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Feature Issue:

CPF First–of–Class Shock Trial

Also:

- ***What's a MARE doing in Japan?***
- ***Looking Back: Will the real impostor please stand up!***

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OUR COVER
The lead ship of the *Halifax* class moves into position for the 1994 CPF shock trial. *(CFB Halifax Base Photo)*

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Commodore's Corner

CPF shock trial a success thanks to "the many"

By Commodore F.W. Gibson, OMM, CD
Director General Maritime Equipment Program Management

On November 18, 1994 at a location approximately 300 kilometres south of Nova Scotia, the first CPF of the class, HMCS *Halifax*, was "bounced" by a proximity underwater detonation of 4,500 kg of high explosive. Several years in the planning and preparation, this last and most powerful test in the CPF shock series was over in a few milliseconds. The ship emerged unscathed, the environment was not adversely affected, and the objective of the entire CPF shock program was finally attained. There was a sense of relief and satisfaction.

It is stressed at the outset that the trial was not a discrete event, but the demonstration of a design qualification and analysis program that spanned the history of the project and its evaluation. It is not therefore the trial event and its analysis alone that should make us confident that we have a robust and capable warship, but the foundation upon which this result was achieved. After all, the actual shock levels experienced by *Halifax* during the trial were less than those that were applied to CPF equipment during the qualification process. What the shock trial provided was a representative response to the integrated ship, as a complete system, within prudent safety tolerances.

It is no secret that this was almost "the trial that never was." Unlike earlier Canadian naval shock trials where the operational and technical considerations were predominant, the CPF trial was planned and executed amid ever-increasing public concern for the environment. Not only did a complete environmental assessment have to be conducted (a significant undertaking), but the individual concerns of both public and government stakeholders — the fishing industry, environmental groups, scientific bodies, etc. — had to be satisfied during public consultation and in the plan itself. This new reality was the reason behind our conducting the trial far enough from shore and late enough in the year to avoid marine life and seasonal marine populations.

The articles presented in this edition will expand on these issues and on the myriad of other preparations and activities that have, in fact, spanned several decades. An overview from the project management perspective is presented by the CPF shock trial director, LCdr Serge Garon. The technical details of the trial itself are provided by the various specialists from the shock trial team. I hope that these papers convince you that the trial was worth doing, was well executed and, most importantly, was successful in demonstrating that the CPF is well designed for a vital operational requirement — resistance to underwater shock.

PMO CPF and other DGMEPM staff are progressing the configuration changes deemed necessary as a result of the trial observations and the post-trial analysis. A few very specific investigations are still in progress to examine potential improvements for system survivability under the CPF mandate. Observations that can be more generally categorized as "lessons learned" (or re-learned), such as improved equipment security and gear stowage, are being incorpoated in a shock video for refresher training. In the longer term, as far as the requirement for shock trials is concerned, we are going to have to examine their continued viability as part of a shock program. Notwithstanding the demonstrable benefits of this whole-ship trial, and the lack of any comparable analytical process, we must accept that the CPF trial was conducted at the margin of practical consideration.

It is important that I pass along a very sincere acknowledgment of the many agencies and individuals responsible for the successful outcome of the *Halifax* shock trial. To Saint John Shipbuilding Ltd., Loral (Unisys/Paramax), MIL Davie and all the many CPF vendors; to Maritime Command (particularly Cdr Dave Sweeney and *Halifax*'s ship's company); to the Department of Fisheries and Oceans (especially Dr. Paul Brodie); to Environment Canada; to the Directorate of Environmental Protection (particularly Maj Mike Fowler); to the DGMEPM (DGMEM) crew for all their CPF support (especially Jan Czaban for his support on the shock program); to the Naval Engineering Test Establishment (where much of the CPF equipment was qualified); and to the PMO CPF team (especially the CPF shock trial director, LCdr Serge Garon) and to all the rest too numerous to mention, my thanks for the professionalism and dedication that enabled our success with this trial.

I hope that you enjoy the articles.

Commodore Gibson was the project manager of the Canadian Patrol Frigate Project at the time of the shock trial.

Managing the CPF Shock Trial — *An Outstanding DND Team Achievement*

Article by LCdr Serge Garon

Spirit of co-operation: Members of the CPF shock trial team pause for a photo in *Halifax*'s hangar. *(CFB Halifax photo by Cpl. R. Duguay)*

On November 18, 1994, after a year of intense final preparations, HMCS *Halifax* was subjected to a controlled, close proximity detonation of five tonnes of high explosive. The Canadian patrol frigate (CPF) shock trial project was thus implemented within time and budget constraints, and without significant incident to personnel, ships, environment, or public image.

Shock trials have been conducted by a number of navies since the Second World War. The CPF trial was conducted to provide conclusive evidence that Canada's new patrol frigates can maintain essential combat capability in the wake of a predetermined underwater shock. "Essential capability" refers to personnel, structure, major equipment and systems as defined in the Statement of Requirements for the class. The trial would also provide the data to support any necessary shock design changes, and present an excellent opportunity to train under action conditions. In addition, a successful trial would augment the established confidence in the class and publicly demonstrate its capabilities.

In the final analysis, the CPF first-of-class shock trial project was a showpiece of adaptable leadership and management, and of exemplary dedication and teamwork by many people. Its successful implementation was a case of focusing on operational objectives, while balancing shock design and trial support requirements, environmental regulations, and national and international considerations – all under the constant pressure of the trial schedule itself. This paper describes the immense complexity and magnitude of the trial, its management approach and its success.

Trial Preparations

The Trial Charter

The CPF prime contract required that a shock trial be conducted before September 1993, but for various reasons this date could not be met. A senior review board was convened by PM CPF in early 1993 to chart the way ahead. The board's membership was made up of (using 1994 designators):

Shock Trial Instrumentation — The NETE Involvement

In support of DSE 5, the Naval Engineering Test Establishment in LaSalle, Que. participated in the many phases that culminated in the CPF first-of-class shock trial. NETE's involvement in this trial goes back as far as 1982 when an invitation was received to participate in the Royal Navy shock trial of HMS *Beaver*. With this trial and many other trials and tests that followed, NETE gained the experience it needed to offer thorough and efficient support to the CPF shock trial.

From the initial surveys of HMCS *Halifax* during her construction, NETE personnel began to accumulate the wealth of information necessary for the conduct of a trial of this magnitude. Details were gathered and stored on a wide range of subjects, including monitoring point locations, bulkhead penetrations, mounting fixtures, accessibility, cable-run possibilities, space availability, transducer mounting methods and more.

Information and experience were also gathered on the types of data recording equipment and philosophies. The digital approach was selected for its flexibility and good frequency range possibility, but the older analogue technology was also included because a substantial amount of that type of equipment was already on hand. The combination allowed NETE to support some 197 channels of digital recording and 72 channels of analogue recording during the trial, for a total of 269 channels.

Different types of transducers were used to monitor the dynamic behaviour of the structure, systems and equipment. All told, there were:

- 139 accelerometers;
- 8 pressure sensors;
- 7 displacement transducers; and
- 13 strain gauges.

The signal generated by each of the transducers was amplified and captured by standalone, single-channel digital recorders. To protect the accelerometers from the severity of the detonation pulse and from the harsh naval environment, a mechanical filter was devised, tested and manufactured for each channel serving an accelerometer. A combination of elastomer and seismic mass achieved the desired frequency cut-off of the generated signal, while an aluminum housing and cover protected the assembly from the environment.

To monitor the behaviour of some 102 selected electrical circuits, isolation amplification and attenuation boxes were devised and manufactured. These boxes permitted recording the high-voltage signals on instruments capable only of recording signals in the order of 10 volts. Thirty of the 197 digital recording channels and all 72 analogue channels were used for this effort. The recorders were installed either singly or in pairs in a resiliently mounted frame inside a protective container.

Once an installation and test plan had been devised, the corresponding charts and drawings were issued and the necessary fixtures and instrumentation cables were manufactured, assembled and tested. An instrumentation headquarters (IHQ) was designed and manufactured, initially to house all instrumentation during the trial, but to simplify the cable routings into the helicopter hanger only a small portion of the recorders and cables ended up in the IHQ. The IHQ provided a command and control centre for shock data acquisition, processing and interpretation.

Using the standalone characteristics of the digital recorders, recording stations were established throughout the ship. Each station contained enough digital recorders to serve the immediate area around the station. In addition to the digital recorders, some stations were equipped with tape recorders for monitoring selected electrical circuits. All of the stations were connected to the IHQ, from which they received a time pulse for synchronization.

A charge firing system devised from an American design was used to set off the explosive charges. A further modification rendered it automatic under the control of a desktop computer. The capacitor banks used to store the energy for the detonations were charged using this system. The analogue tape recorders and high-speed cameras would be started and the charge would be automatically detonated at T=0. The last two minutes of the countdown could be stopped at any time up to T-1 second should an emergency occur. — **by Marcel Baribeau, senior NETE project engineer, and CPF shock trial instrumentation team leader.**

Inside and out: This special-purpose, fully cabled instrumentation HQ trailer was shock-mounted in the frigate's hangar. ***(CFB Halifax photos by Cpl. R. Duguay)***

• Project Manager Canadian Patrol Frigate Project;

• Director General Maritime Engineering and Maintenance;

• Director General Force Development;

• Maritime Command/New Equipment Trials;

• Director Naval Requirements;

• Director Maritime Engineering and Support;

• Director Marine and Electrical Engineering;

• Director Maritime Combat Systems;

• the commanding officer of HMCS *Halifax*; and

• the master of the Canadian Forces Auxiliary Vessel *Riverton*.

The board reinforced that since the trial was a Category III event, the CPF project management office (PMO) would lead the trial effort as a DND activity, with the assistance of many other agencies. A full-time trial director was assigned and the CPF shock trial project was initiated. A "matrix" type trial management team was set up, consisting of 20 full-time members and eventually involving 22 DND agencies, Public Works and Government Services Canada, and three other government departments. More than 100 people would be involved in supporting the trial directly (full- and part-time), not counting ships' crews and aircrews. Trial development work included the production of the "CPF Shock Trial Executive Plan" (also known as the "Trial Charter") which was approved by PM CPF on April 11, 1994. This document formalized the trial organizations, responsibilities, milestones and resources, and would prove essential in keeping everyone focused on the trial objectives of:

• evaluating the operational capabilities of the *Halifax* class against underwater shock in accordance with NATO Standing Naval Agreement 4137;

• initiating the engineering change actions required to ensure the patrol frigates meet essential operational capability at full design shock load; and

• obtaining information to reduce critical equipment down-time.

The Charter also committed to conducting the trial no later than the fall of 1994. Not only would the required combined maritime support units be available in late summer/fall 1994, but the environmental and other public stakeholders had indicated that they were prepared to support a fall 1994 trial. Beyond that point both the availability of the maritime units and the support of the stakeholders were uncertain.

General Preparations

Concurrent with the formulation of the Charter, development activities included preparing a dozen support plans and a large number of test sheets. The support plans were essential, and covered off:

• risk assessment;

• combat testing;

• marine, electrical and ship testing;

• hull testing;

• instrumentation and shock analysis;

• charge handling deployment and firing;

• shock hardening;

• compartment safety inspections;

• training and safety;

• public affairs;

• environmental protection; and

• operations orders (approved by the Commander of Maritime Forces Atlantic).

In addition, teams had to procure special trial equipment and inert ordnance, conduct extensive training (totalling several weeks at sea) for three ships' crews, implement additional hardening precautions in *Halifax* and *Riverton*, and offload 40 tonnes of surplus stores (enough to fill three trailers). They also had to conduct compartment safety inspections, install and set-to-work the instrumentation and charge firing circuit, install and test the charge handling structure (the A-frame) on board *Riverton*, and conduct supportive baseline tests such as noise ranging, vibration analysis, weapon alignment tests, and more.

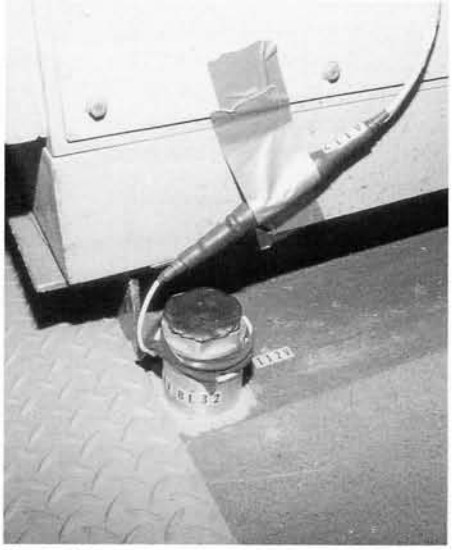
Charge Deployment Considerations

The essence of a shock trial is the underwater explosion, which is usually quantified in terms of the keel shock factor (KSF). The KSF represents the vertical load imposed on the keel, and is a function of charge size and placement geometry. The design KSF for a given class of warship is prescribed in the technical specifications. For safety reasons, however, the KSF imposed during a trial is only a fraction of the design figure, yet sufficiently powerful to provide a basis for evaluation to full design KSF.

To accurately control both the charge placement geometry and the detonation itself (see "Charge Handling Operations for the CPF Shock Trial" by Irek Kotecki), and as a primary safety issue, a "bridle" arrangement was used. The operations support vessel CFAV *Riverton* towed the target ship sideways at about one knot (to keep tension on the lines), with the charge suspended from a float at a specified distance between the ships. Adapting this method for the CPF trial required considerable seamanship and technical effort, including two set-to-work exercises at sea with the two ships.

In all, *Halifax* was subjected to three detonations of increasing magnitude at two-day intervals across five days. The last shot produced the prescribed trial KSF. The two preliminary shots were useful in assessing the risk for each subsequent shot. All three detonations contributed toward proving the effectiveness of both the equipment and the trial management process, and to generating useful shock loading and ship response data.

HMCS *Halifax* passes lines to *Riverton* in preparation for a shot. The charge float is visible on the A-frame, but the charge itself has already been armed and lowered to depth. *(CFB Halifax photo by MCpl M. Ray)*



One of the many accelerometers fixed throughout HMCS *Halifax* to capture data during the shock trial. *(CFB Halifax photo by Cpl. R. Duguay)*

Instrumentation Considerations

When a shock load travels through a ship it affects similar items of equipment or structure in different ways, depending on their location and installation. The local load and response spectra for *Halifax* were recorded at numerous locations via an array of more than 300 sensors (strain gauges and accelerometers), multiple recorders, computers and thousands of feet of cabling to three instrumentation headquarters (one of them a special-purpose trailer that was shock-mounted in the hangar). In addition, pressure transducers were slung over the ship's side at various depths to record the incoming shock wavefront data, and high-speed cameras were installed at various locations to capture details of the ship's dynamic response to the blasts. A full photo/video plan was also implemented, by which photographers were positioned on board the target ship, the charge deployment vessel and in one of the helicopters to capture a complete record of the trial for future training and analysis.

Environmental and Public Affairs Considerations

The environmental and public affairs considerations for the CPF shock trial were heavily interrelated. They consumed more than 25 percent of trial resources and had a significant impact on the trial management plans. By early 1994 the trial had become the subject of public inquiry, newspaper articles, news items on radio and TV, and letters from individuals and groups concerned with the environmental and fishery issues. Because of the requirement to explain the trial with any attendant risks, a communication plan was prepared for most aspects of the trial. An experienced DND Public Affairs officer was assigned to the project to manage all direct contacts with the public.

The trial site itself had to meet numerous operational and environmental requirements. For example, it had to be close enough to shore in case of technical or medical emergencies, but far enough away from the continental shelf and Gulf Stream to avoid potential areas of sea life concentration. The site that was eventually selected was located almost 300 km south of Halifax, and about 65 km from the predicted location of the Gulf Stream. The depth of water at the site was 4,000 metres. For Shot 3, a five-kilometre safety zone and a 10-kilometre observation radius were centred on the site so that the charge would not be detonated if marine life were detected within or approaching the safety range. The trial fleet was equipped with sonobuoys, infra-red cameras and other sophisticated technology to assist in detection.

The shock trial was also of value to the Geological Survey of Canada by providing a sound source, recorded from Halifax, N.S. to Rimouski, Que. by an array of 201 seismic recorders, to study the structure of the earth's crust in that region. To synchronize detonation times with the seismic recorders, a global positioning system was connected to the detonation circuit.

On the advice of the Director of Environmental Protection, two public consultations were hosted in Halifax in the four months prior to the trial by the deputy project manager of the CPF Project in co-operation with the departments of Fisheries and Oceans and Environment Canada. DND discussed its trial management plans openly, and as a result the consultations were very constructive. The sessions significantly contributed toward finalizing the trial site selection, the survey requirements, the environmental contingency plans and the trial environmental resources (see Susan Pecman's Greenspace feature, "Environmental Assessment of the HMCS *Halifax* Shock Trial").

Without question the public consultations and follow-up correspondence were a major factor in obtaining the necessary environmental clearances and general public support. A detailed environmental protection plan was eventually approved by PM CPF in September 1994.

Trial Implementation

Implementation of the trial itself began with the approval of operation orders by the Commander of Maritime Forces Atlantic, RAdm G.L. Garnett in October 1994. The trial was implemented by MARLANT/NET, consistent with any at-sea CPF Category III trial.

The captain, officers and crew of HMCS *Halifax* did an outstanding job of preparing their ship for the trial. Nevertheless, there were a few "real world" limitations. The propulsion diesel engine was not operational, No. 4 diesel-generator was down, and No. 3 had difficulty holding load. Both the forward and after

This bow-mounted high-speed camera was one of several used to capture details of the ship's dynamic response to the detonations. *(CFB Halifax photo by Cpl. R. Duguay)*

Equipment Health Monitoring and Vibration Analysis

An underwater shock can affect equipment even when it is resiliently mounted. If the shock is severe enough, the transmitted force can affect the alignment of coupled equipment, bend motor and pump shafts and damage bearings. Since such types of damage will most likely result in increased vibration of the affected components, it can be tracked by vibration analysis (VA), a standard technique in naval equipment health monitoring (EHM). Although vibration analysis is normally used as a non-intrusive health monitoring tool and as an aid to predictive maintenance, it also offers the ability to track equipment performance during special trials using test equipment and trained personnel already in place on Canadian naval ships.

As part of the instrumentation plan for the CPF shock trial, DSE 5 specified that a complete vibration survey of auxiliary equipment be conducted. Since the *Halifax* class had not yet had a vibration baseline established, vibration levels for each piece of equipment covered by the normal VA program were measured prior to the trial. After each shot, another survey was conducted and levels were once again recorded. The result was a series of four vibration measurements for each point: pre-trial and following shots 1, 2 and 3. By comparing these measurements it was possible to track the vibration at each point and determine if and when any change occurred.

Measurements were taken using the Beta Monitors DataTrap, a portable data logger that is issued to each ship for conducting VA surveys as part of its EHM program. Although the main gearbox is fitted with an on-line vibration monitoring system as part of the IMCS integrated machinery control system, it was decided to take manual measurements as well, using the DataTrap to confirm these readings. Immediately following the shock trial the data was reviewed by DSE 5 to identify any changes. Very few problems were noted, and these were confined to pieces of equipment which had already been identified during the extensive post-trial inspections.

These vibration surveys were important from several points of view. First, they confirmed that the mounting arrangement of auxiliary equipment is generally effective in isolating the equipment from the effects of underwater shock. Second, they established a comprehensive vibration baseline that could be used later during the ship's regular EHM inspections. And finally, by comparing the pre-trial equipment health baseline to corresponding post-trial values, the trial staff was able to confidently assert that damage to auxiliary equipment arising from the trial was negligible. — **Mike Belcher, DMSS VA program authority for naval equipment health monitoring; responsible for acquiring and analyzing shock trial equipment vibration measurements.**

Final preparations: All is just about in readiness. ***(CFB Halifax photo)***

electrical switchboards would have to be fed from the forward diesel-generator sets, as opposed to normal action stations practice. The inertial navigation systems were also acting up prior to entering the trial. Since the effects of these arisings on trial validity and safety were deemed minor, and that the consequences of trial delay would be significant, it was decided to proceed with Shots 1 and 2 before investigating the inertial navigation systems.

Thus, on Nov. 10, after a one-week delay due to bad weather, a full dress rehearsal was attempted. Unfortunately the ends of the bridles were accidentally let go from *Halifax*, leaving the armoured firing cable to take up the towing strain. The cable parted at its intended safety breakaway joint, but still caused quite a surprise and some damage to the A-frame and charge float on *Riverton*. Undaunted, the trial team and the crews of *Halifax* and *Riverton* quickly made the necessary repairs and refined the seamanship and communication procedures.

With good weather in the forecast, the trial was then ready to be conducted. The trial fleet consisted of:

- HMCS *Halifax* (target and trial conduct ship);
- CFAV *Riverton* (operations and charge handling vessel; Fleet Diving Unit explosives experts embarked);
- HMCS *Preserver* (electronic warfare target and support ship; media representatives embarked);
- CP-140 Aurora long-range patrol aircraft (aerial and acoustic underwater surveillance, environmental HQ, and aerial target; biologists and Fisheries and Oceans reps embarked);
- CH-124A Sea King helicopter (to assist the Aurora);
- CH-124A Sea King helicopter (media aircraft); and
- HMCS *Moresby* (surface-led environmental surveys; marine biologists embarked).

All units were carrying full complements and some trial staff. Naval observers from the United Kingdom, Australia and the United States were also embarked in *Halifax* during the shots.

Shot 1

At 12:20 p.m. on Nov. 14 the trial fleet was in position, in sea state 2. Environmental clearance had been obtained. Personnel were cleared from No. 3 deck and below. Action stations were piped and damage control condition Zulu Bravo was assumed for a 30-minute

A Combat Systems Perspective

The CPF shock trial allowed a close examination of the combat system capabilities and operations at the ship level. In this regard the trial was unique because of the added element of actual trial effects. It is normally not typical to exercise a ship's entire combat system in such a meticulous manner during peacetime operations. The added realism of "action effects" simply is not present during regular exercises on weapon ranges, and only single aspects of the combat suite are normally undergoing trial at any one time. The naval shock trial thus has to be considered a vital component of warship combat capability validation.

The combat portions of the *Halifax* shock trial were conducted by PMO CPF in accordance with specific engineering test plans developed by individual DGMEM combat system OPIs. Preparations, including a complete combat system alignment, began six months prior to the shock trial. In the month leading up to the trial the six-monthly maintenance procedures were completed on all combat equipment. Among the many special tests conducted to establish baseline data before the event, electromagnetic impulse tests were made on the tracking and scanning radars so that any radiation changes monitored during and after the trial could be assessed.

To examine equipment functional response during the trial, data recording for the combat suite consisted of various built-in and external recording systems, including:

- history recording of the entire command and control system;
- data logging of the STIR gunfire-control system;
- recording and reduction of missile launch controller data;
- parameter analysis and storage system (PASS) data collection of the close-in weapon system tracking an air target; and
- video/audio recording of the fire-control radar operator screens and weapon control communication circuit.

Underwater shock loading on equipment was measured using accelerometers located in various positions, with video and high-speed cine coverage of various areas including the operations room. The video recordings of ops room deliberations immediately following each shot offer a very descriptive record of the combat system response to each shock load and to its performance afterward. It was also possible to study crew response and corrective actions in a chronological manner.

The combat suite was operated similarly for each of the three shots. Typically, surface and air targets were tracked before, during and after each shot. Simulated firing and launching (with specific data recording) continued until the shot. Following each shot, the ship attempted simulated engagements of the various targets using each combat system.

Shortly after the first shot, the tracking engagement was broken, the systems were reset and the threats reacquired for another engagement run. The VLS and CIWS were designated to the Aurora aircraft (scheduled to close from astern at T-45 seconds), while the 57-mm gun and Harpoon were designated to the surface target, the supply ship HMCS *Preserver*. The four weapon systems were engaged without problem, and all other combat systems functioned properly. Live ammunition was never involved.

Although equipment problems with both inertial navigation systems (INS) prior to Shot 2 prevented a complete combat system performance assessment, no physical damage to combat system equipment was attributed to the detonation. Prior to Shot 3 the ship returned to port to effect repairs to both INS units.

The third and most severe shot produced an unexpected combat suite response – a power interruption that temporarily disrupted the operation of the command and control system. Investigation showed the power interruption to be the result of a combination of an abnormal configuration on the power distribution system and a loose bolt in a power panel. No physical damage was sustained, and full capability was demonstrated at sea on the return transit.

After many years of preparation, the *Halifax* shock trial fulfilled the contractual requirement to prove the ship's capability in a combat environment. The trial provided a situation where all elements of the combat suite could function simultaneously and be subjected to external stresses. Individual system tests had been conducted during the test and trial programs conducted by the contractor, and during in-service operations by the navy, but at no time had the entire suite been on-line for engineering purposes.

Beyond the shock trial data, valuable information was gathered on the interdependencies and operation of the suite. Since the trial, several studies have been initiated to improve combat system survivability under damaged-ship conditions.— **J. Podrebarac, DMSS OPI for various naval gun systems; DMCS onboard shock trial observer.**

Cdr Dave Sweeney, CO *Halifax*, waiting for the whales to clear the area prior to Shot 1. *(CFB Halifax photo by Cpl. R. Duguay)*

An aerial view of the charge deployment vessel CFAV *Riverton* and HMCS *Halifax* as Shot 2 is detonated. Post-shot deliberations concluded it was safe to proceed to Shot 3. *(CFB Halifax photo)*

countdown. At 12:25 two sperm whales and a pod of pilot whales were detected 5,300 metres from the charge location. Although this was more than three times the safe distance required for Shot 1, the detonation was delayed as an extra measure of caution. Eventually the whales moved to beyond 8,000 metres and the countdown resumed, ending in a misfire at 2:30 p.m. due to a faulty relay in the firing unit. A fix was quickly implemented and, finally, there was a successful detonation at 2:42 p.m.

Within milliseconds the shock wave hit the ship with the force predicted and without incident. Ship and trial staff immediately initiated investigations, lasting well into the next day, and concluded that it was safe to proceed to Shot 2. The Aurora aircraft and *Moresby* conducted post-shot environmental surveys for two days and found no apparent environmental damage. The media went ashore on Nov. 15, and returned only for Shot 3.

Trial Director LCdr Garon, FDUA explosives safety officer PO2 Adams and squadron rep PO2 Deschamps at the bridge firing position prior to Shot 1. That's a comm button in LCdr Garon's hand, not the firing switch. *(CFB Halifax photo by Cpl. R. Duguay)*

Shot 2

Shot 2 followed a similar drill, but without the interruptions. The charge, a little closer this time, was detonated at 1:08 p.m. on Nov. 16. Again there was no incident, and post-shot deliberations concluded it was safe to proceed to Shot 3. Shortly after the shot, *Halifax* returned to the dockyard for repairs to the inertial navigation systems and for a combat system alignment test. Thanks to outstanding support by the dockyard, the ship was back on site in short order.

Shot 3

Dawn, Nov. 18. Recent storms had shifted the Gulf Stream, and now the trial fleet was in the middle of a warm eddy 40 kilometres across. There was concern that the warm eddy would attract marine life. Fortunately, the marine animals that did show up "respected" our environmental protection plan and very kindly remained at the edge of the eddy, far enough away to be safe.

We were ready to proceed with Shot 3. RAdm Garnett was on board the target ship. The media was back. Tension was high.

At 12:05 p.m., in perfect weather, Shot 3 was detonated.

As predicted, a very sharp and noisy impulse traversed the entire ship. It felt like being in a car hitting a bump at high speed and with no suspension. Given the design, preparation and training, nobody was injured. Within seconds the sea began to bubble, the upwelling giving us a beautiful show. The detonation caused a few problems which were quickly corrected by ship's staff (see the next section). The Geological Survey of Canada was able to obtain exceptionally high-quality seismic records for the location. Surveys conducted for three days following the shot and later indicated there was no lasting impact on the environment. On Nov. 18 and 19 a number of trial staff were interviewed by the media, and we think we left them satisfied that the navy had acted responsibly, and that the trial results were within expectations.

On her way home on the evening of Shot 3, *Halifax* conducted a full-power trial and verified that all systems were fully functional. A few weeks following the shot, live firings were conducted without problem with the CIWS and 57-mm Bofors. The underwater hull and structural tanks were also inspected and given a clean bill of health.

Post-Trial Close-Out

Within hours of Shot 3 being detonated the weather turned foul and stayed inclement for weeks (making us glad that we had stuck to our deadlines). In the days, weeks and months that followed, the trial technical data was carefully evaluated. The focus was on essential operational capabilities following an underwater shock for a typical CPF ship at action stations in intact condition (e.g. both switchboards unitized and fed by their respective diesel-generators). Due consideration was given to the CPF's particular equipment design and procedures. There was also a mandate to provide conclusions and recommendations which were consistent with the trial objectives, well-documented, cost-effective and timely.

The evaluation has taken about a year to complete and has indicated the need for some minor hardening, but no major redesign. It also highlighted areas for potential shock and survivability improvement in hardware, software and procedures. Most importantly, the trial showed that the patrol frigates have superb shock resistance - probably the best in the world for this type of ship.

Other close-out items included an environmental compliance report, a public affairs follow-up, a trial management training package and a "lessons learned" video (not yet complete). The CPF shock trial project was effectively closed Nov. 30, 1995, the trial senior review board having agreed on the conclusions and recommendations, including the disposition of the remaining trial actions (a few investigations, minor engineering changes and "lessons learned" reports). The PMO CPF shock trial team was disbanded on Jan. 10, 1996.

Conclusions

The CPF shock trial project was an outstanding success. It met its objectives without incident, and within resources, schedule, environmental guidelines and other constraints. It also clearly demonstrated the shock hardiness of the CPF and highlighted areas for survivability improvement, many of which have already been implemented.

The CPF shock trial required an immense and complex management effort. It was effective because clear operational objectives were maintained right through to the final disposition, there was well-defined trial direction, quality materiel, dedicated and competent personnel, full commitment on the part of senior management, and a proactive approach regarding environmental and public affairs.

Shot 3: The big one. This series of photos taken from one of the helicopters shows the effects of the initial shock wave reaching the surface (*top*), the formation of the plume (*centre*), and the formation of a three-metre surface wave. (*CFB Halifax photos*)

Finally, this fast-paced, very exciting and challenging operation captured the interest of Canadian and international audiences. It established a good spirit of cooperation with the public and other government departments, and is now looked upon as a model for other DND projects. Media coverage was well balanced and positive. The foreign observers indicated that they were impressed by the very effective management of the trial, the high standards of the crew, and the shock resistance of the *Halifax* class. It

Free-floating seaweed churned up by the explosion rests on the surface after Shot 3. ***(CFB Halifax photo by Cpl. C. Stephenson)***

was a fitting acknowledgment of an outstanding team effort.

Acknowledgments

The author wishes to express gratitude to Commodore F.W. Gibson (DGMEPM), Captain(N) M. Kling (D Force S) and Captain(N) J.R. Sylvester (PM CPF) for the satisfying challenge of directing the CPF shock trial for two years, and to the members of the trial team for their dedication and support. Special consideration is extended to Cdr Peter Hoes and LCdr Paul Hendry (both of MARLANT/NET), and to Cdr Dave Sweeney (CO *Halifax*) for their dynamic team spirit and for a home away from home. Particular thanks are offered to the following colleagues and friends for their invaluable assistance during the preparation of this paper: Mr Derry Oke (DPM CPF and fellow naval architect), Cdr Fred Jardine (CPF/Ship), and Lt(N) Dave Spagnolo (deputy shock trial director).

Naval Architect LCdr Garon was the CPF shock trial director during the final two years of the trial's development, implementation, evaluation and close-out. A HOD-qualified MSE, he is a registered International Project Management Professional and a member of the Royal Institute of Naval Architects, the Canadian Institute of Marine Engineering and the Ordre des ingénieurs du Quebec. LCdr Garon is currently the deputy project manager for the Canadian Forces Joint Space Project.

A close-up of the plume.

The Canadian Patrol Frigate First-of-Class Shock Trial

Article by Jan Czaban

Canadian naval combatants are designed and built to conduct their missions in hostile combat environments. Shock trials provide the means toward learning about potential ship vulnerabilities under peaceful, controlled conditions rather than the hard way. This article is presented from the perspective of the shock design authority element of DGMEPM. As such, it must be noted that this view is but a part of the larger whole.

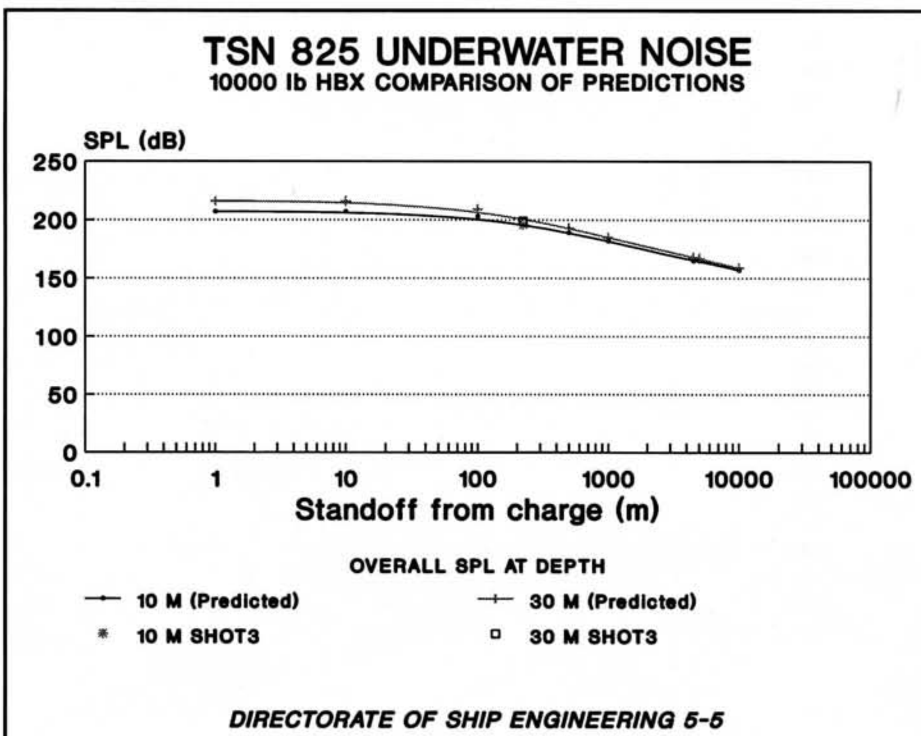
In November 1994 HMCS *Halifax* was realistically tested by a series of underwater explosions as part of the FFH-330 class shock-qualification program. The trial culminated with the detonation of two half-tonne charges and one five-tonne charge of high-explosive HBX at an environmentally approved site south-east of Halifax, Nova Scotia. The ship's performance following each detonation was certainly the best of any previous design tested by Canada, and the trial successfully demonstrated that the FFH-330 class is battle tough and free of serious shock-design defects.

Accomplishing such a complex operation in an environmentally friendly manner under North Atlantic seakeeping conditions was no mean feat. It required professional planning, preparation and perseverance. True to form, the Canadian navy set a new record by completing this arduous three-shot, blue-water trial in five days.

Shock trials are routinely conducted by navies to assess how well ships can withstand the effects of underwater explosions. Such trials are true examples of total-ship-survivability studies under a live-fire scenario. Through a methodical examination of underwater explosion effects on a ship's performance while engaged in a realistic combat scenario, it is possible to determine specific vulnerabilities which may have been introduced either by design, workmanship, wear-out or inadequate maintenance. Short of actual combat, shock trials are the only way to test how well a new class of ship might be expected to survive in battle.

If nothing else, the type of damage to ship systems and equipment uncovered by previous naval shock trials has taught us that we can't afford *not* to shock test ships. The ability to satisfactorily pass a shock trial is a NATO requirement and is routinely incorporated into shipbuilding contract requirements. Although vessel survivability is an important responsibility of everyone involved with warship design, it is the Directorate of Maritime Ship Support at NDHQ that maintains the navy's centre of expertise for ship survivability. DMSS 2-5 maintains the professional skills, tools and procedures necessary for ensuring a ship's design incorporates adequate protection features against detection and the harmful effects of everything from ballistic damage to air blast and shock. The section also verifies the effectiveness of a ship's protective features through the use of simulation testing.

Given the rigorous procedures used to isolate and correct shock defects, ships that have successfully completed a shock qualification program and at-sea shock trials can expect to experience fewer surprise equipment failures during action. While the small explosive scare charges used in sea-training exercises to simulate underwater explosions inevitably get people's attention, their effects are comparatively localized. Shock trials provide a similar function at a complete ship level. Subjecting a ship to such tests provides many collateral benefits. The "kicks" given the ship and equipment by underwater explosions are not unlike the shock-load effects a ship experiences from a nuclear air blast, or from direct missile or projectile strikes. Equipment and structure tough enough to resist the underwater shock will likely survive other weapon effects better than non-shock-qualified items. Studies have shown significant savings in through-life

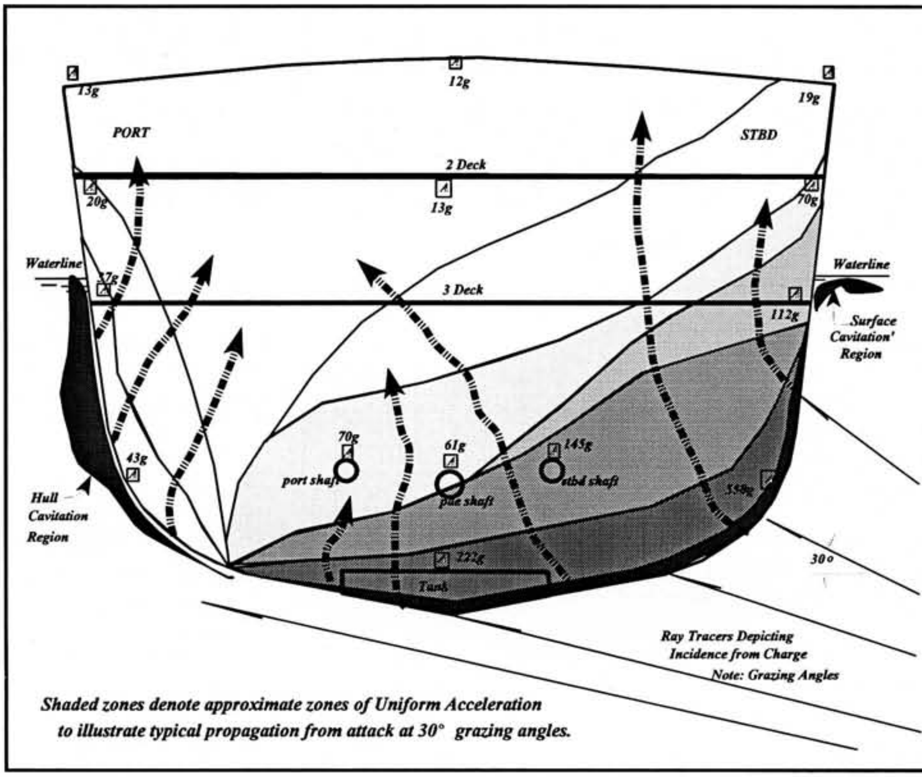


Predicted pressures (hence, shock factors) for Shot 3 were achieved by the tests as shown in this plot format used to predict underwater noise levels to avoid injury to marine mammals. The plot shows expected sound pressure level (SPL) in the trial area. The plots show that the actual sound pressure levels agreed precisely with predictions. This correlation helped confirm that the sea mammal exclusion zones were correctly specified.

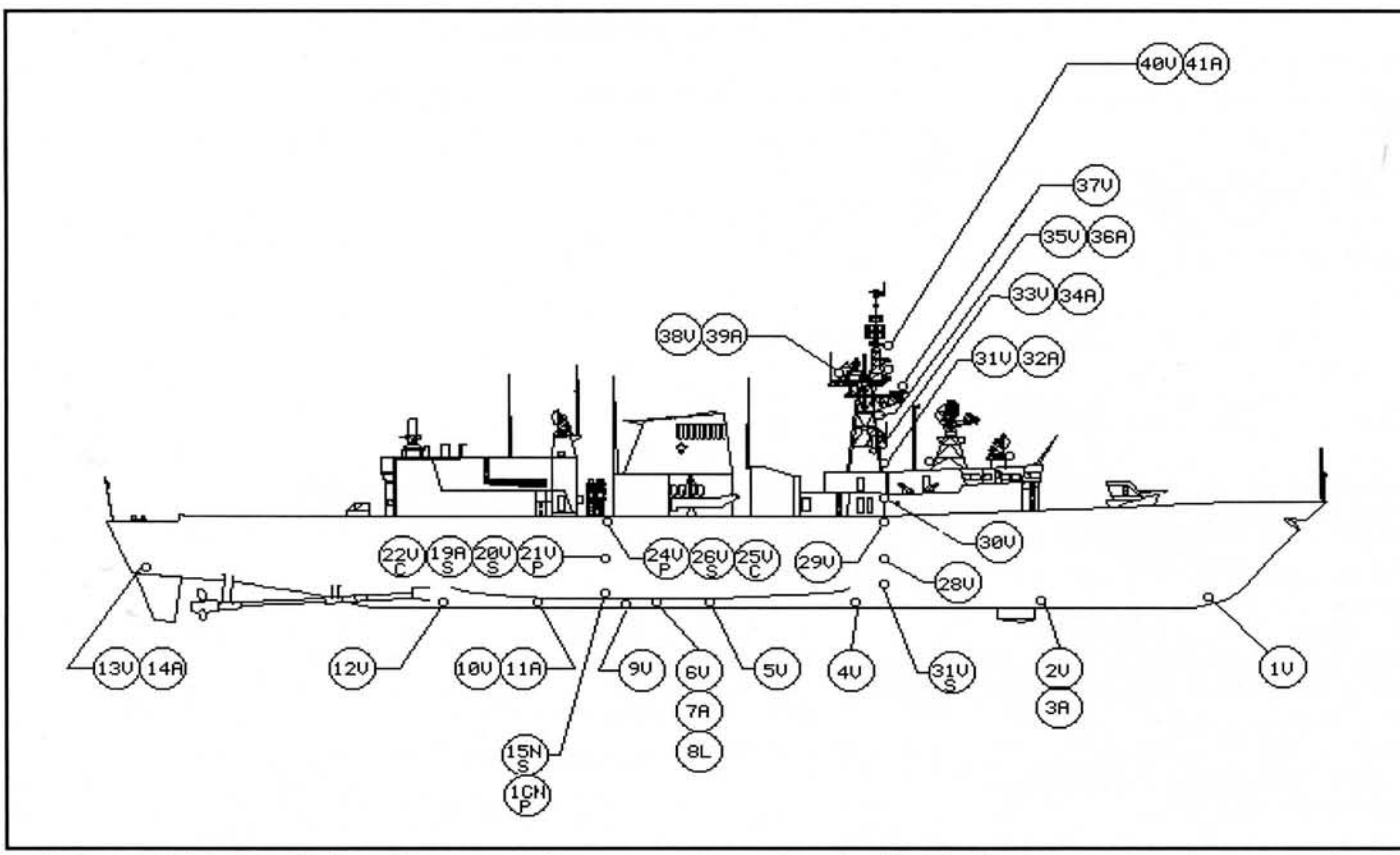
maintenance costs with equipment which has benefited from shock hardening.

In addition to proving combat survivability, the *Halifax* trial allowed a realistic study of crew response and recovery procedures following a near-miss underwater explosion. Although ship staff performed effectively by systematically attacking difficult electrical diagnosis problems and rapidly isolating and securing all anomalies, attention was focused on the need to better integrate maintenance activity with operations following action damage. The point was clearly made that trouble-shooting during action is considerably different from trouble-shooting during peacetime operations. (System restorations were artificially delayed to capture data, but this notwithstanding, many valuable lessons were learned.)

The Canadian shock specification requires that all equipment affecting combat capability or ship safety be designated Grade 1 and shock qualified. All Grade 1 equipment on the CPF was qualified to withstand test levels greater than those planned for this trial. While serious physical equipment damage was neither expected nor sustained, weaknesses in com-



In this example of a shock propagation study, peak acceleration levels are shown to illustrate how the shock environment varies across a transverse section of the ship. Such studies allow definition of shock zones and assessment of design and test criteria for specifications.



In all, about 180 digital monitoring points were used to measure structural acceleration, displacement, strain and pressure on board HMCS *Halifax* during the shock trial. An additional 100 electrical power monitoring positions, 500 static-g gauges, 600 EHM/VA points, along with numerous high-speed films, videos and other devices were used to capture shock response data. Note the placement of structural gauges to measure the shock environment along the keel and the propagation of the shock up through the hull and into the mast.

"(I was) more than impressed by the professional dedicated attitude taken by the trial staff and ship's crew and by the high level of co-operation between these two groups of people, both of whom should be commended for the completion of a successful shock trial." – J.M. Colquhoun, Australian naval observer

ponent assembly and installation cannot be exposed other than by conducting "as-built" full-ship tests. Indeed, the CPF trial located power interruptions and other transient anomalies in equipment that had performed well during laboratory tests.

By studying trial results, the naval shock design authority aims to improve class combat survivability and implement better standards for future classes. Ideally, such trials are conducted early in a class program to allow corrective action in follow-on ships. In the case of the CPF, however, the shock qualification and management programs were so comprehensive that little damage was expected to result from the trial. Instead, the trial aptly demonstrated areas that warrant attention due to in-service wear, maintenance effects and operational configurations on the shock resistance of installations.

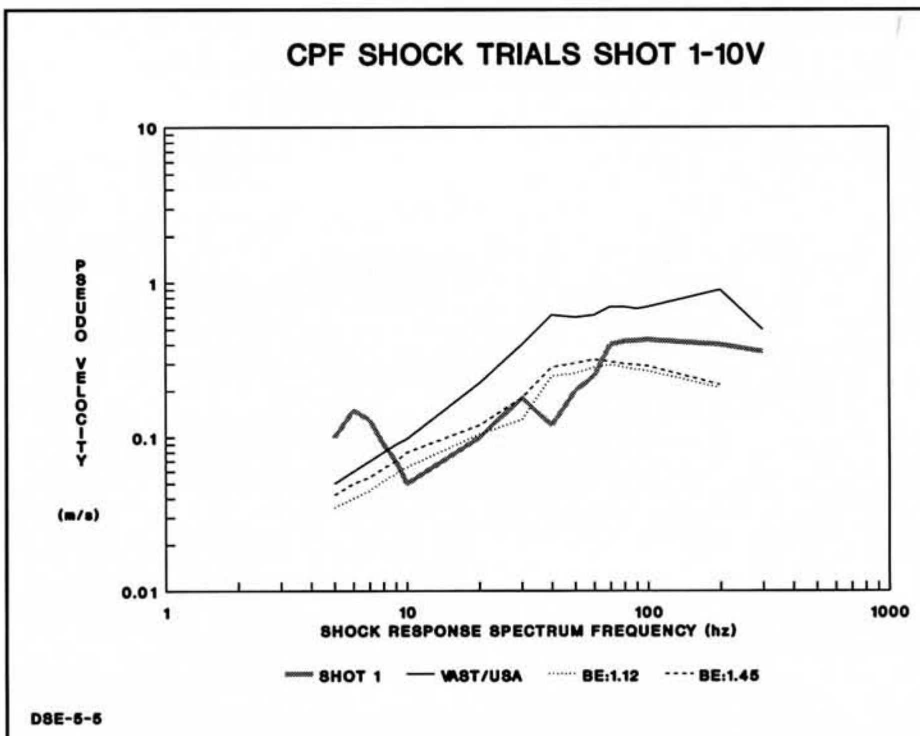
The History

The FFH-330 shock trial was the final and most complex leadship trial of the CPF program. It was the fifth, but by far the most comprehensive shock trial ever conducted by the Canadian navy. In the early 1960s the DGMEPM Ship Survivability section (then DMFR 2) arranged to shock test a wooden-hulled minesweeper at the USN West Coast shock-test facilities near San Diego. Although the trial was somewhat more severe than that required for the CPF and created a variety of power disruptions, the vessel was not damaged. In the mid-sixties DMFR shock-tested the destroyer escorts *Chaudiere* and *St. Croix*, again using the USN facilities. *St. Croix* was exposed to test levels twice those used for the CPF and experienced power losses, combat capability degradation and extensive dishing of hull panels. After that it was nearly 15 years until the first-of-class shock trial was conducted on HMCS *Iroquois* (DDH-280), this time using all-Canadian facilities. The *Iroquois* test levels were similar to those for the CPF, but were achieved using smaller charges. *Iroquois* experienced a variety of power and combat system disruptions which were subsequently corrected during the recent TRUMP conversion.

In 1982 the naval shock design authority (now DMSS 2-5) began preparations for the FFH-330 shock trial. Potential design solutions (e.g. all-welded piping systems, improved power distribution and redundancy, etc.) had been engineered into the CPF design, but remained to be proven for battle. Although demonstration of shock compliance was within the contractual obligation placed on Saint John Shipbuilding Limited (SJSL), the resources and expertise needed to conduct such a trial were beyond commercial capability. It fell to the navy to provide the crew, targets, charges, operations vessel and data acquisition systems for the trial.

The technical support for previous shock trials, including charge design, fabrication, deployment, instrumentation and data reduction had been provided by the Defence Research organizations. Such support was no longer available, so resources needed to be developed for the CPF. Numerous special investigation projects were developed by the shock design authority to allow the Naval Engineering Test Establishment (NETE) to acquire pertinent fielding capability for a shock trial. During this period, participation in Royal Navy and U.S. Navy shock trials (under the auspices of an international exchange program) allowed the development of a new digital data acquisition system in conjunction with Ballistech Systems Inc. (now ATS Inc.) of St.-Hubert, Que. Extensive field tests conducted alongside systems used by other navies proved the Canadian system to be second to none. Through collaboration with the USN's underwater explosion research division, a capable charge-deployment and firing system was developed. This system was adapted for use on board CFAV *Riverton*, which was converted into an operations vessel for the trial. The explosive charges themselves were procured from the USN.

A shock trial committee established early in 1985 included members from SJSL, the Directorate of Ship Engineering, PMO CPF QAM (quality assurance section) and other expert members of the CPF survivability working group. By 1992 the group had developed the shock-test geometry and produced a shock trial



Good correlation between measured shock response spectra and predictions obtained using the DSE UNDEX codes instilled confidence in modelling activity and confirmed validity of analyses conducted under other shock loading conditions.

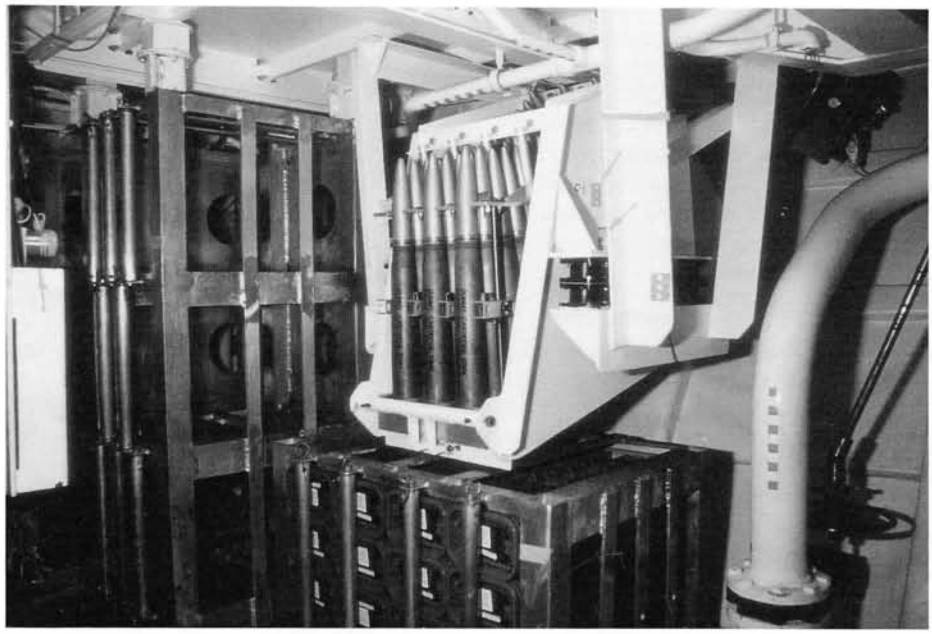
test plan based largely on USN procedures. A complete trial organization was established by PMO CPF in 1993 to bring the trial entirely under naval direction. Intense planning and preparations were then initiated. DGMEM matrix co-ordination within the PMO shock trial team was managed by the shock design authority. Using the earlier shock-trial documents for guidance, new and more comprehensive test plans covering combat systems, marine and electrical systems, the hull system, instrumentation and charge deployment were developed by the matrix and provided to the PMO CPF trial director in early 1994. The plans outlined exact system operational requirements and procedures for monitoring system performance and shock effects, and included data tables for ship staff to complete. The completed documents, which would include detailed shock casualty reports and system performance readings, were designed to form stand-alone shock trial reports.

Although the ship was groomed for the trial, it must be noted that she had seen four years of heavy service by that point. Being a lead ship, *Halifax* had undergone a strenuous pre- and post-commissioning trial program. Numerous surveys were conducted to define additional ship hardening requirements and to prepare for the trial. In most cases, only improved supports and stowage, and securing or removing non-essential stores were required to prepare the ship. In several instances, however, the trial pinpointed inadequately secured internal circuit modules and unsecured objects in power distribution panels. (You can never tighten too many bolts when preparing for battle.)

The Risk Assessment

A formal risk analysis assessed the significance of all aspects of the trial on ship safety, probability of damage, failure modes and the feasibility of all operations, including charge deployment and trial execution. As predicted, it was found that:

- there was no risk of breaching the hull of either the target ship or the charge-handling vessel;
- the danger to personnel was minimal;
- the risk of damage to equipment and systems was minimal given that the CPF shock-qualification control program had certified all Grade 1 equipment (nearly 1,100 item designs);
- the risk of damage to ship structures and foundations was minimal given the extensive structural qualification analysis conducted by the program; and
- there was minimal environmental risk given the procedures for conduct in accordance with an approved environmental protection plan.



Some of the instrumentation details are visible in this view of the 57-mm ready use racks. Note the static-g gauges to the right of the inert shells. These simple "drop and tell" gauges are easy to use, but rather limited in detail. Note also the aluminum housings for the piezo-resistive accelerometers fitted above the light-coloured fixture on the left of the photo. *(NETE photo by George Csukly)*

The risk assessment was supported by extensive computational simulation and analysis conducted to predict the shock response for major ship and combat systems. This was in addition to what was already submitted under CPF shock qualification program data deliverables. The studies, conducted recently by DMSS 2 using UNDEX (underwater explosion) code procedures, proved accurate during the RN/USN trials, and in experiments at NETE's temporary floating shock test platform facility near Bedford, Que. The studies looked at the hull girder, grillage, mast, shafting and other major equipment.

The UNDEX codes use VAST finite element analysis procedures developed by Defence Research Establishment Atlantic and Martec Ltd. of Halifax. Shock loading is accomplished using a number of inputs, including the underwater shock analysis and cavitation fluid analyzer codes developed by Lockheed, an equivalent beam procedure based on techniques originally developed by Dr. Hicks of Defence Research Agency, Dunfermline, Scotland, the dynamic design analysis method procedures used by the USN, the Canadian naval standard shock specifications, and computational fluid dynamics models developed by Combustion Dynamics in Medicine Hat.

Two finite element models of the CPF structure were used. One was adapted from the SJSL/MSEI Maestro model used during the CPF program to prove structural integrity. The other was a detailed model developed in co-operation with DREA. Additional detailed modelling of the shafting and appendages was completed by Martec under a technical investigation and engineering support (TIES)

"(I was) impressed by the relative calmness of the ship's crew under such circumstances....The environmental concerns relating to the trial were handled in a very open and pragmatic manner...the officer responsible discussed all aspects and public concerns in a most efficient and satisfactory manner." – Lindsay Morris, U.K. naval observer

contract. The ship's response to each of the shock trial test geometries was calculated and studied to determine potential areas of concern. The ship's response to a full design shock load was also predicted and studied. Particular attention was given to the shock response expected from ship locations which were fitted with instrumentation.

The shock trial data from instrumented locations obtained for each of the three shots was compared to the code predictions. The trial data confirmed that the models accurately represented the hull girders, ship structure and mass distribution throughout the vessel. Assessment of the ship's ability to withstand full design shock loads can henceforth be safely estimated. The Canadian naval UNDEX codes proved more than capable for these applications and promise great utility for future design purposes.

The Trials

Essential preparations prior to the trial called for ship-level baseline tests and inspections involving drydocking, acoustic ranging, weapon alignment and grooming. PMO/CPF staff included the trial director, two MARE staff liaison officers and three non-commissioned members responsible for seamanship, photography and documentation control. Maritime Command New Equipment Trials (MARCOM/NET) was represented and provided fleet co-ordination and trial control functions. The DGMEM onboard trials team comprised 16 members:

- the shock design authority;
- the operations engineer;
- the electrical power design authority;
- a combat system design authority;
- the survivability and equipment health analysis engineer;
- from NETE, a senior test engineer, an instrumentation technician and a camera specialist;
- two quality control and data processing contractors; and
- six observers (four from foreign navies and two from SJSL).

Each team member (including the observers) contributed specific expertise and performed necessary inspection or operational functions.

On the day of each shot, additional baseline checks were conducted and all equipment was set to operate at a full-alert condition with the combat system tracking and engaging targets. Certain combat system simulations were also conducted. Immediately following each shot the combat system was exercised to

Veterans of numerous personnel vulnerability investigations, mannequins such as this one in *Halifax*'s operations room were fitted with triaxial accelerometers to measure shock response. The gauge on the deck below the seat monitored the shock input. *(NETE photo by George Csukly)*

the fullest extent possible. Following a brief period to conduct safety checks and inspections, the ship successfully completed an arduous series of full power trials.

In short, no noteworthy cases of physical damage arose during the three-shot test series. Electrical power was generally maintained and all automated functions performed as required. The equipment health monitoring/vibration analysis diagnosis found essentially no evidence of equipment degradation. Hull inspections found no need for structural repair other than to retighten a few fasteners.

There was no degradation of combat capability for Shots 1 and 2. For Shot 3, however, ship-level assessments allowed analysis of electrical power problems attributed to non-shock related pre-existing problems with two of the four diesel-generator sets. These led to very interesting insights into combat system performance under damaged ship conditions. As a result, significant battle survivability improvements have been made through simple modifications to command and control system controller configurations.

Ship systems, including propulsion, electrical power and machinery control maintained adequate capability throughout all tests. The ship was able to assume full power trials and support all electrical and auxiliary functions immediately following each test.

The Lessons

It is a commendable demonstration of their combat capability that in-service ships actually complete shock trials. In hindsight, shock testing a "slightly used" rather than an "as new" vessel proved to

The Tough Ship

HMCS *Halifax* (and therefore the FFH-330 class) was technically proven to meet the NATO shock requirement. The lead ship's toughness was well demonstrated. Consider the following:

- only nine of more than 10,000 Grade 1 and 2 shock-qualified items malfunctioned, and none failed;
- fewer than 100 of the 500,000 ship components failed;
- only seven of the 100 or so auxiliary motor, pump and fan sets indicated minor increases in EHM vibration levels;
- only four of more than 1,000 circuit breakers tripped;
- fewer than 15 of more than 5,000 pipe joints in five kilometres of piping had minor cracks or leaks;
- only four of 2,500 pipe hangers showed minor deformation;
- fewer than 10 electrical connections in more than 10,000 joints and 30 kilometres of electrical cables were affected;
- there were no failures in the many kilometres of weld throughout ship primary structure, and there were no hull girder, major bulkhead or stiffener weld failures;
- there were no failures in the mast structure;
- there were no deckhouse-to-deck-to-hull structural failures;
- there were no equipment foundation deformations or weld failures;
- no waveguides were damaged.

be of some merit. By studying typical in-service performance rather than a laboratory conditioned response it was possible to identify invaluable maintenance lessons that will prove useful throughout the life of the class.

For a variety of reasons the trial was conducted under conditions which did not allow full use of several ship design features. In particular, electrical power redundancy was severely degraded (due to non-shock related reasons) with only the two forward generators operating at 100 percent for Shot 3. A few major equipment items were also found to have inadequately secured components. But while such conditions are tolerable during peacetime because they normally do not keep a ship from meeting its operational activities, they become unacceptable in a combat environment. Despite the popular impression that redundancy is only intended to facilitate availability, a ship's built-in redundancies are essential for survival in battle. Ensuring that naval ships are indeed fit for combat includes implementing programs to rid operational ships of any so-called minor nuisance items. With such programs in place the CPF design would need little or no further improvement. Had ship systems been factory fresh without wear or maintenance deficiency, awareness of such potential vulnerabilities might not have emerged.

While some minor hardening activities will need follow-up – including replacing gauge line fittings (some of which leaked) with better materials, providing improved securing arrangements for certain boards, fuses and power supplies, and cleaning tank debris (which had been disturbed by the shocks and fouled some filters) – there were no major design defects that warranted attention.

"The trial was well organized, and ship's staff reacted effectively to all arisings. Crew response, from a damage control aspect was timely and effective...The ability to rapidly adjust to the situation at hand was impressive."– John Ferris, SJSL observer

Recovery from the effects of Shot 3 also highlighted the need for additional "pre-planning" as discussed in LCdr Grychowski's Forum article, "Combat System Damage Control" (*MEJ, June 95*). Ships not exposed to combat on a regular basis must have additional effort placed on developing specific drills and procedures for recovering combat capability following action damage.

Acknowledgment

The author wishes to commemorate the contributions of the original two trial directors, Capt(N) Richard Hitesman (Ret.) and Cdr John Ashfield, (Ret.), both of whom passed away during their assignment to the trial.

Jan Czaban joined DGMEM as a special project officer for ship survivability in 1974. Now recognized internationally as a leading authority in naval ship vulnerability reduction, he is a veteran of many full-scale large weapon effect trials against ships. He has been the naval shock design authority since 1981 and was involved in all shock-related aspects of the CPF program. Mr. Czaban presently heads the DGMEPM subsection for ship survivability and signature management.

Charge Handling Operations for the CPF Shock Trial

Article by Irek J. Kotecki, P. Eng.

Introduction

Shock trials conducted against first-of-class naval combatants are complex operations with many engineering and operational challenges. To ensure a safe and successful trial, appropriate engineering expertise must be assembled to conceive and develop contingency procedures which must then be proven under a variety of exhaustive test scenarios. This article describes certain aspects of the CPF shock trial from the perspective of the author, who was responsible for developing many of the engineering details associated with charge handling, arming, deployment and firing. Although the operations were conducted by DND explosives experts, they were made possible through the use of special hardware and procedures developed for this purpose.

Developing and setting-to-work the various equipment used for the trial required the talents of many members of the trial team. While the Canadian hardware for the shock trial was unique, many aspects of the trial benefited from extensive previous collaborations with USN and RN shock authorities under the auspices of international exchange programs. Specifying the design of handling equipment and data collection instrumentation was the task of the DGMEPM shock design authority, strongly supported by the Naval Engineering Test Establishment (NETE), Naval Engineering Unit Atlantic and Ship Repair Unit Atlantic. PMO CPF staff were heavily involved in the training requirements for the charge deployment to ensure the evolution was conducted safely.

Charge Deployment and Firing

The most important engineering challenge of the shock trial was ensuring that the charges were correctly located and successfully fired. The dangers introduced by problems with either of these aspects were significant and warranted careful attention. Incorrect charge placement could cause undue damage and corrupt data acquisition and prediction analyses. A misfire would (and did) create much anxiety for all trial participants.

Normally, two basic methods are used to deploy shock trial test charges. One is a dynamic technique called a "parallel tow," whereby an operations vessel deploys and tows the charge while the trial (target) ship positions herself parallel to the charge at a predetermined stand-off distance. The charge is then fired from the operations vessel, with both ships under way. The other is a static procedure designated the "bridle method" (*Fig. 1*) by which the test charge is deployed from the operations vessel, but is secured by hawsers to the stationary target ship at the correct stand-off. The bridle method is more complex and difficult, but provides better control over charge placement and allows the charge to be fired from the target ship. Following many analyses concerned with the risks and benefits of both procedures, the bridle method was chosen for the CPF shock trial.

The trial called for three shots of increasing severity to be fired to assess the ship's response to shock loading from underwater explosion. Half-tonne charges were used for Shots 1 and 2, while Shot 3 consisted of a five-tonne charge. The nearly round charges had diameters of .75 m and 1.5 m, respectively. The HBX-1 primary explosive material was detonated using a 10-kg pentolite booster, which in turn was ignited by high-energy electrical blasting caps.

Preparations

Safely deploying these charges 300 km out from Halifax in the North Atlantic during November required the design of very special facilities. The auxiliary vessel CFAV *Riverton* was assigned the role of operations vessel responsible for charge deployment. Given her already busy schedule as a trials support ship, the shock trial equipment was designed for rapid installation and removal. The ship's stern was reconfigured and all equipment was pre-fitted and tested in Bedford Basin to prove operability. The equipment was then removed and stored until the shock trial. *Riverton* was fitted with an A-frame and special cradles (*Fig. 2*) designed to secure a float from which the charge would be suspended to the correct depth. A special winch, fairleads and a

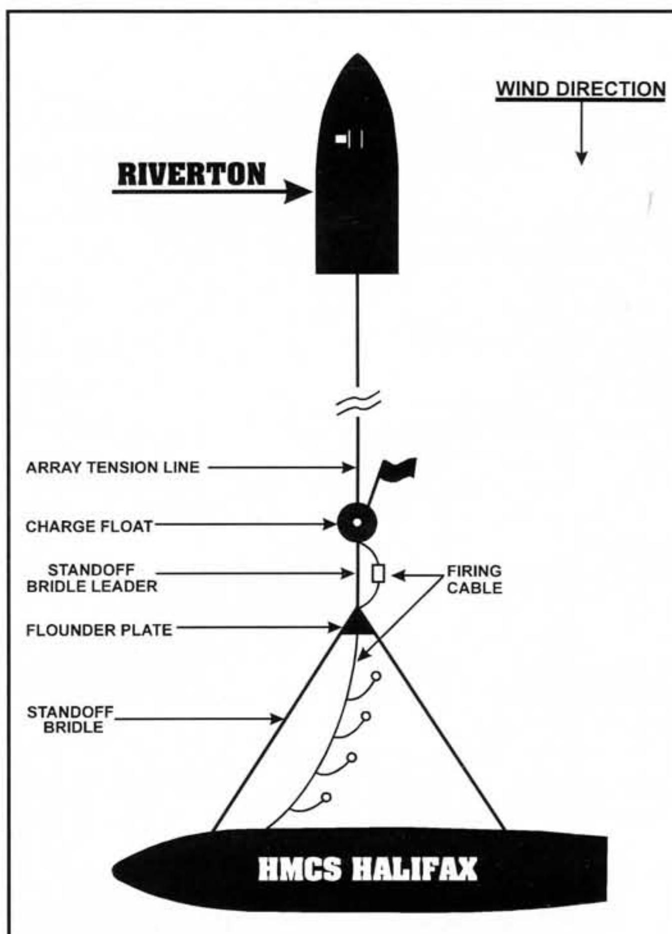


Fig. 1. This bridle arrangement was used to deploy the explosive charges for the FFH-330 first-of-class shock trial. *(Sketch courtesy of PMO CPF)*

working platform for charge arming and deployment were also fitted. The structural fixtures were duly analyzed and proven (as required by the CF Technical Order for lifting appliances).

The charge firing system was also specially designed and exhaustively tested. A series of laboratory tests was conducted at NETE on the prototype system. Field tests were then conducted using 25-kg HBX charges at the NETE underwater explosion facility which briefly operated near Bedford, Que. During trial development, investigations aimed at simplifying the procedure concluded that using non-armoured firing cables would lead to an unreliable firing system due to the extreme loads expected from sea conditions. The final armoured cable system, complete with a "minisafe" instrumentation sequencing system, was tested on board *Riverton*. The firing cable also successfully completed a series of tests that investigated the effects of line and blasting cap impedances. For the trial, the charge firing cable was deployed from the target ship using a special instrumentation grade cable winch. The charge firing module, interfaced to a computer-controlled countdown instrumentation sequencer, was located on *Halifax*'s bridge.

Charge Deployment

For each of the three shots a single charge and float were loaded and secured to the A-frame on board *Riverton* at the CF Ammunition Depot in Bedford Basin. The vessel then rendezvoused with the trial fleet. Once on site and after *Halifax* confirmed all machinery and systems were ready and that the range was clear of environmental concerns, the EOD team armed the booster and inserted it into the main charge. The charge was then lowered into the water using a dedicated winch. The primary firing system cable and demolition charge detonator cord were deployed simultaneously and clamped to the charge support cable. After the charge was lowered to its designated depth, the support cable was clamped to the float and both firing and detonator lines were secured to the float assembly as shown in *Fig. 3*.

HMCS *Halifax* then approached *Riverton* and positioned herself abeam the charge. Lines were passed to *Riverton* to deploy the bridle assembly, including hawsers, flounder plate, leader and firing cable assembly (*Figs. 4 and 5*). As *Halifax* paid out the bridles and firing cable, *Riverton* hauled them in and secured the bridle leader to a pelican hook. The bridle leader was then attached to the float. The firing cable from *Halifax* was connected to the charge firing cable, after which the float was lowered into the water and released. Finally, the bridle assembly (connected to the float hardware) was released from the pelican hook and the towing hawser was streamed.

Charge Firing

The charge firing system was designed to be fired by the target ship's commanding officer from the ship's bridge. In addition, remote acknowledge and abort switching stations were located in the ops room, near the MCR, and at the forward and main instrumentation stations. To arm the bridge firing module, the four remote acknowledge stations needed to confirm all systems were ready. This procedure was conducted during the final ten minutes of the countdown and acknowledged by indicator lights and by voice using the command communication net. Following the order to fire given by the simultaneous engagement of two keyed switches on the bridge, the computer-controlled

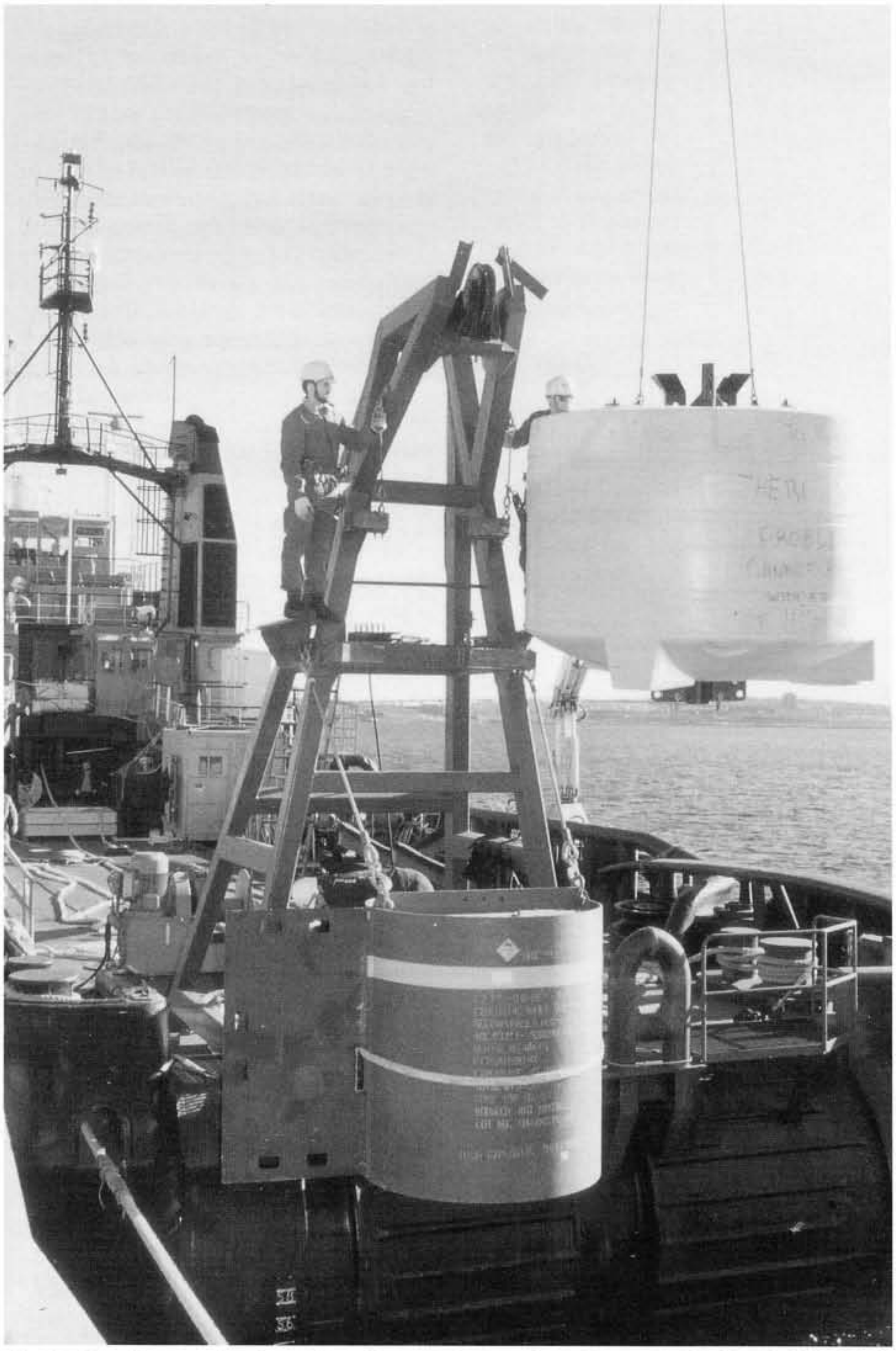


Fig. 2. Handlers at the Canadian Forces Ammunition Depot in Bedford, N.S. load a charge float onto a specially constructed A-frame on board CFAV *Riverton*. (CFB Halifax photo by MCpl M. Ray)

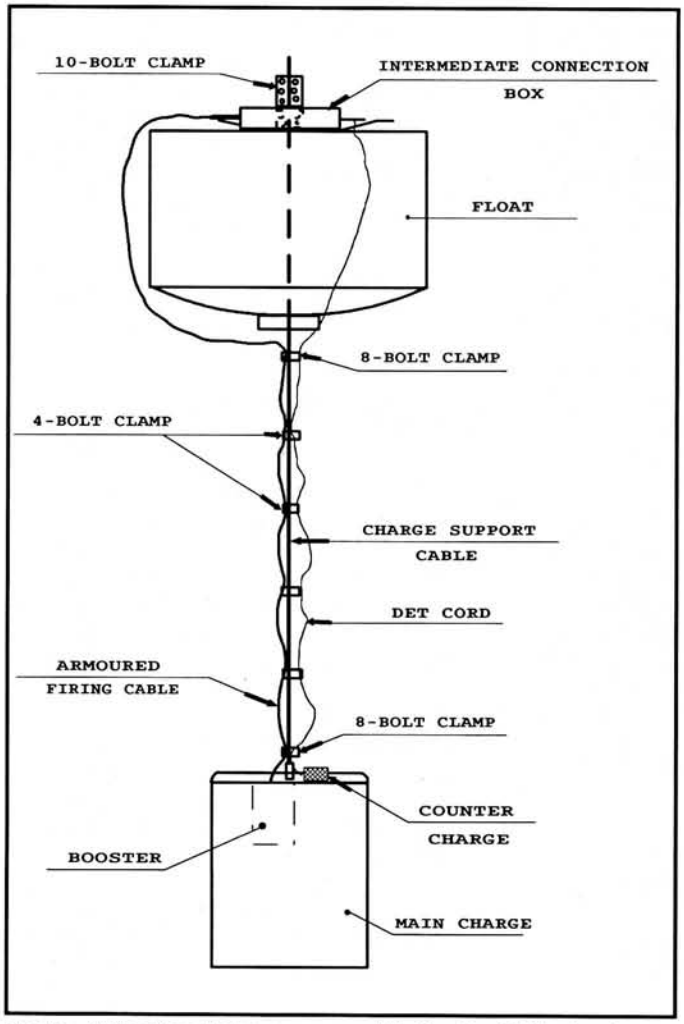


Fig. 3. A float and charge assembly for the CPF shock trial.

firing sequencer initiated a two-minute countdown. This system included a countdown timer in the instrumentation headquarters and a bridge repeater unit which allowed precise synchronization of the two high-speed cameras, tape recorders and several hundred channels of recording instrumentation. It was possible to abort the final countdown and stop detonation anytime during the countdown, either from the bridge or from any of the four remote abort switching stations.

To reduce the likelihood of a misfire, the firing system included two independent firing circuits. The charge firing cable was armoured and able to absorb extreme sea motion induced loads. Firing system continuity was monitored by the instrumentation system at all times. At detonation, interruption of continuity was used to define time zero by the monitoring system. Every component was meticulously checked and tested on board many times. An independent back-up system was also installed in case the primary electrical firing system failed. Had the back-up been required, explosives personnel would have manually ignited a counter charge using conventional detonator cord.

Trial Preparation and Conduct

Preparations for the trial included ship hardening, baseline definitions and crew training. In all cases attention was given to details aimed at reducing the risk associated with undue damage. Ship hardening activities included several surveys of both the target and operations ships. Systems and equipment which required additional hardening, including structural strengthening, hot work, new shock mounts etc., were identified. Given that *Halifax* had undergone a thorough shock qualification control program, the majority of hardening activities involved improving securing arrangements and removing excess stores and personal items.

Special trials and inspections were conducted before the trial to reaffirm the ship's baseline condition. These were re-

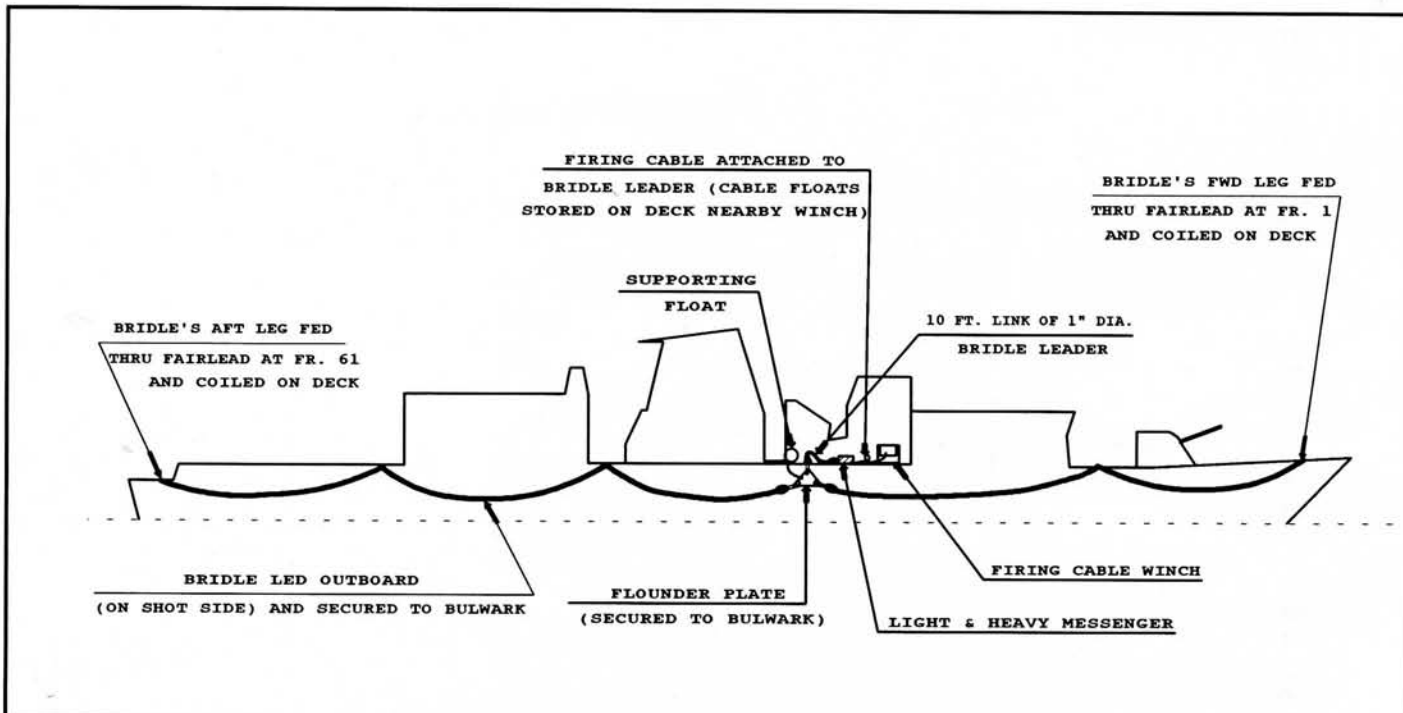


Fig. 4. This is how the bridle assembly and charge-firing cable were stowed on board HMCS *Halifax* prior to deployment.

peated following Shot 3. Ship-level activity included weapon system alignment checks, noise ranging, and infra-red and degaussing trials. Electromagnetic and radiation hazard checks were also conducted, and hull inspections were made using the synchrolift facility. All combat and marine system baseline performance checks were conducted before and after each shot.

The actual trial was conducted in accordance with a series of detailed engineering test plans. The test plans assigned various responsibilities and defined all procedures to be followed for system operation, monitoring and defect recording. The plans were tested at sea and proved suitable prior to the trial. Minor amendments to the procedures were necessary just prior to the trials when several key pieces of machinery (e.g. the propulsion diesel engine) were no longer available.

Logistics

To reduce the potential environmental effects arising from the detonation of such large quantities of high explosive, the trial was moved to a location about 300 km southeast of Halifax. Transit times were in the order of 13 hours and proved close to the endurance limit for shore support. *Riverton* had her charge and float assembly loaded at CFAD Bedford and sailed for the test site approximately 18 hours before the detonation time. *Halifax* was required to conduct a tactical noise ranging and infra-red signature recording on her way out for Shot 1 and hence sailed after nightfall for preferred range conditions. Operational readiness checks were conducted during her transit.

At the test site, a fixed-wing aircraft, a helicopter and two surface vessels acted as targets for *Halifax*'s combat system. The aircraft, one of the vessels and a sonobuoy field were operated in accordance with the requirements outlined by the environmental protection plan. For each shot, *Halifax* was closed-up at action stations in a multithreat environment, tracking targets and battle ready, but configured to preclude live firing. The propulsion plant was on-line with shafts turning at zero thrust.

Following Shot 1, *Riverton* retrieved the charge float and returned to CFAD Bedford for another charge. *Halifax* remained at sea and conducted an extensive series of full power trials and system performance checks. Personnel on board the ship used this time to reduce and analyze the instrumentation data so that the various extrapolations could be prepared for Shot 2. It was concluded that all data were as predicted and no adjustments were necessary.

The second shot was conducted 48 hours after the first. The extra engineering efforts that went into the charge deployment and firing system were successful. The charge and bridle deployment activities went on normally and a successful detonation was staged. Both ships returned to Halifax. The shock data was again reduced and analyzed. Tactical and infra-red rangings were conducted.

Two days later, Shot 3 was conducted under calm sea conditions (*Fig. 6*). After preliminary inspections and system checks, HMCS *Halifax* sailed for home. While in transit, the ship's fighting capa-

Fig. 5. Final preparations: HMCS *Halifax* positions herself across *Riverton*'s stern and passes lines to deploy the bridle assembly. *(CFB Halifax Base Photo)*

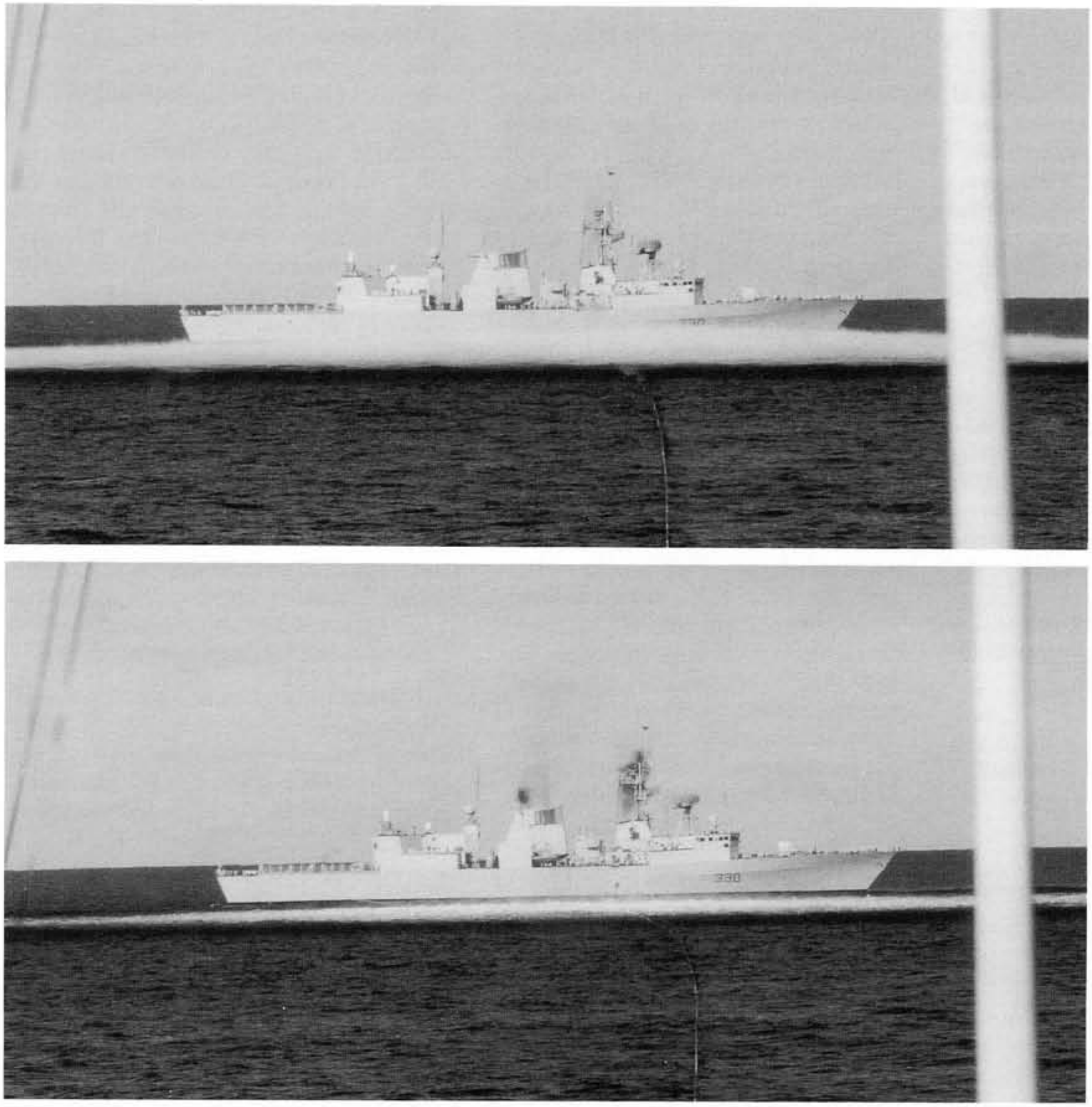


Fig. 6. ***Shot 3:*** **As viewed from *Riverton*, five tonnes of high-explosive were used for the final test in the CPF shock qualification program. The charge geometries were designed to apply uniform keel and hull shock factors along the length of the entire ship. *(CFB Halifax Base Photo)***

bility was assessed and any anomalies found were reported and recorded for further action. This concluded the operational part of the shock trial.

Lessons Learned

The testing and set-to-work proved to be the most important steps for guaranteeing a successful trial. These included a slow-time practice in Bedford Basin, a deep-sea practice, a full evolution involving HMCS *Montreal* and a full dress rehearsal with *Halifax*. The training proved invaluable. The set-to-work exercises allowed improvement of the charge deployment procedures, system debugging and identification of weak points. Certain failure points (both suspected and unexpected) were identified and corrected well ahead of the trial. In addition, the set-to-work improved seamanship and gave the charge deployment and handling team a better understanding of trial requirements and expectations.

Despite such scrupulous preparations, several examples of Murphy's Law were still able to emerge. For example, during the full dress rehearsal a minor electrical fire affected the lighting system for the instrumentation trailers on board *Halifax* while the charge was being deployed. This event was overshadowed later when, because of a communications glitch, the ship's bridles slipped and severed the armoured firing cable. Fortunately, the cable parted at the link designed for this contingency and was easily repaired. The aborted dress rehearsal never got under way again because of the tight trial schedule and deteriorating weather. Later, during Shot 1, an excruciating ten-minute delay was incurred following the initial attempt to fire which failed because of jammed relays. The relays were quickly repaired and from this point the trial was executed flawlessly.

Overall, the trial was a major accomplishment and a big success in many regards. It was the result of excellent engineering, meticulous preparations, professional execution and the dedication of all people involved. The trial objectives were clearly met and valuable lessons were learned.

Acknowledgment

The contributions of the following key personnel in the charge deployment system design implementation are gratefully acknowledged: Captain Pat Richardson (master of CFAV *Riverton)* and his crew; also, the Fleet Diving Unit Atlantic team, especially PO2 Jordan Walsh and PO2 Gordon Jones; and Lt(N) Glen Schjerning, CPO2 Ray Cloutier and CPO2 Rick Anderson from PMO CPF.

Mr. Kotecki was responsible for the engineering aspects of operations as the deputy trial co-ordinator assigned to the shock design authority from 1991 to 1994.