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CNTHA News Inside!

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Director General
Maritime Equipment Program Management
Commodore Richard W. Greenwood, OMM, CD

Senior Editor
Capt(N) Mike Wood
Chief of Staff MEPM

Project Director
Maritime Engineering Journal
Lt(N) Denise Dickson

Production Editor / Enquiries
Brian McCullough
brightstar.communications@sympatico.ca
Tel. (613) 831-4932

Associate Production Editor
Bridget Madill

Production Editing Services by
Brightstar Communications,
Kanata, Ontario (613) 831-4932
brightstar.communications@sympatico.ca

Print Management Services by
Assistant Deputy Minister (Public Affairs)
DPAPS / Creative Services

Translation Services by
Public Works and Government Services
Translation Bureau

ADM(Mat) Translation Co-ordinator
M. Clément Lachance

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FEATURES

BOOK REVIEW

Our Cover: HMCS *Ville de Québec* lost two diesel-generators while deployed off the coast of East Africa, leaving the ship with a questionable power generation system in some of the world's most dangerous waters. *(DND photo)*

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Commodore's Corner

From seemingly small causes...

By Commodore R.W. Greenwood, OMM, CD
Director General Maritime Equipment Program Management

This issue of the *Journal* features two engineering incidents separated by 40 years, both alike in that they serve to remind us of the sudden and catastrophic failures which can arise from seemingly small causes.

October 23, 1969 – A major gearing failure on board the destroyer escort HMCS *Kootenay* results in an explosion and fire that kills nine sailors. Despite fleet-wide gearing inspections, four more steamers experience related gearbox failures just 19 months later. Fortunately, there is no further loss of life or injury.

Flash forward to the summer and fall of 2008. Without warning, the *Halifax*-class frigates begin losing MWM602 diesel-generator engines at an alarming rate. Eight engines suffer catastrophic failure in just seven months. There are no personnel casualties, but the impact on operations, maintenance and third-line resources is heavy.

In both cases, coincidentally, the initial or root cause was a bearing shell: one improperly installed and leading to overheating and a gearbox explosion, and the other wrongly sized, leading to fretting, fatigue cracking and failure with subsequent damage. In each case the initial error lurked undetected in the system until revealed at the moment of catastrophic failure, in one case with significant and tragic loss of life, and in the other with extensive material damage through the fleet.

What can we conclude from these incidents, one that has been *the* professional cautionary tale of the MARE Branch since before I joined, and the other new but (in the final analysis) not really incorporating any "original" or surprising elements from a historical point of view?

Probably the first point is the need for constant vigilance and attention to detail.

Quite apart from "the dangers of the sea and the violence of the enemy," our workplace at sea is a dangerous place with numerous risks from high pressures, temperature, voltage and electromagnetic radiation. The switch from a routine work day to a "bad navy day" can happen in the blink of an eye. Much of our training is directed toward the correct recognition and mitigation of these risks, and their management when they do occur, but nothing can compensate for an ever-present professional belief that *details matter*, and the vigilance that goes with that belief. This need for constant professional attention to detail, and the personal responsibility of the individual engineer for defects or errors reminds me of the first verse of Rudyard Kipling's *Hymn of Breaking Strain*,[1] familiar to many engineers from their iron ring ceremony.

The second point is that new technology does not make these risks go away.

If anything, the increasing sophistication of newer technology, with increased power densities and tighter tolerances, make it all the more imperative that we maintain effective quality assurance in maintenance actions and close adherence to correct operating parameters. Modern high-speed marine diesels are one example of this; the stringent requirements of modern submarine maintenance are another.

A third point is the importance of not losing sight of the perspectives and insights of the past.

The lessons of the past have a habit — a history, one could say — of recurring as fresh and relevant to the present. If nothing else they should be locked in as "part of the process" when we take our technical decisions, sign off on maintenance work, or send our sailors into the engineering spaces. It is just one more thing we can do to ensure the technical health of the navy and the safety of our sailors. It is also, of course, the merit of a publication such as this in capturing these reflections and making them accessible to the naval engineering community.

Remembering and respecting the hard-won insights and perspectives of those who have gone before us may seem like a small thing, but in this business it is the seemingly small things that make all the difference.

1.http:www.kipling.org.uk/poems_strain.htm

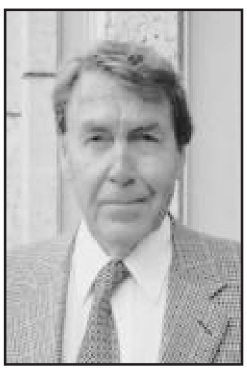
Forum

The Past Meets the Present —

VAdm Stephens and Capt(N) Monteith Visit HMS *Sultan*

By LCdr D.E. Saulnier

It was just over a year ago, on October 8-9, 2008, that 17 Canadian Forces marine systems engineering students on course at HMS *Sultan* in Gosport, UK (just west of Portsmouth) had the honour of meeting retired Canadian naval engineers, Vice-Admiral (ret.) Bob Stephens and Captain (N) (ret.) Rolfe Monteith. The two officers had been invited to speak at the Royal Naval School of Marine Engineering (RNSME) about their experiences as marine systems engineers serving with the Royal Canadian Navy. Captain (N) Norman Jolin, the CF naval adviser to the UK, based at Canadian Defence Liaison Staff (London), also spoke to the group.



Rolfe Monteith

Day 1 began with a call on the commanding officer of RNSME, Captain Graham Watts, RN. After lunch at the wardroom, Capt(N) Jolin gave a presentation on what COs expect of MSEOs, shipboard administration, departmental structure, dealing with external agencies, the divisional system, and more.

VAdm Stephens then described his career (in entertaining detail) to an audience of approximately 45 personnel. One of the admiral's comments that struck a chord with many listeners was that as maritime engineers we support naval command in two of the three vital shipboard capabilities — *Float, Move, Fight*. He stressed that it was "*Move*" that was vital in carrying the "*Fight*" to where it was needed. His opinion resonated strongly with some of the senior members of the audience.

Capt(N) Monteith's message focused on the work he does on behalf of the Canadian Naval Technical History Association (CNTHA) and the Canadian Naval Defence Industrial Base (CANDIB) research project. He also discussed his role as project manager for the Canadian Hydrofoil Project, pointing out the benefits of the program (see *CNTHA News* insert in this issue).

(Continues next page)

Vice-Admiral
Robert St. George Stephens (RCN Retired)

VAdm Stephens was born in 1924, and joined the Royal Canadian Navy in 1941. He served for 37 years. His education included the Royal Naval College Dartmouth, Royal Naval Engineering College Keyham, Greenwich Naval College and the Imperial Defence College in London.

Admiral Stephens was the first Canadian officer to undertake nuclear training. He served in engineering capacities in HMC ships *Iroquois* (Arctic convoys), *Huron* (off Korea), and *Magnificent*, and in HMS *Swiftsure* (flagship for the British Pacific Fleet). Ashore, VAdm Stevens served as Commander Superintendent of Halifax Dockyard, Chief of Staff at Material Command, Assistant Chief of Defence Staff for Information Handling, Commander Training Command, and as the Canadian Military Representative to the Military Committee at NATO Headquarters in Brussels before retiring in 1978.

He has written a biography of his father, engineer Rear-Admiral GL Stephens. VAdm Stevens was interviewed by the CNTHA's CANDIB project team about the design and testing of the *St. Laurent*-class destroyers. A summary of that interview was reported in *CNTHA News* Spring 2009 (*Maritime Engineering Journal* No. 64).

HMS *Sultan* at Gosport, UK

The three VIPs stayed overnight in the wardroom at HMS *Sultan*, and early the next morning watched the CF students as they participated in an integrated machinery flash-up serial. This event had the CF officers run a watch in the school's working machinery control room. One student, designated Chief of the Watch, directed the team to start Royal Navy shipboard machinery and systems, including steering, a diesel generator, air compressor, auxiliaries and an Olympus gas turbine. The machinery is real; they were running and watchkeeping on working training aids. While the flash-up progressed, the visitors toured the machinery locations and could see for themselves that the training at HMS *Sultan* provides a degree of realistic, hands-on training that the CF cannot duplicate in Canada.

The visit provided an opportunity for the class of developing professional officers to learn about CF military history, and the details of decisions and programs that continue to affect us today from people who were there at the time. The insights they shared were revealing, uplifting and inspiring.

Captain(N) Rolfe Gibson Monteith (RCN Retired)

Capt(N) Monteith was born in 1923. He joined the Royal Canadian Navy (RCN) in 1941, and served for 28 years. His education included the Royal Naval College Dartmouth, Royal Naval Engineering College Keyham, Plymouth, and the Imperial Defence College in London. His wartime sea-going experience was aboard the destroyer HMS *Hardy* (1943) — Scapa Flow and Murmansk convoys — and Gibraltar.

Capt(N) Rolfe Monteith aboard HMCS *Hardy* in Gibraltar in October 1943. "One could not obtain bananas in the UK durning World War Two, so one always took a few back from the Med."

Following the Second World War Capt(N) Monteith cross-trained aeronautical engineering, and served in a cruiser, an aircraft carrier, carrier air group, destroyer, naval air station, with FOAC Staff, Canadian Defence Liaison Staff (Washington), and National Defence Headquarters in Ottawa. He retired from the RCN in 1969 and immigrated to the UK in 1970 to begin a second career in UK industry.

Since the late 1970s Capt(N) Monteith has been organizing the recording of technical aspects of Canadian naval aviation (1943-1968), the ship/submarine elements (1904 to the present), and the Canadian defence industrial base since 1904.

Capt(N) Monteith is a founding member of the Canadian Naval Technical History Association (CNTHA), and the Canadian Naval Defence Industrial Base research working group (CANDIB).

At the time of the visit, LCdr D.E. Saulnier was the CF exchange officer at HMS Sultan. He was responsible for all officer training at RNSME, including the Royal Navy's surface and submarine officers, and the electrical-mechanical officer branch of the British Army. His primary role was the course management of the CF MS Eng officers attending the Systems Engineering and Management Course (SEMC). He returned to Ottawa last July

This is Africa — The Challenges of Making Emergency Diesel Generator Repairs While Deployed

Article by LCdr Sean Williams

HMCS *Ville de Québec* loads one of two emergency replacement diesel generator units in Dar Es Salaam, Tanzania while deployed in support of the United Nations World Food Program. The ship's gunshield artwork at left depicts "Lucky Luke" on the job. *(All photos courtesy the author.)*

As HMCS *Ville de Québec* prepared to enter the East African port of Mombassa, Kenya on October 1, 2008, the ship's company was looking forward to a few well-deserved days off. We'd had a busy series of transits back and forth to Mogadishu, Somalia, escorting merchant vessels in support of the UN's World Food Program. That all changed very rapidly when our No. 3 MWM602 diesel generator (DG) failed catastrophically just hours before our scheduled alongside.

Diesel generator failures are nothing new in *Halifax*-class ships. Just weeks before we had suffered what appeared to be a nearly identical failure in our No. 4 DG, the cause of which was still unknown. We then learned that four similar failures had been experienced recently in West Coast ships, indicating a potential fleet problem (see, "*Halifax*-class Diesel Generator Failure Investigation," page 10).

We had approximately one month of operations left before we could get to a reliable port to conduct repairs, but we were now operating in some of the world's most dangerous waters with a very questionable power generation system. A decision was quickly taken to suspend operations until a temporary repair could be made. There was neither time nor sufficient infrastructure in any accessible port to conduct a diesel generator replacement, so the hunt began for a portable unit we could install on the upper deck to get us home.

There was significant debate over the power generation capacity we would require. Four hundred kilowatts would give us enough power for a limp-home capability, but 800-1,000 kW would be extremely beneficial. Thinking that generators in the 400-kW range might be more readily available, we investigated the option of installing two of these units to meet our power needs.

Having to procure diesel generators and install them on the upper deck of a warship while away from home port would be challenging enough at the best of times. But doing so in Africa, we discovered, posed several unique challenges that would make for a very interesting experience. The most significant of these were:

- It is almost impossible to get reliable information;
- It is rare that you get exactly what you either ask for or expect; and
- Nothing ever happens on time.

The reliability of information issue proved to be our toughest challenge. It was easy enough getting someone to tell us they had what we were looking for, but much more difficult getting them to actually produce it.

As we soon learned, this was Africa.

The Search for Engines

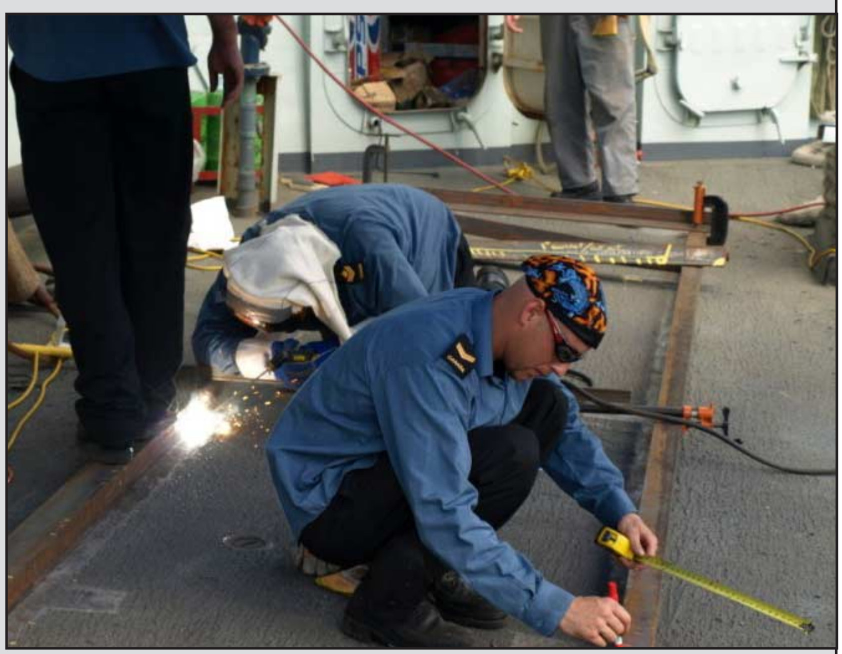
After a few days of scouting about for suitable engines in Mombassa, it appeared that most of the available generators were a few hours away in Nairobi. We decided to send a team inland to investigate any possible options, including a lead we had on a used 1,000-kW Cummins diesel.

To complicate matters, the ship was running out of potable water. We had been unable to find an acceptable source in Mombassa, so staying in port long enough to secure and install generators was not possible. Shortly after landing a two-man team consisting of our resident diesel expert, PO1 Dion Randell, and our Electrical 2 I/C, PO2 Alex Robichaud, *Ville de Québec* left Mombassa to loiter off the coast where we could produce water.

The first calls from our team ashore were not promising. The 1,000-kW Cummins in Nairobi was not in an acceptable condition, and even the Caterpillar dealer there had very little available. Access to reliable information became even more of a challenge at this point. Although the dealers in Kenya insisted to the contrary, a quick search on Google indicated that there was indeed a Cat dealer in the major shipping port of Dar Es Salaam, Tanzania 700 kilometres away to the south. While our two-man team made arrangements to travel to Dar Es Salaam, *Ville de Québec* turned south to await them offshore.

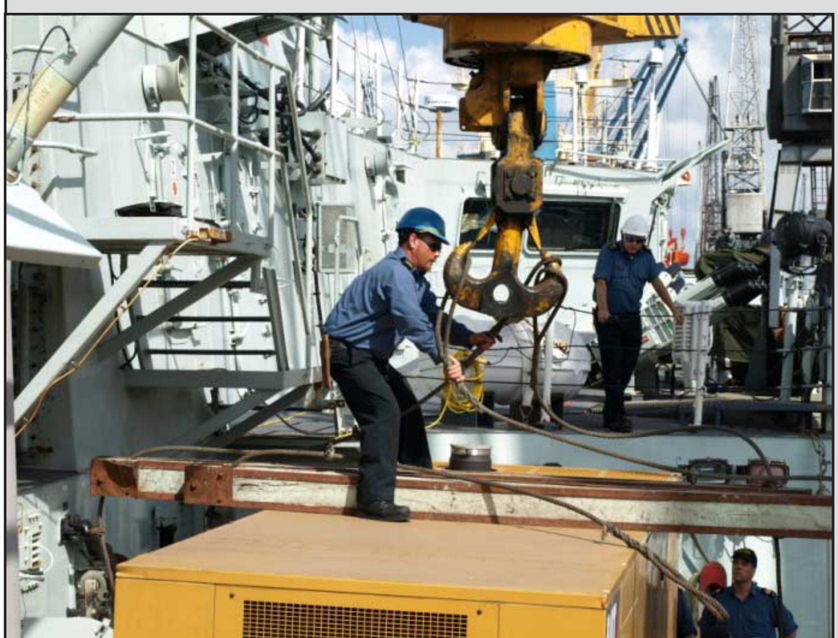
In Tanzania the team found a large state-of-the-art Caterpillar facility. The prospect of finding engines seemed very good, and it also appeared that any necessary conversions could be done. One of the challenges we faced in that part of the world was that Africa runs on 50-Hz power. We of course required 60-Hz generators. Caterpillar advertised that most of its engines could do either, but the dealers in East Africa were very reluctant to do any conversions. In the end, after we found an independent engineer willing to do

Preparation



the work, they agreed to do any power conversions in-house.

The first engines the team looked at were a pair of 436-kW diesel generators complete with acoustic enclosures. Neither had an integral fuel tank, but since the dealer agreed to install a fuel tank on each engine we decided to proceed. This plan fell apart the next day when it was determined that the fuel tanks could not in fact be installed, but then our luck seemed to take a turn for the better. Two other engines were available, a



Installation

635-kW and a 508-kW, and both had integral fuel tanks. Once again we agreed to proceed, and one more time were met with disappointment the following day when we learned that the larger of the two engines could not be converted to 60 Hz. We finally decided to take the 508-kW engine, along with one of the 436-kW engines with a separate stand-alone fuel tank. As the engine conversions got under way, *Ville de Québec* headed in to Dar Es Salaam, arriving there October 11, 2008.

Engineering on the Fly

We weren't the only busy ones. While we were occupied acquiring engines in Africa, Fleet Maintenance Facility *Cape Scott* and MARLANT Fleet Technical Authority back in Halifax were hard at work on some of the engineering support work we would need to install the engines. We received drawings showing recommended placements for the engines, along with welding specifications for constructing the engine footings. It was an excellent piece of work they did for us.

Following a quick inspection of the two engines by the rest of the *Ville de Québec* team, we were ready to begin our installation preparations. We received outstanding support from the ship's deck department, which had the two installation sites stripped and ready for welding by the end of our first afternoon alongside. The momentum was good while it lasted, but this was Africa. The steel we had ordered, which was supposed to be waiting for us on arrival, hadn't been delivered (but would be, we were promised, within two hours). It arrived at ten o'clock the next morning. And there was one more surprise for us. Instead of the 4x6x3/8-inch steel we were expecting, we found ourselves staring at a load of 3x4x1/2-inch angle iron. Getting any steel at all seemed to be a small miracle in itself, so we decided to make do with what we had.

The ship's hull techs got to work straight away fabricating the footings. They began by stitch-welding two parallel rails of angle iron fore-and-aft along the deck to support each generator. To help level the engines on the cambered deck, the two support rails were welded in opposite orientation. The inboard rail was stood on its three-inch "leg" along its length, while the outboard rail was stood one inch higher on its four-inch leg to make up for the downward cant toward the ship's side. Cross-supports were then welded into place, and after nearly 48 hours of almost continuous work the hull techs had both footings finished — an astonish-

A tight fit on the port side. A less-than-ideal sling mechanism and minimal clearances on the superstructure complicated the installation.

ing feat of determination and hard work.

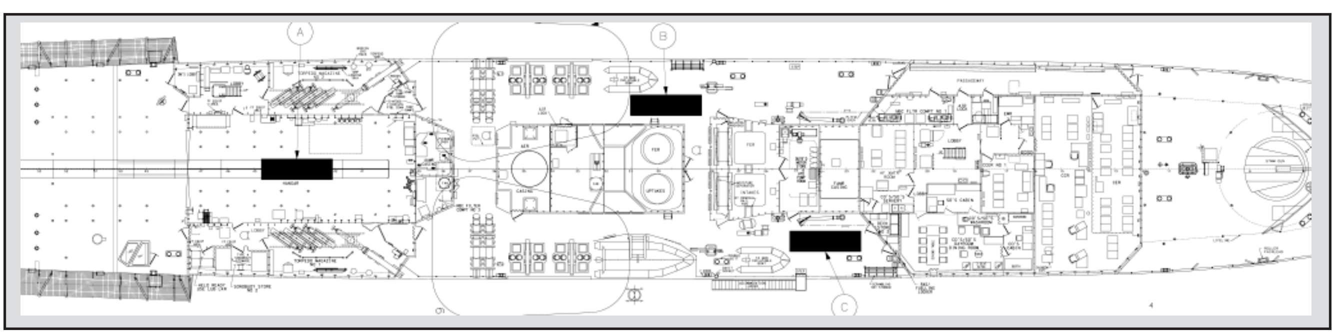
Shortly after receiving the steel, the electrical cable arrived — considerably earlier than expected. Unlike the cable we use in Canada where each phase is its own cable, what we received consisted of four armoured cores bundled together into a cable approximately three inches in diameter. With three cables for each engine (and each one considerably longer than ordered) it took a whole ship effort to move the extremely heavy lengths into position.

While the fabrication of the footings was going extremely well on board ship, there were delays with the diesel generators themselves. The conversion and load banks should have been completed, but the dealer was having difficulty acquiring the passwords to access the electronic controls needed to conduct the 50-to-60-Hz conversion. The passwords apparently had to come from Cairo, but since it was now the weekend the dealer in Dar Es Salaam could not reach his contacts in the Egyptian capital.

This was Africa.

The delays were frustrating, but on October 14 the power conversion of the engines was finally complete. Unfortunately, the load bank equipment was not functioning correctly, so more delays were experienced. Keen to get moving on the installation we decided to have the engines delivered and do the load banks using the ship's load. This proved to be a good decision, and by the end of that day the first engine had been successfully run up to 110-percent power for one hour. The second engine would have to wait until the next day as the dealer reps were unwilling to work into the night. This was typical of the service we saw throughout our stay. It was nearly impossible to get anyone to move quickly on anything, or to put in any additional effort. Still, with a crane reserved for the next day, we were in a good position to be back at sea within 48 hours.

The next morning started well enough with a successful load bank of the second engine, but the crane that was supposed to arrive in the morning didn't show up until mid-afternoon. When it finally did show up we were impressed to see it was a



Fleet Maintenance Facility *Cape Scott* and MARLANT Fleet Technical Authority in Halifax provided engineering support for the DG installations. The three black boxes show recommended placements for the engines. The site located in the ship's hanger at left was not used.

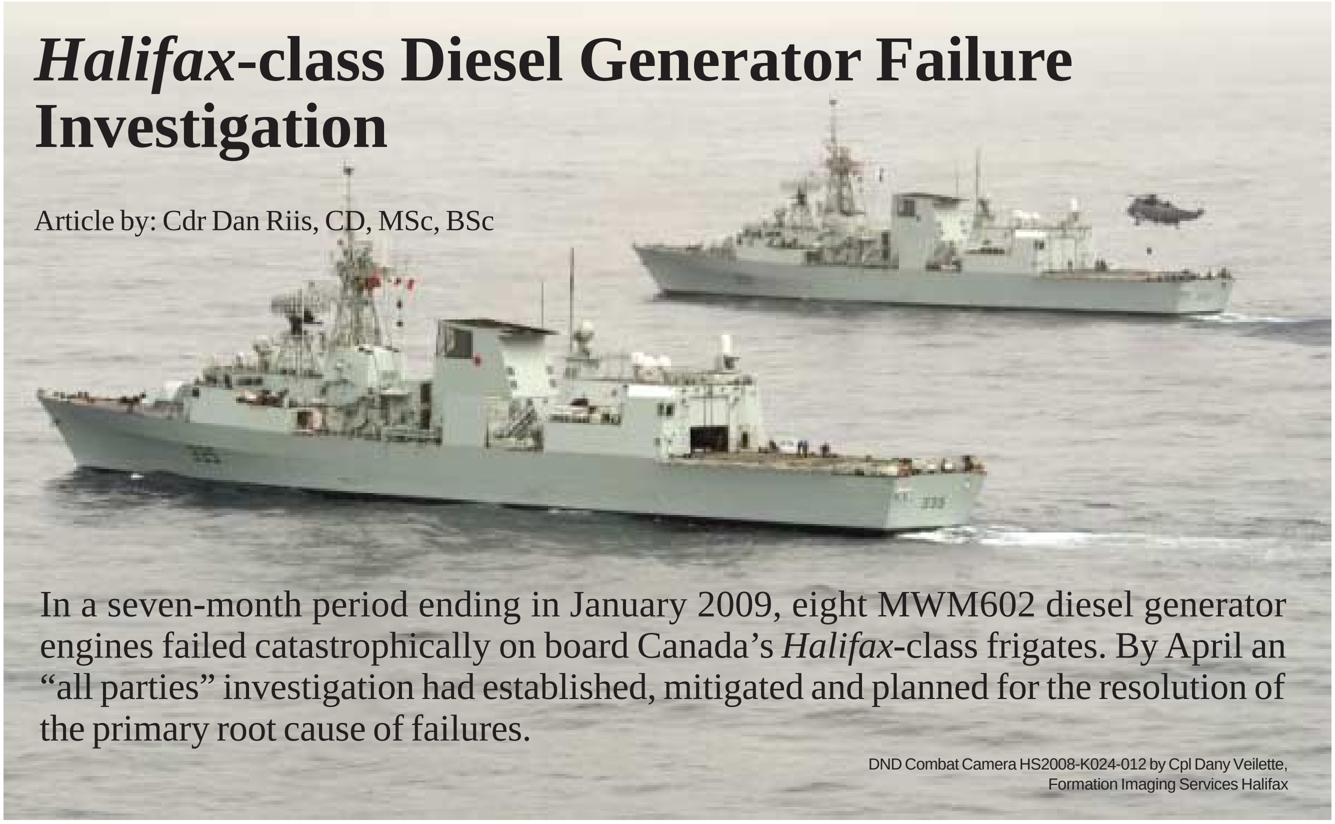
With the installation of an external fuel tanks (top), and the final electrical hook-ups and tests, the ship was "good to go."

brand-new 60-ton crane, more than capable of lifting an engine over the ship and thus saving us having to turn the ship end-for-end to receive the second engine. But while the crane itself was up to the task, the lifting mechanism seemed less than ideal. The slings were of uneven length, and the spreader bars, which were far wider than the engines, looked as if they had been built in someone's garage. These overly wide spreader bars would cause us problems because of the minimal clearances we were working with against the superstructure and around other deck fittings.

The port-side installation of the 436-kW engine went easily enough, tight a fit as it was, but installing the 508-kW engine on the starboard side made real work for us because of interference from an overhanging catwalk. With minimal clearance, the engine had to be lowered outboard of the footing, then pulled, pushed and shoved into position using a combination of come-alongs, 10-foot levers and brute force. It took about an hour of frustrating work, but both engines were finally in place. We were ready to go.

Ville de Québec left Dar Es Salaam on October 16, 2008, ready to resume operations with two emergency diesel generators installed on the upper decks. Although it had been a very challenging and at times frustrating episode, the installation of this field engineering change ended up being a most rewarding experience for all of us. In particular it gave our crew, especially the technicians, an opportunity to show off their skills on a job that would normally be handled by a fleet maintenance facility or by outside contractors. We may have been in Africa, but the *VdQ* team proved that it was, as ever, up to the task.

LCdr Sean Williams was the Marine Systems Engineering Officer on board HMCS Ville de Québec from 2007 to 2009. He is now completing post-graduate studies at the University of Ottawa.



Halifax-class Diesel Generator Failure Investigation

Article by: Cdr Dan Riis, CD, MSc, BSc

In a seven-month period ending in January 2009, eight MWM602 diesel generator engines failed catastrophically on board Canada's *Halifax*-class frigates. By April an "all parties" investigation had established, mitigated and planned for the resolution of the primary root cause of failures.

DND Combat Camera HS2008-K024-012 by Cpl Dany Veilette, Formation Imaging Services Halifax

The MWM602 engine is the prime mover used in the four diesel generators (DGs) which supply all electrical power on board Canada's 12 *Halifax*-class frigates. The engine was manufactured by MWM and supported until 2005 by Deutz, at which time all design rights were purchased by Wartsila. Today, Wartsila provides OEM (original equipment manufacturer) support and technical expertise through the Wartsila Netherlands engineering facility in Zwolle, and R&O and spares support through Wartsila Canada in Montreal.

The MWM602 engine has a history of low reliability in the *Halifax* class, which in turn has had serious impact on operations, maintenance load and third-line resources. The problems have generally been attributed to an aging (and in some cases poor) engine design, and to carbon (coke) build-up and engine seizure through operation at low loads. Low-load operation occurs when the 1,140-kW engine is used to drive an 850-kW generator for an average ship hotel load of 1,100 kW (split across two generators).

Over the past 15 years significant resources have been expended on improving the MWM602's reliability and reducing its maintenance load. The effort has included multiple engineering changes, instituting a policy of high-load decoking operations to burn off carbon, and two consecutive changes to the fuel injector design. The second injector change made from 2006 to 2008 introduced ultra-low load (ULL) injectors to the fleet.

In June 2008 the fleet was hit with the first of what would eventually become eight catastrophic MWM602 engine failures over the next seven months. In all cases the engines were destroyed beyond repair, the majority with "holed" crankcases. An unfortunate complication was that most of the failures occurred while the ships were deployed. This had two major effects:

1. Operations were significantly impacted. In October 2008 HMCS *Ville de Québec* (FFH-332) suffered failure of both after engines while deployed in the Indian Ocean off the coast of East Africa. Two emergency diesel generators (EDGs) had to be purchased in Tanzania and mounted temporarily to the top part of ship to allow the ship to continue its mission. (See, "This is Africa — The Challenges of Making Emergency Diesel Generator Repairs While Deployed," page 5.) A full change-out of both failed engines conducted later in Toulon, France required considerable MARLANT resources.

   HMCS *Calgary* (FFH-335) also suffered two engine failures, and in view of the new increased risk of further diesel generator failures was required to fit an EDG for its transit home across the north Pacific. HMCS *Montréal* (FFH-336), too, had to be fitted with an EDG to continue her mission in the Caribbean.

HMC ships *Calgary* and *Ville de Québec* both experienced diesel generator engine failures while deployed.

2. Information regarding the failures was very difficult to obtain. Where possible, field service

representatives were sent to the ships to view the engines and ascertain the failure modes. Technical investigators were ordered to collect as much failure information as possible, data which would be critical for a subsequent in-depth investigation. The process required lengthy removal and full tear-down inspections of each engine, all complicated by the ships' operational schedules and availability.

By January 2009 enough data had been collected to allow an MWM failure investigation working group to begin a root cause analysis. The group would be chaired by the DMSS 3 section head for propulsion systems in the Directorate of Maritime Ship Support in Ottawa (the author), and include subject matter experts from DMSS 3-4, the Naval Engineering Test Establishment (NETE) in Montreal, the fleet technical authorities and maintenance facilities on both coasts, the OEM (Wartsila), and a contracted independent consultant (Ricardo Ltd).

The working group would also look at four timing gear failures which had occurred on the MWM602s between 2007 and 2009. Only one of these had resulted in catastrophic engine failure, but the working group wanted to analyze this failure mode to determine if it related to the overall problem.

Investigation Findings — Working group meeting, February 2009

The working group determined that four failure modes were present among the 12 failures:

• connecting rod (i.e. conrod) big-end bearing cap cracking (five engines);

• main crankshaft bearing seizure (two engines);

• piston seizure (one engine); and

• timing gear failure (four engines).

Fig. 1. Fatigue cracks occurred in the same spot (indicated) at the big-end of each of the failed conrods. *Inset:* Fatigue failure of a bolt post on the big-end cap.

There was no indication that any of the failure modes were related.

The working group focused its investigation primarily on establishing a root cause for the conrod big-end cap cracking that was behind the majority of the recent catastrophic failures. Analysis conducted during the earlier technical investigations had determined that the cracking initiated at the same location on each conrod (*Fig. 1*), and that each failure had been caused by fatigue. Moreover, on each failure there were signs of a high degree of fretting, or abrasive wear, between the conrod big-end cap housing and the bearing, with significant levels of material transfer evident (*Fig. 2*). Early in its own investigation the working group concluded that the big-end cap cracking was being initiated by this fretting.

Under normal conditions the tolerances in engine design and material strength ensure that fretting either does not occur, or is not significant enough to initiate cracking. The working group therefore focused on the most likely possible causes of both the fretting and the big-end cap's susceptibility to cracking, namely:

- low material strength;
- firing-cycle effects; and
- inadequate interference fit.

Low material strength

Four different versions of conrod were found to exist and to have been installed throughout the Canadian fleet of engines, three under the same part number. The most recent version included a material change and was the only version not to have suffered a failure. It is likely this conrod version has greater material strength and is less susceptible to fretting and fatigue cracking. Material strength was classified as a possible contributing cause, but not a root cause since the engines had operated with the previous three versions for over ten years without big-end cap failures.

Fig. 2. The conrods showed a high degree of fretting and significant levels of material transfer between the big-end cap housing and the bearing.

Firing-cycle effects

A computer finite element analysis (FEA) model built by Wartsila revealed that the conrods did indeed have a risk of fretting at the crack location, and that a high stress point exists at the same location. Both were due to mass forces (*Fig. 3*) and gas forces.

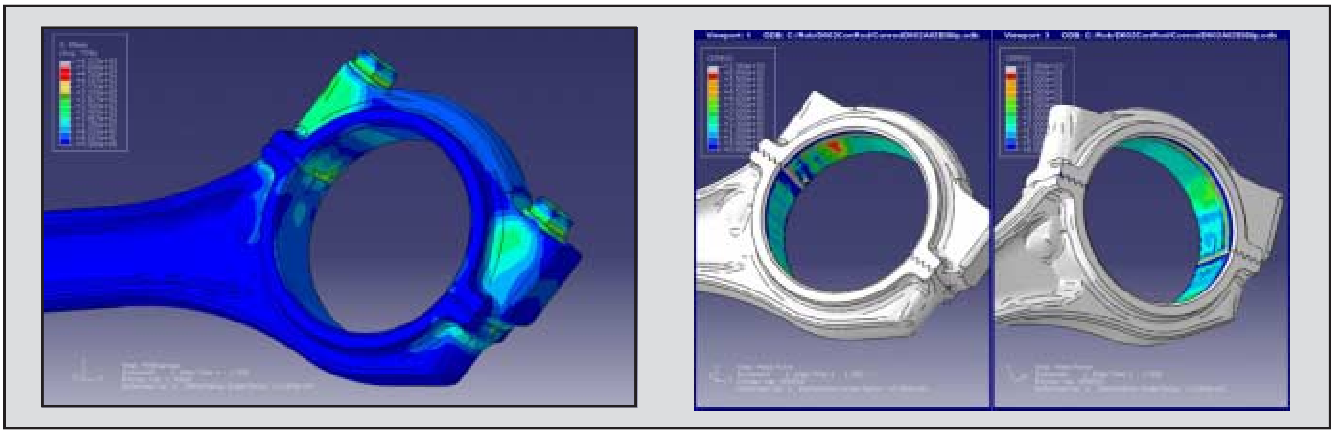


Fig. 3. Finite element analysis results for mass forces acting on a conrod indicate (*left*) the maximum stress points, and (*right*) fretting contact pressures.

High mass (or inertia) forces are generated at low loads when there is little gas force to counteract the piston's high-velocity movement up the cylinder. This can be prevalent under a number of operating conditions for the *Halifax*-class diesel generators, such as:

• tactical decoking (holding one DG near idle while decoking the other engine); and

• blackout drills and load banks (taking load off suddenly).

Once again these were classified as possible contributing causes only. The diesel generators have been working under such operating conditions for years, long before the big-end cap cracks ever turned up.

High gas forces are present at high firing pressures within the combustion chamber and were shown in the FEA model to contribute to stress and fretting. But it was also agreed that high gas forces would exacerbate crack initiation and propagation, made worse by the direction of the forces within the big-end bearing. Oil film analysis (*Fig. 4*) showed that maximum forces are exerted at the big-end cap serrated connection point on A-bank, acting at the weak point of the housing and creating a potential moment arm on the cap. There were no failures on B-bank because the forces there were acting at a more benign point.

While high gas forces occur at high loads such as when decoking, these firing pressures are not normally problematic given the mismatch between the generator and engine sizes. Furthermore, since decoking has been occurring since early in the life of the class, high engine load in this situation was classified as a possible contributing cause only.

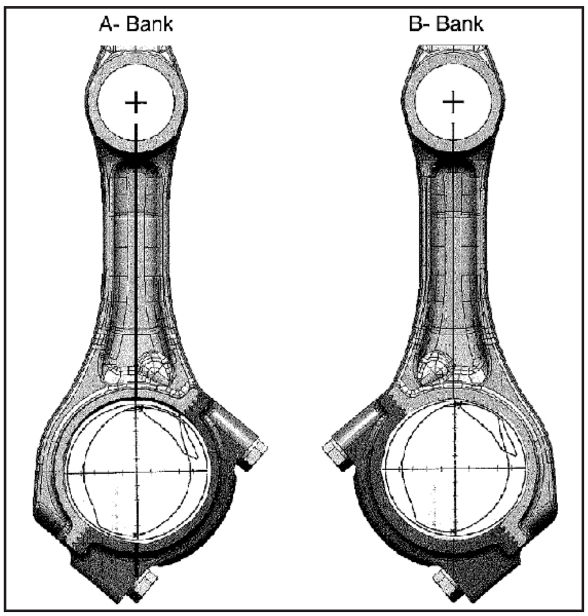


Fig. 4. Oil film analysis reveals maximum forces being exerted at different points on A-Bank and B-Bank conrods. The A-Bank conrods (*left*) were at much greater risk since the forces were acting on the weak point of the housing at the big-end cap serrated connection point.

Tests conducted at the Naval Engineering Test Establishment indicated that the ultra-low load injectors caused both a significant advancement of peak firing pressure, and a significant increase in firing pressure. The firing pressures measured as part of this investigation exceeded those measured during ultra-low load development testing, and at times exceeded the design limits for the engine. The variation in measurements from ULL development tests to failure investigation tests was attributed to variations in injection timing and injector body wear. High firing pressure resulting from ULL injectors was classified as a possible root cause of conrod big-end cap failure since the ULL injectors had been introduced shortly before the failures began, and all failed engines had ULL injectors fitted.

Inadequate interference fit

The conrod big-end bearing is held in place within the housing by an interference fit. This is achieved via an overstand nip length of the bearing, essentially oversizing it to the housing (*Fig. 5*) so that it compresses into position. Possible causes of inadequate interference fit can be attributed to:

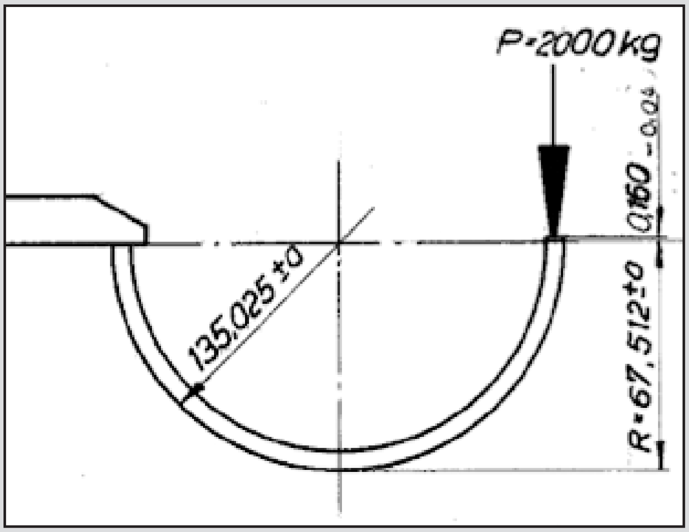


Fig. 5. The circumferential length of the bearing should be slightly longer than the circumference of its housing in the conrod big-end. A proper interference fit of the bearing with the housing is achieved when the "nip" crushes into position when the conrod cap is bolted down. An undersized bearing, and thus too short a nip, would allow the bearing to fret, or move about, inside the big-end housing.

Fig. 6. Wartsila Canada's Halifax facility manufactured this highly accurate jig to measure nip lengths of the conrod bearings.

• Nip length — an undersized bearing would not achieve sufficient crush;

• Surface finish — inadequate friction between the bearing and housing would allow slippage; and

• Assembly — poor fitting of the conrod big-end cap to the conrod could also result in inadequate crush.

Teardown inspections conducted at the time of the first working group meeting revealed that all big-end cap bolt breakaway torques were within spec. Assembly was therefore eliminated as a possible root cause for this failure mode early in the investigation.

The surface finish, however, had interesting possibilities. A surface roughness depth (Rz) of 2.6 µm was measured on a representative conrod big-end cap, which was well within the design *maximum* of 6 µm stipulated on the engine drawings. Wartsila, however, indicated that for their modern engine designs a minimum Rz of 11.76 µm is used. It was surmised that for old engines with less precise manufacturing methods (the MWM602 design dates from the 1970s), a maximum Rz was necessary to reduce the surface roughness sufficiently to achieve the required heat transfer. Since modern manufacturing methods can achieve a very smooth finish, newer designs require stipulation of a minimum Rz to ensure appropriate friction fit. Nonetheless, surface finish was categorized only as a contributing cause since it had not changed since the engines were commissioned.

Wartsila Canada's Halifax facility undertook to measure the nip length on representative bearings, which required the manufacture of a highly accurate jig (*Fig. 6*). The measurements revealed the nip length to be short compared with the engine specifications, and so at the time of the first working group meeting nip length was categorized as a possible root cause.

Final Analysis — Working Group Meeting, February 2009

The analysis that thus emerged from the first working group meeting in February 2009 revealed a number of possible contributing causes and, significantly, two possible root causes of big-end cap fretting and failure; namely:

• High conrod big-end cap stress caused by high firing pressures due to the ultra-low load injectors; and

• Inadequate interference fit caused by undersized bearings (i.e. short nip length)

The working group concluded that the issue of the undersized bearings would have to be explored with the supplier. As for the high firing pressures, it was concluded that introducing a delay in the injection timing would reduce peak firing pressures and thus avoid having to abandon the ULL injectors. Before introducing this as a permanent solution, however, more testing would be required on the NETE diesel engine test bed and with Wartsila's finite element analysis model. This would identify the optimum timing required and assess any possible secondary effects of injection delay. To mitigate risk in the meanwhile, DMSS 3 imposed power limits on the engines and mandated a verification, and slight delay, of injection timings. Restrictions were also placed on the frequency of significant power changes such as for blackout drills and load bank testing. No further conrod failures have occurred since these measures were introduced.

Establishing and resolving the root cause of the conrod big-end cap failures

In April 2009, after much investigation and negotiation by Wartsila, the big-end bearing supplier made a startling discovery and admission. The master bearing used to calibrate the bearing fabrication machinery was not of the correct dimensions. The supplier further admitted that the same undersized master bearing had also been used for quality control checks at the end of the manufacturing process. As a result of this a run of undersized bearings was supplied to customers around the world between 2004 and 2009.

The MWM failure investigation working group reconvened to review the new findings, and concluded that the undersized bearings were the root cause of the conrod big-end cap failures. The working group also noted that the contributing causes, including the high firing pressures, were having a significant impact on the failure situation. This was evidenced by two key factors:

• No other user of the bearings had reported any similar failures; and

• Although the bearings had been installed since 2004, the failures only began following the installation of the ultra-low load injectors.

A number of measures were therefore imposed to resolve the failure mode and provide additional risk reduction:

Bearing Change Program

As there was no means for accurately determining which fitted bearings were undersized, a bearing change program was initiated in June 2009 to replace all MWM602 conrod bearings throughout the fleet. Engines were prioritized by such technical criteria as hours run on the ULL injectors and hours from rebuild, and then by availability as determined by the ships' operational schedules. To Wartsila's credit, the company undertook to conduct the bearing changes nominally at no cost even though the program was beyond their contractual and warranty obligations.

Injection Timing

It was decided to continue using the ULL injectors because of their excellent record with respect to engine cleanliness, but the slight injection timing delay introduced in February would be left in place to reduce peak firing pressures. In view of the potential variation in timing that can occur when using different timing methods, a single method using a dial indicator was mandated for all engine timings. Since timing engines is a second- or third-line function, ships were directed not to time engines unless in an emergency.

Conrod Replacement

Conrods would be inspected during the bearing replacement program for fretting or onset of cracking, and replaced as required. It was agreed that the newest version conrods would be used as replacements given their apparent resistance to fretting and cracking.

Conrod Shot Peening

Wartsila would shot-peen all further new version conrods to increase surface roughness, improve interference fit, and improve resistance to surface cracks.

Help Wanted

CANDIB oral history project needs volunteer interviewers

The Canadian Naval Defence Industrial Base working group of the Canadian Naval Technical History Association has an ongoing oral history project to record people's memories regarding the influence of naval contracting on Canadian defence industries from 1930 to the present day.

If you would be interested in volunteering as an interviewer to help people record their experiences, or if you would like to be interviewed yourself about your own involvement with naval projects, please contact CANDIB leader Tony Thatcher by telephone at (613) 567-7004 ext. 227, or by e-mail at Tony.Thatcher@snclavalinom.com

DMSS 3 released a message outlining these measures and authorizing a lifting of engine restrictions once the bearings have been changed. The work has placed a significant resource and financial burden on the coasts and DGMEPM. As of the end of September 2009, 11 engines had been completed and another eight were being worked on. Of the 11 that were complete, eight required complete conrod replacement. The other three had either very low, or no running time on them. The bearing change program will likely conclude in 2010.

Decoking operations for all MWMs have ceased indefinitely. Wartsila and DMSS 3 are establishing a more proactive relationship to address other areas of reduced reliability. A study is also ongoing into the feasibility and cost benefit of replacing the MWM602 engines during HCM/FELEX — the upcoming *Halifax* Class Modernization and Frigate Life Extension project. The study is carefully analyzing the financial business case, and at the same time exploring less tangible issues such as maintenance load and operational availability.

The working group is continuing its investigation of the other failure modes behind the main bearing seizures, piston seizure and timing gear failures. It appears one of the main bearing seizure failures was due to inadequate conrod assembly (loose bolts) which resulted in bearing movement cutting off the oil supply to the main bearing. The single piston seizure is believed to be an isolated incident, while the cause of the timing gear failures is believed to be related to repair and overhaul standards, methods and quality assurance at the overhaul facility. Wartsila Canada has taken measures to ensure there is no recurrence.

Conclusion

The catastrophic failures of *Halifax*-class MWM602 diesel-generator engines had a serious effect on operations and continues to impact coastal and NDHQ resources. The root cause of the majority of these failures was a manufacturing and quality assurance error by the conrod big-end bearing supplier which resulted in undersized bearings. The situation was made worse by a number of contributing causes, most significantly high peak firing pressures due to the use of ultra-low load injectors.

The root cause of the conrod big-end cap failures was established, mitigated and is being resolved through close co-operation between all stakeholders, including NDHQ, the coasts, NETE, the original equipment manufacturer and an independent consultant. It was through the hard work, initiative and expertise of personnel from all of these organizations that a solution was able to be established and implemented in a relatively short period of time.

Cdr Dan Riis served as the DMSS 3 Propulsion Systems section head at NDHQ from November 2007 to July 2009. He is currently attending the Joint Command and Staff Program at the Canadian Forces College in Toronto.

Acknowledgments

The assistance of **Brian Cox** (DMSS 3-4 project manager for Marine Diesel Systems), and that of **Mark Keneford** (General Manager, Montreal, Wartsila Canada Inc.) in the preparation of graphics for this article is gratefully acknowledged.

Submissions to the *Journal*

The *Journal* welcomes **unclassified** submissions in English or French. To avoid duplication of effort and ensure suitability of subject matter, contributors are asked to first contact the **Editor, Maritime Engineering Journal, DMMS, National Defence H.Q., Ottawa, Ont., K1A 0K2.** Letters are always welcome, but only signed correspondence will be considered for publication.

HMCS *Kootenay* — 40 Years of Lessons Learned

Forty years ago this destroyer escort suffered a devastating gearbox explosion and fire that claimed the lives of nine of her crew. The tough lessons from that tragedy may seem well entrenched now, but other main gearing failures on board *Skeena*, *Gatineau*, *Chaudière* and *Fraser* in the early days created worrisome bumps for naval engineering credibility which are lessons in themselves for our fleet today.

Article by Claude Tremblay

The Incident

The engineering officer entered the engine room at 8:16 a.m. Minutes earlier he had called the bridge to request full speed ahead, the final step in the ship's engineering trials that had begun a few hours earlier when *Kootenay* detached from the *Bonaventure* carrier task group. The ships were 200 nautical miles west of Plymouth, England.

Many things have to be monitored during full-power trials, and in a ship where the main propulsion machinery is spread over two compartments — boiler room and engine room — it is a physical affair. The EO was returning from the boiler room where he had just confirmed the machinery was operating normally, and was now making a quick walkaround of the engine room, routinely touching the gearboxes to feel their temperature at high power. The date was October 23, 1969, and on this day it would be his last routine gesture.

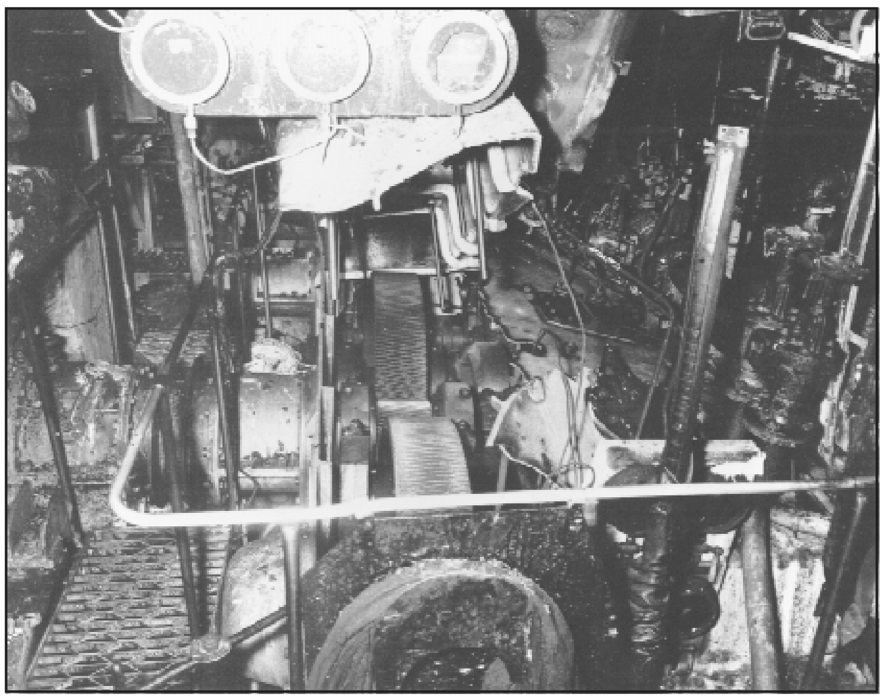


Fig. 1. The blackened engine room of HMCS *Kootenay* in the aftermath of a devastating gearbox explosion and fire bears dark witness to the horrific events of October 23, 1969. An improperly assembled forward pinion journal bearing lay at the heart of what should have been an avoidable tragedy. (All photographs property of DND)

At 08:21 what sounded like a welding torch was heard, and suddenly the engine room was engulfed in flames. A body fell forward, clothes afire. The engineering officer of the watch and the EO attempted to close the throttles and call the bridge, but they were forced to evacuate the space. The open after engine-room hatch let the flames out to run along Burma Road, the main fore and aft passageway above, and in moments the whole ship was filled with thick oily smoke.

Power was lost, the wheelhouse just off Burma Road also had to be evacuated, the ship could not be steered, and no communication was available with the boiler room. It would be 40 minutes before the main stops could be tripped and the ship would finally lose way from over 20 knots. Only after some power was restored around 08:45 could the task group be alerted to the emergency, and within minutes the ships were on the way, preceded by helicopters and Tracker fixed-wing aircraft from

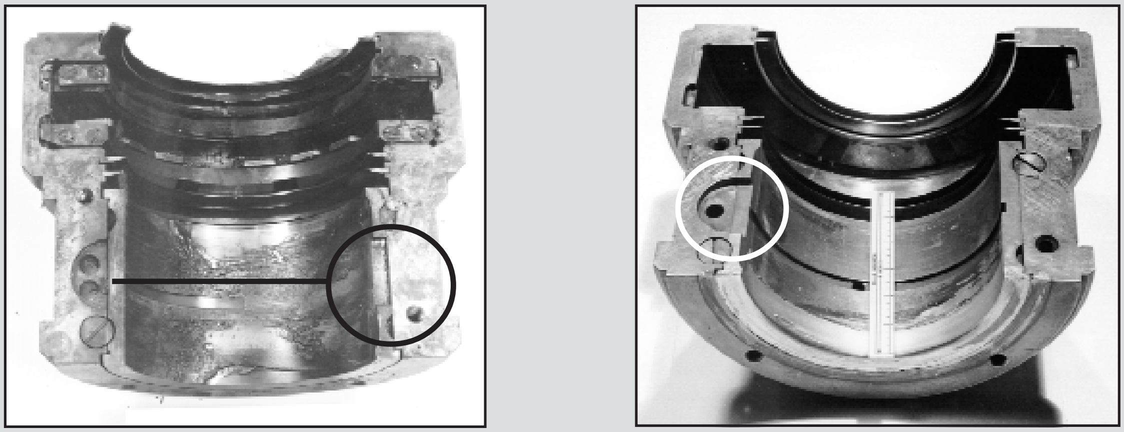


Fig. 2. These two pinion bearing halves from *Kootenay* (left) and *Chaudière* (right) illustrate the difference between incorrect and correct assembly of the bearing inserts. In *Kootenay*'s starboard forward bottom-half bearing the insert is installed back to front such that the cut-out (black circle) to allow oil into the insert is opposite the lube oil inlet port at left. In *Chaudière*'s port forward top-half bearing the cut-out (white circle) is properly matched to the oil inlet.

HMCS *Bonaventure*. Help from these units was crucial as *Kootenay* had only seven Chemox breathing units on board, and at one point had just one can of foam left to fight the massive fire.

It wasn't until 10:15 that all fires were reported out. For two hours, hundreds of sailors and airmen had given everything they had to fight the fire, deliver firefighting supplies from the other ships to the fire attack teams, rescue the trapped sailors in the cafeterias and boiler room, and treat and evacuate the more seriously wounded to *Bonaventure*. It was then, and remains, the Canadian navy's greatest peacetime tragedy.

The Cause

Unknown to *Kootenay*'s crew, the ship's two gearboxes had been improperly reassembled four-and-a-half years earlier.[1,2] Both journal bearings on the primary pinion gear had been installed incorrectly inside the starboard gearbox, as had one in the port gearbox. It was a disaster waiting to happen (*Fig. 1*).

Journal bearings are essentially smooth cylinders. Friction between the journal (shaft) and the bearing is reduced by a constant supply of lubricating oil that is pumped in through carefully designed openings and grooves in the bearing insert structure. The bearings were constructed as top and bottom halves to allow installation, and great care had to be taken by fitters and inspectors to ensure the two pieces were oriented correctly to maintain the flow of lube oil. To reduce the number of spares that had to be carried, the bearings for the Y-100 gearboxes were designed to fit in more than one location inside the gearbox. Unfortunately, because of the commonality of their design, it was possible to install them backwards.

This is exactly what had occurred in *Kootenay*. Installing the three primary pinion bearings — the highest speed bearings in the two gearboxes — back to front blocked the supply of oil to the surfaces (*Fig. 2*). By itself the high heat generated by the friction was not enough to ignite the oil. The ship had attained full power many times during the previous four-and-a-half years without producing enough heat to trigger ignition. In October 1969, however, the failure of the forward pinion thrust bearing at full power suddenly provided the increased heat necessary for ignition.

In single helical gearing designs the thrust bearings handle the large axial load generated by the helical gears. The thrust bearing in *Kootenay* failed because after four years of excessive bearing wear the journal began to rub against the labyrinth seal of the thrust bearing oil chamber, wearing it away on the bottom half by a third of an inch (0.85 cm). This left a gap at the top for the oil to escape, and with only half the required oil in the chamber it was just the bottom thrust pads that could receive lubrication. To make matters worse the pinion shaft had become misaligned due to the wear of the journal bearing, thus increasing the load on the unlubricated top pads. The sudden failure of the pads at full power produced temperatures in excess of 900ºC, sufficient to heat the oil mist into ignition.

The rapidly accelerating combustion in the starboard gearbox produced high-pressure gases which evacuated through the gearbox vent just before the gear casing fractured. This is what made the "organ-like" sound reported by people in the cafeteria. The subsequent initial fracture of the aluminum casing produced the "welding torch" sound heard by the engineering watchkeepers, and at this point the complete casing ruptured (*Fig. 3*)

It was later calculated by NDHQ gearing technical authority Don Nicholson[3] that a failed primary pinion thrust bearing at full power would develop a friction power loss that could reach six megawatts (over 8,000 h.p.). If *Kootenay*'s starboard pinion thrust bearing had failed earlier at lower power the ship would never have been able to reach full power and the friction loss would not have been large enough to generate the heat to sustain a fire. It was because the ship was already at full power when the failure occurred that the casing exploded.

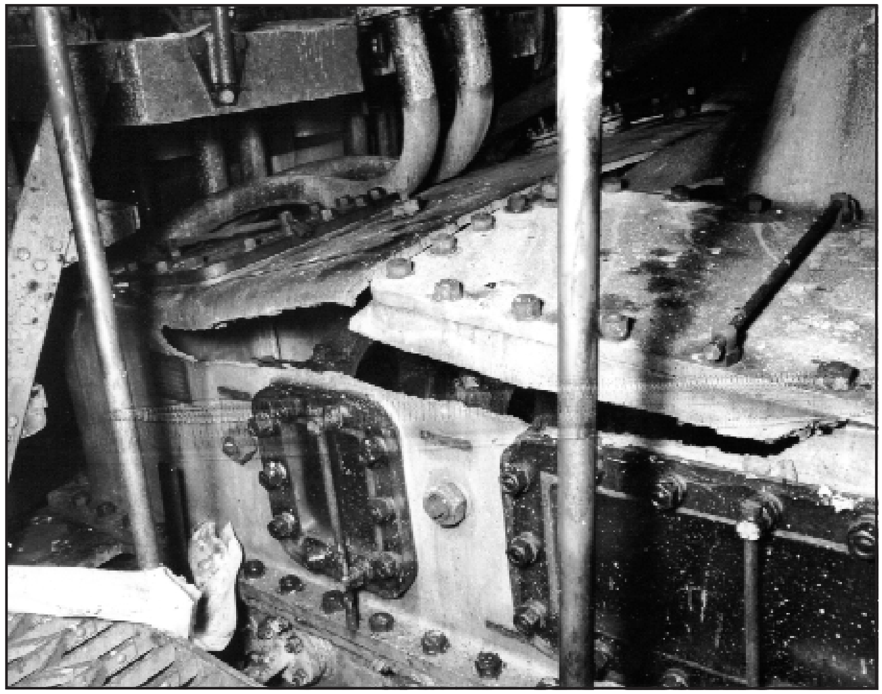


Fig. 3. The violent force of the explosion inside *Kootenay*'s gearbox ruptured the aluminum gear casing. Steel is now used in place of aluminum in modern gearbox covers.

More Incidents

Early lessons from the October 1969 disaster were quickly applied. All gearboxes were inspected and fitted with thermocouple bearing heat sensors in December that same year, but in June 1971, barely 19 months after the explosion, *Skeena*, *Chaudière* and *Gatineau* experienced major gearbox failures within ten days of one another. Two of the ships reported a fire in the gearbox.

These incidents came close enough to repeating history that the maritime commander released a message in language rarely seen in the navy: "I believe we have reached the point where our technical credibility has been severely compromised by these events. We are also beyond the point where messages to the fleet that – quote – the situation is well in hand – unquote – will suffice." A board of inquiry was immediately set.[4,5]

Skeena, it turned out, had an incorrectly fitted bearing on the port outboard primary gearwheel. The top and bottom parts had been interchanged, cutting off the oil supply to the bearing surface. The newly fitted thermocouple was not monitored. Oil ignition produced a small pressurization in the gearbox which caused a small discharge of black smoke through the vent.

Gatineau had the identical bearing misassembly problem. When a millivoltmeter was connected to monitor the bearing during post-refit full-power trials, an abnormally high temperature was detected. There was no oil ignition.

Just the day before *Gatineau*'s incident, *Chaudière* had reported ignition in the port gearbox during the second day of trials. Her problem was quite different. Contamination of the lubricating oil by loose zinc particles from oil canisters downstream of the filters caused the failure of the primary pinion thrust bearing. The bearing's temporary detection system showed higher temperatures than normal, but because the vibration analysis readings appeared normal the trials were not interrupted. It wasn't until a flash of burning oil was observed by a persistent assistant engineering officer that speed was reduced. The vibration detector was later found to be defective.

How could the gearboxes be failing like this again?

A Question of QA

The board of inquiry identified the main problem to be at the level of supervision and inspection, coupled with management trying to do too much too quickly. At the time that Gatineau's gearing was being inspected and the thermocouples were being installed, two other ships were also being worked on. Difficult scheduling combined with limited expert resources produced a situation where some bearing installations were checked only by the fitters themselves, not by the lead hand or charge hand of the shop (who were technically responsible, but too busy

Gearing incidents in four other destroyer escorts in the two years following the 1969 *Kootenay* explosion highlight the need even today for attention to detail with all matters of engineering maintenance, and constant vigilance over machinery. (HMCS *Fraser* shown.)

on other tasks), nor by the one gearing inspector. During the work on *Skeena*, for example, the contractor's schedule required the gearing work to be done in two shifts. The gearing inspector would have had to work sixteen hours a day, seven days a week for three weeks to meet the contract refit deadline. It was an impossible situation.

Machinery monitoring in 1969 consisted mainly of gathering temperatures, pressures, speed data, etc., directly from the equipment. It involved physical contact with the machinery, listening for uncharacteristic sounds and feeling for temperatures and vibrations. Although using temperature-sensitive thermocouples to monitor bearings was not new, *Kootenay*'s gearboxes had not been equipped with these simple devices. Due to cost, a proposed engineering change in 1958 to retrofit all ships of the *St. Laurent* and *Restigouche* classes with bearing thermocouples and monitoring systems resulted in only the two lead ships being fitted with the equipment that had been acquired for evaluation. By contrast, the newer *Mackenzie*-class ships were fitted with 40-point bearing monitor systems.[1,2]

Soon after the disaster the navy determined that bearing temperatures should be monitored with thermocouples, and indeed some ships were equipped by the end of 1969. Unfortunately, a console thermocouple monitor system to display alarm situations would not be available for another three years. The 40-point monitor installed in the *Mackenzie* class was no longer in production, and the only systems available commercially used resistance temperature detectors (RTDs). Since the decision had already been taken to go with thermocouples, a completely new monitoring system had to be designed and produced — a process that took until 1972. In the meantime the ships used a mixture of systems, some routinely monitoring just six bearings (the other bearings being monitored only during trials).

Thermocouples played a major role in one other thrust bearing failure, this one in HMCS *Fraser* just a year after the explosion in *Kootenay*. Thermocouples had been installed in *Fraser* and other ships at the same time as the gearboxes were being inspected in December 1969. Unfortunately, some installations were done incorrectly. The impending failure of *Fraser*'s thrust bearing in October 1970 was not detected because the oil bath thermocouple in the primary pinion thrust bearing housing did not protrude through the housing into the oil bath as required by the design. It could not possibly indicate the temperature of the oil bath.

Other Findings

The board of inquiry also determined that the details of *Kootenay*'s explosion were not properly communicated throughout the fleet. The disaster was still somewhat of a mystery to most crews who had heard only rumours of "organ-like noises" and a "fireball," but very little information on the actual causes of the explosion. This lack of information may have led *Chaudière*'s crew to delay corrective action when high temperatures were detected. The fact that the West Coast was concentrating more on the ventilation of the gearbox than the temperature detection system — contrary to headquarters' findings — likely affected the crew's reaction as well.

In July 1970 the British Ministry of Defence set up a gearbox explosion working party[6] mainly because of the *Kootenay* incident. After studying the behaviour of atmospheres inside gearboxes, they noted in their report: "…under normal running conditions the oil mist atmosphere is too lean for ignition to occur. The oil mist present is continuously eliminated by the scrubbing action of the relatively coarse oil spray and splashing which occurs in a running gearbox."

The report also pointed out that it would take exceptionally high temperatures to overcome this effect, and that ventilation was not a factor. Nonetheless, even today gearbox ventilation is often presumed to be at the centre of explosion risks.

The last critical area commented on by the Canadian board of inquiry was the degree of experience and expertise of fleet engineering personnel. The board noted that the sea experience of engineering officers and even chief ERAs was becoming more and more limited. It may be hard to imagine today, but in those days engineering officers even had additional bridge watchkeeping duties.

HMCS *Chaudière*

Lessons for Today

Modern gearing designs include many direct lessons learned from the *Kootenay* explosion. The journal bearings shell design now includes dowels in unique positions to prevent incorrect assembly, and every single bearing is closely monitored by RTDs or thermocouples connected to a controls system. As well, the use of double helical gearing has practically eliminated the gear-generated axial loads and the requirement for highly loaded thrust bearings. Gearbox covers are today made of steel rather than aluminum.

Many things have changed since 1969, and it may well be that full-power trials have become routine, dull affairs as viewed from the relative comfort and safety of a fully instrumented machinery control room. In a modern frigate as soon as an abnormal increase in a bearing temperature is detected, audible and visible alarms warn the engineering officer of the watch of the problem, and speed can be reduced immediately. It all seems so controlled, but the same risks remain. The complex issues of quality assurance, personnel training and technical accuracy addressed in the aftermath of the *Kootenay* incident still require constant vigilance to ensure history does not repeat itself yet again.

The seeds of major disaster were present in *Kootenay* and in other ships well before the accident occurred, but there was almost no way to detect them. If the gearbox had not exploded in *Kootenay* it would have happened in another ship. The human cost was horrendous, but over the last 40 years the hard-won lessons of *Kootenay*'s tragedy have no doubt saved countless other crews in navies around the world from a similar fate.

References:

1. Report of the Board of Inquiry – HMCS *Kootenay* – dated November 7, 1969.
2. Report of the CFHQ investigation team – HMCS *Kootenay* – dated December 4, 1969.
3. D.K. Nicholson, "The *Kootenay* Gearbox Explosion," The Institute of Marine Engineers, 1981 (R-23-050-001/AB-001).
4. Boards of Inquiry – *Chaudière*/*Gatineau* – dated July 2, 1971.
5. DDE/DDH main gearing problems – Report of the technical task group – dated July 16, 1971.
6. Final report on investigations carried out by the MOD(N) gearbox explosion working party (July 1970 to December 1978).

Acknowledgement:

The assistance of Stephen Dauphinee in reviewing this article prior to publication is gratefully acknowledged. Mr. Dauphinee is the Marine Systems Engineering Officer of Fleet Maintenance Facility *Cape Scott* in Halifax, and previously worked for gearing expert Don Nicholson in the Directorate of Marine and Electrical Engineering in Ottawa from 1982 to 1988.

Claude Tremblay is the Transmission Systems Engineer in the Main Propulsion section of the Directorate of Maritime Ship Support in Ottawa.

A New (Dräger) Self-Contained Breathing Apparatus for the Canadian Navy

For half a century the Chemox® BA chemical oxygen breathing apparatus was the Canadian navy's primary respiratory system for fighting fires. Having stood the test of time for so long, the now unsupportable Chemox is giving way to a state-of-the-art replacement apparatus — the Dräger SCBA.

Article by Cdr Marc Batsford
Photos courtesy CFNES Damage Control Division *Kootenay*, Halifax

During the world wars sailors were sent in to fight fires wearing rudimentary combat flash gear and multiple layers of clothing. After being soaked with water to protect against heat and flash, they advanced on a fire using hoses to push back flames, smoke and heat. Following a technique still taught by the navy's damage control divisions into the 1980s, the modestly equipped firefighters found clean air to breathe next to the stream of water rushing from the hose nozzles.

The navy's first formal breathing apparatus — the Chemox BA system — was introduced in the early 1950s. The system had been designed and produced by the Mine Safety Appliances Company in Pittsburgh, Pennsylvania in 1947, primarily to support mine rescue operations in the United States and Canada. The original Chemox set underwent numerous modifications and improvements prior to being marketed as firefighting gear to the United States Navy, and later, the RCN.

The Chemox BA is a closed circuit breathing device worn over the chest that uses a disposable canister filled with potassium superoxide (KO_2). The moisture and carbon dioxide from the user's breath reacts with the potassium superoxide to produce oxygen. The user breathes the oxygen and releases more moisture and carbon dioxide into the closed circuit of the Chemox, continuing until the potassium superoxide is depleted.

The Dräger SCBA is a self-contained unit consisting of a rechargeable cylinder worn on the back, high- and low-pressure lung-demand valve regulators, a face mask with colour head-up display, and a harness. The bottle is rated for 4,500 psi (300 bar) and can last 60 minutes.

Throughout its naval service life the Chemox system was modified with improved face pieces, a bail to replace the screw-in canister insertion method, and the addition of an oxygen-generating, sodium chlorate activation "quick-start" candle.

The Need for Change

The need for a new firefighting breathing apparatus became apparent when problems were experienced with the quick-start candles in the Chemox canisters. When activated, this candle is meant to provide oxygen until the moisture in the user's breath can initiate the chemical reaction with the potassium superoxide. As early as 1999 users began to experience excessive heat along with sparks and fire when the quick-start candles were ignited. After repeated unsuccessful attempts to have the manufacturer rectify the problem the navy decided to search for a new breathing apparatus system. In the meantime, a supply of Chemox canisters without the quick-start candles was purchased.

A similar requirement for a breathing apparatus replacement existed on board Canadian submarines. While submariners do not use Chemox for firefighting, their system, the SUBRON self-contained breathing apparatus (SCBA), was no longer supportable. A replacement had to be found. To attain consistency in the navy's surface and subsurface components, the two separate projects that had been stood up to replace the Chemox and SUBRON systems were combined under a single procurement process.

After extensive technical and logistical analysis and consultation, Public Works and Government Services Canada awarded a contract in March 2008 to Dräger Safety Canada to provide 1,571 SCBA sets to the navy for use on board HMC ships, submarines and auxiliary vessels. The contract, which includes provision for maintenance support at two new OEM repair centres being set up on the coasts, was expected to be fully implemented by December 2009.

The New Apparatus

The Dräger SCBA is a self-contained unit consisting of a rechargeable cylinder worn on the back, high- and low-pressure (HP/LP) lung-demand valve regulators, a face mask with colour head-up display, and a harness. The bottle is rated for 4,500 psi (300 bar) and can last 60 minutes. The head-up display in the face mask provides the user with indicators corresponding to 100%, 75%, 50% and 25% air remaining in the bottle, with an audible alarm sounding at 25% to signal that a bottle change-out is required. A fleet SOP will mandate that a user must leave a damage control scene once the audible alarm has sounded.

The increased reliability and improved individual protection promised by the Dräger SCBA system will offer crews an increased level of confidence during firefighting operations on board Canadian navy ships and submarines.

As a temporary measure, air bottles on board the frigates, destroyers and AORs will be recharged using one of two diesel-driven compressors that will be installed on the weather decks. Two were provided so as to provide emergency charging capability at opposite ends of the ship. A second benefit is that the temporary compressor units can be connected to a ship's HP air system to charge the main air bottles should the ship's compressors sustain major damage. When implementation of the Dräger system is complete the bottles will be recharged from the ships' own fitted HP air systems, and the weather-deck compressors will be used as an emergency backup recharging capability.

The smaller *Kingston*-class maritime coastal defence vessels (MCDVs) will carry one compressor, while *Orca*-class patrol vessels will normally recharge their bottles ashore. Submarines will continue to use their existing breathing air charging panel that was installed for charging the old SUBRON system.

Halifax and *Iroquois* Class Implementation

The Dräger SCBA for the *Halifax* and *Iroquois* classes is being introduced in three phases:

Phase One, which is now complete, included the installation of 29 sets of the new SCBA, 25 spare cylinders and two diesel-driven compressors in each ship to recharge the cylinders. The fleet maintenance facilities (FMFs) will mount the SCBA sets and spare bottles in pre-determined locations throughout the ship, nominally in the vicinity of the section base team areas. Due to the phased implementation plan, all Chemox sets will remain on board until Phase Two is complete to ensure operational capability. Chemox will be the backup in the event that Dräger bottles cannot be filled, but attack teams will use either the new Dräger SCBA system or the Chemox, and not a mixture of the two. The SCBA sets currently held by ships' crash rescue teams, air departments and training units will also be replaced with the Dräger apparatus.

Phase One implementation also included a one-day session of initial cadre training for all ships' crews on both coasts at the formation damage control divisions. Having the entire fleet undertake this training simultaneously allowed the DC training facilities to resume their normal training programs with the least disruption and establish SCBA training as core training as soon as possible. Sea Training will be conducting mini ship readiness inspections (SRIs) to ensure the new equipment is being used correctly and within accepted damage control doctrine and standard operating procedures. The new equipment is not expected to significantly alter navy damage control tactics.

Phase Two will see necessary modifications to the HP air system in *Halifax*- and *Iroquois*-class ships. Filling stations will be installed in the vicinities of the forward and after section bases, hangar and manning pool. These filling stations will boost the air pressure to 4,500 psi (300 bar) and filter the air to CSA Standard Can/CSA Z180 Compressed Air Systems. The Naval Respiratory Protection Program has adopted this CSA standard.

Once the air filling stations have been installed and commissioned, an additional 31 SCBAs will be installed, bringing the total on board to 60 SCBA sets. At this point in the project, all Chemox sets and spare canisters will be returned to stores for disposal. On completion of Phase

Two only the Dräger SCBA will be carried on board ship.

Phase Three will allow time for ships' staffs to become comfortable with the charging stations and give Sea Training an opportunity to conduct a final SRI of the complete system. This will ensure that the new system and equipment are well understood.

Kingston Class

The 12 *Kingston*-class MCDVs will be fitted with one diesel-driven compressor, 13 SCBA and 26 spare cylinders. There is no phased fit required due to the small number of sets required. Because of the concern with the frequent crew changes in these ships, all *Kingston*-class crews will be trained at the same time to ensure that everyone sailing in the MCDVs is trained in the proper use of the Dräger SCBA and compressor. Also, since an outside contractor (SNC Lavalin) will be conducting the installation, this will have no impact on FMF resources.

Victoria Class

The *Victoria*-class submarines will be fitted initially with a one-for-one replacement of the eight SUBRON SCBAs now carried on board. The submarine version of the Dräger SCBA will differ slightly from the surface fleet SCBA in that it will be fitted with a capability to have two masks breathe from the same SCBA. The CANAVMOD fit on the *Victoria* class also includes replacement of the cylinder charging hoses and the 15-metre (50-foot) extension hoses with ones of equivalent length, but with compatible Dräger quick-connect fittings. The completed installation will also see the emergency breathing system (EBS) masks, fittings and hoses replaced one for one with Dräger masks and Dräger-compatible fittings and hoses. These changes mean that the same mask can be used with a myriad of hose combinations with the EBS rail or the SCBA. Such interoperability will enhance the firefighting capability on board.

Protecteur Class

Protecteur and *Preserver* will be fitted with two large electric "breathing air charge centres" similar to the units used at the damage control divisions. The two AORs will each be fitted with 77 SCBA, 77 spare cylinders, and two emergency diesel compressors.

Orca Class

The eight *Orca*-class patrol vessels, the navy's newest addition, will soon be outfitted with four SCBA sets each. As mentioned, the *Orca*s will not be fitted with a dedicated compressor.

Conclusion

In retiring the Chemox and SUBRON firefighting breathing systems, this engineering change introduces state-of-the-art self-contained breathing apparatus equipment to the Canadian navy. The increased reliability and improved individual protection promised by this equipment will offer crews an increased level of confidence during firefighting operations on board our ships and submarines. While the procurement of the new Dräger SCBA has taken considerable time to materialize, this new equipment is the best and safest available to replace the Canadian navy's current firefighting breathing systems.

Cdr Batsford is the former DMSS 4 section head for Marine Auxiliaries and Damage Control Systems in Ottawa.

Acknowledgments

The assistance of **David Sankey –** DMSS 4-2-9 project manager for the Chemox Replacement Project, and life-cycle materiel manager for Compressed Air Systems (Surface) – is gratefully acknowledged; as is the photographic support of **CFNES Damage Control Division *Kootenay*** in Halifax.

Objectives of the Maritime Engineering Journal

- To promote professionalism among maritime engineers and technicians
- To provide an open forum where topics of interest to the maritime engineering community can be presented and discussed, even if they might be controversial.
- To present practical maritime engineering articles.
- To present historical perspectives on current programs, situations and events.
- To provide announcements of programs concerning maritime engineering personnel.
- To provide personnel news not covered by official publications.

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Book Review

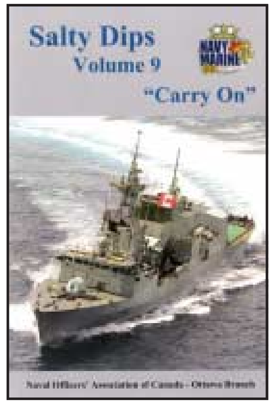
Salty Dips Volume 9 “Carry On”

Reviewed by Bridget Madill

Salty Dips Volume 9 “Carry On”
Naval Officers’ Association of Canada, Ottawa Branch © 2008
ISBN 978-0-9691342-9-9 (soft cover)
393 pages, illustrated, index
$15.00 soft cover, $25.00 hard cover

The ninth volume in the *Salty Dips* series, *“Carry On,”* continues the tradition of capturing the history of the Canadian navy through the personal recollections of Canadian sailors. This edition concentrates on the post-Korean War years, with stories about peacekeeping, humanitarian operations, ship trials and modern wars. The 31 stories are set in such places as Africa, Asia, Viet Nam and the Middle East.

Two prologues open the book. The first, entitled “The Neglected Service,” describes the Royal Canadian Navy before World War II; the second, “Unification,” is a frank discussion of the integration of the Canadian Forces in the 1960s. Where space permits, nautical poems appear between the stories, and at the end of the book there is a summary of the previous eight volumes in the *Salty Dips* series.



The dips (or stories) all come from conversations with old salts (sailors), hence the name of the series. The conversations were taped, transcribed and edited by volunteers from the Naval Officers’ Association of Canada (Ottawa Branch), and reflect the personal memories of the storytellers. Told in the first person, the stories — from Whit Armstrong’s humorous *Blue Cheese Incident*, to Stoker Petty Officer Hank Porter’s engaging 1944 logbook narrative, *Destroyer Action in the Bay of Biscay* — are richly varied and warmly intimate.

“Carry On” is well illustrated with about 200 photographs, maps and graphics. The book is easily accessible to a wide audience. For the most part the inevitable acronyms are well explained, and the abundant footnotes give context to the stories without interrupting the flow of the tales.

The Naval Officers’ Association Ottawa Branch started its *Salty Dips* oral history project in 1979, and the nine volumes in the series tell the history of the Canadian navy in a way that is intensely personal, colourful and alive. *Salty Dips Volume 9 “Carry On”* is available from the NOAC Ottawa Branch, by mail at NOAC Salty Dips, PO Box 505 Station B, Ottawa, ON, K1P 5P6.

More information on the Naval Officers’ Association of Canada Ottawa Branch and the *Salty Dips* series is available on-line at www.noac.ottawa.on.ca

Bridget Madill is an Associate Editor of the Maritime Engineering Journal.

Guidelines for Book Reviewers

The *Maritime Engineering Journal* is always on the lookout for upbeat, positive reviews of recently published naval/nautical books that you would recommend to other readers.

Reviews should be about 250 words in length, and should generally tell us:

- what the book is about;
- how well the author did with the work, and if there are any minor drawbacks; and
- what you like best about the book.

Please include the following book information with your review:

- Title
- Author
- Publisher
- Date of publication
- ISBN
- Number of pages

Also mention whether the book contains photos, illustrations, glossary, bibliographical references or index.

Finally, send us a high-resolution scan of the dust cover if possible.

Reviewers are encouraged to express themselves creatively, and in their own words.

News Briefs

NTO Award winners and runners-up

Lt(N) Steve Parker, Lt(N) Mike Noel, SLt Ed MacKenzie, Lt(N) Mathew Webb, Lt(N) Patrick Larose, SLt Michael Bathurst, Lt(N) Sarah Roberge, Lt(N) Jeffery Vanderploeg, Lt(N) Denise Dickson, SLt Chris Lien, Lt(N) Max Dion, Lt(N) Matt Cleary, Lt(N) Chris Vandenhoven *(Photo by Cpl Robert Leblanc, Formation Imaging Services, Halifax)*

Journal Production Editor Receives MarCom Commendation

Production editor **Brian McCullough** has received the Maritime Command Commendation for his "Outstanding contribution to the Naval Technical Community through his dedicated management and production of the *Maritime Engineering Journal*." The commendation is awarded in recognition of exceptional services to Maritime Command. The long-serving editor began working full time on the *Journal* in 1985 while on Class C service, and has been producing the Branch technical publication on civilian contract through his company Brightstar Communications since 1994.

Cmdre Richard Greenwood (DGMEPM), Lt(N) Patrick Fortin (Journal PM), and Capt(N) Mike Wood (COS MEPM) were on hand to offer their support. Former *Journal* PM Lt(N) Mark McKiel was unable to attend.

2008 Naval Technical Officer Awards

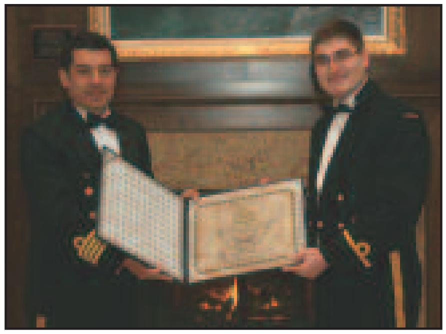
Photographs by Cpl Robert Leblanc, Formation Imaging Services, Halifax

The NTO awards recognize the dedication, hard work and technical excellence of NTOs in obtaining their training milestones during the previous year. Regardless of who wins any particular award, it is a significant accomplishment even to be considered a candidate. The 2008 awards were presented at the Naval Technical Officer Mess Dinner on March 26, 2009 at the CFB Halifax Wardroom.

Naval Officers Association of Canada (NOAC) Award

The NOAC Award is presented annually to the candidate with the best academic performance and officer-like qualities on completion of the Naval Engineering Indoctrination Course. Lt(N) Andrew Sargeant accepted the award shield and the book, *The Ships of Canada's Naval Forces 1910-1985*, from Cmdre (ret.) Mike Cooper, NOAC, on behalf of **NCdt Jay Murray** who was absent due to illness.

Mexican Navy Award



The Mexican Navy Award is presented annually to the candidate with the best academic standing and officer-like qualities on the NCS Eng Applications Course. Mexican Naval Attaché, Captain Hector Capetillo presented the award plaque and Mexican naval sword to **SLt Chris Lien**.

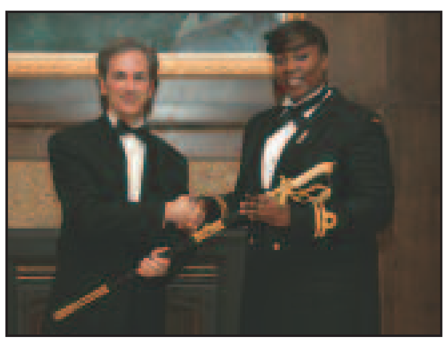
L-3 MAPPS Saunders Memorial Award

The L-3 MAPPS Saunders Memorial Award is named in memory of Lt(N) Chris Saunders. It is presented to the candidate with the best academic standing and officer-like qualities on the MS Eng Applications Course. Gwen Manderville (Saunders) and her children Ben and Luke joined Wendy Allerton of L-3 MAPPS in presenting the award plaque and the *Modern Marine Engineer's Manual* to **Lt(N) Chris Vandenhoven**.

MacDonald Dettwiler Award

The MacDonald Dettwiler Award is presented annually to the best overall naval technical officer who achieves Head of Department qualification. Simon Jacques of MacDonald Dettwiler presented the award plaque and naval sword to **Lt(N) Patrick Larose**.

Weir Canada Award



The Weir Canada Award is presented annually to the best overall Phase VI candidate who achieves MS Eng qualification. Serge Lamirande, Weir Canada Inc., presented the award plaque and naval sword to **Lt(N) Denise Dickson**.

Lockheed Martin Canada Award

The Lockheed Martin Canada Award is presented annually to the best overall Phase VI candidate who achieves NCS Eng qualification. Lt(N) Terry Moore accepted the award plaque and naval sword from Steve Marsden of Lockheed Martin Canada on behalf of **SLt Byron Ross** who was absent due to his deployed status on board HMCS *Winnipeg*.

A photo of award winners and runners-up appears in the News Briefs section of this edition of the Journal.

National Defence / Défense nationale

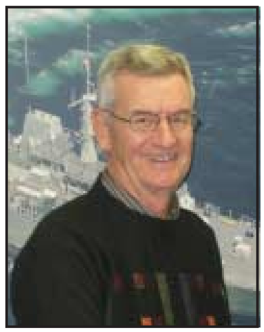
FALL 2009 / WINTER 2010

News

CANADIAN NAVAL TECHNICAL HISTORY ASSOCIATION

New Way Ahead for CNTHA and CANDIB

After 14 years at the helm of the Canadian Naval Technical History Association, Mike Saker has relinquished his chairmanship of the CNTHA to co-founding member Pat Barnhouse and is moving to Mahone Bay, Nova Scotia. Mike's move provided an opportunity to review the mandates of the CNTHA and its main subcommittee project (CANDIB) investigating naval technology links to Canada's industrial base. In recent years the distinction between the two had become increasingly blurred as more resources were directed toward CANDIB.



Mike Saker steps down as CNTHA Chairman

At a combined CNTHA/CANDIB meeting on November 6, members agreed that the all-volunteer organization should be restructured to allow the CANDIB subcommittee to widen its focus to encompass the broader objectives of the CNTHA under the new chairman. CANDIB itself will remain under the direction of Tony Thatcher, who was newly appointed as the executive director of the CNTHA. CANDIB will continue its work as normal, but has been redesignated as a working group of the CNTHA.

Pat Barnhouse (left) takes over as CNTHA Chairman, while Tony Thatcher continues his CANDIB Project leadership as Executive Director of CNTHA.

CNTHA News *Est. 1997*

CNTHA Chairman
Pat Barnhouse

CNTHA Executive Director and CANDIB Project Leader
Tony Thatcher

Directorate of History and Heritage Liaison
Michael Whitby

Maritime Engineering Journal Liaison
Brian McCullough

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Kanata, Ontario

CNTHA News is the unofficial newsletter of the Canadian Naval Technical History Association. Please address all correspondence to the publisher, attention Michael Whitby, Chief of the Naval Team, Directorate of History and Heritage, NDHQ Ottawa, K1A 0K2. Tel. (613) 998-7045, fax 990-8579. Views expressed are those of the writers and do not necessarily reflect official DND opinion or policy. The editor reserves the right to edit or reject any editorial material.

cntha.ca

FHE-400 in Retrospect

By Rolfe Monteith

A great deal has been written regarding the Canadian Hydrofoil Project of the 1960s. While the media viewed it as yet another DND disaster of escalating costs and program delays, within naval circles it became the centre of attention partly for another reason. Should sea trials of FHE-400 prove the effectiveness of using many relatively cheap hydrofoils to counter the Russian nuclear submarine threat, it could create a dilemma for proponents of large, "bluewater" ships for this purpose.

Setting aside details of how the project escalated from an initial objective of demonstrating the seaworthiness of a 200-ton hydrofoil (estimated cost of $10.1 million) to a complete ASW weapon system costing some $51 million before it was mothballed, it is important to remember what accrued from this. What has not been widely acknowledged is the fact that through the project the navy reaped many benefits in terms of new methods of design and acquisition, weapon systems, and infrastructure that might not otherwise have been developed.

The acquisition process used for the hydrofoil FHE-400 *Bras d'Or* was radically new for the navy. Traditional warship procurement had been based on a detailed specification of the vessel and its systems, linked with comprehensive oversight. For the hydrofoil, a contract was awarded to a prime contractor based upon a statement of requirements and a design concept. This approach was common practice in aeronautics, but presented the navy with an agonizing learning curve. The experience was invaluable, however, as this procedure worked so well it was successfully adopted for follow-on ship new-build programs.

It was deemed important to merge the separate responsibilities of the Department of National Defence and Defence Production into a small joint project office with a project manager responsible for *all* aspects of the program, including in-service support. The navy was breaking new ground throughout the project, and mistakes were inevitably made because of inexperience. Much was learned from these errors, and the benefits were obvious. As with the acquisition process, the

(Continues next page)

FHE-400 *Bras d'Or* — foilborne! (DND photo)

Disposition of Hydrofoil Technology

By Pat Barnhouse

[This edited excerpt is from the author's article, "The Canadian Hydrofoil Project," which appeared in the Winter 1985 issue of the *Journal*.]

The computer-based command and control Action Information System (AIS) developed for HMCS *Bras d'Or* required the formation of a naval programming team at Westinghouse in Hamilton, Ontario. This expert team later developed computer programs for the naval tactical data command and control system (CCS) for the DDH-280-class ships; thus, the CCS system owes part of its existence to the hydrofoil project.

A variable depth sonar was designed and built for the FHE-400, with Canadian Westinghouse responsible for the electronics, and Fleet Industries Ltd. supplying the over-the-stern handling gear. Sales of this technology were later made to the Italian and Swedish navies.

The hull structure of HMCS *Bras d'Or* was designed to aircraft standards. By appropriate instrumentation of the hull for sea trials, the strengths and weaknesses of this technology vis-à-vis conventional ship design practices for hydrofoils were ascertained.

A number of other technologies developed during the hydrofoil project have not been directly applied elsewhere:

a. the use of maraging steel (an extremely high-strength steel) in the main foil structure;

b. the innovative design for the transmission of high power from the main engines through the narrow foil-struts to the screws;

(Continues next page)

c. the use of aircraft electronics and preformed aircraft wiring harnesses; and

d. the design of the hydrofoil bridge in the manner of an aircraft cockpit.

Rigid adherence to a 60-knot foilborne performance requirement was the main offender in the evolution of the ship from a relatively cheap vessel, suitable for construction in large numbers, into a highly sophisticated design requiring construction techniques of the greatest refinement. Today, in the advanced marine vehicle field, the specification of maximum speed is tempered greatly by anticipated costs and by careful assessment of the related operational advantages.

The most visible achievement of the FHE-400 design was her speed of 63 knots which made *Bras d'Or* the world's fastest warship. A more meaningful accomplishment was the demonstration that a 200-ton hydrofoil could operate successfully in the open ocean, both foilborne and hullborne.

The use of aircraft technology in hydrofoil construction is a mixed blessing. It undoubtedly results in weight saving, but leads to a less robust ship that costs more. There are also expensive infrastructure and support costs over and above the support base required for conventional warships.

Undoubtedly, the most valuable contribution of FHE-400 has been the footing gained for Canada in the general field of advanced marine vehicle technology.

Pat Barnhouse is Chairman of the Canadian Naval Technical History Association.

joint project office model became accepted practice for all future projects.

Early in the design phase both the prime contractor and the Hydrofoil Project Office became confident in the viability of the hydrofoil and, in light of the increasing ASW threat, proposed expanding the project to include a weapon system. The Naval Board accepted the HPO recommendation, and one specific consequence of this decision was that a contract was awarded to Westinghouse for an action information system (AIS). Upon the demise of the hydrofoil project, the AIS became immediately available to the DDH-280 tribal-class destroyer project.

Once it was accepted that the hydrofoil would have a weapon system, it was also envisaged that FHE-400 would tow a variable depth sonar at 45 knots. Again, funding was made available for research in the ASW field.

The HPO recognized the need for research into the issue of habitability for the crew of 18, and funded extensive research at the Institute of Aviation Medicine in Toronto. The results of this habitability research became available to follow-on ship projects.

While FHE-400 had only one gas turbine, it was a first in the navy and provided an early training ground for future frigate programs.

As part of the HPO responsibility for support, the project's funding acquired a Syncrolift ship lift and transfer system. It was installed at the Halifax naval dockyard where it is now an invaluable asset for submarine support.

And finally, even today, FHE-400 *Bras d'*Or holds the record for being the fastest warship in the world. To those intrigued by this fascinating saga, I recommend John Boileau's book, *Fastest in the World*, and a visit to FHE-400 *Bras d'Or* at the Musée maritime Bernier at L'Islet, Québec.

Rolfe Monteith is a founding member of the Canadian Naval Technical History Association. He writes from his home near London, England.

Musée maritime du Québec (formerly Musée maritime Bernier) east of Québec City obtained HMCS *Bras d'Or* in 1983. *(DND Photo).*