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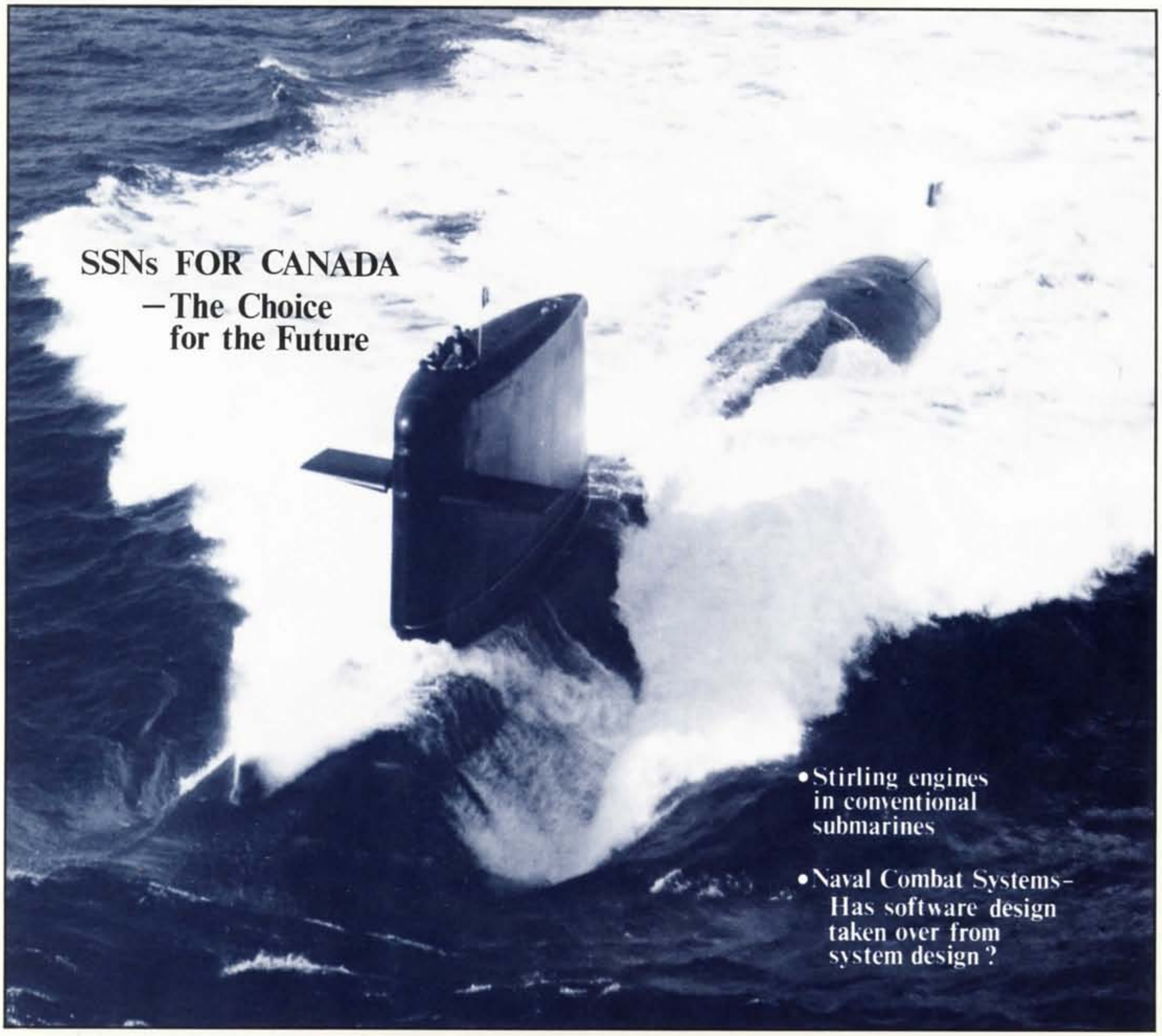
Maritime Engineering Journal

April 1988



Canada

Gloria Jessup

Profile begins on page 27

Maritime Engineering Journal

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DEPARTMENTS

FEATURES

OUR COVER

A Rubis class SSN of the French navy

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Editor's Notes

The success of the *Maritime Engineering Journal* can be attributed to a handful of volunteers who willingly contribute their skills and personal time to ensure our journal maintains a professional standard that is reflective of the MARE classification. DMEE, as the appointed editor, has the responsibility to maintain or improve this high standard. All events and issues that impact on the MARE classification should be presented in the *Journal*, and it is the editor's responsibility to ensure that controversial issues receive a proper and balanced treatment. The bulk of the submitted *Journal* articles are technical, and reflect those technologies or projects with which most of us identify. Seldom does the *Journal* receive articles that deal with personnel, training, promotion or other non-technical issues. Perhaps with a renewed emphasis being placed on MARE training, the time is right for junior MAREs to put pen to paper and tell us how they see these issues impacting on their futures.

The future of the navy and the MARE classification has never been brighter. The White Paper offers the navy the challenge and opportunity of a lifetime. The opportunity to procure modern frigates and nuclear submarines during the same time frame will task us all to the limits of our training, experience, initiative and personal commitments to excellence during these exciting, but demanding times. Even now MARE training is being reviewed to ensure we are achieving the best possible MARE within the available training time. Junior MAREs will be posted to a host of organizations and projects in support of both the White Paper initiatives and the existing fleet. Opportunities for expanded employment and postgraduate training are steadily increasing and now offer career options that were not possible only ten years ago. The variety of postgraduate courses is impressive and certainly challenges the ambitions and capabilities of all MAREs who wish to apply for such training. The increased scope of MARE postgraduate training is a direct reflection of our changing and complex technologies. The addition of the MBA and RAM courses will certainly bring new skills to our major capital projects in the coming years. Where we will be ten years from now is anyone's guess. It is a safe assumption that career options and opportunities for MAREs will continue to rise as we meet and master the White Paper commitments. The *Journal* will try to remain current with all the new changes and hopefully will be in an ideal position to report all those activities that will impact on all of us.

Captain(N) Baxter was posted to PMO CASAP in January, just as this issue of the Journal *was entering the late stages of production. The editorial staff wishes him all the best in his new posting.*

Letters

We received two pieces of correspondence concerning our January issue. The first was the following note addressed to DGMEM:

I congratulate you on a very excellent bilingual journal. This publication is a credit to your and my organization.

E.J. Healey
Assistant Deputy Minister
of Materiel

. . . and the second was from Don Nicholson, whose retirement from the public service we covered in last issue's News Briefs:

Many thanks for the copies of the January issue. I passed one to Commodore MacGillivray, who was Deputy Engineer-in-Chief at the time the Y-100 machinery was developed. He is now 82 and was most interested in that issue — he knew the officers in the photo of the Naval Board on P.35!

*I am hoping that he can fill in some of the blanks in my own recollections of the Y-100 era.**

Cheers,
Don

**Plans are afoot for Don to write an article on the development of the Y-100 machinery plant.*

Commodore's Corner

By Commodore M.T. Saker

With the ink barely dry on the contract to acquire six more CPFs, this column provides a good opportunity to pause and reflect on the CPF Project and the influence it and other current projects have had on the MARE community.

Over the past few years I have often heard comments and complaints from some members of our naval engineering community lamenting the passing of direct naval control and involvement in the design and construction of our warships. There is a perception amongst some that the assumption by industry of greater control and responsibility of our projects — be it the CPF, TRUMP or CASAP — has somehow reduced our engineering responsibility and involvement. I do not accept this perception, nor do I think should you. On the contrary, I believe our challenge is not less but greater than it has ever been before.

To understand the current situation, one must have some vision of what it was like back in "the good old days". I first arrived in what we know today as DGMEM in the summer of 1971 as a junior lieutenant commander. At that time the navy was just commencing the set-to-work and trials of the long-awaited DDH-280 Class and winding up the introductory phase of the two new AORs on the east coast. It seemed as though everyone in DGMEM was totally occupied with the 280s, and that was probably not far from the truth. A great deal of the engineering support for the steamers had to be done on the coasts and we had cancelled all SHIPALTS for the ISL Class and were beginning to think in terms of phasing them out as we anticipated more new ship programs to follow. It certainly was an exciting time. But there was no doubt about it — DGMEM was almost totally absorbed in supporting that one major program.

Today we are four and a half years into the implementation phase of the twelve-ship CPF Project, two years into the TRUMP Project, and on the brink of launching the submarine project and the procurement of minor war vessels for the naval reserves. In addition, numerous other equipment projects fostered by DGMEM are in various stages of implementation in our new ship programs: SHINPADS; SHINMACS; SHINCOM; CANTASS; Message Handling Systems; Reverse Osmosis and Desalinization; and the DDH-280 cruise engine change-out, to name some of the larger ones. We are accomplishing all of these projects with only a marginal increase in departmental personnel over what we had back in the early '70s. The only way we could achieve this was to change our approach to managing these projects by passing more responsibility to industry. So now we are doing more with basically the same in-house resources; but what does that mean to the average engineer or technician working in the Department today? In general terms it means that each individual is responsible for obtaining more equipment, possessing greater capabilities and involving greater sums of money than ever before. The DDH-280 Project cost about $260M in the early '70s (about four times that amount in today's dollars — say $1 billion), whereas the combined value of CPF and TRUMP in today's dollars is about $10 billion. That represents a ten-fold increase, and of course it does not include the current planning for the multibillion-dollar nuclear submarine program or the minor war vessels. Some order book! Some responsibility! Some challenge! Some fun! (Sorry Winston.)

The challenge for today's naval engineers is not much different from what it used to be, that is to manage these projects through acquisition and into the in-service phase. This involves the same type of project and contract management activities that we performed in the "good old days", only now we are doing it on a wider basis, for more ships and for more complex systems. We are still dealing with contractors (only now we deal more with prime contractors, not with systems vendors); we are still reviewing drawings and documentation to satisfy ourselves that they meet our requirements; we are still making important decisions on the design and construction of our ships; and we are still intimately involved in the trials and acceptance activities. In addition, to make best use of the newer and more capable ships, we are putting a new generation of support systems in place that will involve our engineers as well — new training centres, software support systems and computer-based configuration management systems, to name a few. For the first time in my career I can see an assured future for our navy, and the engineering responsibility and challenge that goes with a stable shipbuilding and modernization program. For the next ten years at least, we have more to do than we have ever had to do before. Let's get on with it.

Commodore Saker is the project manager of the Canadian Patrol Frigate Project.

Nuclear-Propelled Submarines for Canada

The Choice for the Future

By Capt. Simon MacDowall

Of all the policies set out in the recent White Paper on defence, perhaps the most exciting, and certainly the most controversial, has been the decision by the Canadian government to purchase a fleet of nuclear-propelled submarines (SSNs). It is intended in this article to look at this decision, examining the rationale behind it, discussing a few of the concerns expressed by some members of the public and to try to get a feel for what the SSN acquisition will mean to the sailors of our navy.

A Three Ocean Navy

When most people think of the oceans that surround Canada, the Pacific and Atlantic easily come to mind, yet a vast amount of our territory is in fact bounded by the Arctic Ocean, a rich vital area, the importance of which is, perhaps, only just being realized. Therefore, when looking at how best to develop the fleet of the future that will defend our maritime interests, the reality of Canada's three oceans must be reflected in the mix of ships and aircraft that are employed to do the job.

Over the past two decades, with the development of nuclear propulsion, the Arctic has become an operating area for submarines. Deep channels through the Canadian Arctic offer a means of passing between the Pacific and Atlantic oceans. In a period of war or tension, enemy submarines, hiding under the ice in the Canadian Arctic would pose a severe threat to shipping. It is vitally important, therefore, that the Canadian navy be capable of determining what is happening under the ice in the Canadian Arctic and to deter hostile or potentially hostile intrusions.

At present, the Canadian navy cannot carry out, in the Arctic, these roles essential to our security and sovereignty. To correct this and other shortfalls in our maritime defences, the Government has embarked on a vigorous naval modernization program. The goal is greater flexibility, a more appropriate balance among air, surface and underwater assets and the reorientation of Canadian naval forces towards effective operations in the Atlantic, the Pacific and the Arctic oceans.

A New Submarine — SSN or SSK?

Submarines are essential to meet current, and evolving, long-range ocean surveillance and control requirements in all three oceans. They are a vital part of the mix of forces required to counter the threat posed by enemy submarines. Our present fleet of submarines, all based on the Atlantic coast, was purchased in the 1960s and is nearing the end of its design life. Clearly a modern replacement is in order, the question is, will a conventional submarine (SSK) do the job?

To answer this question we have to look at the major differences between an SSN, which is a submarine utilizing energy produced by a nuclear reactor for propulsion, and an SSK, which is a submarine that stores electricity, usually produced by diesel generators, in batteries and uses that electricity for propulsion. Of course the differences are many and varied but some of the more important can be clearly seen. In contrast to an SSK, the SSN can maintain higher speeds for long periods without giving its position away. It can, therefore, reach its operational patrol area faster and stay there longer. The SSN can also shift rapidly from one area to another to meet changing circumstances.

Essentially an SSK is a vehicle of position which must remain in place for any given operation. It has only a limited ca-

The Rubis *class submarine "Saphir" of the French Navy off the coast of Nova Scotia. This is one of the contenders for the Canadian submarine replacement. (IHC87-028-5 by Cpl Denise Ménard).*

pability to make long rapid transits in response to changing situations. Additionally, since an SSK has to use its snorkel regularly to "breathe", it is generally not capable of operating in areas of ice. SSNs, on the other hand, are vehicles of manoeuvre. Their speed, underwater endurance and relative invulnerability, provide much greater operating flexibility. Furthermore, only SSNs are capable of travelling under the Polar Ice Cap, through the Northwest Passage and into the Arctic Basin. Given the vast distances in the three ocean areas in which Canada requires maritime forces and the SSN's unlimited endurance and flexibility, the Government has decided to acquire a fleet of nuclear-propelled submarines as the most cost-effective way to enhance the overall effectiveness of the Canadian navy.

A Safe Bet

Nuclear-propelled submarines are safe. To some people, however, they conjure up images of mushroom clouds and Chernobyl-like disasters. With the announcement by the Canadian government of its intention to build a fleet of 10 to 12 nuclear-propelled submarines (SSN), some of these fears have risen to the surface (so to speak!). Such worries are, however, unfounded and result from a faulty understanding of the subject.

Nuclear propulsion with a conventional role

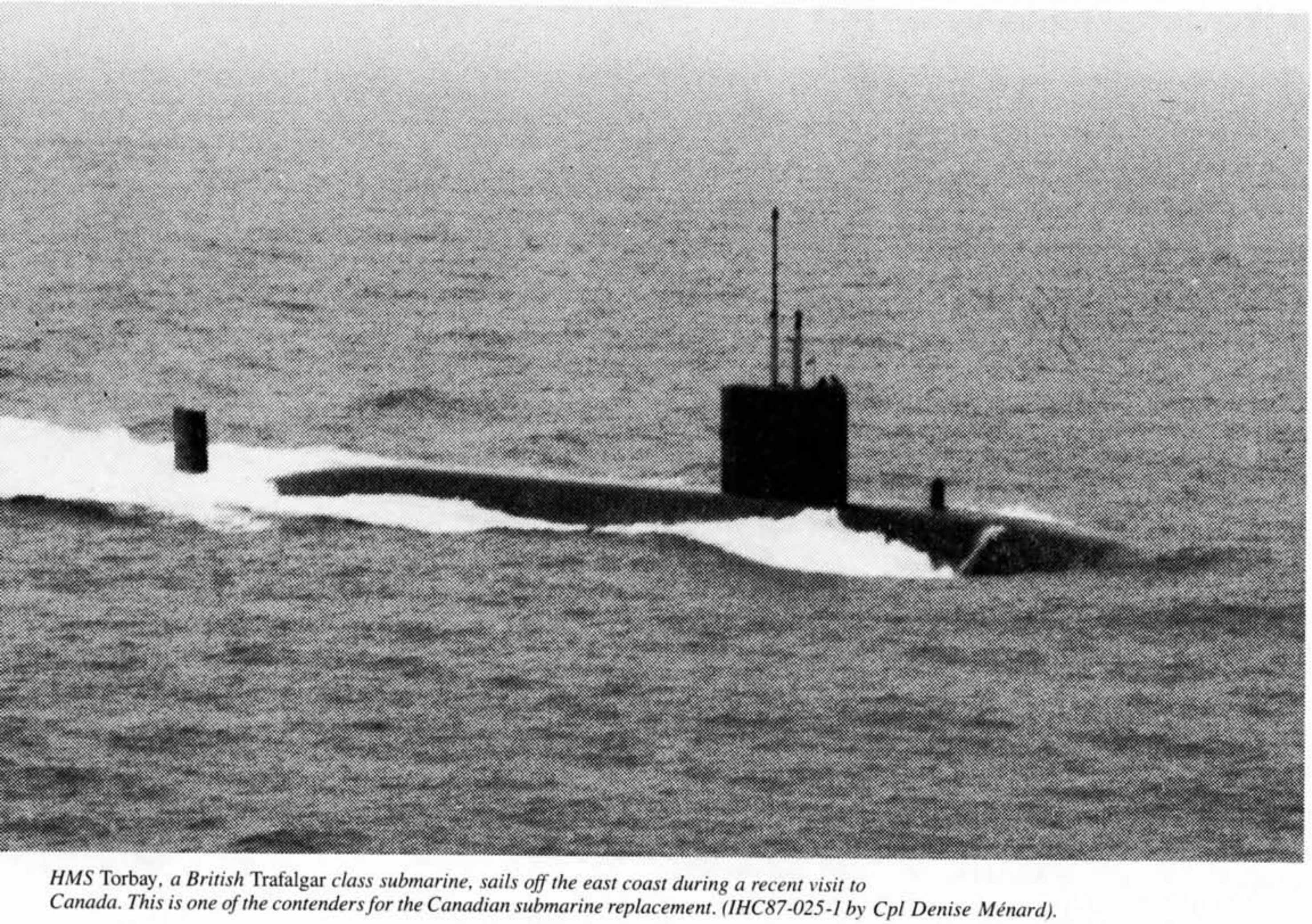
First of all, an SSN is a submarine that is propelled by nuclear energy rather than a submarine that carries nuclear weapons. Canadian SSNs will carry conventional torpedoes and anti-ship missiles and will be employed in a role similar to our existing diesel-electric submarines. To all intents and purposes an SSN is a conventional submarine with a conventional role, the only thing nuclear about it is its propulsion system. This allows it to remain under water indefinitely and to move faster and less vulnerably than its diesel-electric counterpart. It is also the only system that allows a vessel to operate year-round in the Arctic.

Unjustified fears

There are still some concerns voiced about possible danger from the reactor used to propel the submarine. These fears are equally groundless. In the 34-year history of nuclear propulsion in the US, British and French navies, there has not been a single accident resulting in a radioactive release.

Naval reactors are much smaller and lower in power rating than commercial plants. They also operate at lower power levels. Thus the average radioactivity potentially available for release is less than one-hundredth of that of a typical commercial reactor. The boat is also sitting in an unlimited amount of sea water which, if necessary, can be used to prevent the reactor from overheating and being damaged.

The safety of our sailors is a matter of paramount concern. Naval reactors are built to stringent requirements to withstand battle shock and ensure crew safety. The fuel is of such high integrity it can withstand over ten times more dynamic shock



HMS Torbay, *a British* Trafalgar *class submarine, sails off the east coast during a recent visit to Canada. This is one of the contenders for the Canadian submarine replacement. (IHC87-025-1 by Cpl Denise Ménard).*

than commercial fuel and remain undamaged. It is also designed to sustain rapid changes of temperature and pressure experienced as the boat manoeuvres.

Proven record

The low power of naval reactors and the requirement to design a system that can survive wartime attack makes for a very safe system, as attested by the 3,200 reactor-years without accident in the combined UK, French and US nuclear-propulsion programs.

The decision, by Canada, to purchase SSNs marks no departure from previous policy. The decision is based on a modern SSN being the most cost-effective vessel for countering enemy submarines in conjunction with our other naval assets. It is a safe, proven system that will take our navy into the next millenium.

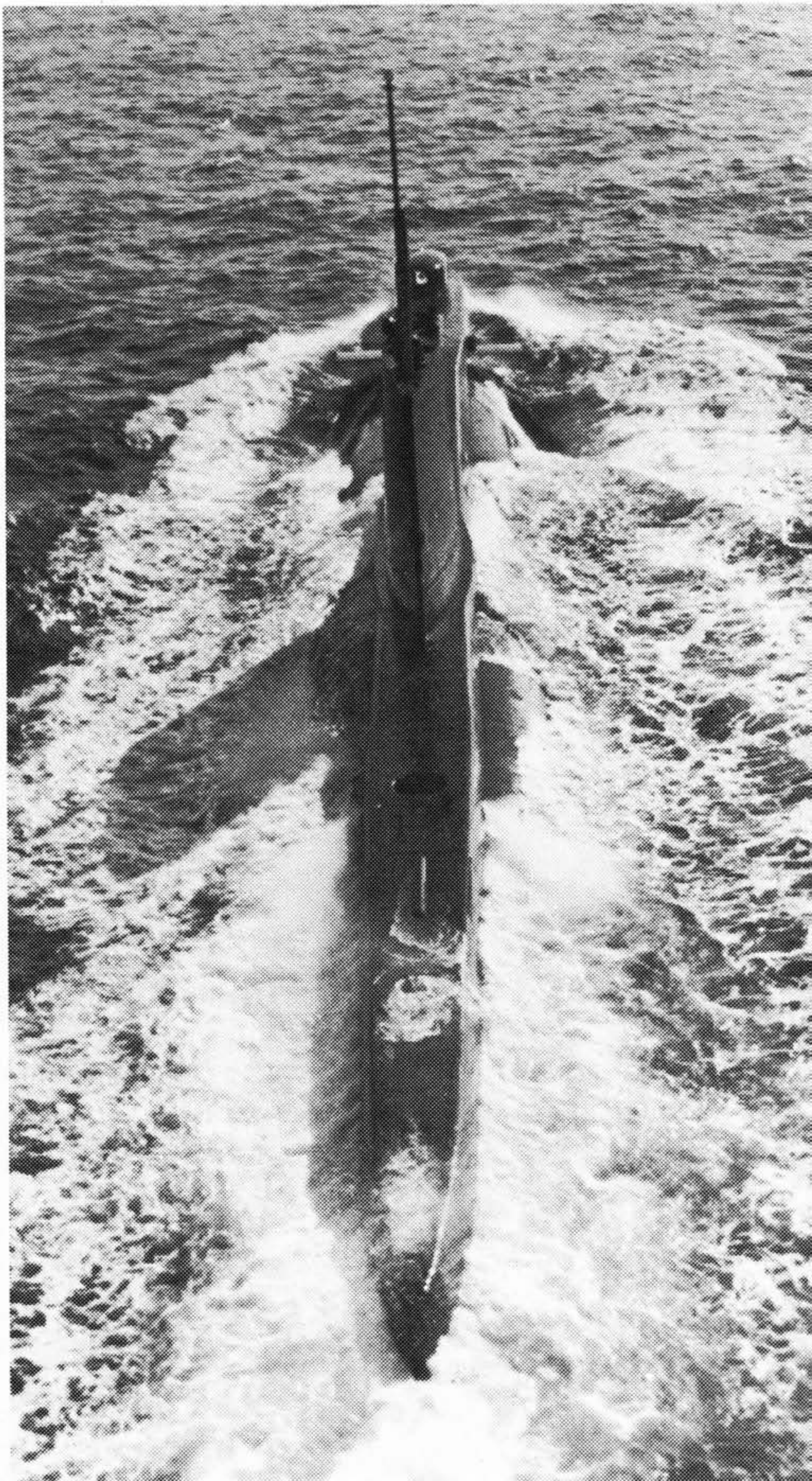
What Will it Mean to the Sailors?

We have heard what the purchase of nuclear-propelled submarines (SSNs) will mean for our country's defence: how we will have a most cost-effective contribution to a balanced fleet; how we will be able to operate in all three oceans; and how we will have a well balanced navy capable of reacting quickly to a variety of situations. But what does all this mean, in personal terms, to the sailors of our navy?

Actually the question should probably be better phrased as what will it mean to the next generation? For even though it is intended that the contender (either the French *Rubis* or British *Trafalgar* class) be selected by the spring of 1988, the delivery of the first submarine is not expected until late 1996. Even so, many sailors now in the navy will serve on these boats and training will begin before the arrival of the first submarine.

Quality of Life

Life on board our present diesel-electric submarines is always challenging and crew amenities are few and far between. This will change with the advent of the SSN. The challenge will remain — even increase — but the quality of life at sea, and ashore, will improve. Gone will be the pervasive diesel fumes, replaced by the cleanest propulsion system known to man. Gone too will be the overly cramped quarters with men "hot-bunking" and sleeping over the torpedoes. Every sailor will have his own



HMCS Onondaga, *one of Canada's current diesel-electric submarines that will be replaced by the new nuclear-propelled boats. (ISC73-686).*

bunk and the extra power and energy on board will allow such luxuries (by today's standards) as sufficient water for washing laundry and greatly improved cooking facilities.

The long endurance of the SSN will mean that time at sea will be greater, and certainly the boat will remain submerged considerably longer than with our present submarines. This means that it is likely that an SSN will require more than one crew in order to keep it at sea on patrol. Therefore, while a sailor may be away longer at one time, his time ashore will increase correspondingly and will fit into a more regular and predictable routine.

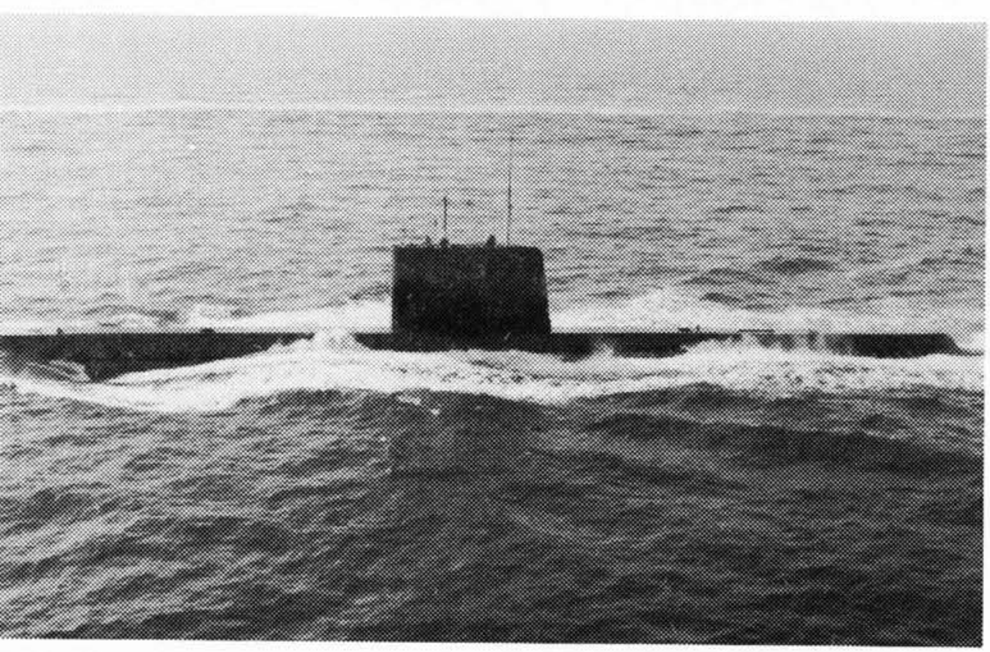
Pride and Challenge

The challenge of operating a modern fleet will be great. The navy will be able to take pride in knowing that they are finally equipped with the best there is to work with. The sailor will be working with modern, high-technology equipment and will be secure in the knowledge that he is operating in a vessel with very high survivability in war and an unmatched ability to carry out its mission. The skills required of the sailor in our fleet of the future will be very high but the rewards will be higher.

The variety of employment in the navy will be greater. With the increase in our submarine fleet from the present three to at least 10, many more sailors will serve below the waves than at present. Service on a submarine will become as normal as service on a destroyer is today. Tasks at sea will become equally as varied, with the ability of the SSN to move between the Atlantic, Pacific and the Arctic. There will certainly never be a dull day.

In 10 years' time Canada will have begun to possess an effective, modern submarine fleet to match the improvements now being realized in the surface fleet. The quality of life for our future submariners will be very high, compared with that of today. Our sailors will face demanding challenges and will be able to respond to any sort of threat to Canada in any of the three oceans, with the best equipment available.

Capt Simon MacDowall is a public affairs officer with NDHQ's directorate of information service.



HMCS Onondaga *on patrol in the North Atlantic. (ISC73-704).*

MARE

MARITIME ENGINEERING JOURNAL OBJECTIVES

- 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 may 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.

WRITER'S GUIDE

We are interested in receiving unclassified submissions, in English or French, on subjects that meet any of the stated objectives. Final selection of articles for publication is made by the Journal's editorial committee.

Article submissions must be typed, double spaced, on 8½" × 11" paper and should as a rule not exceed 4,000 words (about 17 pages). The first page must include the author's name, address and telephone number. Photographs or illustrations accompanying the manuscript must have complete captions. We prefer to run author photographs alongside articles, but this is not a must. In any event, a short biographical note on the author should be included with the manuscript.

Letters of any length are always welcome, but only signed correspondence will be considered for publication.

An Introduction to Stirling Engines and their use in Submarines

By Lt(N) Richard Sylvestre

Foreword

Canada's decision to acquire a fleet of nuclear-powered submarines (SSNs) is intended to provide the navy with an effective three-ocean strategy in which an extended under-ice capability is implicit. To date this capability has only been achievable with nuclear-powered submarines and that is unlikely to change in time for the Canadian Submarine Acquisition Project (CASAP). Nevertheless, one should ask whether this very expensive, extended under-ice capability is necessary for all of Canada's new submarines.

Recent breakthroughs in atmosphere-independent propulsion (AIP) systems have shown the potential to significantly improve the underwater endurance of conventional submarines (SSKs). Extended endurance, along with the inherent quietness and much lower cost of SSKs, should continue to make them the preferred submarine for coastal patrols and stealth operations. This suggests that Canada with her many miles of coastline may best be served by a combination of new SSNs and SSKs. However, due to the relatively unknown and unproven nature of AIP systems, there is an understandable reluctance to pursue this option. Indeed, the CASAP and current SSN mandate precluded any technology that was not yet proven. This implies that AIP systems will probably not see service in the Canadian navy until well after the turn of the century.

The technology does, however, present interesting possibilities for the future. One AIP system was investigated by the author in his MSc thesis project when he carried out a detailed assessment of a Stirling engine's potential for increasing the submerged endurance of a conventional submarine. It was shown with an advanced Stirling engine simulation that a Type 2400 SSK could have its submerged endurance extended to 8.9 days with an add-on Stirling generator system. This paper contains excerpts from the dissertation[1] and is intended as an introduction to Stirling engines and their use as AIP systems in submarines.

Introduction

During World War II the need to extend the submerged endurance of submarines was identified. All submarines were then powered by diesel-electric systems whose lead-acid batteries had to be recharged daily by interrupting the mission to surface and run the diesel engines. This essential evolution exposed the submarine to detection and thereby reduced its combat effectiveness. The Germans attempted to overcome the endurance limitation by developing two AIP systems: the Walter turbine which used the combustion products of dissociated high-test peroxide and a hydrocarbon fuel; and the Krieslauf closed-cycle diesel. This work was overtaken by the events of the war, but was resumed by the British in the early post-war period. By the mid-1950s the Royal Navy had installed the Walter turbine system in Her Majesty's submarines *Explorer* and *Excalibur*, and were close to doing the same with a closed-cycle diesel system. However, further developments of AIP systems virtually stopped in 1957 with the introduction of nuclear power to submarines. Nuclear submarines promised much longer endurance, higher speeds and better living conditions than SSKs, so research efforts were concentrated almost entirely on nuclear plants.

Today most navies still use SSKs since they are quieter and less expensive than SSNs; but, recent advances in radar and weapon systems are making low-endurance SSKs unacceptably vulnerable. Extended endurance is crucial in minimizing detection, but for many navies the nuclear option is either technologically unsupportable, politically unacceptable or too expensive. Consequently, there has been a resurgence of development effort in AIP systems for SSKs. The systems being developed in various countries include Stirling engines, fuel cells, closed-cycle diesels and the low-power nuclear system, AMPS.

The first of these to be operational should be the Stirling system, since Kockums shipyard and United Stirling Engineering of Sweden are expected to complete work on a *Knacken*-class SSK for the Royal Swedish Navy by mid-1988. The submarine is being retrofitted with Stirling engines which should significantly increase its submerged endurance. The use of Stirling engines has therefore become a current issue with NATO navies, but until recently little was known about their use in submarines. The following provides an explanation of the concepts of Stirling engines and a description of an assessment made for their use in a Type 2400 submarine.

History of Stirling Engines

The Stirling engine was invented in 1816 by Robert Stirling, a Scottish clergyman. Throughout his life he remained actively involved in the development of his engine, but was never to see its wide commercial success. Although the materials technology of the era was his stumbling block, he was convinced of the engine's potential. "It remains," he wrote at the end of his life, "for some skilled and ambitious mechanist in a future age to repeat it under more favourable circumstances and with complete success...."[2]

Since Stirling's death in 1876 there have been many applications of the Stirling engine, mostly in low-power machines such as fans and water pumps. The medium-to-high-power requirements were satisfied almost entirley by steam and internal combustion engines (ICEs), which although theoretically inferior were easier to manufacture. The success of the ICE soon made Stirling engine development moribund, but interest was rekindled in the 1930s when Philips of the Netherlands developed a quiet, efficient Stirling engine to power remote radio sites. The advent of the transistor in the 1950s eliminated that need, but by then Philips had proven the potential of Stirling's invention. Today almost all companies involved in the research and production of Stirling engines started that work as licensees of Philips. They include United Stirling of Sweden, MAN/MWM of Germany, and General Motors, Ford, Mechanical Technology Inc. and General

Electric of the United States. These companies are developing Stirling engines for use in the automotive, underwater, space, solar power and medical fields. With all of the attention, it seems only a matter of time before Stirling engines begin to share the market with ICEs. The reason for all this effort is that the material difficulties have been largely overcome, thus making way for the realization of the Stirling engine's superior operating characteristics.

Principles of Operation

Stirling engines are externally heated and operate on a closed regenerative thermodynamic cycle with cyclic compression and expansion of an enclosed working fluid at different temperature levels. The transfer of heat into and out of the engine via the heater and cooler tubes, respectively, is a continuous process during which there is a net conversion of heat to work. The basic arrangement of each cycle consists of two variable-volume working spaces and three fixed-volume heat-exchangers. The working spaces are the expansion (hot) and the compression (cold) spaces, and the heat-exchangers are the heater, regenerator and cooler. The working fluid is usually helium or hydrogen since the high specific heat and low density of these gases allow maximum heat transfer rates with minimal flow losses.

This general description is true of many variations of engine which operate on the practical Stirling cycle. The example of a "double-acting" Stirling engine (Figure 1) illustrates the cylinder and heat-exchanger arrangement of an engine in which four pistons operate vertically, driving two crankshafts which are geared in turn to one drive shaft in a U-drive configuration. The heater tubes receive heat from the hot gases of a central, overhead combustion chamber. The heated working fluid then expands in the top of the cylinder, thereby forcing the piston down in its working stroke. On the piston's return, the gas (now at low pressure) is displaced back through the heater, regenerator and the cooler to the underside of the adjacent piston. In this process heat is stored in the highly effective fine-wire mesh of the regenerator before the gas is cooled to its lowest cycle temperature in the cooler. The cooling of the gas reduces the work required to compress it back to the operating pressure before it returns through the regenerator where it reclaims up to 98 percent of the previously stored heat. Each piston in this type of engine serves both to deliver work to the crankshaft and to compress the cooled working fluid from another cycle; hence the term "double-acting". This principle is illustrated further in the step-by-step description of Figure 2.

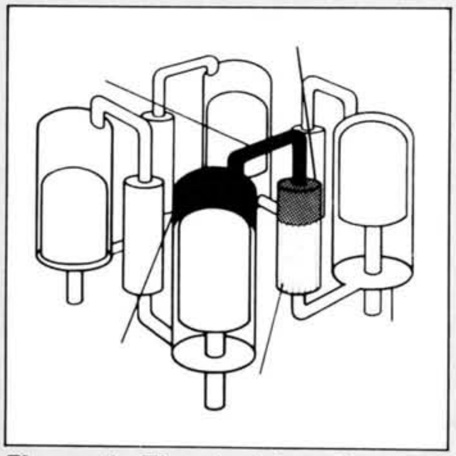
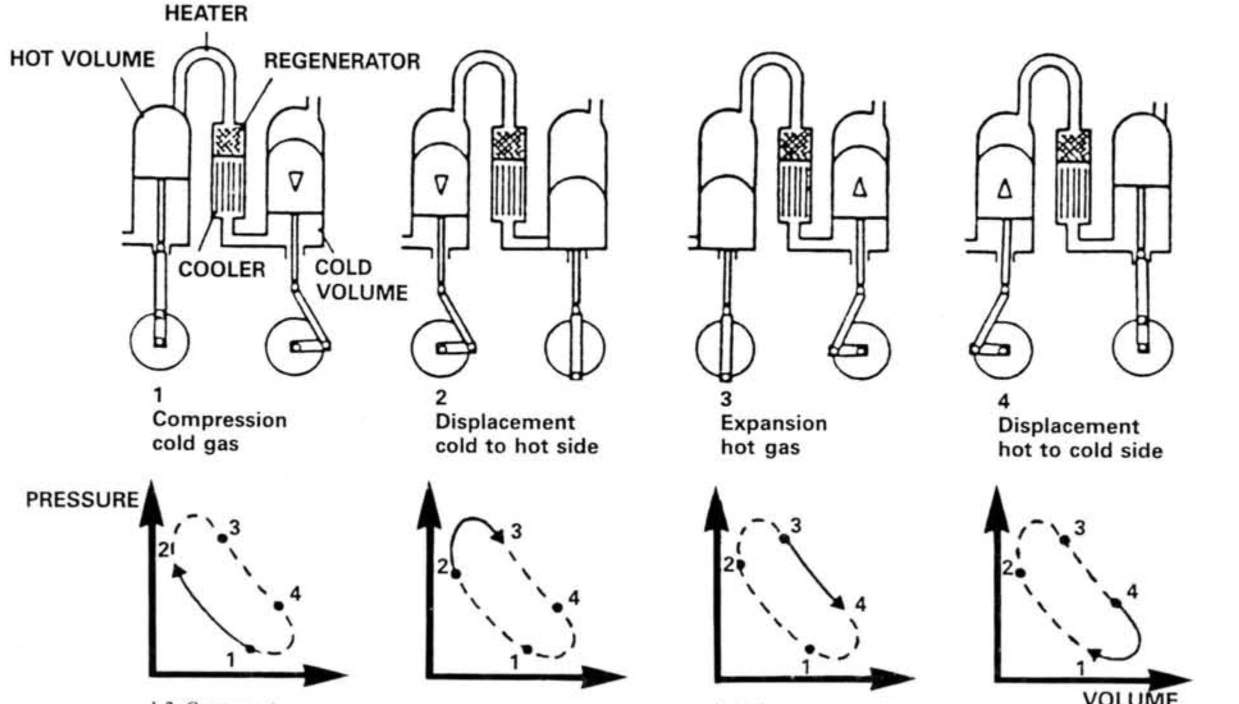


Figure 1. The double-acting Stirling working principle (from Nilsson[1])



1-2 Compression
Work is supplied by compressing the working gas on the cold side; the gas is cooled at low pressure.

2-3 Displacement
The gas is moved from the cold to the hot side at constant volume. The regenerator gives off stored heat. Pressure increases.

3-4 Expansion
Work is performed when the working gas expands on the hot side while it is heated at high pressure.

4-1 Displacement
The gas moves from the hot to the cold side at constant volume. Heat is stored in the regenerator. Pressure declines.

Figure 2. Stirling principles of operation (from Nilsson[1])

Theoretically, the Stirling engine with perfect regeneration and no heat, aerodynamic or mechanical losses realizes the Carnot efficiency (the maximum possible thermal efficiency for a heat engine) which is proportional only to the temperature differential across the engine. In reality, regeneration is not quite perfect and all of the noted losses do attenuate the ideal cycle performance. However, the actual thermal efficiency of some Stirling engines is already in excess of that so far achieved by any other production heat engine. As technology advances to allow higher continuous heater temperatures, Stirling engine efficiencies should also continue to rise beyond those obtainable with competing engines. Other practical advantages of Stirling engines, especially for use in submarines, are:

* since combustion is steady, and not a series of explosions as in ICEs, Stirling engines are very quiet and exhaust emissions are negligible;
* combustion gases never enter the cylinders, so contamination and consumption of lube oil is not a maintenance concern;
* since the engine is externally heated, combustion may occur under pressure which allows for disposal of exhaust gases without the need for a noisy, power-consuming exhaust compressor;
* the engine may be adapted to burn any fuel;
* there is no valve gear, hence fewer wear parts.

Stirling engines have disadvantages as well and these have been due primarily to the high pressures and continuous high temperatures of the operating cycle. To date, the resulting mechanical and material difficulties which have persisted since 1816 have been largely overcome by using precise production techniques and expensive superalloys.

Submarine Requirements

The Swedish submarine with retrofitted Stirling engines will have the new systems incorporated in a separate "add-on" package. The submarine will be cut in two and the new section welded in place. If the system achieves the expected level of success, future submarine designs will probably have the Stirling engines incorporated in the design from the beginning. For the purpose of this study, a separate add-on section of ten percent of the submarine's length was considered.

The Submarine

The assessment of the Stirling system could have been done with a hypothetical submarine, but it was considered more realistic to use an existing SSK. The Royal Navy's new Type 2400 submarine was chosen since it is modern, and basic information is documented in the open literature[4]. The general arrangement of the Type 2400 is shown in Figure 3. The major parameters required for the study were:

Length overall	70 metres
Pressure hull diameter	7.5 metres
Submerged displacement	2400 tonnes
Main propulsion motor	4 megawatts
Maximum speed ..	about 20 knots
Usable fuel oil ...	214 cubic metres
Battery cells	480 × 8800 amp-hours
Diving depth	over 200 metres

The Stirling system was to be wholly contained in a seven-metre-long package welded into the 7.5-metre diameter parallel middle section of the submarine between the control room and engine-room. The system includes the Stirling generator sets, stored oxidant and compensation tanks, control systems, exhaust disposal system and all associated pipework and auxiliaries.

Electrical Load

Since speed/power curves for most naval vessels are classified, approximate curves were generated using Jackson's approach[5] with unclassified Type 2400 parameters. It was shown that the propulsive power requirement at four to five knots for the extended Type 2400 submarine would be about 55 kW.

The propulsive load is relatively small when compared to the hotel load; i.e. that drawn by domestic, navigational and combat systems. In modern SSKs the hotel load on patrol varies from 100 to 200 kW. This depends on the quietness state of the submarine which dictates the number of fans, pumps and other auxiliaries that may be in use. In the "ultra-quiet" state only the minimum number of life-support systems are operational while maintaining the combat effectiveness of the submarine. This state could not be maintained indefinitely as the internal atmosphere of the submarine would eventually deteriorate to an unsafe level. At the upper end of the hotel load range the submarine may be operating active sonar, radar and much domestic equipment. Clearly the instantaneous power requirement formula is complicated, so for the purpose of this study an average hotel load of 175 kW was considered. Therefore the endurance enhancing system must provide 230 kW for the total electrical load. This is not contin-

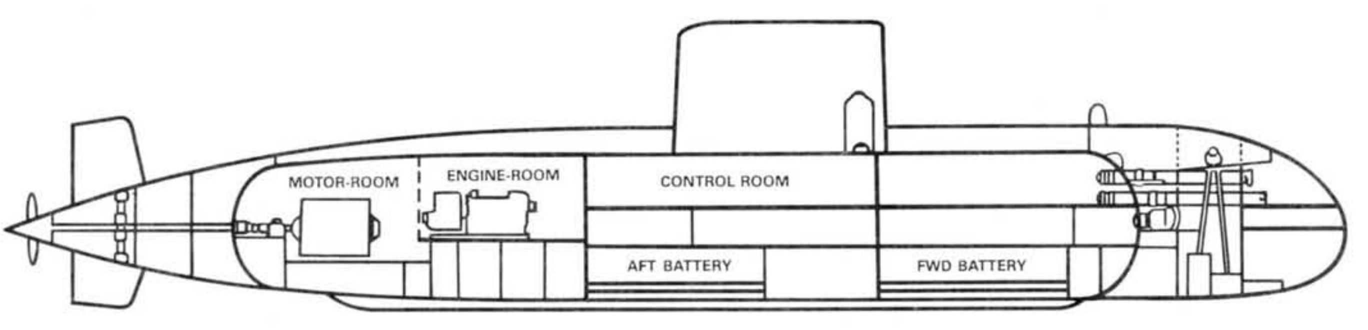


Figure 3. Type 2400 submarine general arrangement

uous, however, as there are times when the Stirling system would be shut down in order to minimize noise transmitted from the submarine. To assess this aspect the submarine's mission profile was considered.

Mission Profile

During most of the submerged patrol the submarine would be proceeding at three to four knots and listening for targets. When a target is engaged the speed of the submarine would vary according to the situation. It may come to an almost complete stop in the ultra-quiet state to listen and not be heard or it may proceed at up to 20 knots when attacking or evading the target. During the ultra-quiet phases it would be undesirable to operate the Stirling system due to the extra noise which might make the difference in being detected or not. At high speeds the submarine's hull and propeller noise would make the Stirling system's noise insignificant. Nevertheless, the safest policy may be to shut down the Stirling systems during target engagement periods. On a typical patrol, target engagement would comprise about five percent of the total sumberged time during which the batteries would have to provide the power from their stored energy. This energy must be maintained above a tactical reserve of battery charge in case the surface situation is too dangerous for running the diesels at the end of the submerged patrol.

A realistic speed/time profile for target engagement during a ten-day submerged period was assessed with a lead-acid battery simulation[6]. With target engagement making up five pecent of the submerged time, it was predicted that there would be sufficient reserve at the end of the patrol for the submarine to remain submerged at slow speed for several hours if necessary.

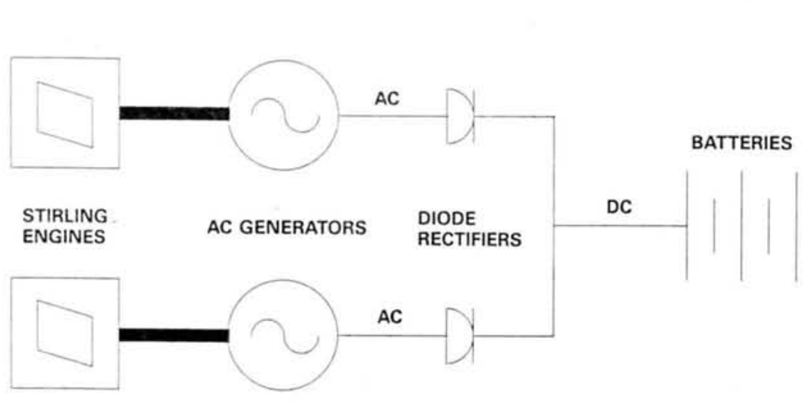
Power Generation Duty

Conventional submarines usually have the electrical load placed directly on the batteries, as would the submarine with an add-on Stirling system. A Stirling engine driving a generator that is connected to the batteries is intended to just compensate for the electrical load, thereby "floating" the batteries at a constant charge while on slow-speed submerged patrol. A design output of 240 kW was selected for the Stirling system which should provide a safety margin above the already conservative estimate of 230 kW for the total load on submerged patrol.

The Stirling system could comprise just one generator set, but that would present a safety hazard particularly if the submarine were intended for limited under-ice operation in Canada's Arctic waters. A failure of the set could leave the submarine stranded under the ice beyond the transit range of the battery capacity and with little hope of survival. In keeping with common practice the minimum number would therefore be two generator sets, each with a rating of 120 kW. The failure of one set may then necessitate that all non-essential equipment be shut down until the submarine clears the danger area. This implies a reduction in combat effectiveness, but safety should not be unduly compromised. To provide redundancy, three 120-kilowatt generators may be considered. In a vessel where space is not at a premium this may be the best solution, but in the confines of an SSK space is a limiting factor and so two generator sets were chosen for this assessment.

Battery charging requires a DC supply which may be provided by DC generators or AC generators with diode rectification. Neither type has a performance advantage over the other for this application, but since AC generators are cheaper to maintain they were chosen. The proposed configuration of generators is as per Figure 4. Each AC generator has its own rectifier tied to a common DC bus bar. By this method there is no need to synchronize the two generators to each other or to the main AC distribution system. Nevertheless, it would still be very important to operate the generators at their design speeds in order to optimize on efficiency. The higher the efficiency of the generator set the longer the submarine would be able to remain submerged for a fixed amount of oxidant. It is therefore critical that the best matching of Stirling engine and generator speed be made such that the generator set would be optimized for both efficiency and power in a compact package.

Figure 4. Generator Configuration



Stirling System Installation

Having established the Stirling system requirements, it remained to assess whether or not the system would fit into the seven-metre submarine section and provide a significantly increased endurance. The assessment involved several practical considerations.

Fuel and Oxidant

To simplify logistics and design, naval distillate fuel was chosen for the Stirling system since the type 2400 design already incorporated plenty of distillate storage. The choice of oxidant was between high-pressure gaseous oxygen (GOX), high-test peroxide (HTP) and liquid oxygen (LOX). All three present safety hazards, but so do the fuels and ordnance carried in any combat vessel. The intent was to minimize danger, cost and storage space. GOX was discounted due to the need for bulky, very-high-pressure containment. HTP produces oxygen in a catalytic exothermic reaction with water and is the most compact method of storing oxygen; but, it causes fire or explosion in reaction with many substances and is very expensive. So the choice was for LOX to be stored within the pressure hull of the add-on section.

Calculations of the amount of LOX required were based on the chemical reaction equation considering seven percent excess oxygen. This should ensure complete combustion, yet not unduly waste oxygen or present a noticeable bubble signature in the overboard exhaust. Complete combustion would require 3.65 kilograms of oxygen per kilogram of fuel.

The First Law of Thermodynamics may be used to show that the adiabatic flame temperature (AFT) of combustion for the pure oxygen/hydrocarbon reaction would be about 5500° C. In reality, flames are not adiabatic and energy is lost through dissociation, so the flame temperature would be about 4000° C which is still too high for Stirling engine materials. This problem may be solved with 90 percent exhaust gas recirculation which should reduce the flame temperature to about 2200° C.

Exhaust Disposal

Exhaust gas disposal is an important consideration. With the submarine submerged to 300 metres, the exhaust would have to be at 30 bar before it could be dumped to the sea. This is achieved in United Stirling's engines with overpressure combustion. Since the Stirling engine is externally heated, exhaust back-pressure has no effect on the working cycle. The fuel and oxidant are supplied to the combustion chamber at a pressure of 20 to 30 bar and the exhaust gases are merely released overboard in a carefully controlled manner. (Since the oxidant is pure, unlike air which is about 80 percent nitrogen, the quantity of exhaust gases is only about 20 percent that of normally aspirated engines.) Fuel is brought to combustion pressure with a small pump and LOX is bunkered at pressure. Pressurization of the LOX is controlled by heat leakage into the tank via a pressurization loop in the cryogenic system. According to Lefebvre[7], the overpressure effects on combustion are insignificant at 30 bar.

LOX Tank Design

The design of the LOX tank was done by first determining the space available in the submarine, then consulting: the standard codes for cryogenic and pressure vessel design; Polak's design text[8]; and manufacturers of double-walled cryogenic storage tanks.

The seven-metre add-on section would contain the Stirling generator sets, exhaust disposal system, control system and auxiliaries on a deck the same height as that of the control room (see Figure 3). The lower level would be one room for the location of the storage tank, compensation tanks and most of the cryogenic pipework. In addition, the wiring and piping systems that would be broached by cutting the submarine in two would be extended through the appropriate level.

The dimensions of the Stirling generator sets were deduced from the description by Nilsson[3] for the V4-275R engine, with consideration for mounts and acoustic enclosures. The space envelope for the tank had to be based on the maintenance philosophy. The tank itself should not require any maintenance throughout its design life of about 20 years, except for the renewal of the insulating vacuum every five to seven years which could be done in situ. However, the tank would be mounted with shock-absorbing resilient mounts to a concentric frame at each end. The resilient mounts would probably require replacement at least once in the life of the submarine. This could be done by cutting the submarine in two and removing the tank, which would mean only minimum clearance was required at each end. The other, and more space-limiting, option is that all maintenance would be done with the tank in place, which would necessitate leaving adequate clearance for mount maintenance and painting of the hull. The latter more limiting option was chosen and based on nominal submarine scantlings; the space available for a cylindrical tank was calculated to be 5.47 metre long × 3.83 metre diameter. This would include the outer shell, vacuum gap, wrapped insulation and the inner pressure vessel. Figure 5 is a scale drawing of the add-on section with LOX storage tank. Allowing an ullage space of five percent, the usable volume of the LOX tank was calculated to be 40.6 cubic metres, which equates to 46.3 tonnes of LOX.

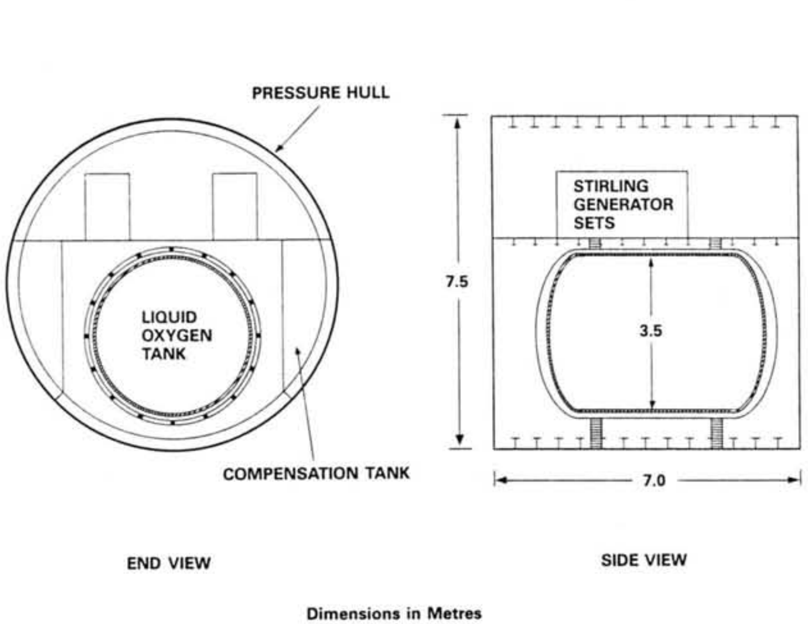
Submerged Endurance Calculation

In the project, an existing Stirling engine design was uprated to provide the generator output of 120 kW. The engine performance was then modelled with an advanced Stirling engine computer simulation which had first been developed and validated against test results for a real engine. The predicted brake specific fuel consumption for the hypothetical engine running at 3000 rpm and delivering 128 kW was 0.26 kg/kW-hr. Assuming that the engine would be running 95 percent of the submerged time, the submarine's endurance was calculated to be:

$$\frac{46.3 \text{ tonnes LOX} \times 1000 \text{ kg/tonne}}{0.26 \, \frac{\text{kg(fuel)}}{\text{kW-hr}} \times 3.65 \, \frac{\text{kg(LOX)}}{\text{kg(fuel)}} \times 24 \, \frac{\text{hr}}{\text{day}} \times 240 \text{ kW} \times 0.95}$$

$$= \underline{8.9 \text{ days}}$$

Figure 5. Submarine add-on section



Discussion

It was shown that the submerged endurance of a Type 2400 submarine could be increased to 8.9 days with the addition of a Stirling generator system. The Stirling system would be wholly contained in a seven-metre add-on section to the submarine.

Two imporant factors not considered in detail for the design were the stability and habitability of the submarine. The stability considerations were the submarine's buoyancy and ability to trim for diving or surfacing. Neutral buoyancy must be obtainable under all conditions or the submarine may be unable to dive or, conversely, may sink to the bottom. Therefore, the permanent weight of the add-on section must be in balance with the upward acting buoyant force. In addition, the submarine must have the ability to compensate for spent LOX and a variation in seawater relative densities. The latter should be accommodated by the design margin of the Type 2400's existing tanks, and the former was accounted for by two LOX compensation tanks, (see Figure 5). The correct trim of the submarine (bow up or down) when breaking the water surface serves to minimize its inherent danger of capsizing during that particular manoeuvre. The trim tanks may require modification to account for the add-on section. However, approximate calculations[1] indicated that the structural modifications necessary to satisfy stability should be feasible for the Type 2400 submarine.

The habitability of the submarine must be maintained at a safe level for the entire submerged endurance which would necessitate careful control of the air quality. It is possible to use some of the LOX for the crew's oxygen supply, but carbon monoxide and carbon dioxide must be removed with burners and scrubbers which would increase the electrical load.

The study described herein considered a Type 2400 submarine out of convenience only — it could have been done for any SSK. The important thing is that the Stirling engine concept has great potential as perhaps do other AIP systems. In the case of Stirling engines the proof should be forthcoming soon from either the Royal Swedish Navy (RSwN) or the Comex company of Marseilles, France which is installing the same United Stirling engines in a commercial submersible. The cost to the RSwN of the add-on section containing two Stirling systems is about $20 million. This price is only about five to ten percent of the cost of a modern SSK, which in itself is roughly one half the cost of the available SSNs. Clearly, the cost savings and diverse capabilities provided by a mixed fleet of SSNs and modern AIP system equipped SSKs could be very beneficial to Canada. However, it appears as if the proof of technology specified in the CASAP will, if forthcoming, arrive too late for Canada's next submarines.

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The Perfect Inspection

Many years ago a young hull inspector was tasked with the routine inspection of the admiral's barge. The inspector, unfamiliar with wooden boats but wanting to make a good impression, set out to perform the perfect inspection. He engaged the services of a number of shipwrights to assist in opening the vessel up and bore-testing the larger components to ensure no defects went unnoticed. The inspection took an abnormally long time, but in the end showed that the admiral's barge had very few defects and was in exceptionally good shape. Unfortunately, the cost of renewing and replacing the items that were removed to facilitate this perfect inspection rendered the vessel uneconomical to repair — the barge was condemned.

Clyde Noseworthy, Chief Hull Inspector, NEU(A)

Do you have an amusing anecdote you'd like to share?
See p. 1 for our address

System Design
The Missing Element

By Cdr Roger Cyr

SYSTEM: *A combination of complete operating equipment, assemblies, components, parts or accessories, including software and man-machine interfaces, integrated to perform a specific operational function.*

Introduction

The biggest single advance in the evolution of combat systems has undoubtedly been the introduction of embedded computers. Modern combat systems rely heavily on embedded computers and software to attain their expected performance levels, and in the past decade embedded computers have become an integral component of every major weapon and sensor system. In the USN the number of combat systems that employ embedded processors will grow from 10,000 in 1980 to an estimated 250,000 by 1990, with expenditures increasing from $4.1 billion to $38 billion. Remarkably, software costs will represent 85 percent of the estimated 1990 expenditures.

This sudden heavy reliance on embedded computers and software is causing immense problems with the development and implementation of error-free, reliable combat systems. As more and more emphasis is being placed on embedded software as the best means of improving reliability and performance, combat systems are becoming more complex and thus more vulnerable to catastrophic failure. Software, rather than hardware, is now the major component of combat systems, and the main bottleneck in their development as well. Combat systems have become so totally dependent on software that software concepts rather than *system* concepts dominate their development.

Before the software revolution of recent times it was accepted that any system needed to be designed in a top-down fashion, with all elements and methodologies of design taken into consideration. Lately, however, in a push to produce the required software, fundamental design steps are being discarded. Software design has taken over where system design should be done, and in some cases actually dictates system configuration. Instead of being a supporting element in the design process, it has become the driving force at the exclusion of most other design factors. Software which was intended to provide added system verstaility has, instead, become its Achilles' heel.

System Shortfalls

Proper design hierachy (Figure 1) starts with first evaluating the requirements and then analyzing all of the elements which

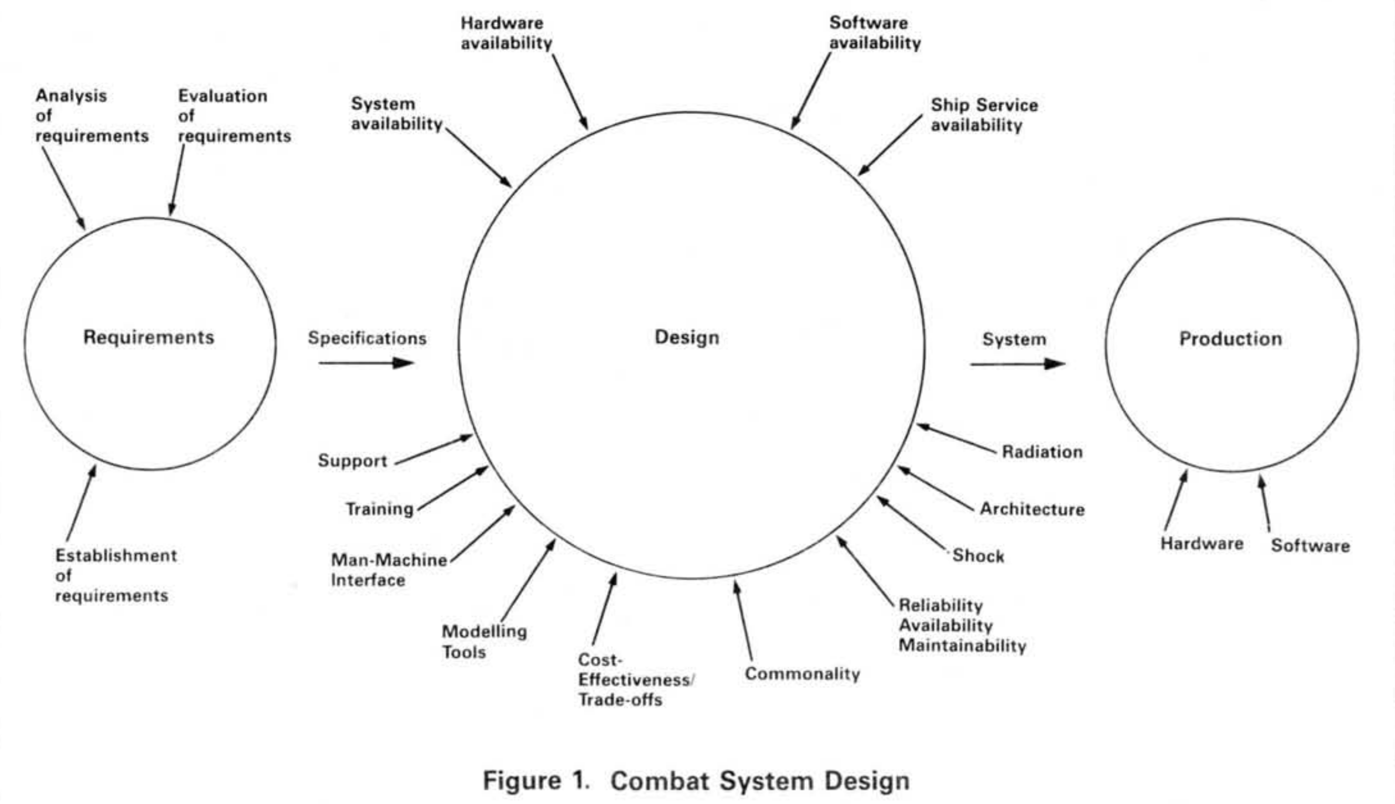

Figure 1. Combat System Design

may affect the design, yet the trend today is to short-circuit established system design techniques. Instead of addressing system needs, contractors will simply select available hardware, then develop software to make the hardware fit and possibly work, or to fill the holes left by the hardware. The result is a fragmented system characterized by:

- ill-defined requirements
- undefined system boundaries
- inadequate system performance
- unrealistic maintenance burdens
- significant increases in life-cycle costs

The intent of software was to make systems more versatile in that change could be made with software at little cost or effort. However, in most systems, this is no longer the case since it has become less complicated to modify the hardware than to alter its software. Software is what gives a system its flexibility and adaptability. It should enhance overall system performance and not place limits on it. To say that a system will attain a certain level of performance based on a particular software limitation is wrong. When software approaches are permitted to delineate system design, then system attributes are lost.

System design encompasses both hardware and software building blocks which need to be closely interrelated. In major projects, though, these building blocks are often addressed as separate entities. It is considered that this is due in major part to the lack of a system-based organization in project management offices (PMOs).

Fragmented Design Approach

With regards to system design, PMO organizations offer a fragmented structure (Figure 2) which undoubtedly affects the design function; the support elements not being directly integrated with the combat system organization is a particular deficiency.

Certain combat systems are particularly dependent on sound system-design methodologies. When these systems are implemented, specific attention must be paid to their integration and end-use in order to achieve the expected performance levels. Implementation in a patchwork approach could lead to sub-optimization of the system.

For example, if system design methodologies are not employed in the implementation of the SHINPADS serial data bus, many of the basic attributes of SHINPADS, such as survivability, versatility and growth, will be lost. Improper design in the implementation of SHINPADS could result in excessive processing overhead inside the computers being served by the data bus, thereby significantly reducing the speed of data transfer between those computers. In that instance, the data bus almost acts as a computer bus, something for which it was not designed, and as a consequence operates in a degraded condition.

The optimization of combat system equipment locations in a ship is another aspect of system design which tends to be neglected. As a consequence, maximum allowable distances for interfaces are often exceeded, requiring converters to be introduced to compensate for the added distances, thereby creating additional points of possible failure.

System-based Organization

In a system-based organization (Figure 3) all system related functions are centralized under a structure which responds to system design needs. Services common to all warfare areas are performed in a matrix-type manner, with the responsible common services sections calling on the applicable warfare area sections for the necessary subsystem expertise and guidance.

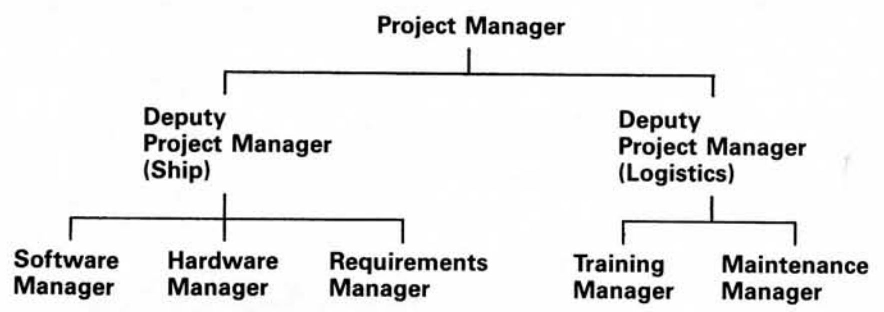

Figure 2. Fragmented PMO Organization

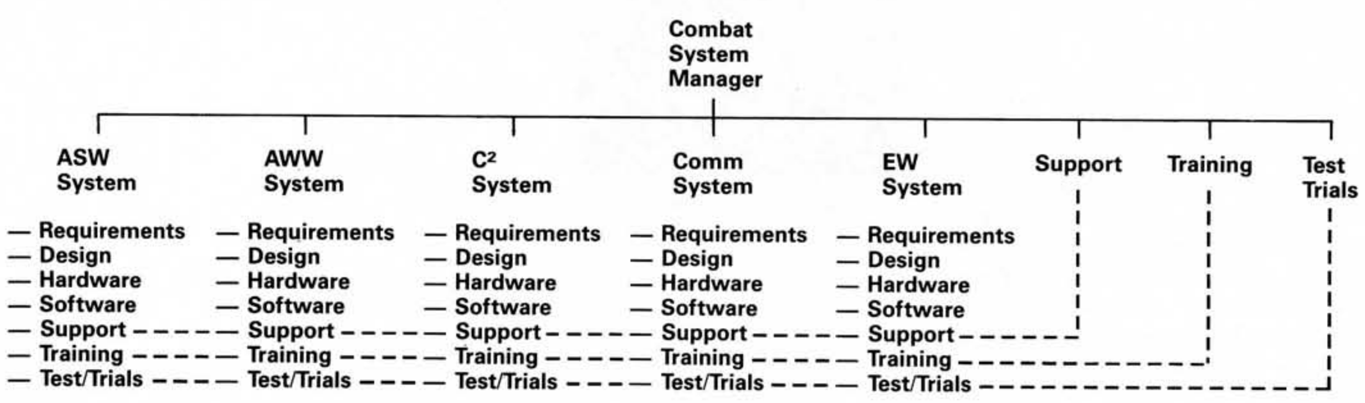

Figure 3. System-based PMO Organization

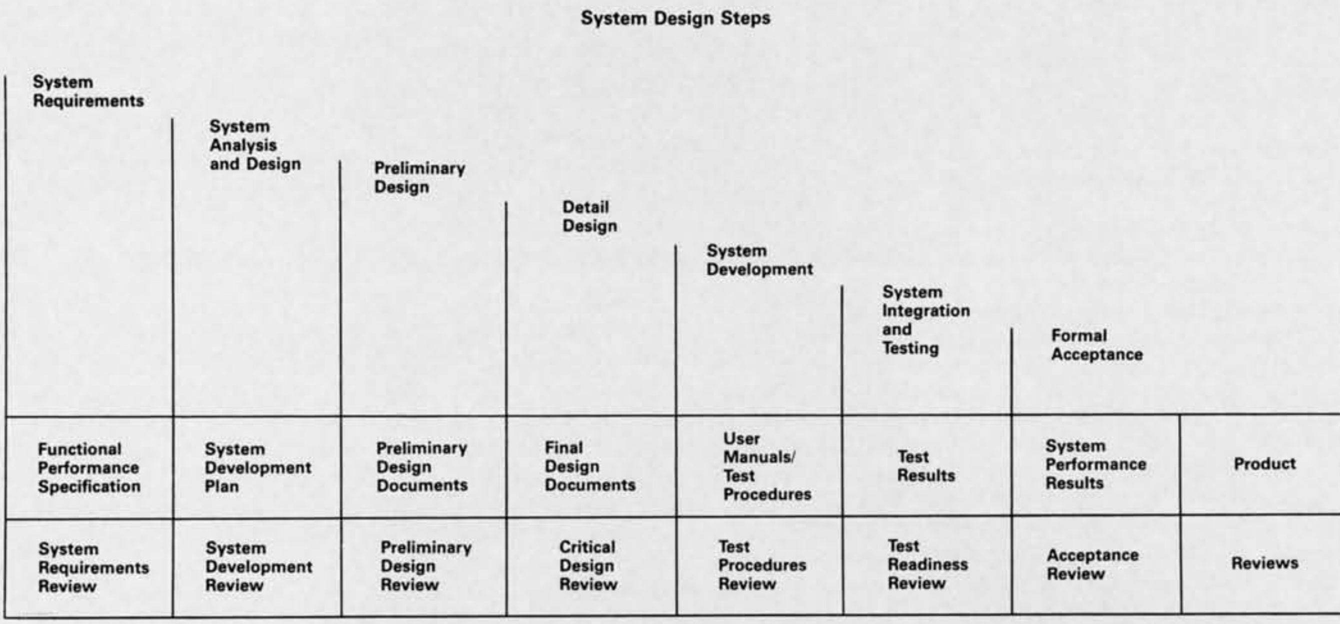

Figure 4. System Design Steps

In addition to a system-based organization, a system-based approach to project implementation (Figure 4) must be followed. (Although it is often espoused, such an approach is rarely followed.) Here, both hardware and software are treated as components which, although they influence each other, do not determine the design in isolation. The system engineering method recognizes each system as an integrated whole even though it is composed of diverse, specialized structures and subfunctions. It further recognizes that any system has a number of objectives, and that the balance between them may differ widely from system to system. The methods seek to optimize the overall system function according to weighted objectives and to achieve maximum compatibility of parts.

Conclusion

A fragmented approach to system design and development must be avoided as it can result in the development of unrelated and incompatible subsystems. Thoughtful system planning centres around a total system that provides coherence of architectural design, methods, standards and other commonalities important for implementation and operation. The overall system should be structured as a set of integrated subsystems and component parts that is flexible enough to accommodate change.

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The CPF Combat System Test and Trials Program

By Lt(N) David MacDougall

Introduction

It can be argued that the single common thread running through the Canadian Patrol Frigate project may be neither the integrated command and control system nor the integrated machinery control system. Rather, the one and only fully integrated aspect of the project may be the test and trials program, for it covers every aspect of hardware and software related to CPF marine and combat systems. The CPF test and trials program activities occur throughout the project, proceeding in a logical sequence from the lowest practical level of assembly (hardware and software) to the fully integrated and operational warship at the highest. The program even encompasses shore establishment trials conducted on CPF shore-support facilities.

It is the aim of this article to describe the concepts behind the CPF test and trials program, both in a historical perspective and in recognition of the unique characteristics of the CPF. Since the topic of CPF tests and trials is all-encompassing, it is necessary to limit the scope of this article and discuss the program as it relates specifically to Combat System tests and trials.

The CPF Combat System (Figure 1) has the capability to perform automatic detection, tracking, threat evaluation and weapon assignment. This optimizes system reaction time and maximizes weapon effectiveness against threats in all phases of naval warfare. The Combat System is made up of sensor, weapon, communication and support systems that are all functionally tied together by the command and control system. The price of this capability is enormous complexity, but the CPF test and trials program is designed to contend with such complexity in a structured and integrated fashion. A bottom-up trials plan ensures subsystem performance is proven correct in a logical sequence. An integrated plan assures that all aspects of the CPF project will be treated uniformly and use resources efficiently.

Background

The ultimate objective of any test and trials program is to demonstrate that a piece of equipment, a subsystem or system achieves its specified performance requirements. For CPF these specifications are set out in the implementation contract, and it is the responsibility of the contractor* to demonstrate to DND that they have been achieved.

**The prime contractor for the CPF project is Saint John Shipbuilding Limited. Paramax Electronics Inc. of Montreal is the subcontractor responsible to SJSL for the CPF Combat System.*

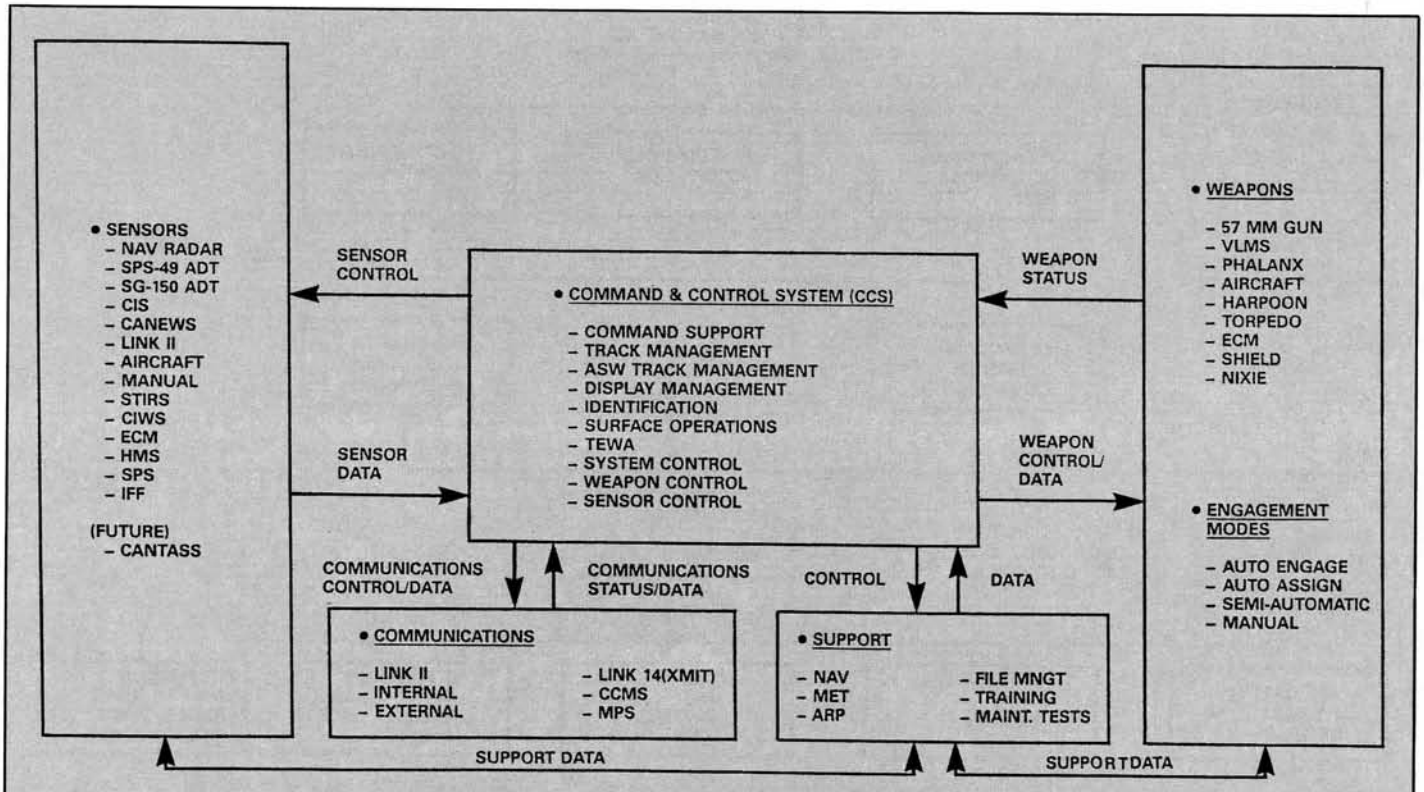


Figure 1. Functional Distribution of the CPF Combat System

The CPF test and trials program is designed to reduce the technological risk of system implementation and, concurrently, keep associated shipboard testing time to a minimum. The logical sequence of the trials program, from lowest level of assembly to highest, consists of the following phases:

a. Vendor Phase;
b. Shore Facilities Phase; and
c. Shipboard Phase.

The implementation of this risk-reduction plan has resulted in five basic stages of development for the CPF Combat System:

1. Combat System Test Support Facility (CSTSF) Test and Trials;
2. Ship Construction Tests and Trials;
3. Alongside and Sea Trials;
4. Incentive Trials; and
5. Facility Trials.

These individual stages are further described in this article.

CPF Test and Trials Plan

The Combat System test and trials plan defines the process by which the CPF Combat System is tested and demonstrated at the CSTSF, at other shore facilities and on board ship in order to verify compliance with the ship's overall contractual specification.

Combat System inspections, tests and trials are stratified into the following seven discrete levels:

Level 1: Material Receipt Inspection – Level 1 encompasses those inspections that provide for visual confirmation of material, equipment and associated documentation received in the CSTSF and contractor facilities. This level is considered a part of the quality assurance program and as such is not included in the overall trials program. Thus, government surveillance at this level is conducted by quality assurance representatives;

Level 2: Installation Inspections and Tests – Level 2 includes tests and inspections of equipment, cabling, waveguides, piping, ventilation, etc., to ensure that each installation has been accomplished in accordance with PMO CPF approved procedures. This level is also part of the quality assurance program, and inspections are conducted by quality assurance representatives;

Level 3: Installed Equipment Inspections and Tests – Level 3 includes those operational tests which demonstrate that the individual equipment performs within specifications. These inspections and tests are generally conducted independently of the related system. The activity may be viewed as the equipment set-to-work phase and is considered to be part of the test and trials program. Monitoring of the test/trial activities is a quality assurance function, however, DND inspection authority witnesses drawn from related engineering agencies are present;

Level 4: Intrasystem Tests and Trials – Level 4 tests and trials are those which demonstrate that all equipment, entirely within one independent system, performs required functions within specifications. Independent system integration testing and related software debugging/certification take place at this level. Monitoring of the test and trial activities is conducted as outlined for Level 3;

Level 5: Intersystem Tests and Trials – Level 5 tests and trials are those which demonstrate that two or more independent systems interface and perform required functions within specifications. Intersystem integration testing and related software debugging/certification take place at this level. Monitoring is conducted as outlined for Level 3;

Level 6: First-of-Class Trials – Level 6

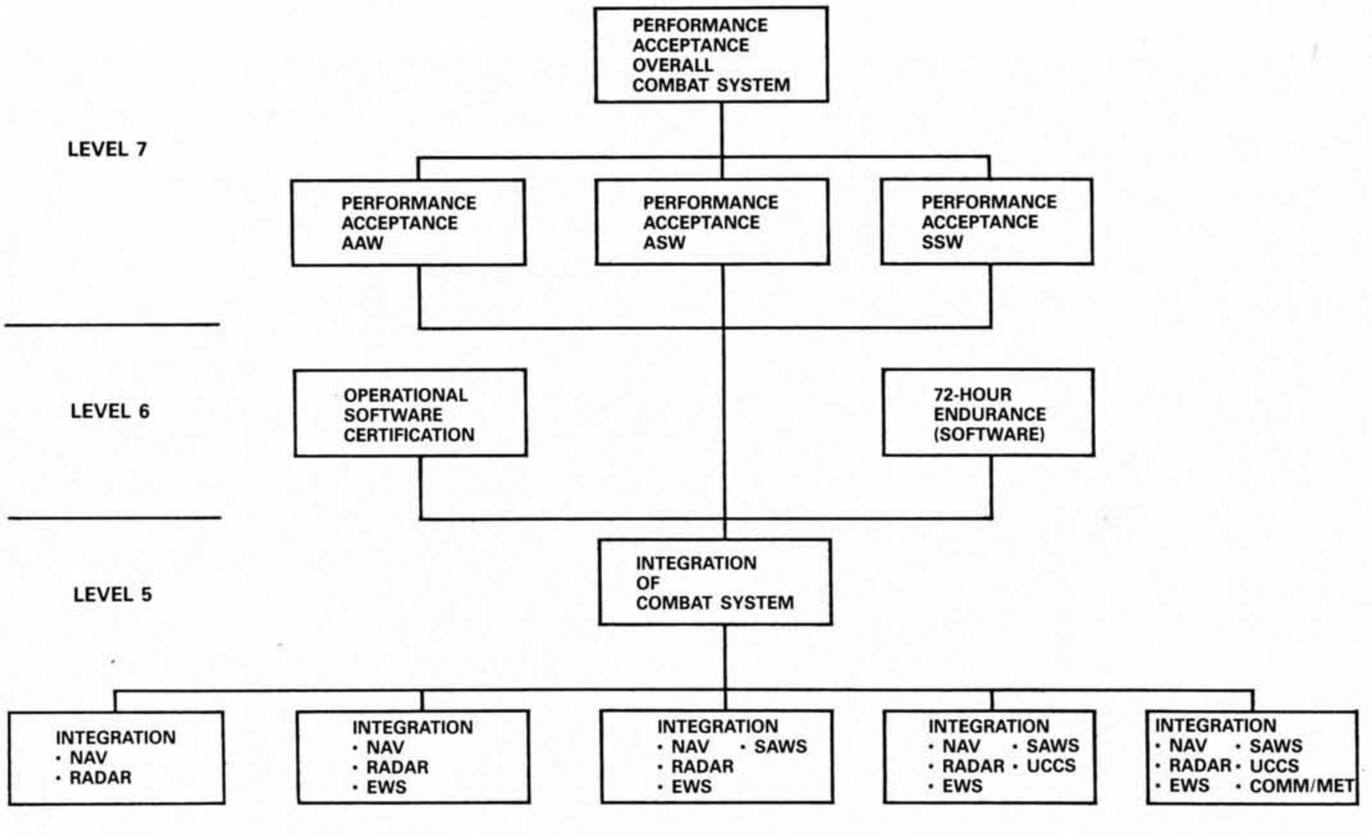


Figure 2. CSTSF Facility Trials — Level 5 to 7 Progression

trials are completed in the first ship of the class to prove system design and/or performance. The objective evidence of design/performance, resulting from the successful completion of these trials, constitutes their completion for the class. Again, monitoring of the related trial activities is conducted as for Level 3;

Level 7: Performance Tests and Trials – Level 7 tests and trials are those which demonstrate and prove that overall ship-system performance is achieved, and are conducted in the CSTSF using simulation where necessary. The ship's performance, however, is not fully verified until it has completed Level 7 trials at sea. Each level of tests and trials must be successfully completed before progressing to the next higher level, until final system performance is proven both in the ships and the facilities.

It should be noted that separate test procedures and trial agenda are prepared by the contractor for Levels 3 through 7. Levels 4 and above include test sheets that specifically address software testing.

Level 1 and 2 inspections in the CSTSF are conducted by 207 Canadian Forces Technical Services Detachment. All other tests and trials in the CSTSF are witnessed by DND inspection authority personnel tasked from PMO CPF Ottawa and/or DGMEM. The upper three levels of tests and trials for the CSTSF are depicted in Figure 2.

Facility trials such as those for the CSTSF, Combat System Training Centre and Gunnery Support Facility are conducted by the contractor to prove that the particular facility is fit for purpose and function.

A separate type of test is the factory acceptance test conducted by a sub-contracted vendor, at his facility, to demonstrate that the equipment he is providing is technically compliant with the purchase contract specification. The actual tests are witnessed by Paramax equipment engineering and quality assurance personnel, as well as by SJSL and DND. Reports are generated as a result of the tests, noting any malfunctions or non-compliance with the procedure specifications. These reports also serve to identify any design deficiencies which may require corrective action.

CSTSF Test Plan

The physical (PMU) and functional mock-up (FMU) areas in the CSTSF, shown in Figure 3, are used to support three basic tasks:

a. computer program certification;

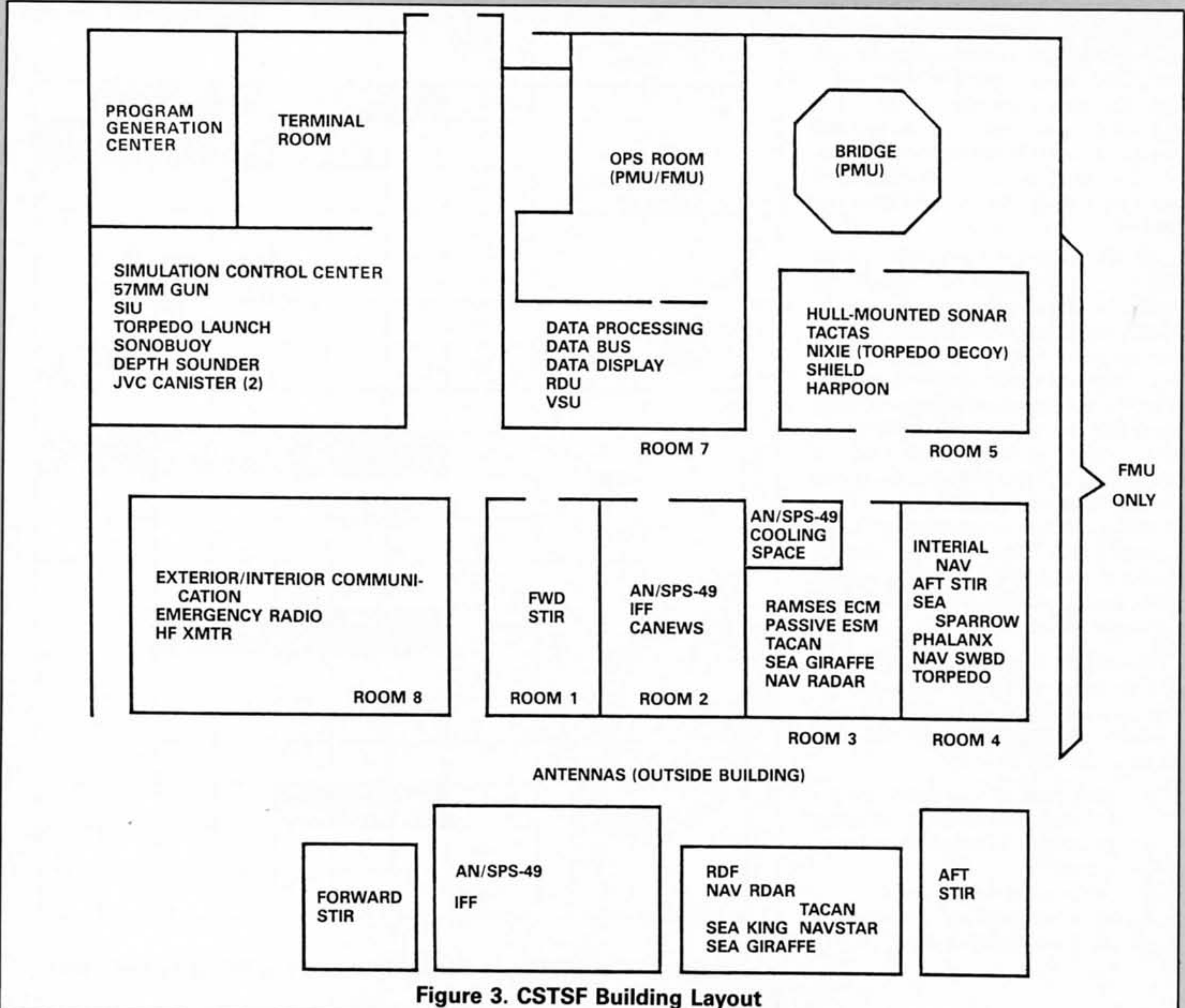


Figure 3. CSTSF Building Layout

b. hardware and computer program integration; and
c. the development, refinement, and validation of the ship-test procedures.

Work at the PMU/FMU is directed through four non-sequential stages which, of necessity, overlap and backtrack in a controlled order. The stages are:

a. hardware installation and checkout;
b. software development, refinement, and certification;
c. system integration; and
d. test procedures development, refinement and validation.

The primary objective of the CSTSF is to provide confidence that, after a combat system is installed on board the CPF, it can be set to work in the shortest possible time with a minimum of shipboard testing and interference with other work. This objective is achieved through the development of an integrated CPF combat system suite in the CSTSF, using simulation where necessary. This suite is identified as the prime equipment option (PEO) set, and provides an experimental platform on which operational software, as well as test procedures and trial agenda, can be developed and verified.

Combat system test proceudres for the PEO set are developed by Paramax, approved by SJSL and concurred with by PMO CPF. If the procedures are verified, and the tests successfully conducted, the procedures will be considered to be acceptable. The test procedures will then be baselined, and thus will form the primary text of the related trial agenda which must then be approved by PMO CPF. Combat system shipsets destined for installation in CPFs 01 through 06 will be tested in the CSTSF grooming area. These tests will be conducted to ensure that each set, as a minimum, functionally integrates with the CPF command and control system.

Hardware installation and checkout (INCO) at the PMU/FMU will involve the first three levels of testing in a manner similar to that planned for the ships. The sequence for INCO is:

a. equipment is staged and given a QA inspection prior to installation;
b. equipment is installed and connected;
c. power is turned on; and
d. system parameters are checked in the local operating mode.

In summary, the objectives of CSTSF tests and trials are to:

a. verify that equipment/system performance is in accordance with contractual requirements;
b. verify the integrated performance of the Combat System; and
c. collect objective evidence of performance for acceptance of CPF PEO systems by SJSL from Paramax Electronics Inc.

Ship Test Plan

The CSTSF trials program is conducted to verify that test procedures properly demonstrate performance requirements under controlled and repeatable conditions, given the limitations of a shore-based facility. The final proof of performance will be demonstrated aboard ship during sea trials.

The purpose of shipboard integration tests is to demonstrate the continuing validity of the accumulated objective evidence within the limitations of the shipboard environment.

Construction tests and trials are conducted by SJSL or its representatives during ship construction. They include structural inspections and tests, pre- and post-installation inspections, and set-to-work and equipment/system integration testing. These activities are coordinated by SJSL through the shipbuilders' shipyard inspection and test plan. *Alongside and sea trials* are conducted by either SJSL, or by PMO CPF (on behalf of SJSL), to determine performance of the equipment, subsystems and ship.

Ship trials are divided into three categories, as follows:

Category I are those trials for which SJSL has total responsibility for the

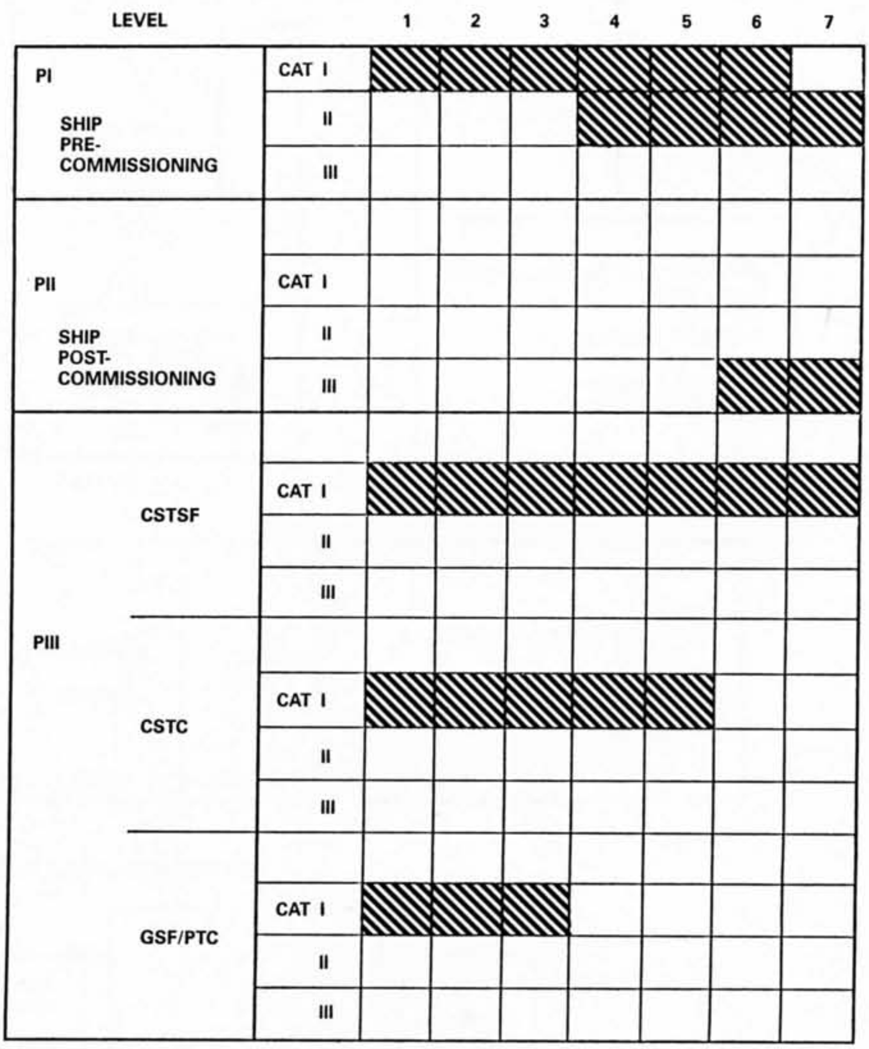


Figure 4. Test and Trials Distribution by Part, Category and Level.

conduct of trials and the provision of related facilities and resources;

Category II are those trials for which SJSL has total responsibility for the conduct of trials, where the government accepts the responsibility to provide specific resources and/or services; and

Category III are post-commissioning trials which are scheduled and conducted by PMO CPF on behalf of SJSL, and for which PMO CPF accepts the responsibility to provide specific resources and/or services. System performance responsibility remains with SJSL, including the responsibility for repair of defects in accordance with the warranty provisions of the contract.

Figure 4 shows the distribution of ship trials categories versus test levels 1 to 7.

Acceptance of a CPF System by the Canadian government takes place at the end of the Category I and II trials period. Acceptance is subject to the completion of outstanding trials and the rectification of defects and deficiencies, all of which are listed in the Report of Inspection. Category III and post-commissioning incentive trials are also included as outstanding trials in the Report.

Incentive trials may be scheduled and conducted by either SJSL or PMO CPF, depending on the trial category under which they fall. They are trials where the contractor demonstrates that a CPF system or subsystem exceeds the performance criteria set out in a mutually exclusive performance specification of the CPF contract. In these cases, the amount of the contractor's profit is increased by the amount appropriate to the performance demonstrated. Ship incentive trials will be conducted in the lead ship only. Those classed as Category III will be conducted within eighteen months of delivery and acceptance of the lead ship.

Facility Trials

The responsibility for the conduct of building and performance trials in CPF shore facilities rests with the contractor. He must also prepare all related trial agenda and submit them to PMO CPF for approval.

Facility trials are conducted by SJSL or its representatives in CPF shore facilities which include:

a. Combat System Test & Support Facility (at Montreal);

b. Personnel Training Facility (Halifax) which includes:
   (1) Combat System Training Centre (CSTC), and
   (2) Propulsion Training Centre (PTC):

c. Gunnery Support Facility (Dartmouth).

The facility trials are conducted to determine fitness for purpose, and function. They are categorized either as building trials, which deal primarily with the building structure and services, or as equipment/system trials which deal with the CPF hardware and software to be tested and trialed in the facilities.

As indicated, there are two shore facilities (other than the PMU/FMU at the CSTSF) involved in the test and trials program which are located within the Canadian Forces Fleet School, Halifax. These are primarily designed as training facilities, although there may be some testing done at each to augment the objective evidence obtained from the trials conducted at the PMU/FMU, or to assist in solving shipboard problems.

The Propulsion Training Centre, collocated with the CSTC in the Personnel Training Facility, will house a Paramax-supplied integrated machinery control system (IMCS) trainer, consisting of a partial IMCS, a simulation computer, instructor's console, Local Operator Panel emulators and the assorted peripherals required to operate the system.

The outfitting of the CSTC will be the last major task in the CPF project. It involves the transfer of all the government-purchased equipment in the PMU/FMU from Montreal to Halifax under the responsibility of Paramax. Detailed procedures for the teardown and shipment of the equipment are being developed. The installation plan for the CSTC is being developed as the plan is developed for the PMU/FMU. When the plan for the installation, checkout, and set-to-work for the PMU/FMU is completed and proven through usage, it will be modified, as necessary, for the CSTC.

The Gunnery Support Facility (GSF) in Building 21 of the Naval Armament Depot at Dartmouth will house the Bofors 57-mm gun, the close-in weapon system, an abbreviated set of weapon launchers, and classrooms for instructing the operation and maintenance of the weapons. Installation of the facility is supported by a facility test plan which includes QA procedures for inspection of the construction and the installed systems. The plan will be supported by a trial agenda which will be used to demonstrate installation, checkout and set-to-work of CPF equipment fitted in the GSF.

Concluding Remarks

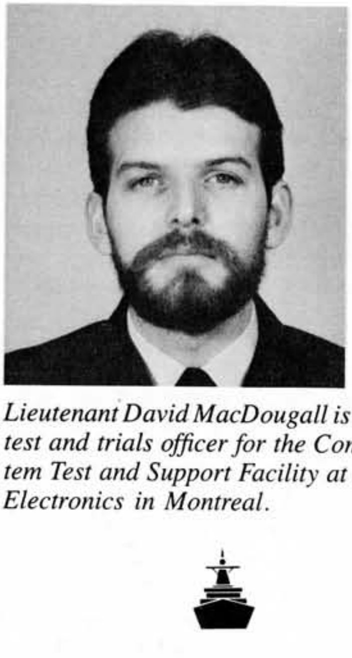
The objective of the CPF test and trials program is to ensure that all CPF systems and facilities meet or exceed the performance requirements specified in the contract. It is the contractor's responsibility to demonstrate CPF system performance.

The CPF test and trials plan is developed around the philosophy of total system integration. This is reflected in the integration of CSTSF, shipboard and other facility trials all under the same program guidance. The result will be that, through demonstration, the ship, its systems, subsystems and equipment will meet or exceed the contracted performance requirements.

References

1. CPF Concept of Operations — Test and Trials, PMO CPF, January 1987.

2. CPF implementation contract, 29 July 1983.



Lieutenant David MacDougall is the DND test and trials officer for the Combat System Test and Support Facility at Paramax Electronics in Montreal.

Requirements Influencing the Design of Canadian Naval Gearing

By D.K. Nicholson, P. Eng.

Adapted from a presentation made to the Naval Propulsion Gearing Symposium at Royal Schelde, Vlissingen, The Netherlands, 3-4 September, 1987.

Introduction

In 1950 the Royal Canadian Navy with its *"St. Laurent"*, or DDE-205 Class of destroyer escorts, was reputed to be the first navy to adopt surface hardened and ground propulsion gearing on a class-wide basis. This commenced a practice which continued through subsequent classes of destroyers up to and including the DDH-280 Class COGOG destroyers. It was perhaps a matter of surprise in some quarters when in 1983 the Canadian navy accepted a "hard-on-soft" hobbed and shaved design of double helical propulsion gearing for the Canadian Patrol Frigate program.

The purpose of this paper is to provide an overview and appreciation of the changing requirements and their influence on the type and design of Canadian naval propulsion gearing over the last 35 years, particularly as they relate to noise reduction. While the Canadian navy's gearing requirements have generally been seen to be pushing the state of the art, they are in fact based simply on what is attainable at an affordable cost.

Dominant Requirements

Figure 1 shows how the dominant requirements influencing the design of propulsion gearing have changed since the DDE-205 Class. Next to high reliability, which is *the* dominant requirement which all naval propulsion gearing must satisfy, the DDE-205 Class or Y-100 type gearing was primarily influenced by the need for minimum weight and space. This was certainly a major factor in a 2600-tonne steam destroyer and called for gearing using the highest attainable, tooth load-carrying capacity; e.g. surface hardened and ground gearing.

Low noise was not a requirement in the DDE-205 Class. Cost was not a dominant

	DDE-205 (1952)	DDH-280 (1966)	CPF (1983)
Reliability	●	●	●
Minimum Weight & Space	●		
Low Noise		●	●
Life-Cycle Cost			●

Figure 1. Main Gearing — Dominant Requirements

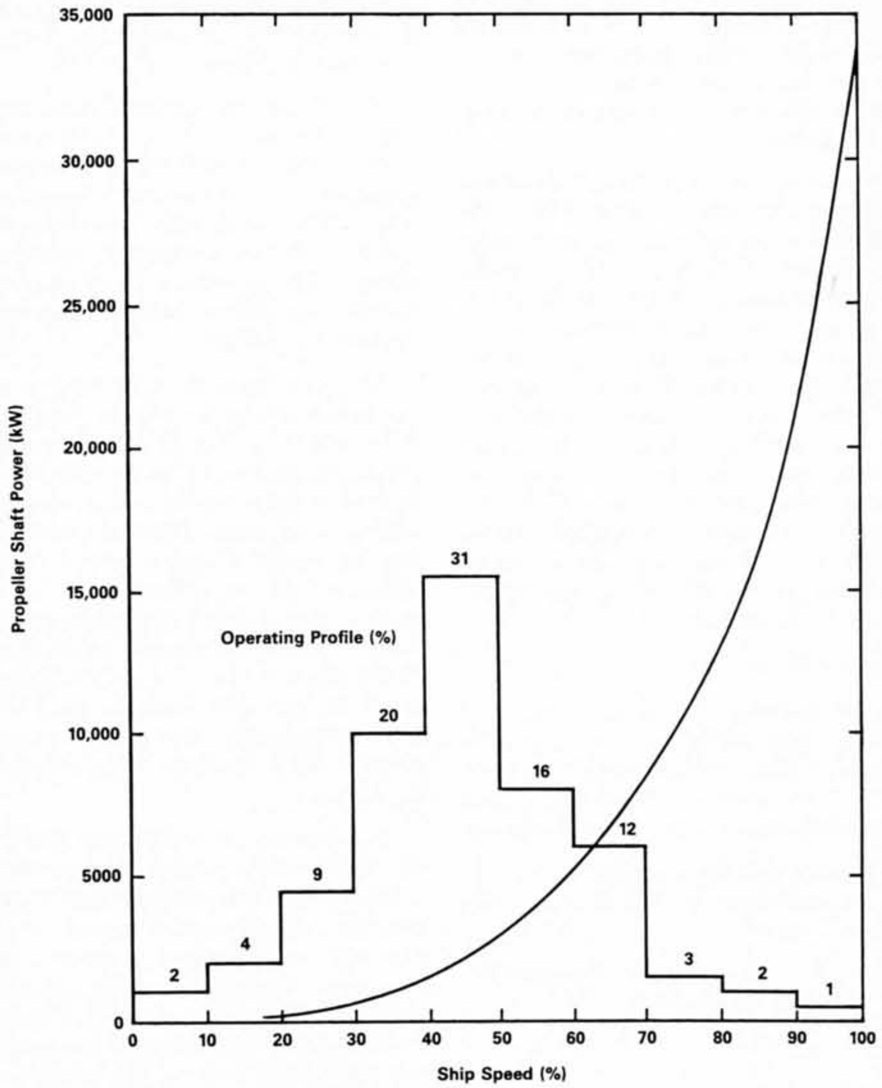


Figure 2

factor under the then current defence industry preparedness policy of setting up facilities for the manufacture of naval propulsion gearing in Canada.

By 1966, when the DDH-280 Class gearing design was selected, anti-submarine warfare requirements were dictating the need for the lowest attainable levels of machinery noise and vibration. These levels were satisfied in the DDE-280 Class with precision surface hardened and ground gearing, but with lower specific tooth loading and therefore higher specific weight and space than for the DDE-205 Class. (This was acceptable in a 4500-tonne ship.)

In the Canadian Patrol Frigate (CPF), which is nominally 4600 tonnes, the main gearing design and type has been predominantly influenced by low-noise requirements — even more stringent than for the DDH-280 — and by cost, including life-cycle cost. Minimum weight and space were important, but were not a dominant factor for CPF.

Case for Cross-Connect Gearing

Following the 1973 oil crisis, fuel consumption and projected life-cycle fuel cost became a major factor in propulsion plant selection. For CPF, combined considerations of propulsion plant capital cost and in-service operating cost weighed very much in favour of the case for cross-connect gearing — giving the capability for maximum use of single-engine, two-shaft operation.

Figure 2 shows a typical power versus percentage speed curve for a nominal 4600-tonne destroyer. A typical destroyer speed profile, giving the percentage time spent at each increment of speed, is superimposed. It will be seen that two thirds of the ship-operating profile is spent at half maximum speed or less. Ninety percent of the time is spent at not more than two thirds maximum speed.

Figure 3 shows the percentage speed attainable with a number of the engine-drive options considered for CPF; namely, two main gas turbines, two cruise gas turbines, one main gas turbine, and one cruise diesel. By considering the propulsion fuel consumption (given in Figure 4) in barrels per hour for these engine-drive options, the fuel economy to be derived from operation on a single main gas turbine or a single cruise diesel can be well appreciated. Single-engine operation saves on fuel and engine maintenance, but without cross-connect gearing to drive both propeller shafts a trailing propeller can create unacceptable noise and drag.

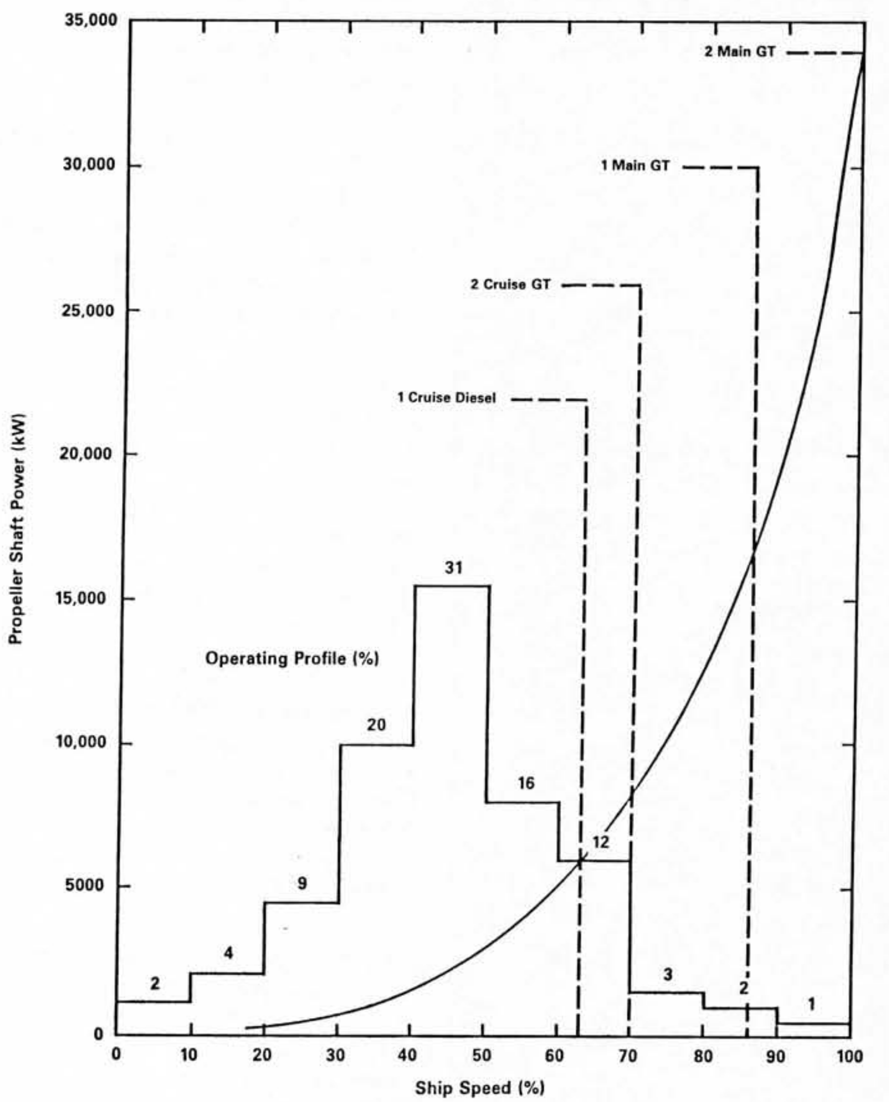


Figure 3. Engine Drive Options

Figure 5 gives a comparison of fuel consumptions for operation at 15 knots under each of the four engine-drive options or modes considered. The saving of just one barrel an hour can mean an annual fuel cost saving per ship of over $100,000 (U.S.) at recent fuel prices.

Weight and Space

At least one surface hardened and ground gearing proposal submitted for CPF was judged to be capable of satisfying the stringent noise and vibration requirements. Surprisingly, the acceptance of the hobbed and shaved "hard-on-soft" gearing proposal did not involve an undue weight or space penalty. The dimensions of the main bull-gear, which must transmit the maximum propeller shaft torque, provide a useful indicator of the size and weight of propulsion gearing.

Figure 6 provides a comparison of bull-gear sizes and of specific gearbox weights for DDE-205, DDH-280 and CPF gearing. Allowing for the additional weight of the cross-connect unit in the CPF gearing, it will be seen that there is a surprisingly small difference between the specific weights of the DDH-280 and CPF gearing which are both designed to meet low-noise requirements. The size of the CPF cross-connect gearing is clearly shown in Figure 7.

Noise and Vibration Reduction

The sectional arrangement of the CPF gearing in the ship is shown in Figure 8. The gearbox is supported on four longitudinal lines of soft resilient mounts, providing both shock protection and vibration attentuation.

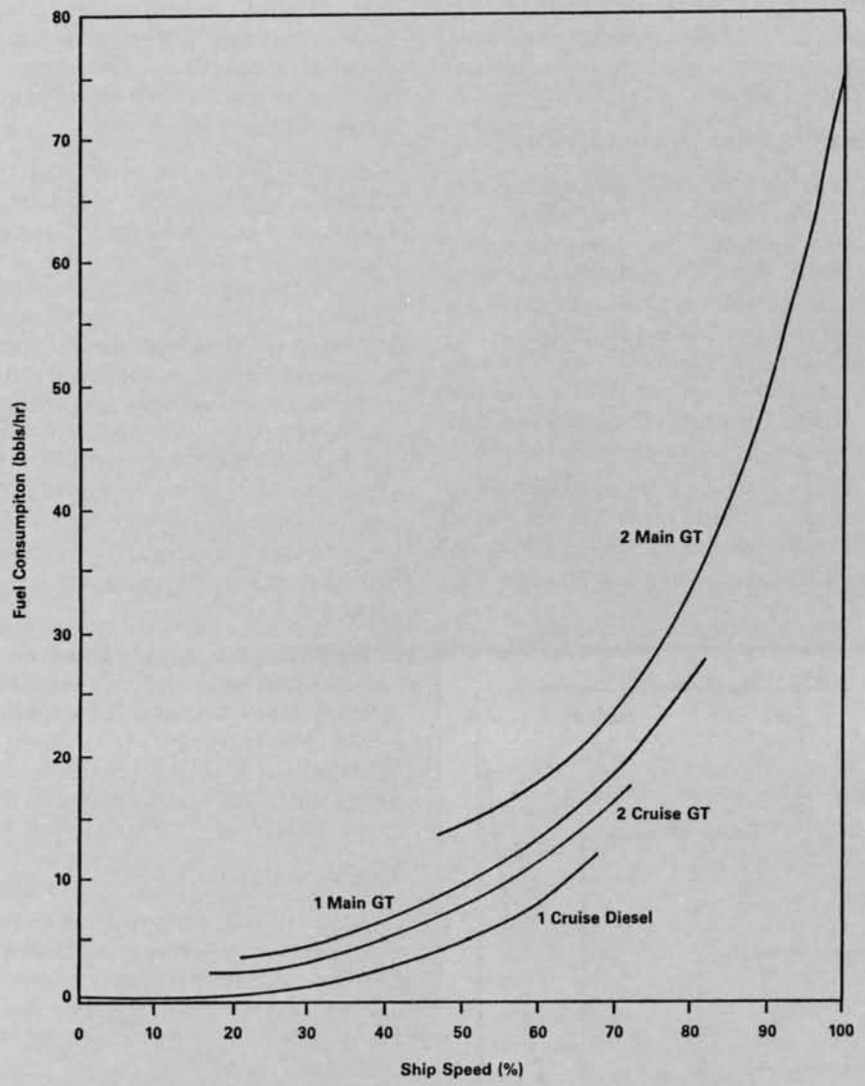


Figure 4. Fuel Consumption vs. Percentage Speed

	Bbls/Hr
2 Main GT	15.0
1 Main GT	10.0
2 Cruise GT	9.0
1 Cruise Diesel	6.0

Figure 5. Fuel Consumption at 15 knots

	DDE-205	DDH-280	CPF
SHP/Shaft	15,000	25,000	23,000
Reduction	25.3	15.6	17.2
GW II Diameter (mm) Face (mm)	1720 350	2516 500	2500 688 + 120
Weight kg/SHP/Shaft	1.14	1.82	2.36
Relative Weight per Unit Shaft Torque	1.0	1.67	1.92

Figure 6. Comparison of Power, Weight and Size

Ship machinery noise and vibration requirements are of course determined to satisfy the required underwater noise performance. It is the practice in the Canadian navy to define the equivalent maximum permissible vibration levels measured at the skin of the ship for specific ship speeds. The responsibility for determining the type and design of the gearing and of the mounting arrangement, necessary to meet the specified hull-vibration levels, is left entirely to the ship contractor. In the case of CPF, the contractor confirmed the need for resiliently mounting the gearing, and then identified the maximum acceptable, 15-knot above-mount vibration levels to be complied with during the partial-load shop testing conducted on the first shipset of gearing.

Figure 9 shows the measured DDE-205 and DDH-280 Class gearing vibration levels at 15 knots, expressed as relative octave-band values to the CPF gearing shop-test requirements. It should be noted that the DDE-205 vibration levels would be at least 3 VdB higher had the gearing been resiliently mounted as for the DDH-280. At the same time, the 15-knot datum level for the CPF gearing in the ship installation could be 3 VdB higher than for the partial-load shop test. The DDH-280 gearing clearly provides a very significant improvement in vibration levels over the earlier DDE-205 Class. It can be seen how the DDH-280 below-mount vibration levels have influenced the setting of the required hull-vibration levels, also shown in Figure 9.

The above-mount vibration levels, measured during the partial-load shop testing on the first shipset of CPF gearing, are seen to compare very favourably with the shop-test requirements. The loading attained during the testing corresponded approximately to the 13-knot ship condition, but there can be little doubt of the ability to satisfy the specified 15-knot vibration level.

Specific Tooth Loading

The CPF propulsion gearing has unquestionably attained an outstanding level of noise and vibration performance for the power and size of the unit involved. Given the use of appropriate tooth contact and overlap ratios, and the attainment of the highest practicable standard of gear accuracy, the CPF results may well suggest that low gearing noise is equally dependent on the use of lower specific gear-tooth loading; falling within the range of finishing by gear shaving.

While there is no evidence to show that precision ground gearing designed for the same tooth loading would be quieter, it should at least be capable of being as quiet. The question that must be asked, however, is "How far, with surface hardened and ground gearing, can specific tooth loading and bending be increased before higher vibration levels would result?"

The major factor inhibiting the advancement of tooth loading in quiet gearing is seen to be the problem of minimizing, if not eliminating, the effect of tooth bending and deflection on the smoothness of power transmission. The provision of profile and helix modifications, to equally satisfy ideal load distribution and meshing conditions at full power as well as at quiet running part-powers, is still considered to involve two incompatible requirements.

Figure 10 compares the secondary reduction tooth loading of the three classes of gearing. Given that both the DDH-280 and CPF gearing have been manufactured to very high standards of accuracy, it is a matter of conjecture as to whether, and how, the relatively small difference in tooth loading and module sizes between the two designs can be related to the measured difference in vibration levels. It may at least be postulated from this comparison that the design of quiet gearing cannot readily utilize the full tooth load-carrying capacity available in either surface hardened or through-hardened gearing.

It will be seen that considerations of minimum weight and space have not unduly influenced the ability to satisfy the Canadian navy's *quiet* propulsion gearing requirements to date. This has permitted the use of modest tooth-loading factors in both hardened and ground, and in hobbed and shaved gearing designs. Future surface ships, and certainly future submarine propulsion gearing requirements, can however be expected to impose severe limitations on weight and space. Together with a trend to higher output shaft torques, this will unavoidably raise specific tooth loadings up to and beyond the DDE-205 Class levels and could require the fullest utilization of the load-carrying capacity obtainable only with surface hardened and ground gearing.

Conclusion

The Canadian navy can be expected to continue pushing the state of the art with its future propulsion gearing requirements. It will particularly be looking to the gearing industry for its response to the challenge of meeting future naval propulsion gearing requirements calling for more compact and more highly loaded designs, with noise and vibration performance at least equal to that achieved in the Canadian Patrol Frigate.

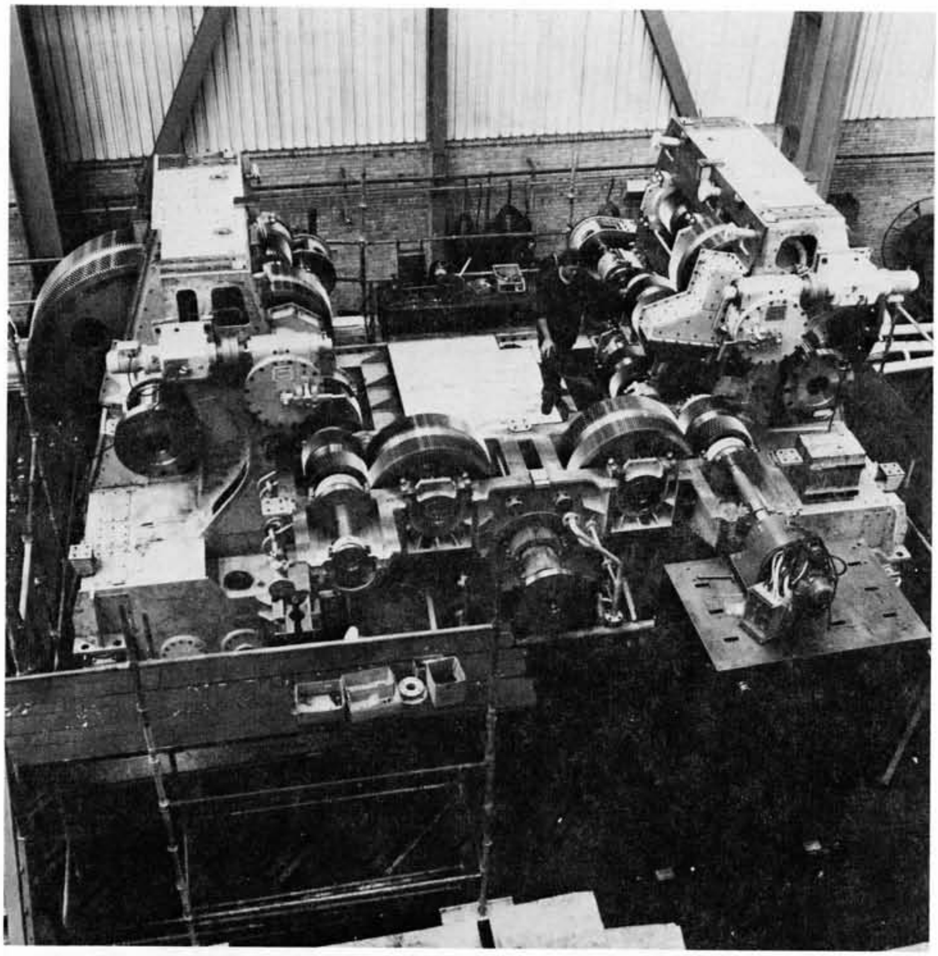


Figure 7. CPF Gearing Assembly (covers removed)

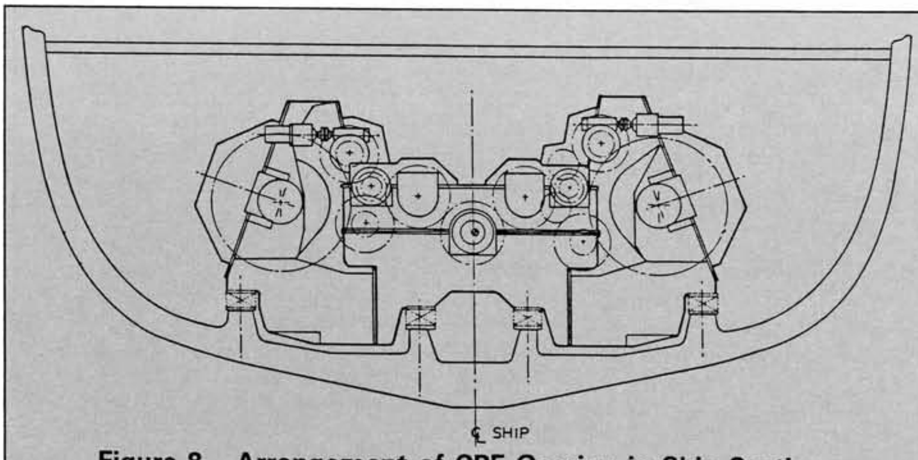


Figure 8. Arrangement of CPF Gearing in Ship Section (view from aft)

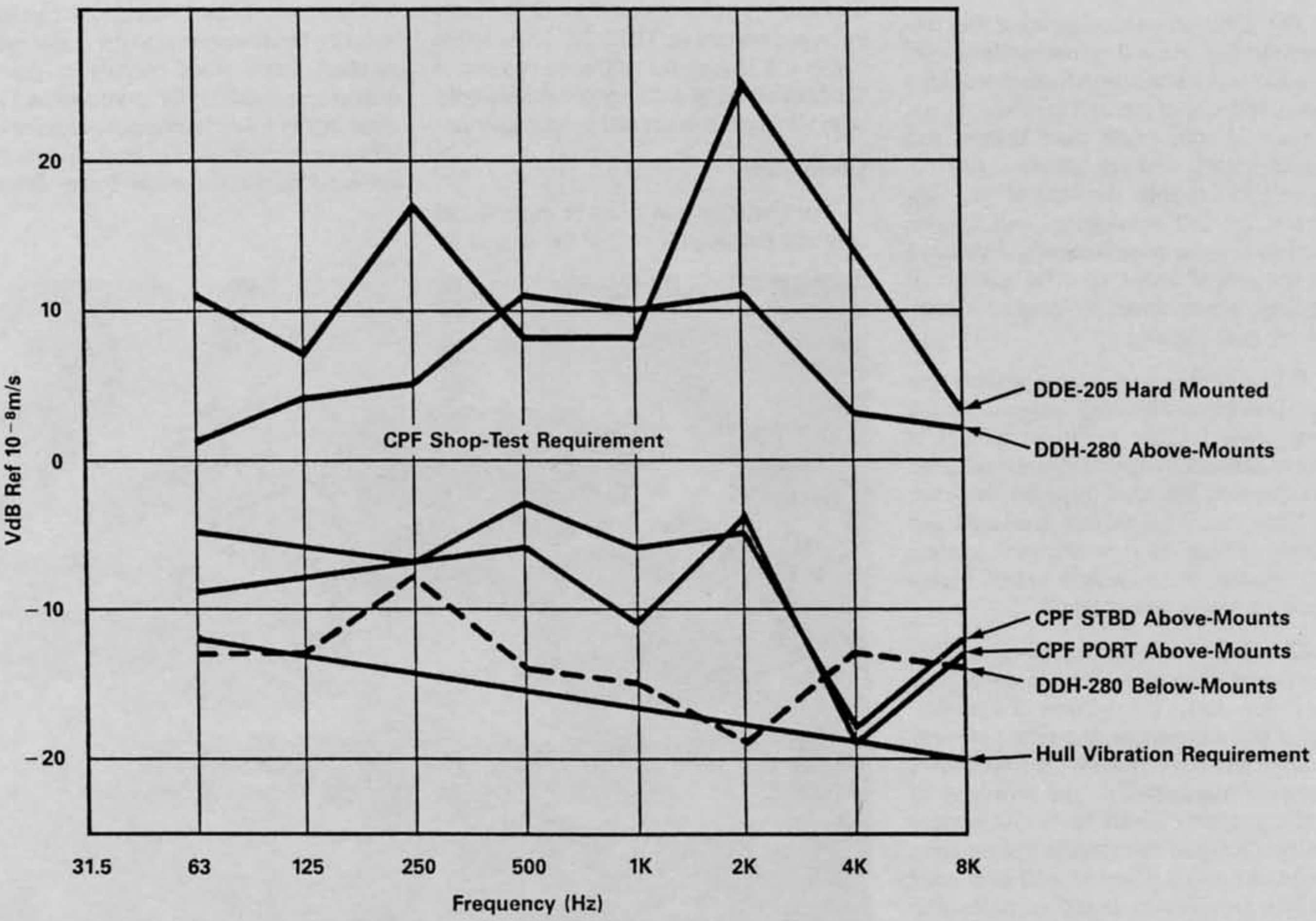


Figure 9. CPF Main Gearing Vibration (shop test)

		DDE-205	DDH-280	CPF
Material	(Pinion)	Carburized	Carburized	Nitrided
	(Gear)	Carburized	Nitrided	Thru Hard
K Factor	N/mm²	2.83	1.62	1.37
	(lb/in²)	(411)	(235)	(198)
Module		9.00	8.32	8.07
Unit Load/Normal Module N/mm²		90.54	74.74	61.44

Figure 10. Second Reduction Gear Tooth-Loading

Don Nicholson is an internationally respected naval gearing expert. At the time of his retirement from the public service last September, Mr. Nicholson was head of the DMEE 3 Propulsion Systems section in NDHQ.

Profile: Gloria

A familiar face in NDHQ's maritime engineering division.

By LCdr(R) Brian McCullough

Ask Gloria Jessup what the best part of her 30 years' civilian service with the navy has been, and she'll tell you it's the people she's met in the job. Ask her what she has liked best about being DGMEM's personal secretary for the last 18 of those years and she'll tell you that it's the unpredictability of the work.

"I know one thing for sure," she said in an interview last January, "when I get up in the morning I don't know what I'll be doing during the day — something like Maggie Muggins — and that makes it interesting."

Chaotic as this might seem, it's more an indication of how quickly change can happen in the course of a day than of how the office is managed. "I've run into problems," she admitted, "but you have to square them away in a hurry — which I do because that's my job."

Listening to the determination in her voice it's hard to imagine that there was ever a time when Gloria lacked self-confidence. But she told of starting her career as a "painfully shy" 17-year-old secretary to the Naval Hydrographer in 1958, the same year the St. Lawrence Seaway opened. She had just completed the commercial course at Ottawa's Fisher Park High School, learning her trade the traditional way, yet it hardly prepared her for the frustration she would face in overcoming her uneasiness with people and her particular fear of using the telephone.

For reasons she wasn't able to pin down, Gloria said she always wanted to be a secretary and for the most part saw her career develop much as she hoped it would. Only once did it take a turn for the worse, when after five years with the Naval Hydrographer's Office she moved on to a secretarial position in Naval Personnel.

The move was a mistake. Working for a man whom she could only describe as miserable, she missed the team-oriented atmosphere of the hydrographer's office and at the end of a year decided to compete for another position — that of secretary to the project manager of the FHE-400 hydrofoil project. There was a sour note, though, when her boss at Naval Personnel warned her not to bother coming back if she decided after the interview not to take the job at the hydrofoil office. This only made her more determined than ever to get out and she took the gamble. "I went for the interview," Gloria said, "and, my God, I never looked back."

The next six years turned out to be some of the most enjoyable of her career, working first for the hydrofoil project and, when that project ended, for the project manager of the DDH-280 program which had just geared up. Then, in 1970, she finally got a shot at a job she'd only dreamed about: personal secretary to the "big boss" — the Director General of Maritime Engineering and Maintenance. "It was a little hard on the nerves," she said, recalling that she went into the job without a turnover from her predecessor. "I was feeling my way in the office for a while." Now, almost 20 years later, she is a veritable fount of knowledge and has become something of an institution within the maritime engineering division.

The worst part of it all, Gloria said, has been the increasing amount of paperwork coming into the Division. Today she works with an assistant, but until three years ago she was handling it all on her own. "I look back and wonder how I ever did it," she said. As far as the correspondence leaving the office goes, Gloria readily admits she is a stickler for perfection. "People probably call me 'picky, picky, picky', but that doesn't really bother me. I'd rather see the work going out the way it should."

According to Commodore Boyle, DGMEM, Gloria is more of an executive assistant than a personal secretary. "I manage the Division — Gloria manages me," he said. "Gloria manages my time, and she's very good at that. She has a good sense of what's important and what's not important."

Commodore Boyle, who will be promoted rear admiral at the end of April and appointed Chief of Engineering and Maintenance, said that the executive assistant role also means having to be a "bulldog", screening callers to prevent unnecessary interruptions. "Gloria does that very nicely," he said, "without anybody getting upset or offended. But they also know they won't get in here."

Controlling access to the inner office calls for judgment, a delicate balance of tact and steadfastness, and for occasionally resorting to polite subterfuge with bothersome callers. But to Gloria's mind that goes with the turf. "The way I look at it," she said, "my job is to make my boss look good. I feel that that's my responsibility. He should never look bad."

Apart from the day-to-day challenges of managing the office, the internal changes brought about over the years by successive directors general have kept the job interesting for Gloria. As she said, "They're all different, and want things done differently. Although you don't change your job, it's almost like you have gone to another position."

When Commodore Broughton takes over as DGMEM in May he will be the eighth DG Gloria has worked for. Four of them she has seen promoted rear admiral. Several of the eight, including Commodore Broughton, Gloria knew earlier as lieutenants or lieutenant commanders, and she said there is nothing strange about working for them later under their broad pennants. "I'm just glad to see that they are able to come back as commodores," she said. "I'm happy about it."

Does she have a favourite? One director-general who perhaps meant a little more to her than the others?

"I've thought about that," she said, pausing to choose her next words. "I think to myself, well I liked this one because . . . or I liked that one because . . ., but I liked all of them for certain things. They're all wonderful. They're such gentlemen, they really are."

Although Gloria may choose to continue working for another five years, she finds that with 30 years' service behind her, and with her two children grown her thoughts are turning more and more towards retirement. Her plans in that direction are still a bit sketchy, but she said that she would love to spend more time on her flower gardening and would like to get into some kind of volunteer work.

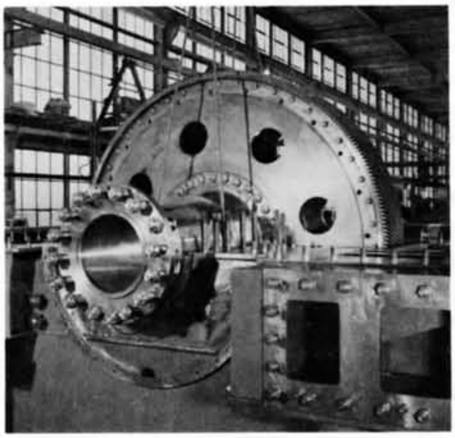
As far as her career is concerned, the good experiences have obviously remained foremost in Gloria's mind. She said that she had no regrets. "If I had to do it over," she said, "I would do it exactly the same way. I've really enjoyed my thirty years."

LCdr McCullough is the Production Editor of the Maritime Engineering Journal.

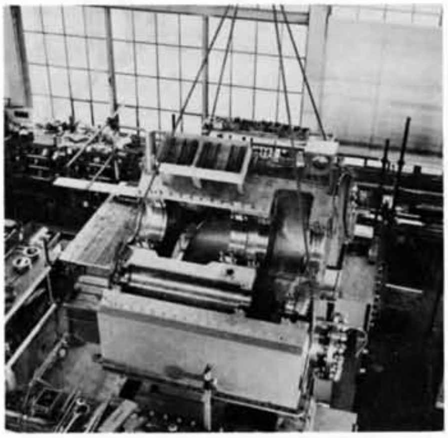
Looking Back: DDH-280 Gearbox Assembly

By Steve Dauphinee, DMEE 2

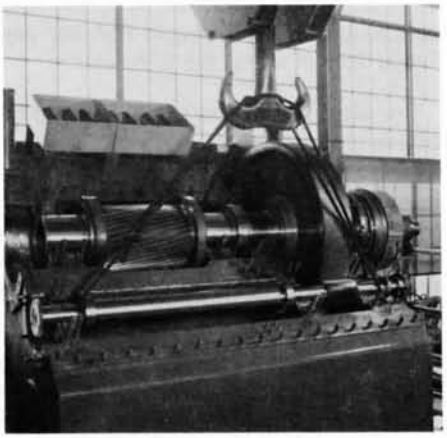
This remarkable series of photographs taken at the Maag plant in Zurich in 1968 clearly shows the final assembly of the first DDH-280 gearbox components.



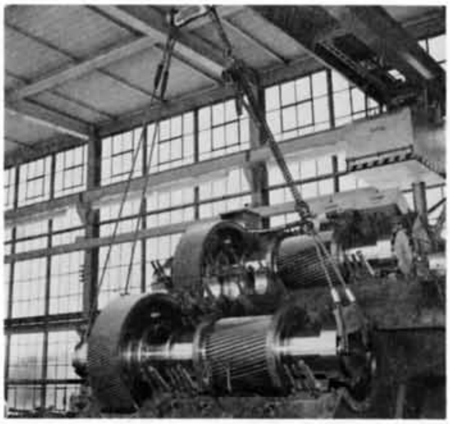
1. First, the eight-foot diameter bull gear is placed in the lower gearcase.



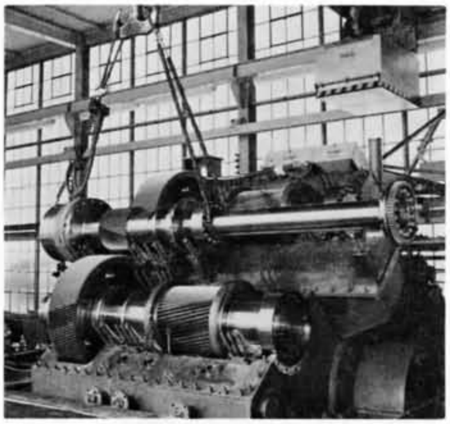
2. The upper gearcase is lowered over the bull gear and attached to the lower gearcase



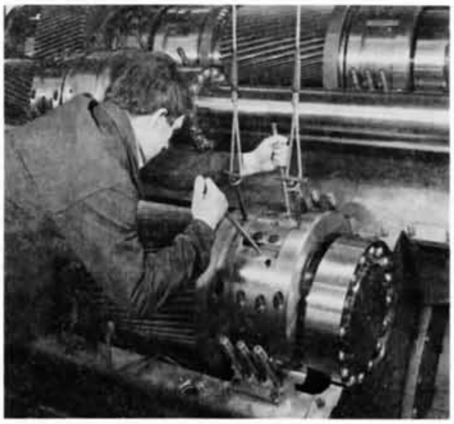
3. Then, the cruise engine input pinion ...



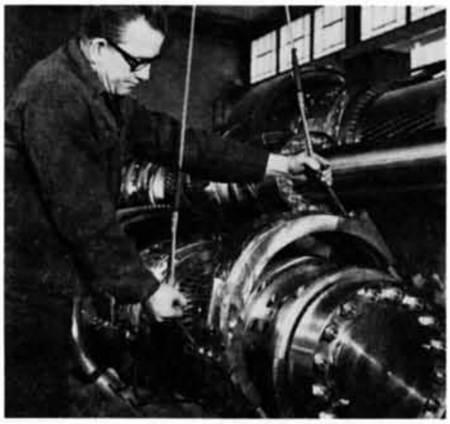
4. *... main engine intermediate pinion and gear ...*



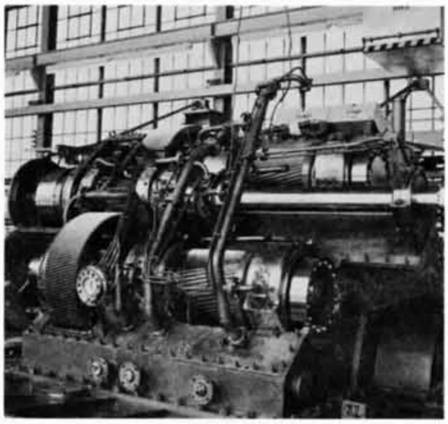
5. *... and main engine input pinion and clutch are placed in the upper gearcase.*



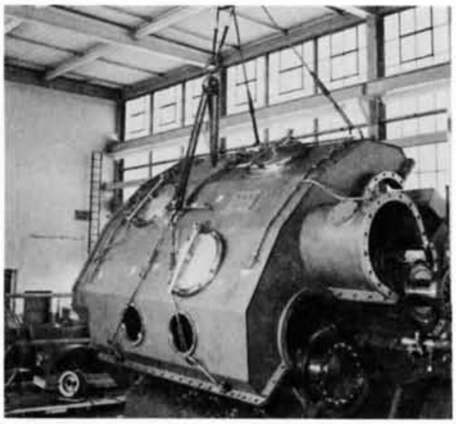
6. *The bearings are positioned ...*



7. *... and bearing caps installed.*



8. *Lube oil piping is attached.*



9. *Finally the gearcase cover is installed, and once bearing temperature probes are attached the gearing is ready for shop testing.*

News Briefs

CANTASS joins the fleet

In February, the advanced development model (ADM) of the CANTASS towed-array "dry end" (display and processing equipment) was installed in HMCS *Annapolis* and integrated with the ship's array receiver, AN/SQR-19 towed array, and handling and stowage gear. The system is currently being extensively trialed so that lessons learned from the ADM can be incorporated into the final eight production units.

Delivery of the "dry end" marks the near-completion of an intensive four-year CANTASS development effort by the navy and by Computing Devices Company Ltd. of Nepean, Ontario. ADM trials are expected to be completed this summer.

NATO AAW System

A NATO anti-air warfare system (NAAWS) development program commenced last year, with participation by six nations: Canada, Germany, the Netherlands, Spain, the United Kingdom and the United States. The rationale for Canadian involvement was that NAAWS potentially offers the only economical way for Canada to participate in AAW development and gain access to modern AAW weapon technology.

The requirements for NAAWS include the enhancement of sensor coverage using multiple sensors, decreasing the reaction time to engage incoming targets, and increasing the capability to engage new threats. The NAAWS program is a three-phased effort to develop a system that will comply fully with NATO Staff target requirements by 1988, and to develop upgrades to existing AAW system components for use in an interim system by 1994.

Last October the six nations signed a memorandum of understanding to participate in a $35-million (U.S.) concept exploration (CE) phase. During this initial phase of the NAAWS program, industrial study contracts will be issued to three international consortia, and engineering experiments and studies will be conducted using national government laboratories or industries. The United States contributed 47 percent of the funding for this phase, while the remaining 53 percent was divided among the other five nations.

St. Barbara's Day 1987

One of the people in this photo does *not* use the new microscreen shaver from Remington. (If you said the one in the middle, you were right.) She's St. Barbara — patron saint of gunners.

Each year in early December the folks at the fleet school's Osborne Head gunnery range near Halifax commemorate St. Barbara by inviting the fleet gunners out for a day of competition and bonhomie. According to range OIC LCdr Tom Willdey, "It's a good, fun type day."

St. Barbara (A.K.A. naval weapons tech P 2 Bruce Raymond) was putting in an appearance at the 1987 celebrations when she took time to pose for a few snaps with fleet school commandant Captain (N) Thomas F. Brown and guest, Commodore D.R. Boyle, DGMEM. Captain Brown said it was wonderful that the navy's senior engineer found the time to attend the gunners' celebration of their patron saint.

The Product Work Breakdown System
— blueprint for CPF construction

— Coming up in our September issue