removal ranging from 10 to 70% of plate thickness on the hull and deck panels. The pipes had regions representing material loss of 10, 30, and 50% of wall thickness. These regions were in a variety of configurations, including 6 in (15.25 cm) diameter circular patches, 1 in (2.54 cm) diameter areas, 0.5 in (1.27 cm) wide bands on the inner circumference of the pipes, and areas of thinning at the bends. Pitting corrosion was introduced into the hull and deck panels as isolated flat bottomed holes with a diameter of 0.5 in (1.27 cm) and depths of 10 to 70% of the plate thickness. The crevice corrosion was simulated on bolts by removing 20, 30, and 40% of the major diameter thickness, 0.4 in (1.02 cm) below the bolt head, which corresponds to where the wastage would be expected to occur when used as fasteners, and on the inside diameter of pipes by 70% of their thickness (30% remaining), just above where they were welded to the plate, and direct access was restricted by non-skid coating (Figure 4).

The locations of the flaws on the test panels and pipes were not disclosed to Innovators. The Innovators were challenged to demonstrate that their solutions could quickly and accurately detect and report the size and location of the flaws. Each Innovator was assigned at least one scientific observer who had knowledge of the locations and size of the flaws, and could confirm the accuracy of the detections.

The test panels were biased towards technologies which were based on thickness measurements, such as Ultrasonic Testing (UT). This presented challenges for solutions which required actual corrosion product to be present, such as optical imaging + AI/ML, or the corrosion damage to be on the near-side of the panel. These technologies were able to demonstrate their solutions under real-world conditions on the RCN and CCG ships, and the smaller dive boat.

Figure 1: Dry hull test panel[(1)]. Large circular defects representing general corrosion and small blind holes representing pitting corrosion were machined into the back side of the plate at depths ranging from 10 to 50% of the material thickness, and covered with insulation so they were not visible to the Innovators.



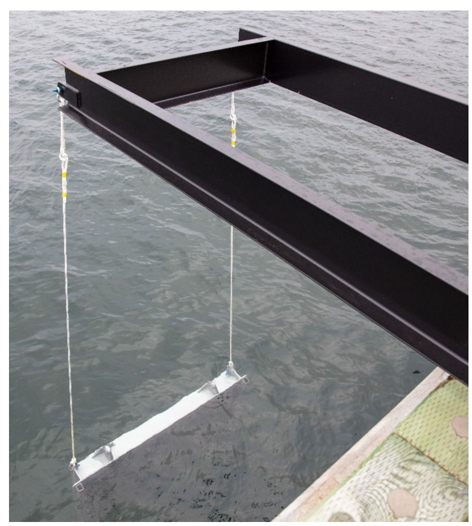


Figure 2: Under water hull test panel drawing (left) and panel suspended in the water (right). Drawing courtesy of M. Legge, Naval Engineering Test Establishment, Department of National Defence, Government of Canada.

(1) Photo credit for all images, unless otherwise noted: Steven Berry, Defence Research and Development Canada, Department of National Defence, Government of Canada.

Figure 3: Seamless decking test panel before (left) and after (right) coating. Large circular defects representing general corrosion and small blind holes representing pitting corrosion were machined into the front side of the plate at depths ranging from 10 to 70% of the material thickness, and covered by seamless decking or quarry tile.

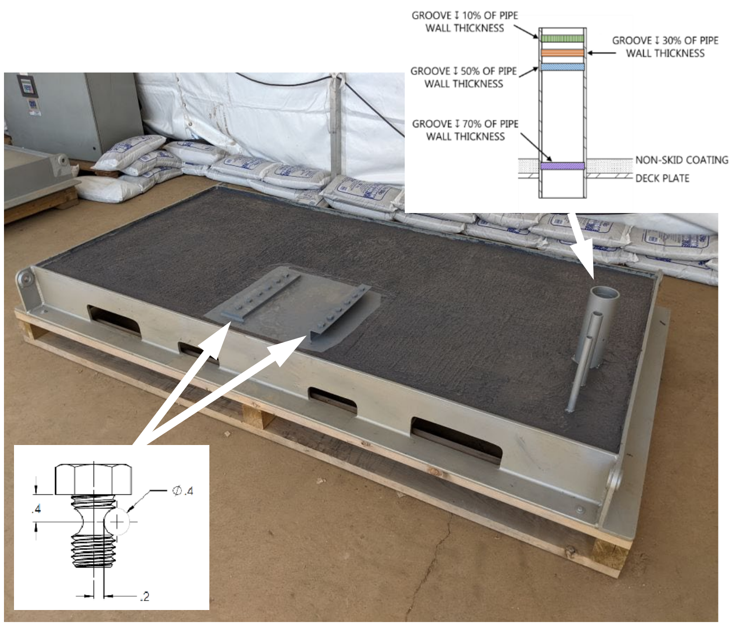


Figure 4: Non-skid decking / crevice corrosion test panel. Large circular defects representing general corrosion and small blind holes representing pitting corrosion were machined into the front side of the plate at depths ranging from 10 to 50% of the material thickness. Crevice corrosion was represented by thinning the bolts (bottom inset, dimensions are in inches) and inner diameter of the pipes just above where they were joined to the base plate (top inset). (Drawings courtesy of M. Legge, Naval Engineering Test Establishment, Department of National Defence, Government of Canada).

Figure 5: Steel fuel oil transport pipe test panel. Large circular defects representing general corrosion and small blind holes representing pitting corrosion were machined into the inner surfaces of the pipe at depths ranging from 10 to 50% of the pipe wall thickness.

Figure 6: Copper-nickel seawater cooling pipe test panel. large circular defects representing general corrosion and small blind holes representing pitting corrosion were machined into the inner surfaces of the pipe at depths ranging from 10 to 50% of the pipe wall thickness. The entire pipe was wrapped in 1" thick insulation which could not be removed for inspections. Photo credit: Centre de Métallurgie du Québec.

3.2 Demonstration on Ships

All of the Innovators were given the opportunity to demonstrate their solutions on the operational RCN ship. The locations of inspections were limited to easily accessible areas that were likely to have corrosion:

- Decks
- Exterior structures
- Hull above the water line
- Showers and heads
- Laundry areas
- CuNi Seawater pipes

On the ship, the state of the material was unknown to both the Innovators and the observers. Some of the corrosion damage identified by the Innovators was confirmed by traditional means (e.g., hand-held UT probes) by DND/CAF Non-Destructive Evaluation (NDE) personnel.

4.0 DEMONSTRATION OF SOLUTIONS

4.1 Types of Solutions Demonstrated

The solutions brought to the Sandbox were a range of early stage prototypes (SRL 5) to more mature and commercially available solutions (SRL 9). The technology types were broadly categorized as either conventional or unconventional / emerging approaches based on the corrosion detection technology or sensor platforms. These will be discussed in the following sections. Table 2 is a summary of the solutions demonstrated and their ability to detect the corrosion damage in the test panels.

4.2 Demonstration of Conventional Approaches

The conventional NDE technologies demonstrated at the Sandbox included the UT, Phased-array UT (PAUT), Eddy Current (EC), Pulsed Eddy Current (PEC), and Magnetic Flux Leakage (MFL) systems, which were all at SRL 9. These technologies are well developed and understood, and are already widely used in the oil and gas industries, as well as on the RCN ships. There were a wide variety of probe sizes and configurations available for each technology, which leant flexibility to the inspections. The probes were primarily on handheld or "push broom" types of platforms.

The conventional solutions performed as expected, and were able to detect the large areas of general corrosion, as well as the pitting corrosion under paint. The thicker or rougher coatings such as the tile and non-skid decking, and insulation presented a challenge to most of the technologies demonstrated, and none of the conventional solutions were able to detect the crevice corrosion. Additionally, none of the conventional technologies were successful at locating defects on the insulation-wrapped CuNi pipe, nor were they demonstrated underwater.

4.3 Demonstration of Unconventional or Emerging Corrosion Inspection Solutions

The unconventional or emerging solutions were also generally less mature. The range was from SRL 5 to 9, and most of the solutions were at SRL 7 (prototype demonstration in an operational environment). None of these unconventional or emerging solutions or platforms were specifically designed for the inspection of ships. They were primarily intended for use in the oil and gas industry or on fixed infrastructure such as bridges.

4.3.1 Imaging Based Solutions

There were three different approaches to imaging demonstrated at the Sandbox. These were optical imaging with AI/ML; hyperspectral imaging with an AI/DL component; and thermography. The sensor platforms were drone-mounted, cart mounted, and/or tripod mounted. The imaging solutions were attractive since they enabled rapid scanning of large areas, due to the large field of view that they could capture. Additionally, the ability to rapidly scan large areas and maintain a visual record of locations and severity of corrosion, and progression of corrosion with subsequent inspections was of great interest.

Optical imaging for inspection is not new, however its integration with an AI/ML algorithm was considered to be an innovative and emerging approach. The AI/ML algorithms were purportedly sensor agnostic, and could potentially be used with any of the other imaging solutions (e.g., thermal imaging) or image sources (e.g., cell phone cameras, drone-mounted cameras, etc.) with sufficient training data.

The optical imaging solutions required the presence of visible corrosion product, as they could not “see” through any coatings, even thin coatings such as paint, which limited their potential use on the ships. While the results were not available in real-time as the gathered images needed to be downloaded and run through the AI/ML algorithm for analysis, the software attached to this solution generated a 3D model of the ship from the images, and indicated where corrosion was found. Comparing models between inspections could enable tracking of the progression of corrosion damage over time.

The hyperspectral imaging solution used a hyperspectral camera to collect the chemical “finger prints” or spectra of each location it was inspecting, including corrosion product or other surface contaminants. As such, it was not expected to be able to detect corrosion in areas where there was no coating failure, or under insulation. The camera demonstrated at the Sandbox could purportedly penetrate through thin paint to identify areas of corrosion, but this capability was not confirmed at the Sandbox. As with the optical solution, much of the corrosion identified on the ships using the hyperspectral solution was in areas with visible corrosion product (i.e., coating failure).

The thermography solution used an infrared camera to detect different cooling rates due to changes in materials or material thickness (e.g., corrosion) following the application of heat from an external heating source (induction heating). It was able to detect the large patches of thinning as well as some of the deeper pits through the thicker coatings such as the non-skid and seamless decking. However, the use of a heating element would limit its usefulness around fuel tanks and ammunition stores.

4.3.2 Drone-Based Solutions

Two drone-based solutions were demonstrated at the Sandbox. One solution relied purely on optical images and used AI/ML to analyse the images and identify the areas of corrosion (discussed above in the Imaging Solutions), and was therefore sensor-agnostic. The second solution integrated a UT capability into the drone along with optical imaging. Inspections using the drone-based solutions are limited to good flying conditions: good visibility, low wind, and no rain. Inspection was further restricted to areas where flights would be permitted, free of obstructions. However, they offered the flexibility of inspecting difficult to reach areas that would normally require scaffolding to access.

The optical imaging + AI/ML drone solution was extremely fast, and was demonstrated on the RCN ship (length 55 m) and the CCG ship (length 90 m). The flights for the corrosion surveys took on the order of 2 and 4 hours respectively. The drone could be flown manually, or in a pre-programmed flight pattern.

The drone-based solution that integrated UT and optical imaging capabilities could be manually flown for UT inspection on vertical and angled surfaces. The drone operated by flying to an area of interest, and then attached itself to the surface with magnets. The drone then took a series of UT point measurements in a 5 cm x 5 cm window. As with traditional hand-held UT point measurements, the probability of corrosion detection was based on how closely spaced the point measurements were. The drone was tethered, which limited its range before the base station (power supply) had to be repositioned. As a result of the time required for individual UT measurements and repositioning, its speed of inspection was considerably slower than the optical image-based drone-based solution. However, it did not require that there be visible corrosion product present, and could quantify the corrosion damage.

4.3.3 Passive Magnetic Field

The passive magnetic field inspection system measured the residual magnetism of the material. Any discontinuities such as corrosion or cracking produce a change in magnetic properties. This solution demonstrated the ability to detect the artificial corrosion patches through all of the coating types on the test panels. It was also able to find areas of thinning underneath the insulation on the CuNi pipe test panel, and was the only technology demonstrated at the Sandbox able to do so. The system was also demonstrated on the RCN ship, and was able to detect areas of actual corrosion under the tile and other thick coatings.

4.3.4 Impulse Excitation

The impulse excitation system is based on the mechanical excitation of a solid body by means of a light impact. The resulting frequency and decay is analysed for anomalies. It is primarily used to detect delamination between bonded isotropic materials such as the ship’s hull or deck and paint or tile. By analysing the change in frequencies between measurement points, it can also detect changes in thickness or materials due to the presence of welds or corrosion products. While the post-processing time required to analyse the frequency signals was extensive, it was possible in some cases for the human operator to hear the changes in sound in real-time as the unit traversed an area of thinning on the engineered test panels and pipes.

4.3.5 Capacitance Imaging

The capacitance imaging system applies an AC voltage between two co-planar capacitor plates to establish an electric field. Any discontinuities or defects in the sample between the plates affects the field pattern, and is reflected in the output signal. The system encountered difficulties in detecting defects on the engineered test panels, particularly when the defects were on the back side of the panel, but it was able to detect areas of corrosion under coatings such as seamless decking and vinyl floor tile on the RCN ship in areas such as the laundry room and showers.

Table 2: Summary of the solutions and their ability to detect corrosion. Some of the "somewhat effective" depend on measurement conditions including thickness of coating or insulation, and the base material being inspected, or the resolution of measurement points.

	Corrosion Type Hull & Decking Panels or Ship			Test Panel Type			Coating Type				
NDE Solution Type	**General Corrosion**	**Pitting Corrosion**	**Crevice Corrosion**	**CuNi Piping**	**Steel Piping**	**Underwater**	**Paint**	**Insulation / Lagging**	**Decking: Seamless**	**Decking: Non-skid**	**Quarry Tiles**
EC / PEC	Yes	Somewhat effective	ND*	ND	Yes	ND	Yes	Somewhat effective	Yes	Yes	Yes
MFL	Yes	Yes	ND	ND	ND	ND	Yes	Not effective	Not effective	Not effective	Not effective
UT / PAUT	Yes	Yes	ND	ND	Yes	ND	Yes	Not effective	Not effective	Not effective	Not effective
Optical + AI/ML	Somewhat effective**	Not effective	ND	ND	ND	ND	Somewhat effective	Not Effective	Somewhat effective	Somewhat effective	Somewhat effective
Hyperspectral Imaging	Somewhat effective**	Not effective	ND	ND	ND	ND	Somewhat effective	Not effective	Not effective	Somewhat effective	Not effective
Thermography	Yes	Somewhat effective	ND	ND	Somewhat effective	ND	Yes	Not effective	Somewhat effective	Somewhat effective	Somewhat effective
Drone-mounted UT	Yes	Somewhat effective	ND	ND	ND	ND	Yes	Not effective	Not effective	Not effective	Not effective
Passive Magnetic Field Sensing	Yes	Somewhat effective	ND	Yes	Yes	ND	Yes	Yes	Yes	Yes	Yes
Impulse Excitation	Yes	Not effective	Not effective	ND	Somewhat effective	No Results	Yes	Not effective	Somewhat effective	Somewhat effective	Somewhat effective
Capacitance Imaging	Somewhat effective**	Not effective	ND	ND	Not effective	ND	Somewhat effective**	Not effective	Somewhat effective**	Not effective	Not effective

* ND = Not Demonstrated at the Sandbox
** Demonstrated on the ships with more success, vs. the test panels

4.4 Opportunities for Innovation

Regardless of solution maturity, there were a number of opportunities for innovation identified amongst the conventional and the unconventional/emerging approaches to corrosion detection alike. Many of the approaches would benefit from the development of:

- Semi-autonomous or robotic platforms to facilitate the inspection of large areas.
- Positional encoding to enable comparison to previous inspections and track the evolution of corrosion damage.
- Real-time feedback to operators so they could identify which areas required more attention/further inspection.
- Low power requirements, and small footprints to enable fast inspections while the vessel is operational.

There were also gaps in capabilities of the corrosion inspection systems that were demonstrated at the Sandbox, which represent additional opportunities for innovation:

- Crevice corrosion detection.
- Inspection of CuNi pipes under thick insulation.
- Inspection under thick or uneven coatings without visual cues (e.g., delamination, corrosion product).
- Underwater corrosion detection.

5.0 CONCLUSIONS AND LESSONS LEARNED

The IDEaS Corrosion Detection in Ships Sandbox was a useful activity for DND/CAF to understand the capabilities and limitations of both current and emerging corrosion inspection technologies, especially how they may be used to inspect a system as complex as an RCN ship. It was a good opportunity for the Innovators to demonstrate their conventional and unconventional approaches to corrosion detection under both ideal and real-world conditions to the DND/CAF and RCN, and to seek feedback from potential end-users. It was also an opportunity for the Innovators to gain a better understanding of the requirements of the DND/CAF and RCN, how their solutions might be used on board a naval ship, and to assess their technical limitations.

The Sandbox demonstrated to the DND/CAF and RCN stakeholders that there was no "one-size fits all" solution. Each solution had its own niche, and a suite of solutions would be required for a full inspection of the ship. There were a number of solutions that could rapidly scan and report on the overall state of an asset, and identify areas that need more in-depth inspection.

While many of the solutions demonstrated at the Sandbox were able to detect the areas of thinning on the engineered test panels, it was acknowledged that the design of the engineered test panels was biased towards the more conventional inspection technologies. Technologies which use other methods to detect corrosion product would not be expected to have performed as well.

The Sandbox also helped to identify gaps in capabilities representing opportunities for further development and innovation. Solutions that can address these gaps will be of interest not only to the RCN, but to the greater corrosion inspection and maintenance community.

Finally, the IDEaS Program is working to incorporate feedback from the Innovators and Sandbox teams into the design of future Sandboxes for other DND/CAF challenges. The following are some lessons learned over the course of the three Sandboxes that the IDEaS Program has run since 2019, which may prove to be useful for others who may be considering running similar events:

A dedicated team to handle the logistics and administration of the sandbox is crucial. Their role may include tasks such as coordinating all of the on-site contractor teams, facilitating bringing technology into the country, or acquiring last-minute supplies during the Sandbox. Equally crucial is a dedicated team of SMEs to focus on observing the technologies and documenting results, in order to be able to provide expert feedback to the Innovators. These should be two separate teams, so that they may each focus on their assigned roles.

Providing a well-designed test environment and scenarios relevant to the challenge is key to the Sandbox's success. In the case of the CDIS Sandbox, this was through engineered test panels and access to operational ships. Regardless of how well this part is planned, there may still be some solutions demonstrated that don't perform well in the pre-determined scenarios, and some flexibility and creativity will be required to facilitate their demonstrations. (i.e., solutions that relied on the presence of visible corrosion product to assess the state of material vs. thickness measurements).

Incorporating a dedicated day and space for set up and trouble-shooting is required for each Innovator before the start of their sandbox demonstrations.

Finding ways to identify and provide a post-sandbox investment to encourage further development of promising but still immature technologies would enable the innovators to incorporate the feedback received at the Sandbox and develop their solutions into something that would be of interest to the DND/CAF, in order to address their current or future challenges.

The Sandbox has generally been a positive exercise for both DND/CAF and Innovators alike. The IDEaS Program is continually improving the Sandbox concept, and adapting it to help DND/CAF evaluate new and emerging technologies to solve current and future operational challenges.

6.0 REFERENCES

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