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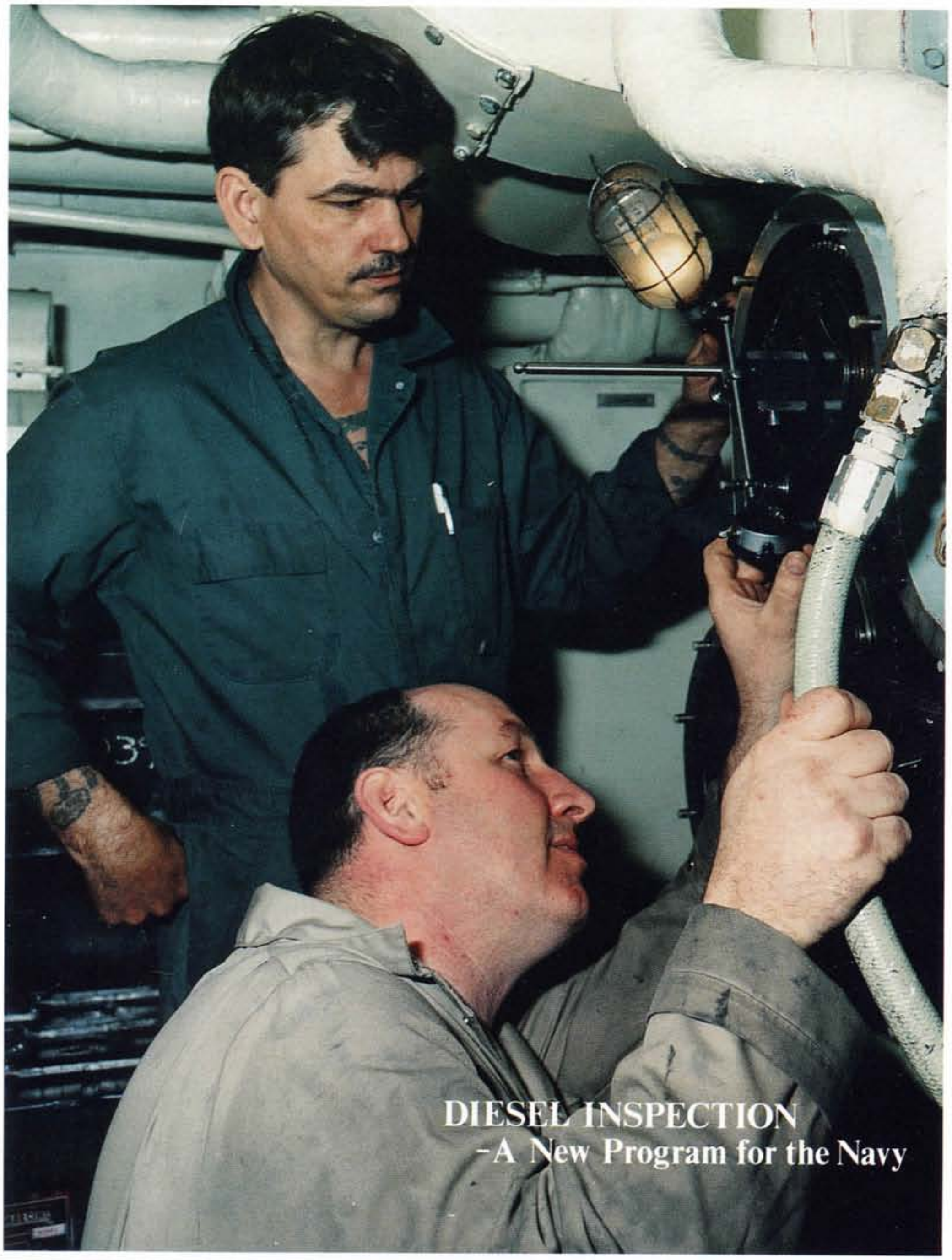
Maritime Engineering Journal

September 1988



Canada

Halifax Float-up
19 May, 1988

Story and more photos on page 21

Maritime Engineering Journal

Director-General
Maritime Engineering and Maintenance
Commodore W.J. Broughton

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DEPARTMENTS

FEATURES

OUR COVER

John Henderson of the U.S.-based American Management Systems looks on as FMG(P) Diesel Inspector, CP01 Bruce Ferrie inspects a diesel engine on board the harbour training ship *Columbia*.

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Editor's Notes

It is a pleasure, this issue, to welcome the newly appointed Director General of Maritime Engineering and Maintenance — Commodore W.J. Broughton. By way of introduction, we offer this biographical sketch of our new MARE Branch Adviser.

Commodore Broughton joined the RCN in 1953 under the Regular Officer Training Plan. He attended Royal Roads and the Royal Military College, graduating in 1957, and received a BSc in mechanical engineering from Queen's University in 1958. Following basic officer training he completed postgraduate studies in science and naval engineering at the Massachusetts Institute of Technology. He is also a graduate of the Canadian Forces Command and Staff College and the National Defence College.

During the early part of his career he served as a project officer for the FHE-400 hydrofoil and was involved in structural design work for the *Restigouche* Class (IRE) conversion. He also served in HMC Dockyard, Halifax where he was responsible for hull system surveys and repair specifications for east coast ships and auxiliary vessels. He spent three years in Ottawa as senior naval architect, then project systems engineer for the DDH-280 new construction program, followed by two years in Halifax in charge of DDH-280 post-commissioning trials of operational and combat systems.

On his promotion to Captain(N), Cmdre Broughton attended National Defence College. Afterwards, as Director of Maritime Engineering and Maintenance, his responsibilities included CPF and Destroyer Life Extension project development, fleet improvements, R & D in hull systems and ship design, and major ship projects. He subsequently served as Director Program Analysis, responsible for the development of the Defence Program Management System, and in 1983 was appointed to the Personnel Group for one year as the MARE Get-Well project officer. In 1984 he assumed the position of Director of Postings and Careers Other Ranks.

Commodore Broughton was promoted to his present rank in August 1986 and appointed Director-General of Recruiting, Education and Training. He was appointed DGMEM on May 23rd of this year.

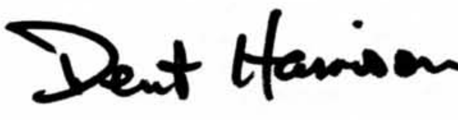
He is married and has three grown children.

Turning to our lead article, the implementation of the diesel inspection program is proceeding as planned with the first official course to be held in Halifax this autumn. As an interim course it will be administered by DMEE 2 with the help of NETE. Successful candidates are expected to be posted to annotated Diesel Inspector positions in the naval engineering units and fleet maintenance groups.

The qualification of Marine Diesel Inspector should soon be recognized in the CF. With approval of a Special Personnel Qualification Requirement recently submitted to the Director of Military Occupational Structures, the diesel inspector's course taught on a trial basis last year should become a fully recognized occupation specialty qualification course.

Since that trial course in July 1987, there has been an increasing wave of support for diesel inspections on both coasts. Dozens of inspections have been performed which, in some cases, have revealed serious problems before major damage occurred and in other cases resulted in the deferral of costly, unnecessary overhauls.

There is still much work that needs to be done to attain a common high standard of diesel training, operation, inspection and maintenance throughout the navy. To that end, everyone's continued support of the diesel inspection program will ensure its success.



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.

Letters to the Editor

Dear Sir:

I continue to read the Journal *with interest; congratulations on another series of interesting articles.*

I am writing to put an operator's perspective on Lt(N) Sylvestre's article "An Introduction to Stirling Engines". He begins with the premise that SSKs are a valid vehicle to support the emerging Canadian Maritime Strategy and therefore propulsion enhancements would be appropriate. The recent White Paper clearly differentiated between submarines of "position" and of "manoeuvre" which places an entirely different perspective on the operational requirements to which the engineering design must be subordinate.

The history of experimentation with Atmosphere Independent Propulsion Systems has been a chequered one, marked by periods of bright prospects offset by disapointing results. AIP systems have failed to reach operational status in open-ocean navies for the very reason that they did not support a strategy of "manoeuvre". Lt(N) Sylvestre cites the Swedish experiment as a sign of the way ahead; but consider the Swedish operational requirement — it is largely one of "position". Swedish submarines operate in a very restricted belt of National Waters and in the Baltic. They are of 1200-ton average displacement (submerged) with complements of less than 30. They operate on patrols averaging less than a week and are as limited by food storage and oxygen capacity as much as by their propulsion system. Despite the presence of ice in the Baltic, Swedish submarines operate only on the ice fringe.

Now consider the Canadian situation. By the mere facts of geography, Canadian Submarines must operate thousands of miles and several weeks away from home port. These factors alone require an ocean-going submarine of considerable dimensions and with a larger complement. Add the requirement for an under-ice capability and the Swedish experiment is not a relevant example. Submerged patrols within the "manoeuvre" strategy now being advocated for the Canadian Navy could easily reach into weeks rather than days. A time-limited propulsion system is clearly an unacceptable restraint.

We should always be ready to consider new and innovative solutions. But, our solutions should emphasize achievement of the strategic arm through technology as opposed to finding a place to apply a technology by justifying the strategy.

D.C. Morse
Commander
Commanding Officer
HMCS Skeena

Dear Editor,

I am pleased to see that my article on Stirling engines aroused some interest, but am surprised that Cdr Morse does not seem to consider marine systems engineers to be "operators."

That aside, I regret to note that he apparently misinterpreted my premise which was that a combination *of SSNs and AIP system-equipped SSKs,* not *solely the latter, might be a more broadly capable submarine force than one comprised only of SSNs.*

On the point that small 1200-tonne RSwN submarines are not particularly relevant to Canadian operations, I agree. That is why I based my thesis on the 2400-tonne Upholder Class submarine. It should be noted as well that the first RSwN submarine with Stirling engines has not yet completed sea trials. In a couple of years, when they have the capability, they may well be operating under the Baltic ice.

We should indeed "always be ready to consider new and innovative solutions." For that reason it is important to keep abreast of developing technology in other navies while we strive to meet the needs of our present strategy.

R.A. Sylvestre
Lieutenant Commander

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.

Commodore's Corner

By Commodore W.J. Broughton

Your editor has kindly invited me to write an article for this issue of the *Journal*. As the new MARE Branch Adviser, I think it is only appropriate that personnel matters be my chosen theme.

Much of what I will say is a reflection of the deliberations of the April meeting of the MARE Council. So let me emphasize at the outset that these remarks are largely a reflection of the excellent progress made under the leadership of RAdm Boyle, my predecessor. You should all be aware that he "turned over" an active, healthy program for which, I know, you would want me to express publicly the thanks of the MARE community.

Although I just used the term "MARE" community, the Council is equally concerned with the NCM sea technical occupations. Our collective ability to man, support and renew the fleet is directly affected by their "health". Full strength and adequate training are essential. Accordingly, deep concern was expressed by the Council about maintaining "production" in the face of increased target strengths and the additional training load as we prepare to receive the new CPFs and TRUMPed Tribals. You should know that some shortfalls are unavoidable within our share of total CF training credits. Generally, the situation has been and should remain manageable. The one critical area is the MARE ELs and E Techs. Higher recruitment rates have been instituted to ensure steady progress in their trained strength.

The Council gave unanimous approval-in-principle to seek the establishment of a new Control and Instrument Technician occupation. Command and DGMEM staffs will jointly develop the proposal to meet the future operations and maintenance requirements of digital technology in machinery control systems. In the interim, a specialization course has been established.

When it came to MARE officers, the Council received two excellent reports on MS and CS training audits. Their conclusions and recommendations were essential to the refinements now under way to improve the timing, emphasis and content of that training. Briefly, the findings were:

- the basic structure of the MARE occupation is sound
- there are no fundamental structural problems with the training schemes proposed in the MARE Study
- the implementation of the training details to meet this structure has not been thorough and accurate
- in some cases less than optimum location of requirements within the basic occupation, sub-occupation and head of department specifications has caused some elements of training to be included too early in the training progression
- the AMSEO and ACSEO jobs must be for a minimum of twelve months
- for the MS sub MOC, operator training had been de-emphasized more than intended in the MARE Study.

During June, a MARE specification review board with MARE officers from the Command and NDHQ, including representatives of all sub-occupations, met to work the kinks out of the specifications. Rapid staffing and approval is planned. The next step in September will see Course Training Standard boards working to amend the training documentation that controls the context of courses and on-job training. So you can see, there is concerted follow-up action in train to overcome the weaknesses found in the training audits.

In closing, I wish to say how delighted I am to have been offered the opportunity to be DGMEM and the MARE Branch Adviser. My role, as I perceive it, is to ensure that the best possible policies, planning and procedures are in place so that the productivity of our people is happily optimized. In this way I believe I can best serve the community. I am committed to that aim in these most challenging times.

The Diesel Inspection Program

By LCdr Richard Sylvestre

Introduction

The major projects under way to upgrade the Canadian navy are placing a new and greater emphasis on diesel engines for propulsion and electrical power generation. Modern diesels offer advantages over rival systems in part-load fuel consumption, reliability, ease of on-board repair, maintenance costs and availability of spares. But to capitalize on these important benefits, it is essential that operating standards be kept high and that maintenance be based on engine condition rather than on traditional calendar-based criteria. In the past these basic rules of good diesel engineering practice have usually not been adequately taught or applied — particularly where surface vessels are concerned — meaning that now significant improvements will have to be made to diesel engine operation and maintenance standards across the fleet if the technical demands of the future are to be met. Several initiatives are now addressing this issue, one of which is the Diesel Inspection Program[1] being implemented by the Director of Marine and Electrical Engineering with the assistance of the Naval Engineering Test Establishment.

Background

Historically there has been little success in ascertaining diesel engine condition prior to repair or overhaul. Engines have been overhauled at considerable expense whether they needed it or not, and some have been run almost to the point of self-destruction because defects were not recognized in their early stages. Operating standards have also been somewhat less than ideal, leading invariably to premature failures. This unsatisfactory state of affairs can be attributed to a lack of effective diesel equipment health monitoring techniques and to inappropriate marine engineering occupation courses. A recent study at Fleet School Halifax[2] showed that diesel courses lacked sufficient hands-on training and were not adequately preparing marine engineering personnel to operate and maintain engines at sea.

Until recently these problems did not receive a great deal of attention. Certainly the increasing costs of diesel support for the aging submarines and auxiliary vessels were a concern, but since the major warships only used diesels for emergency or standby electrical power the problems never assumed major importance. That changed overnight, however, when the design for the Canadian Patrol Frigate was determined. The CPF's dependence on sophisticated, modern diesels for all cruise propulsion and electrical power elevated the navy's concern for diesel operation and maintenance to high-profile status.

Initiatives now under way in the diesel field include the construction of a well-equipped training facility and the revision of occupation courses in Fleet School Halifax, implementation of a diesel inspection program, replacement of obsolete engines, various SHIPALTs to improve filtration, lubrication and oil testing, and improved control of spare parts' quality. In addition, overall diesel support policy for the entire inventory of about 500 engines is being promulgated in the Marine Diesel Engine Equipment Logistics Directive[3], and diesel entries to the Naval Engineering Manual are being revised and expanded.

Diesel Condition Analysis

Overhauling engines at fixed calendar intervals regardless of accumulated running hours or engine condition is a simplistic approach which often introduces new problems in the process of correcting old ones. The move towards logical, condition-based maintenance (CBM) is therefore welcomed. The difficulty in this new approach to maintenance is in reliably determining engine condition. The established naval equipment health monitoring (EHM) techniques of spectrometric oil analysis and vibration analysis have been ineffective for this purpose, so there is a requirement to adopt new techniques. Better procedures for oil and coolant testing are now being implemented, and investigations are under way to identify suitable, automated electronic EHM equipment. Although these latter methods have high potential, they are still in early development and it will be many years before their impressive potential can be realized.

Lacking any other form of definitive EHM technique to support CBM, it is essential that the navy's technical personnel be more effectively utilized. This can be done by training select individuals in the skills of engine condition analysis. As the United States and British navies have both proven by their respective diesel inspector and specialist programs, significant gains can be made in increasing engine reliability and reducing maintenance costs. Although both these navies are investigating electronic EHM techniques as well, they foresee much value in the continued employment of personnel for engine diagnosis.

Diesel Inspections

In July 1987 a highly acclaimed diesel inspector's course was given in Halifax by ex-USN diesel inspectors. During and after the course, on-site inspections of operational diesel units revealed an alarming lack of expertise among Canadian diesel operators and maintainers. Common diesel equipment deficiencies across the fleet included excessive leaks and accumulations of dirt and engine fluids, faulty instrumentation, incomplete and inaccurate engine records, scored cylinder liners, piston blow-by, faulty injectors, worn rocker arms and incorrect lock-wire procedures. In particular cases, broken piston rings, defective bearings, unserviceable emergency trips and dangerous fuel leaks were discovered before major engine damage occurred.

The evidence arising from the inspections caused a great deal of discussion, which eventually led to the decision to implement a Canadian diesel inspection program[1] using ideas from both the USN and RN. The concept as described here is not complicated. It is a fundamental EHM technique based on trained observation of defects. A diesel inspection will entail a thorough mechanical and administrative examination, wherein a qualified diesel inspector, over two or three days will:

a. assess the state of all technical documentation associated with the engine, including manuals, logbooks, oil and coolant analysis records and maintenance records;

b. assess the general housekeeping and instrumentation state of the engine;

c. by removing inspection covers and components as necessary, examine wear components such as bearings, rings, cylinder liners and valves, and examine the adjustment of fuel racks, timing mechanisms, governors and safety devices;

d. by monitoring the engine under normal operation, identify deficiencies indicated by leaks, incorrect operating temperatures, pressures and flow rates, and reduced power output; and

e. prepare a formal inspection report with computer assistance for distribution to the ship and relevant shore authorities.

Diesel inspections will provide detailed assessments of mechanical condition for the internal engine components such that corrective maintenance may be targeted to specific defects. This should greatly reduce the overhauling of engines needlessly, and will identify minor malfunctions before they develop into serious failures. In addition to their obvious utility in making maintenance decisions, regular inspections should also:

a. increase the fleet's awareness and application of correct procedures for operation and maintenance, thereby reducing the incidence of preventable corrective maintenance; and

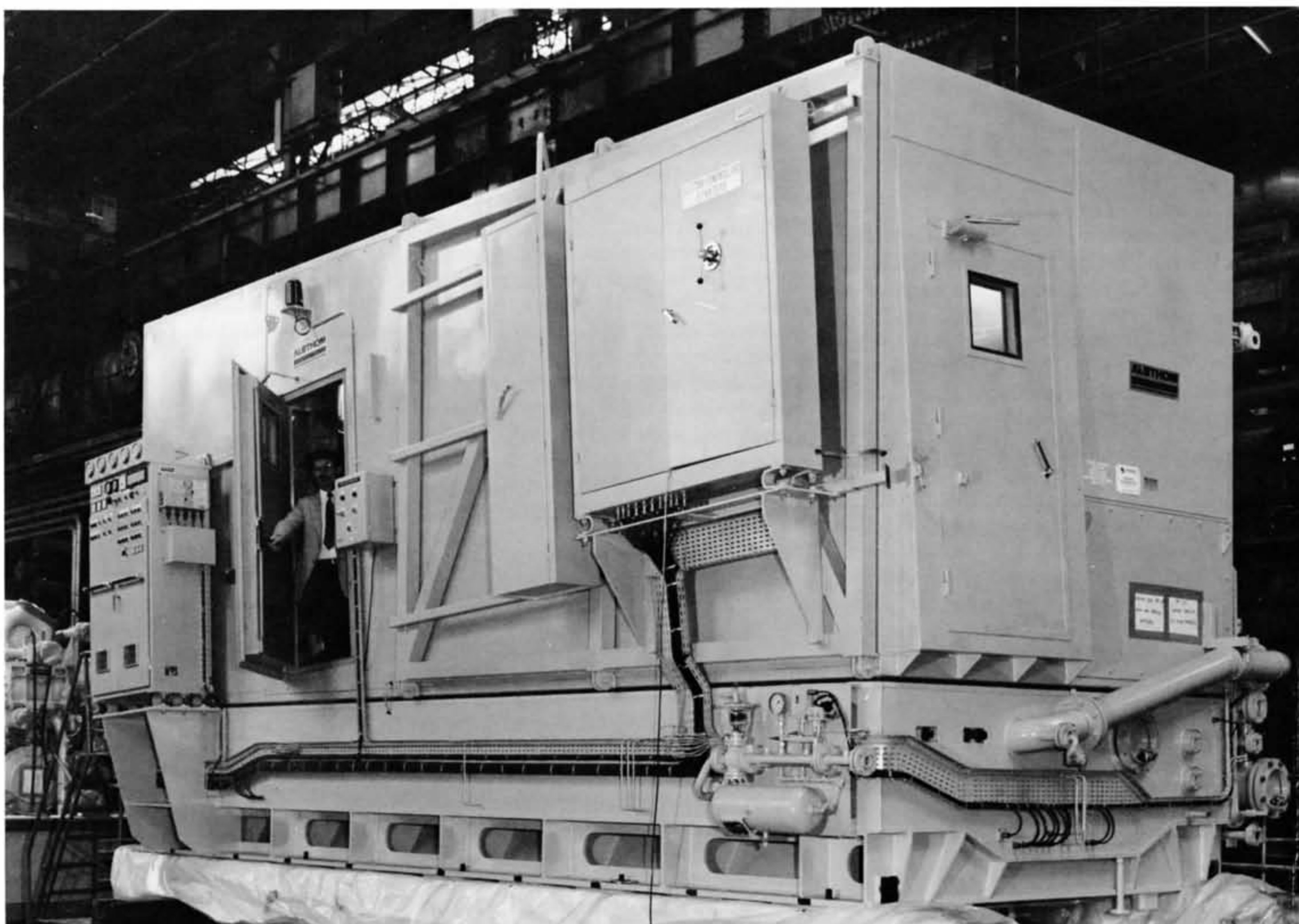
b. serve as a constant and visible indicator of the fleet's diesel operation and maintenance standards.

Initially, inspections will be done annually and during pre- and post-refit/overhaul on most engines over 200 kW, and on other critical or costly engines. As the program is integrated into the maintenance management system, inspections will be called up by preventive maintenance schedules and may be extended to include other engines.

Inspectors

The primary role of the diesel inspectors will be to perform inspections in accordance with a diesel inspector's handbook and relevant technical orders. Other duties will include:

a. assisting and advising ships' staffs in trouble-shooting diesel engine problems;



A 6.2-MW Pielstick cruise engine ready for installation in a Canadian patrol frigate. The CPF's dependence on sophisticated, modern diesels for all cruise propulsion and electrical power has given diesel reliability high-profile status within the navy.

b. advising NDHQ of deficiencies in preventive maintenance schedules, equipment support lists and other documentation;

c. advising the training establishments of apparent training deficiencies in the fleet; and

d. assisting and advising as appropriate on diesel engine trials.

Most of the inspectors will be marine engineering articifers, and when employed in an official capacity as command diesel inspectors will occupy established shore billets for two- to three-year tours. On completion of a tour an inspector may resume normal seagoing duties (albeit with a valuable and much enhanced knowledge of diesel matters), and subsequent shore postings may include senior inspector positions in local or NDHQ establishments.

Applying the basic rules of good diesel engineering practice is the key to the navy's new diesel inspection program. The program holds great promise for significantly increased diesel reliability throughout the fleet.

Diesel inspector training will comprise a comprehensive three- to four-week course, with selection based on experience and past performance as well as on individual availability and other manning requirements. The course is modelled on the USN inspector training and will be contracted to a professional commercial agency until such time as it may be done competently in-house. Subsequent qualification to the diesel inspector's occupation specialty specification will involve on-the-job training, and normally will be done in the first few months of assuming a junior inspector position.

The Way Ahead

With the commissioning of the CPFs and the upgrading of many existing diesel installations over the next ten years, the navy will come to rely on diesel engines for at least 80 percent of electrical power and more than 50 percent of propulsion power. These figures attest to the urgency of the diesel improvement measures described here. Thorough implementation of the inspection program and the other important initiatives will ensure that we manage our new diesel technology at least as well as we have done with steam and gas turbines in the past.

References:

1. 12815-119 (DMEE 2) 22 March 1988, *Diesel Inspection Program*.
2. CFFSH: 4500-1 (ENG/DCOMPT(D)) 8 June 1987.
3. 12815-0 (DMEE 2) 29 January 1988, *Draft Marine Diesel Engine Equipment Logistics Directive*.

LCdr Sylvestre was the DMEE 2 Diesel Projects Officer before taking up his present assignment last June as Machinery Controls Project Officer in DMEE 7.

ASW Frigate Electrical Propulsion

The Way Ahead

By W.A. Reinhardt and J.R. Storey

Introduction

Electrical propulsion for ships has many advantages when compared to the various forms of conventional mechanical propulsion. These advantages include:

* Inherent low noise;
* Minimized fuel consumption;
* Infinitely variable speed and precise control of propeller rpm;
* Simple and rapid reversal;
* Inherent cross-connect capability; and
* Greater flexibility in the propulsion system design and ship arrangements.

(* For Canada there is the additional advantage of easy manufacturability in Canada in time of war.)

Such advantages have permitted electrical propulsion systems to find applications in aircraft carriers, tankers, ocean liners, submarines, icebreakers and oceanographic research vessels. To date, however, an all-electrical propulsion system has never been used in a frigate. This has generally been attributed to the somewhat greater weight, size and acquisition cost of electrical systems compared to mechanical propulsion systems, but these disadvantages can be minimized by the use of modern design techniques, equipment and materials.

In light of developments in high-power, solid-state electrical devices, and today's greater emphasis on low fuel consumption, reduced manning and low noise signature for anti-submarine vessels, electrical propulsion is a viable alternative to conventional drive trains. The Royal Navy, for example, is using an electrical cruise propulsion system for its *Duke* Class (Type 23) ASW frigate.

Since gearboxes and controllable-pitch propellers contribute significantly to ship noise, it is especially desirable to eliminate them from the propulsion systems of ASW frigates. One solution is to use electrical propulsion power for the entire range of ASW frigate speeds.

With this possibility in mind, the Directorate of Marine and Electrical Engineering initiated a feasibility/design study and a simulation study for an all-electric propul-

DIMENSIONS	
Waterline Length	130 m
Beam	14.4 m
Displacement	4354 tonnes
Endurance	5500 nm @ 18 kts 3200 nm @ 23 kts 1500 nm @ 28.5 kts
Speed	28.5 kts (full power) 25.9 kts (GT gen. alone) 23.1 kts (diesel gen. alone)

PROPULSION PLANT	
Propellers	(2) fixed-pitch
Propulsion Motors	(2) 12.5-MW synchronous motors [4160-volt]
Prop. Generators	(3) 6-MW gas turbine gen. sets [4160-volt, 60-Hz, 3-phase] (3) 4-MW diesel gen. sets [4160-volt, 60-Hz, 3-phase]
Prop. Motor Control	(2) 12.5-MW cycloconverters
Propulsion Power	25 MW

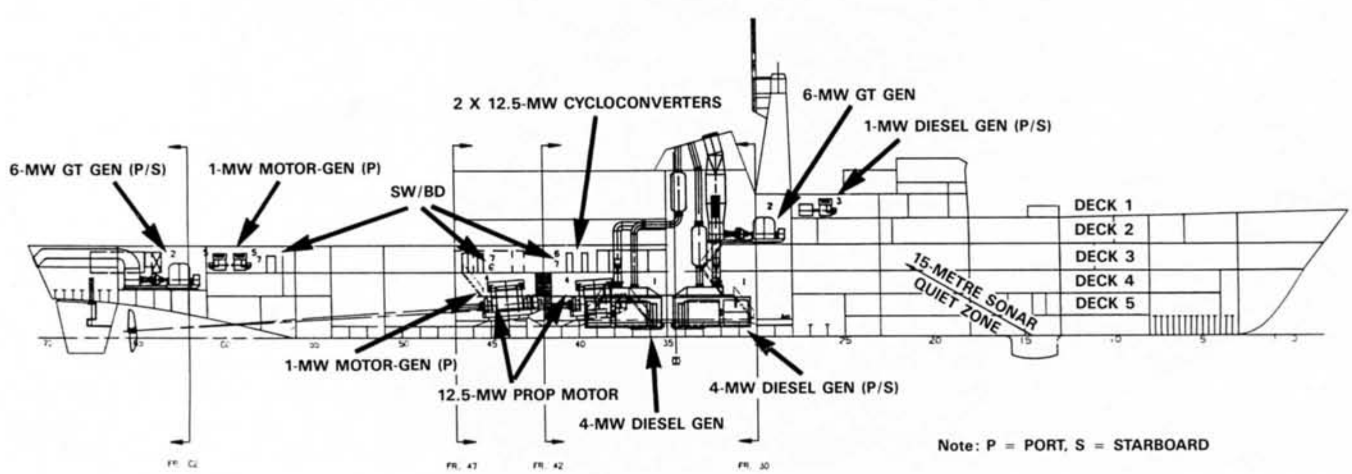


Fig 1. Profile of Proposed COEDAG System

sion system for a frigate-type ship. The objectives of these studies were:

a. to determine the feasibility of satisfying frigate operational and technical requirements by electrical propulsion; and

b. to develop a concept design which would achieve the best results.

In this paper, a frigate design is outlined with background information on the ship design and electrical technology. The system design and machinery arrangement are examined, the advantages and disadvantages discussed, and the results of a simulation study are reported. Finally, conclusions and possible future developments are presented.

Ship Design

The design study demonstrated that an all-electric propulsion system, using current Canadian icebreaker propulsion plant design practices, is a feasible and viable alternative to the conventional mechanical propulsion plant. One of a number of possible general arrangements is shown in *Figure 1*, with the electrical power plant arrangements shown in *Figure 2*.

Machinery Arrangement

The machinery arrangement demonstrates the flexibility of the electric propulsion system, in that the prime movers do not have to be lined up with the shafts or gearboxes. The motors are installed in staggered motor-rooms as far aft as possible, and are limited only by shaft rake, flooding considerations and clearance of the propeller. The arrangement offers improvements in survivability, acoustic signature and reduced infra-red susceptibility of the gas-turbine exhausts. The removal of the large central trunks frees valuable space.

Ship's Service

Ship's service 440-volt, 3-phase, 60-Hz power is provided by two 1-MW synchronous motor-generator sets powered from the propulsion bus. In addition, two 1-MW diesel generator sets are included as backups, in keeping with Canadian navy practice.

Design Rationale

Frigate Design

The design study modelled a frigate using recent NATO frigate characteristics and displacements. This baseline frigate was developed around a CODOG (Combined Diesel Or Gas turbine) system which was also used as a comparison for the electric frigate.

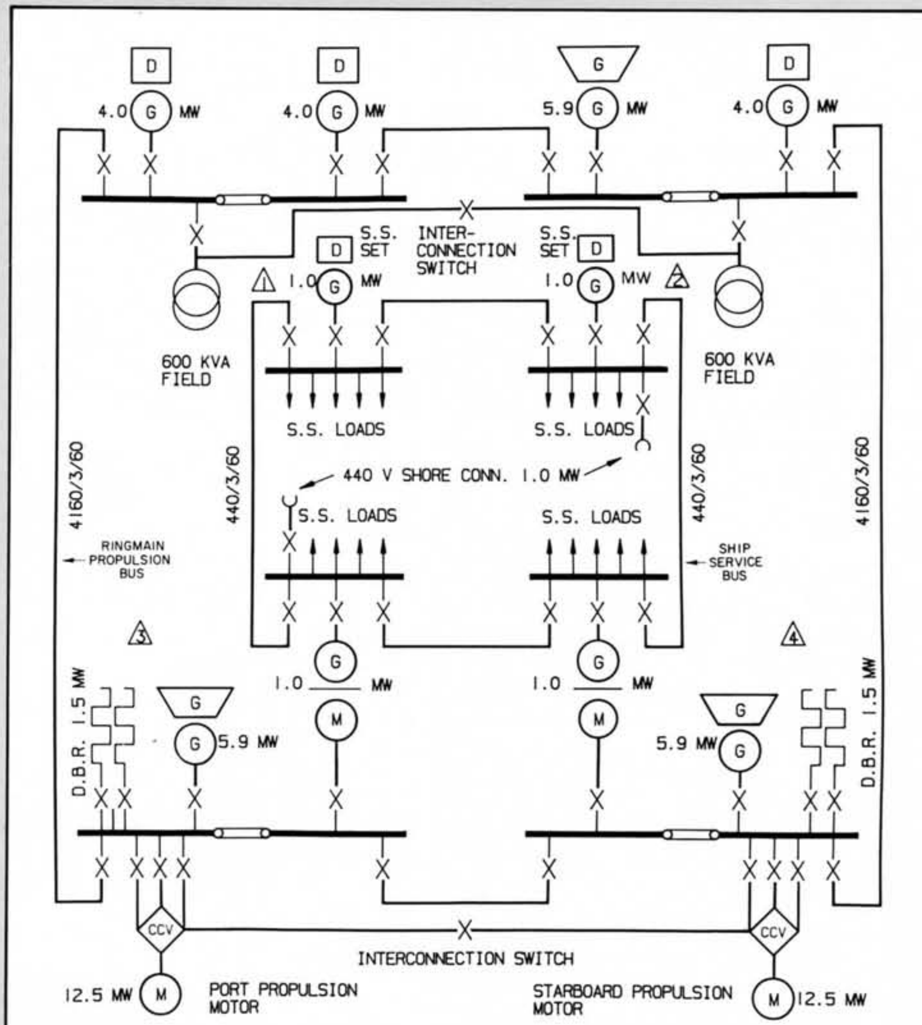


Fig 2. Power Plant Arrangement

PLATFORM CHARACTERISTIC	COEDAG	CODOG
Displacement (tonnes)	4,354	4,247
Fuel (tonnes): To Meet Endurance	402	554
Consumption (Lifetime)	111,000	150,221
Per 100 hrs: (Normal)	113	153
(Defence)	123	163
(Quiet)	177	300
Shaft Power (MW): at 15°C	25	30
at 38°C	25	26.4
at 43°C	25	24.9
Volume of Machinery and Fuel (m^3)	1,362	1,188

Table 1: Platform comparison

The electric frigate was next evolved from the baseline frigate with consideration for Canadian navy design practice. The electric propulsion frigate is COEDAG (Combined Electric Diesel And Gas turbine).

A comparison summary of the electric and baseline CODOG ships' characteristics is given in *Table 1*.

Electrical Technology

The propulsion motor is the most significant component in the propulsion system and requires careful selection. The DC motor is larger than an AC motor of the same power rating (see *Figure 3*) and is therefore unsuitable for a frigate application. The AC induction motor is air-gap sensitive (i.e. requires a small concentric air gap) and hence is more susceptible to damage from shock and deflection of the shaft; a serious disadvantage for a frigate. The AC synchronous motor suffers none of these problems.

Three AC systems that can be used to drive a fixed-pitch propeller are shown schematically in *Figure 4*. The load-commutated inverter (LCI) drive has a wide speed-range, but the minimum speed cannot be lower than ten percent of rated speed due to insufficient motor EMF to self-commutate the thyristors. The cycloconverter drive provides speed control to zero rpm, comparable to DC drive systems. The force-commutated inverter (FCI) drive has only limited power levels, as solid-state devices such as gate turn-off thyristors in the required ratings are still under development.

With regard for the preceding observations and the desire to stay within the Canadian technology base, AC synchronous motors with cycloconverters were selected. *Figure 5* shows the propulsion motor and cycloconverter developed for the Coast Guard Type 1200 icebreaker. The motor is rated for 9.4 MW, which is approaching the 12.5-MW rating required by the frigate model.

Propulsion Bus

For reasons of improved survivability and maintainability, the ring main system was selected as shown in *Figure 2*. The 4160-volt system was chosen due to the decreased size of the motors and generators, and because of the lower current ratings (smaller cables and circuit breakers). Cable selection and installation must also take into account electromagnetic interference and compatibility (EMI/EMC) and the harmonic distortion created by the cycloconverter.

Ship's Service

The ship's service power must meet the requirements of STANAG 1008. A number of different methods to derive ship's service power from the propulsion bus were examined, including transformers, inverters and motor-generator (MG) sets. Transformers and inverters were discarded due to a combination of poor power quality and EMI problems. MG sets were examined in more detail and then incorporated.

Propulsion Generator Prime Movers

It was determined that between three and seven propulsion generator sets could be used with regard to reliability, maintainability, complexity, weight and space limitations, etc. Working with the requirement of a minimum of 25 MW of propulsion

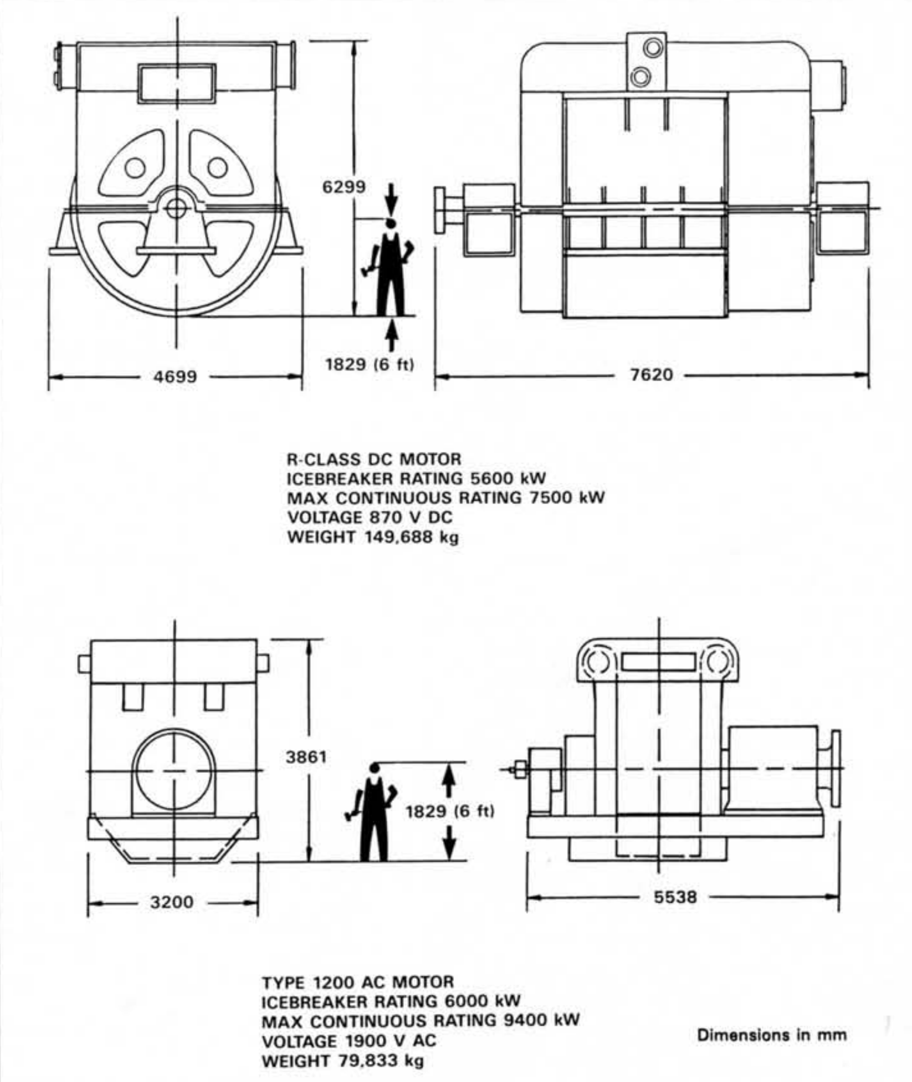


Fig 3. R-Class (DC) and Type 1200 (AC) Motors

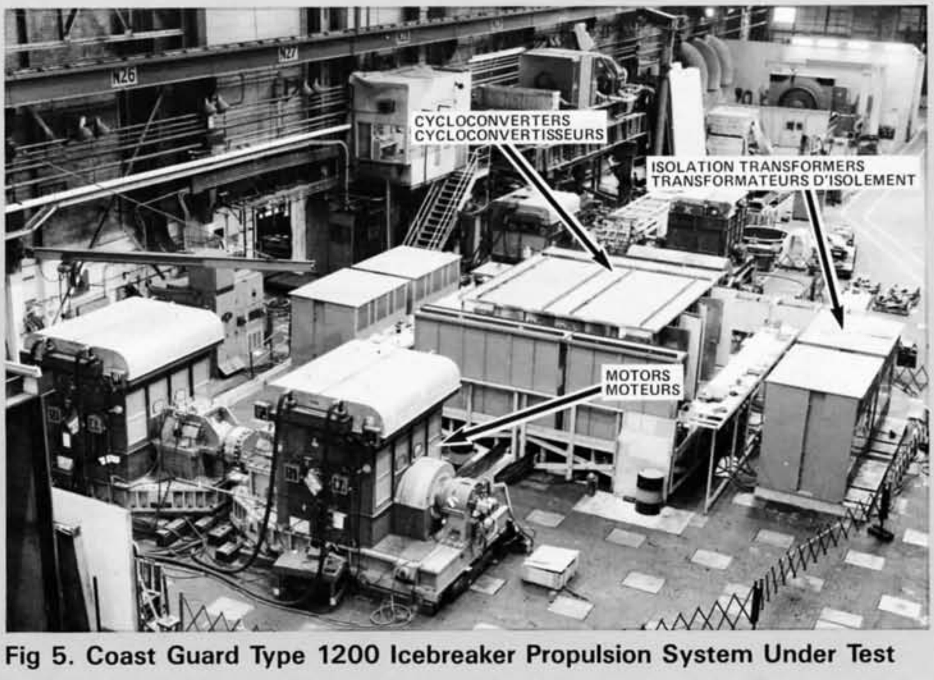


Fig 5. Coast Guard Type 1200 Icebreaker Propulsion System Under Test

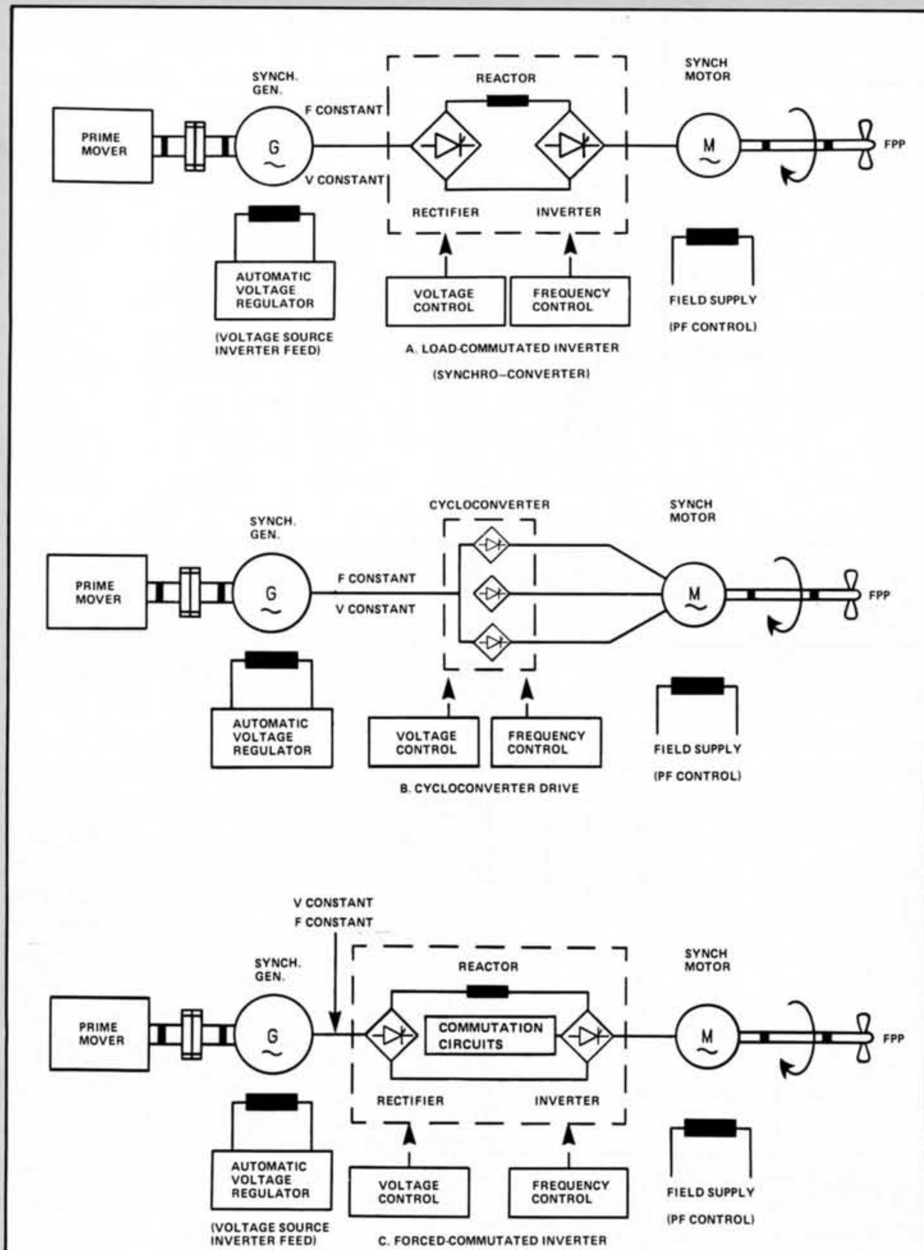


Fig 4. Three AC Propulsion Systems for a Fixed-Pitch Propeller

OPTION	LIFETIME FUEL CONSUMPTION (Tonnes)	% LIFETIME CONSUMPTION LESS THAN BASELINE	FUEL TO MEET ENDURANCE (Tonnes)	% FUEL TO MEET ENDURANCE LESS THAN BASELINE	PROPULSION SYSTEM WEIGHT (Tonnes)
A	155,500	-3.5	490	11.6	681
B	128,110	14.7	481	13.2	709
C	115,220	23.3	414	25.3	740
D	111,000	26.1	402	27.4	768
E	107,160	28.7	371	33.0	872
F	108,380	27.8	371	33.0	887
G	119,920	20.2	483	12.8	687
H	107,630	28.3	375	32.3	838
I	147,540	1.8	705	-27.3	674
B/L CODOG	150,221	0	554	0	506

Table 3: Summary of options [Fuel consumption and weight]

OPTION	NO. OF ENGINES	ENGINE RATING (MW) AND TYPE (GAS/DIESEL)
A	6	6.0 (G)
B	5 1	6.0 (G) 4.0 (D)
C	4 2	6.0 (G) 4.0 (D)
D	3 3	6.0 (G) 4.0 (D)
E	2 5	6.0 (G) 4.0 (D)
F	1 6	6.0 (G) 4.0 (D)
G	2 2	12.0 (G) 4.0 (D)
H	1 5	12.0 (G) 4.0 (D)
I	2 1	15.0 (G) 4.0 (D)

ELECTRICAL SYSTEM = Common Bus

Table 2: Summary of generator system options

power, nine different configurations were selected for evaluation as per *Table 2*. Fuel consumption and fuel weight were calculated for the nine configurations and summarized in *Table 3*. Lifetime fuel consumption is based on the operating profile of *Figure 6*, which is 20 years of peacetime (150 days per year) and five years of tension/conflict (220 days per year) operation.

The best five configurations were studied further; a comparison summary is given in *Table 4*, and a ranking in *Table 5*.

System D was chosen as the system to develop because it had the highest ranking and offered the greatest potential to demonstrate the flexibility of electric propulsion.

Electric Propulsion Plant

The generators are heavy-duty marine type, brushless, synchronous machines designed with a 0.65 power factor.

The two propulsion motors are 10-pole AC, synchronous machines rated at 12.5 MW with a reversible speed range of 0 to 200 rpm. Each motor is speed-controlled by a cycloconverter over the frequency range of 0 to 16.7 Hz.

The cycloconverter, shown schematically in *Figure 7*, functions by means of thyristors in a back-to-back connection. The useful frequency range of a cycloconverter, due to harmonics, is zero to one half the input frequency. The 16.7 Hz required by the propulsion motors is well within this limit.

Power plant control will be by a microprocessor-based ship's automatic

OPTION	C	D	E	G	H
Power(MW): @ 15°C	32.0	30.0	32.0	32.0	32.0
@ 38°C	27.0	26.3	29.5	29.1	30.6
Fuel Consumption (Tonnes);					
Lifetime (normal operation)	115,220	111,000	107,160	119,920	107,630
Endurance (normal)	414	402	371	483	375
Per 100 hrs (normal)	117.6	113.3	109.3	122.4	109.8
Per 100 hrs (quiet)	196.7	176.8	247.3	252.6	300
Weight of Propulsion Equipment and Fuel (Tonnes)	1195	1210	1281	1219	1251
Displacement (Tonnes)	4337	4354	4424	4362	4394
Prop. Eqpt. and Fuel Weight as a Percentage of Displacement	27.53	27.79	28.96	27.95	28.47
Volume of Prop. Eqpt. and Fuel (m^3)	1319	1362	1490	1455	1519
Deck Area of Equipment (m^2)	224	237	280	231	283
Reliability of Prime Movers	.7919	.7845	.7877	.6791	.6395
Lifetime Maintenance Costs ($ Million)	8.68	6.20	6.52	9.27	6.56
Initial Generator Set Purchase and Installation Costs ($ Million)	24.90	24.71	28.09	20.51	25.67

Table 4: Comparison summary

OPTION	MAXIMUM MARKS	C	D	E	G	H
Total Power	10	10	9	10	10	10
Fuel Consumption:						
Normal	10	6	8	10	5	10
Quiet	10	8	9	10	6	7
Total Weight	10	10	9	6	9	6
Space Requirement	10	10	9	6	9	6
Reliability	10	10	9	9	7	6
Maintainability	10	6	10	9	6	9
Capital Cost	20	14	15	10	20	13
Survivability	10	9	10	10	8	5
Noise & Vibration	10	10	10	10	10	9
TOTALS	110	93	98	90	90	81

Table 5: Ranking matrix

power management/control system which will select the most efficient mode of operation.

Discussion

The potential benefits of electric propulsion for an ASW frigate may be best realized by reviewing the advantages and disadvantages of the system.

Noise and Vibration

As submarine noise-reduction measures become more effective, the primary task of the ASW frigate (to locate targets) becomes more difficult. The limitations of hull-mounted sonars due to hydrodynamic noise are well known; hence the development of sonar arrays which can be towed many metres astern in undisturbed water. Yet in spite of the length of tow the performance of the array can be severely degraded by the ship's radiated noise, especially at low speed.

When ships move through the water at speeds below the cavitation inception speed of the propeller, the dominant radiated noise is normally that generated by the main propulsion and auxiliary machinery. The combination of gas turbine and controllable pitch propeller does not lend itself well to low noise at the low rpms that are required during sonar surveillance.

Figure 8 shows typical straight-line approximations of radiated noise from steam, gas turbine and electric propulsion systems. Mounting the gas turbine and gearbox on a raft has provided a marked improvement over the steam turbine ship, but at low speed the controllable pitch propeller becomes a noise problem. An electric propulsion drive using a fixed-pitch propeller system eliminates the main gearbox and the controllable pitch propeller, thus reducing the low-speed noise.

Studies conducted for the RN Type 23 frigate indicated that a diesel-electric system could reduce the octave-band noise levels by 10 dB. A gas turbine electric system, with the same degree of noise reduction measures can give further improvements due to the basic characteristics of the prime movers. Still greater benefits are realized by locating the power generators high in the ship, thereby lengthening the noise transmission path to the water.

A gas turbine electric ship with the gas turbines high in the ship is expected to be 15 to 20 dB quieter than a mechanical drive ship in broad-band noise and even better in narrow-band noise performance. This reduction in noise greatly increases the ship's active and passive sonar capability and decreases its likelihood of detection by a submarine.

Minimized Fuel Consumption

Comparing the data for AC electric propulsion with that of the baseline CODOG ship, the electric ship will be approximately 30 to 40 percent more fuel efficient over its life.

The effects on efficiency of the diesels and small gas turbines can be readily seen from *Table 3*. The small gas turbines make the electric frigate more fuel efficient when operating in the ASW mode, when gas turbines would be required for low noise at low speeds.

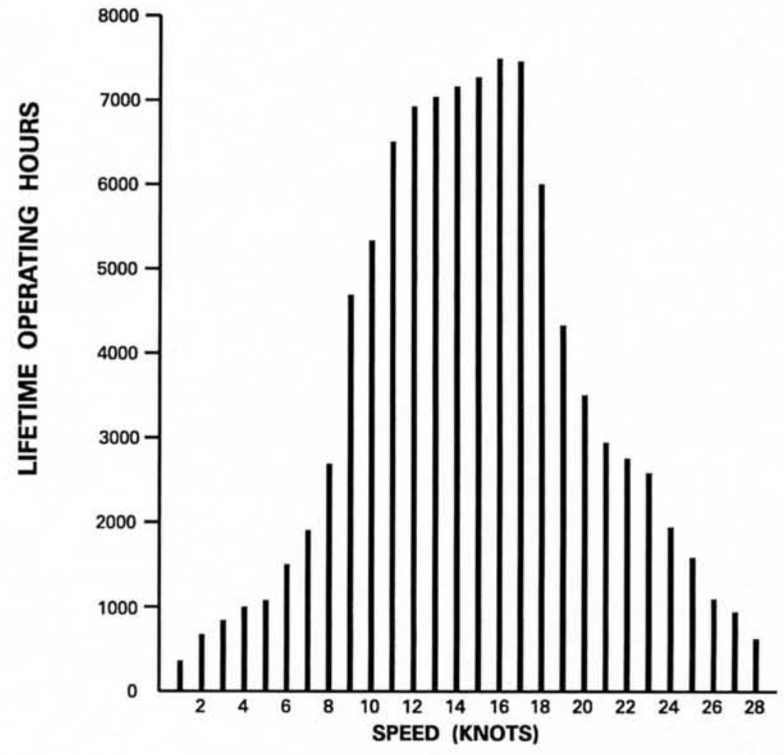


Fig 6. Lifetime Operating Profile

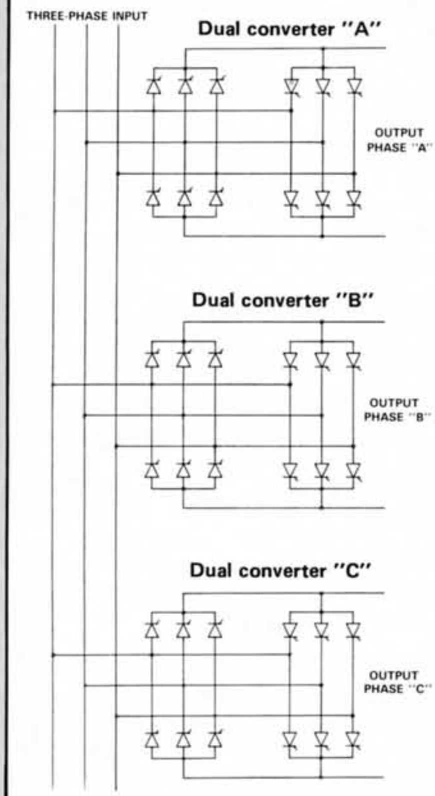


Fig 7. Three-Phase, Six-Pulse, 36-Leg Cycloconverter

The fuel consumption per hundred hours of operation, *Table 4*, follows the same curve as the lifetime profile (i.e. if the ship spends 7.5 percent of its time at 18 knots, this corresponds to 7.5 hours out of the hundred hours). The fuel required for one hundred hours of operation is stated in Table 1 for both normal and quiet operations.

The better fuel efficiency is due to the inherent cross-connectability of the different generator sets with the motors. The power generation can continually be matched to the propulsion motor load and thereby follow and match the ship's power/speed curve much closer than a mechanical ship, as shown in *Figure 9*.

In essence, the electric ship has the advantages of the quietness of the gas turbines and the efficiency of the diesel prime movers. It can give more for less; that is, it goes farther on less fuel and does it more quietly.

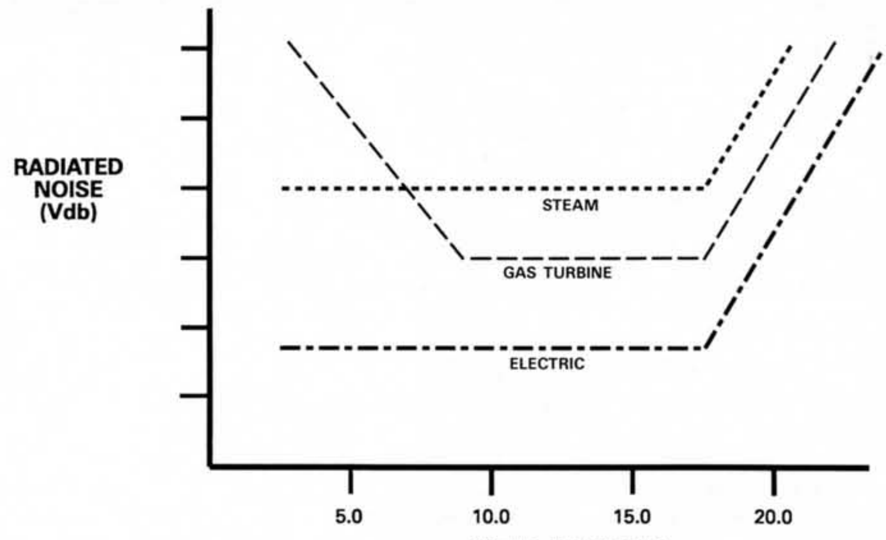


Fig 8. Propulsion System Vibration Characteristics

Manoeuvring

The electric propulsion system provides an infinite number of operating speeds throughout the motor speed-range (-200 to 0 to 200 rpm), without any time limitations except those imposed by total fuel carried. Acceleration and deceleration within the speed range is controlled by the propeller and shaft thrust limitations and generator prime mover characteristics which may impose some limitations on "bang-bang" type operations. Reversing the motors is accomplished by simply changing the cycloconverter control reference signal.

When a crash stop is executed, negative power is generated by water flowing through the propeller, and by the system's inertia after the propulsive power has been removed. Usually this negative power is greater than the level that can be absorbed by the engines, ship's service, losses, etc., and therefore accelerates the prime movers and MG sets. The overspeed can be partially contained by the governor, but the generator set could still be tripped on overspeed.

To overcome this deficiency, the prime absorption capacity of the system has been increased by the use of dynamic braking resistors. The resistors, based on icebreaker control design, are sized at approximately ten percent of propulsion plant size and can be used with any combination of diesel and gas turbine generator sets. The resistors will be switched in when a two-percent speed rise is detected, and will remain connected only for the duration of the regeneration; approximately ten seconds.

Survivability

The two major survivability considerations are underwater shock and direct physical ballistic damage.

The potential shock problem area for the electric system is considered to be the main motors, which are envisaged as hard-mounted units due to their weight and alignment requirements. The main motors are based on icebreaker technology which requires a limited level of shock hardening, mainly in the vertical and longitudinal directions. Other equipment will be shock-mounted in standard military fashion as required.

Since direct physical damage involving penetration of the hull would likely put equipment in the affected compartment out of action, protection is only practical by physical separation. The layout flexibility of the electrical system allows the prime movers to be located considerable distances apart and the main motors to be in staggered compartments.

Reliability

A number of possible propulsion system events and problems were analyzed to identify the operational conditions for the vessel. Where applicable, the results for the COEDAG plant were compared with those for a conventional CODOG plant for the following:

* one main-engine generator shut down for maintenance;
* one power generation compartment extensively damaged;
* partial loss of power supply to a main motor;
* loss of cooling of a main motor; and
* loss of a ship's service generator set.

The principal conclusion that was reached from the investigation of the postulated incidents is that there would be limited effect on the capability of the ship in light of the flexibility of the system configuration. The COEDAG ship is considerably superior to a CODOG vessel in this regard. It is felt that the increased complexity of the system was unlikely to cause significant problems due to the high intrinsic reliability of most of the major components. Planned maintenance and accidental or action damage are the most probable causes of equipment unavailability, and the basic operational consequences are summarized in *Table 6.*

Manufacturability in Canada

The Canadian Coast Guard is presently constructing AC electric propulsion icebreakers using Canadian sources. However, there is no similar Canadian engineering or manufacturing capability for large marine gearboxes, controllable-pitch propeller systems or high-power/torque, flexible shaft couplings. At present these components come from the United States and Europe, and in time of conflict these sources could be expected to be disrupted.

Canada presently has the design and manufacturing capability for propulsion generators, motors and cycloconverters and could probably acquire the rights to manufacture diesel engines and gas turbines under licence.

Electromagnetic Interference/Compatibility

Electromagnetic interference is an increasing problem for the ever-sensitive electronics in ships, and can be caused by induction, conduction and radiation. Since the propulsion system, distribution cables, and virtually all electrically powered equipment are potential EMI sources, a good design philosophy and construction methodology are of paramount importance in reducing the effects of EMI in an electrically driven ship.

As much as possible, the propulsion network should be kept in a confined area of the ship, distant from sensitive equipment. Each propulsion bus cable must be carefully shielded and possibly housed in steel conduit; in which case, three-phase symmetry must be maintained to reduce currents induced in the conduit, and heating effects due to hysterisis. Sensitive cables passing in the vicinity of high-voltage cables must also be properly shielded.

Waveshape Distortion

Harmonics and waveshape distortion are created by the waveshaping function of the cycloconverter. The higher the cycloconverter output frequency the greater the harmonic contribution transmitted to the

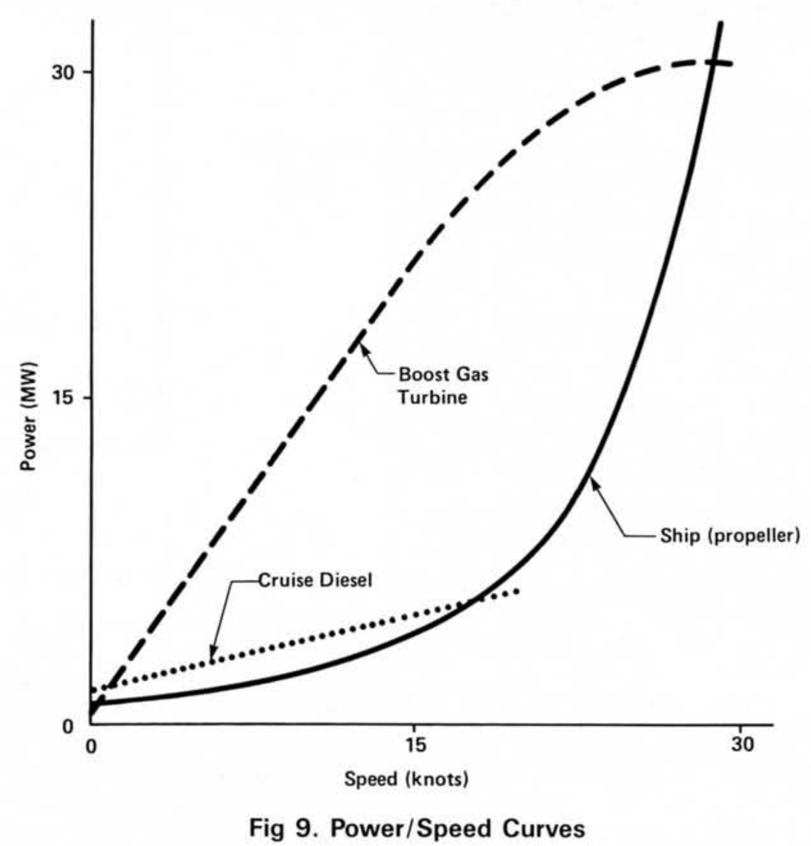


Fig 9. Power/Speed Curves

motor and reflected back to the propulsion bus.

The level of distortion of the voltage on the ship's service bus is limited by STANAG 1008 to total harmonic distortion (THD) not exceeding five percent, with single harmonics not exceeding three percent. Since ship's service power is provided by MG sets, the distortion of the propulsion bus waveform need not be controlled within the low limits for ship's service voltage specified in STANAG 1008. Nevertheless, it is important to determine the distortion of the propulsion bus waveform in order that the effects of harmonics are recognized in sizing components of the electric plant. For example, cables will need to be oversized by 10 to 30 percent; generators will require large amortisseur windings and more iron; switchgear will have to be oversized, and protective relays, automatic voltage regulators and control equipment will have to be immune from harmonics.

In theory, harmonic distortion can induce vibrations in the propulsion motors that could cause underwater noise. Testing is planned in the near future on the Coast Guard icebreakers to determine the extent of these vibrations.

Size, Weight and Acquisition Cost

The electric propulsion plant, based on existing industrial technology using air-cooled machines and control and switchgear designs, is approximately 50 percent heavier than the mechanical system. It also requires more space. Consequently, an electric frigate must be longer to accommodate the extra weight and volume. The longer ship has improved seakeeping capability, higher top speed for the same power, and a larger platform for mounting combat systems. This longer, heavier ship, though, does have a greater front-end cost. As the electric frigate can sail farther on less fuel than a mechanical ship, fuel savings are realized that will provide payback of the initial cost, but the amount will be dependent on the future cost of fuel.

System Simulations

Computer simulation was used to investigate the electrical system and ship manoeuvring performance under various operating conditions.

Electrical Simulation

The electrical system simulation was performed by modelling each component in the system; i.e. cables, motors and generators appropriate for the range of frequencies (0 to 1 000 Hz). The sub-networks were combined to make a system model. Distorting currents of the correct magnitude and frequency[1] were injected into the network and the resulting voltages at various points in the system were evaluated.

a. *Harmonics* (Voltage and Current Distortions). The worst case of THD was 18 percent, with a worst single harmonic of nine percent. This indicates that care in the selection and design of the equipment on the propulsion bus is required, and that MG sets are necessary for clean ship's service power.

b. *Transient Analysis*. The transient analysis simulation simulated the extent to which disturbances occurring on the propulsion bus would penetrate via the MG sets onto the ship's service bus during ship manoeuvring. The voltage and frequency transient simulations demonstrated that the disturbances are well within the limits of STANAG 1008.

c. *Load Level/Fault Analysis*. Load flow and fault level diagrams for the electrical ring main systems were generated. Fault levels due to faults at all main breakers were calculated, and showed little variation around the ring main propulsion bus because of low cable impedance. Fault levels at half cycle, three and eight cycles were calculated with results well within the capabilities of the circuit breakers.

Load level analysis was performed for various propulsion plant configurations. It was discovered that a minimum of two generators were required to provide sufficient power for the main motors and ship's service requirement. This minimum requirement arose because at the lower propulsion power levels the generators were limited more by their MVAR capacity than by their MW capacity. The high reactive power demand was caused by the cycloconverter. At low motor speeds (lower output frequencies) the output voltage of the cycloconverter must be decreased to prevent motor overfluxing.

Ship Manoeuvring Simulation

The simulation models for the diesels, gas turbines, cycloconverters, motor-generator sets, dynamic braking resistors and propulsion motors were developed and interconnected through an overall control system. The models of the diesels, gas turbines and cycloconverters also had their own dedicated control systems.

The real-time simulation encompassed various combinations of propulsion plant scenarios, loads, control system characteristics and transient constraints.

The ship manoeuvring transients (acceleration, crash stop—full ahead to full stop) required load control to maintain the frequency within the specified limits of STANAG 1008. This load control was accomplished by controlling the prime mover governors and by using dynamic braking resistors to absorb the regenerative power generated during ship manoeuvring.

The simulation results showed that the performance available from an electric ship would match or exceed a similar mechanical ship in terms of reversing time, stop-

	PERCENT POWER AVAILABLE	SPEED AVAILABLE (KNOTS)
COEDAG		
Loss of:		
1 GT gen (normal mode)	80	27
1 GT gen (quiet mode)	67	20
1 diesel gen (normal mode)	87	27
1 diesel gen (economical mode)	67	20
1 motor	50	23
1 cycloconverter	50	23
CODOG		
Loss of:		
1 GT (normal mode)	50	24
1 GT (quiet mode)	50	24
1 diesel (normal mode)	100	30
1 diesel (economical mode)	0	0
gearbox	0	0

Table 6: Summary of reliability assessment

ping distance, acceleration, etc. The ship accelerated to 25 knots (90 percent of top speed) in 40 seconds, and to top speed in 60 seconds. The ship stopped in 50 seconds, within 400 metres (3 ship lengths), from top speed using the braking resistors to help absorb the regenerated power.

The simulation aided in establishing and confirming the correct control sequencing and limits for the propulsion system.

Future Development

This section addresses technological developments that are still maturing or have not yet been used in a marine application. The discussion of the developments will largely address what is possible in the immediate future and outline the anticipated benefits and/or drawbacks.

Immediate volume and weight reductions could be made to the motors and generators by utilizing a higher temperature insulation (180°C) in lieu of 155°C for the windings. This would provide a five- to ten-percent reduction in overall weight, and possibly enhance the sprint capability of the ship.

The use of a higher propulsion bus voltage (6.6 or 10 kV) would lead to size and weight reductions in the motors, generators, cabling and switchgear. But with the thyristors presently used in the cycloconverter it would mean an increase in the number of thyristors required to handle the higher voltage, thus increasing the size of the unit.

Increasing the propulsion bus frequency to between 60 and 400 Hz would enable the gas turbine generators to operate without a gearbox, thereby decreasing generator size and weight. An added benefit of higher frequency operation would be reduced voltage waveform distortions generated by the cycloconverter. The distortions are a function of the input to output frequency ratio of the cycloconverter. The higher frequencies require faster control strategies and components.

Direct water cooling of the rotor and stator of the main motors and of the cycloconverters produces a large reduction in size and weight. The cycloconverter's weight would be affected only slightly, but its volume would decrease by 33 percent. The motor size would be reduced by 50 percent. The generator stator could be water-cooled, but cooling the rotor is complicated due to rotating, high-speed shaft seals. The auxiliary cooling systems would have to become larger, but would not necessarily be mounted on the equipment itself.

The use of high-energy density materials with high magnetic permeability would decrease the size and weight of the motors and generators. Weight and volume reductions of 40 percent have already been achieved by Siemens in the design of a 1.1-MW motor. The PERMASYN motor uses samarium cobalt and has 20 percent less loss than a comparable DC machine.

New thyristors rated at higher voltages will decrease in size and weight. The higher power gate turn-off thyristors coming on the market will allow much better control of the power converter. With proper control these thyristors can be triggered to counteract the expected harmonics and voltage waveform distortion. The control system would have to process non-linear, transcendental equations for the magnitude of waveform.

Conclusions

An electric propulsion system has been defined in sufficient detail to give confidence in its ability to meet or exceed the specific targets initially laid down. It has been shown that in many areas where operational effectiveness is concerned, the electric ship has markedly superior performance over the baseline CODOG ship. The electric ship scored higher under more onerous operating conditions such as state of tension, conflict, or damage; a valuable characteristic for any warship.

Fuel consumption and endurance data for the electric ship compared to that of the baseline CODOG ship confirmed that the electric system is approximately 30 to 40 percent more fuel efficient, offering even greater efficiency during operations requiring quietness, low speed or a high state of readiness.

The electric propulsion frigate with current equipment designs would have to be longer than an equivalent mechanical ship. The increased weight and length would result in an increased front-end cost, but the longer ship would have better seakeeping capabilities, require less propulsion power and provide increased deck area to mount weapon systems.

An electrical ship design based on Coast Guard icebreaker AC/AC electrical propulsion plant design, utilizing standard industrial equipment packaging is a feasible alternative to traditional frigate designs. Potential developments to decrease the volume of the electrical plant are real and achievable, and will lead to a frigate comparable in size to the present generation of CODOG ships.

AC electric propulsion provides a quieter ASW ship with greater range capability, fuel economy through inherent cross-connect capability, optimized manoeuvrability by virtue of infinitely variable speed and simple rapid reversal, and improved ship survivability.

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The Product Work Breakdown System
Blueprint for CPF Construction

By LCdr Richard Payne

Introduction

When the CPF program office first opened its doors for business 11 years ago, the challenge was to define, solicit and procure a contract with Canadian industry for the turn-key delivery of a new fleet of Canadian patrol frigates. These objectives were pursued at a relentless pace, and in 1983 history was made when the largest Canadian defence procurement contract ever was awarded to Saint John Shipbuilding Limited. Since then Saint John Ltd and its numerous subcontractors worldwide have joined efforts to deliver within very stringent constraints of cost, schedule and performance.

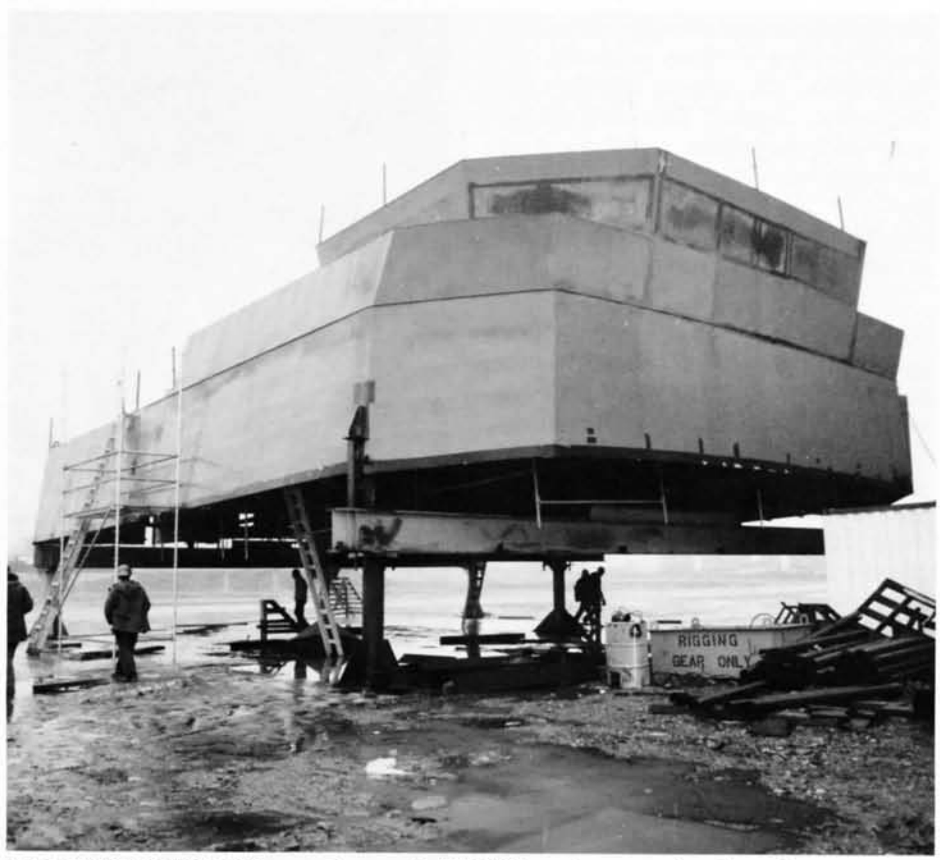
Significant milestones such as contract definition, contract procurement and detailed ship design have been successfully accomplished, and the CPF program is now clearly focused on actual ship construction. Last May during a double ceremony at the Saint John shipyard (see "New frigates...") the "keel" section of CPF 02 was laid in the dock, and CPF 01 was floated-up and christened *Halifax*. Halifax's first plate of steel was cut in June 1986, and in October 1989 she will be turned over to the Maritime Commander as the first of 12 modern naval platforms. That the steel, machinery, computers and weapons can be "built" into a fully operational warship in just over three years is due to a managerial construction blueprint called the *Product Work Breakdown System*, or PWBS. Conceived by a Japanese shipbuilder in the 1960s, PWBS has evolved into a widely used management tool which is particularly suited to complex technological projects such as the construction of aircraft, nuclear power plants and warships.

The Product

The product is a state-of-the-art Canadian patrol frigate, fully tested and ready to fight. By using a concept called group technology, PWBS breaks the product down into manageable production objectives, or *interim products*, which can be grouped into similar construction processes. In the construction of a patrol frigate some 262 interim products are organized into five construction processing groups for steel unit assembly, zone outfitting, special installations, modules and batch manufacturing.

The ship has been divided into superzones, areas of the ship divided by girth and level. An *assembly unit* is usually a single deck-level structure, shell to shell. The CPF is divided into 58 such units which are then joined into 26 *erection units*. For example, erection unit 2150 comprises assembly units 2130, 2140 and 2150. The hull of the CPF, then, requires the processing of a total of 84 units.

Once the units have been erected, work shifts to the outfit zones. Typically, the boundaries of an outfit zone are bulkhead to bulkhead and deck to deck, and can be a compartment, lobby or passageway, or an external area such as the fo'c's'le. In the CPF there are a total of 111 outfit zones, each requiring outfitting work by various trades such as electrical, pipe fitting, joining and painting.



ERECTION UNIT. **This erection unit #4110 has just received a primer coat of paint in the blast and paint facility. The bridge superstructure is an erection unit product resulting from the joining of assembly units 4110, 4120, 4210 and 4220.**

Some products cannot be confined to a specific area such as a unit or zone, so must be processed independently as special installations. These products are usually complicated in nature and require unique procedures for their fabrication, assembly and installation. In the CPF there are 26 special installations in all, including the main shafting, the 57 mm Bofor gun, the rotary vane steering system, the kingpost and the RAST gear.

There are only eight modular products in the CPF. These items can be processed entirely off-line and then installed in the ship at the appropriate stage of construction. For example, the fuel oil centrifuge and drain tank can be fabricated, welded, assembled, painted and tested on the workbench before being shipped to the warehouse as a product ready for installation in the ship.

Products having common processing characteristics are manufactured in batches. Swaged bulkhead panels, lighting supports and fire-hose racks are some examples of the 33 manufacturing jobs used in the construction of the CPF.

The Work

Once a product has been dissected into manageable production targets, the work required to build it can be addressed. Ship construction will differ in approach from shipyard to shipyard, depending on such variables as the human, technical and capital resources at hand. In the Saint John yard, as in most modern shipyards, construction of a warship is very much an assembly line process.

The basic concepts used in ship construction have been around for many years. HMS *Warrior*, the world's first ironclad, was recently restored to exacting detail and is now on display in Portsmouth, England. One of the less noticeable, yet salient, features of this formidable monument is that she was built, back in 1860, using certain basic principles of unit construction still in use today. What has changed over the years is the refinement and improvement, particularly in automation, of the basic processes for hull construction, zone outfitting and zone painting

HULL CONSTRUCTION. Steel construction involves seven distinct manufacturing levels. *Part fabrication*, the first level, produces finite components which by nature cannot be further subdivided. For example, flat plates of steel are marked, cut, bent or shaped into specified parts. During *part assembly* these fabricated bits and pieces are assembled into built-up components, such as T- or L-shaped girders, and then *sub-unit assembly* processes them into structures such as deckpanels, bulkheads and shell plates.

Unit assembly involves the welding of all sub-unit components and other assembled and fabricated parts into complete assembly units (there are 58 of them in the CPF), after which *unit joining* will combine the assembly units (two to four at a time) into the 26 erection units which will be lowered into the dock. *Hull erection* constitutes the joining of erection units in the dock, which eventually results in a ship's hull, and finally, *onboard outfitting* ties in all the loose ends, from back-up structure to tank testing.

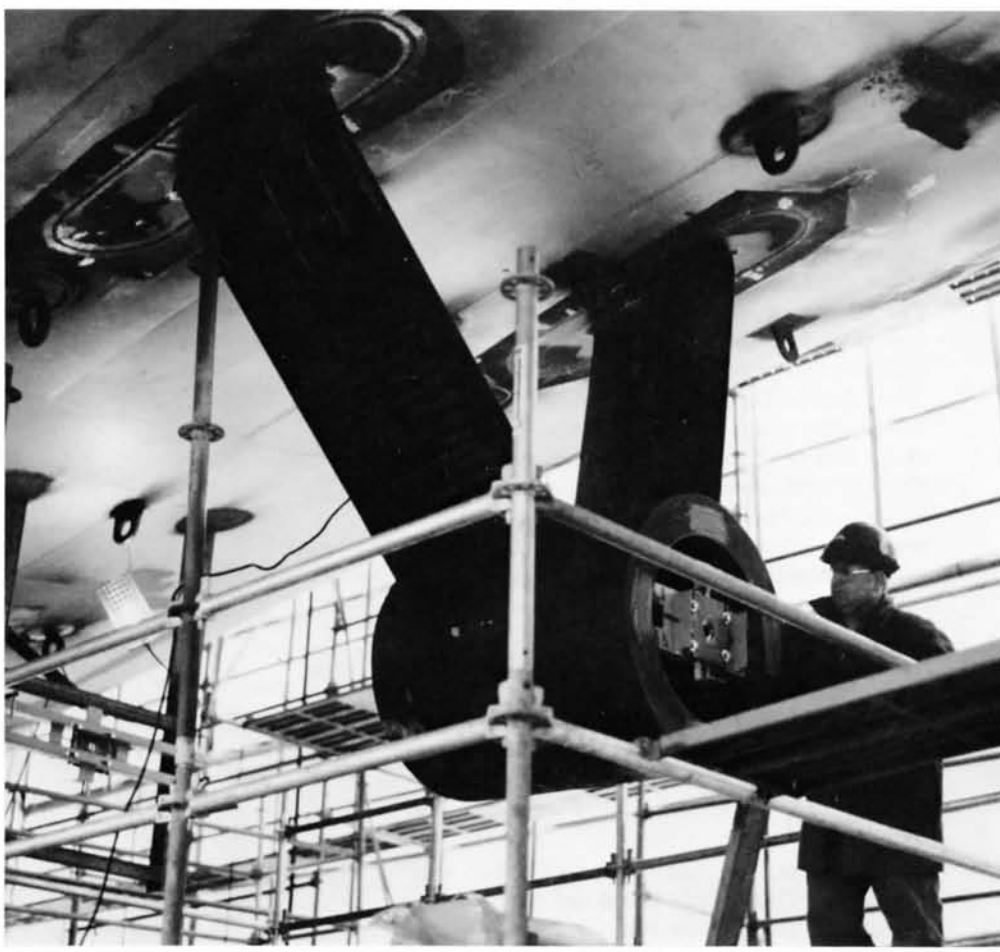
ZONE OUTFITTING. This second process is subdivided into three phases: *on-module outfitting* is work which can be performed in the shop or at the workbench, *on-unit outfitting* involves both hot and cold pre-outfit work at the unit stage of construction when the unit is still under cover in the assembly line, and *onboard outfitting* is work which can only be performed once the hull has been erected.

These three different stages of outfitting are significant in terms of cost. For outfitting labour, a common rule of thumb is that what takes one man-hour of work in the assembly shop is equivalent to three man-hours in the drydock and as much as seven man-hours of work in a ship that is afloat. Small wonder that pre-outfitting is considered to be such a significant concept in modern ship construction!

ZONE PAINTING. The third major construction process has four categories: *shop primer, primer, finish undercoat* and *finish paint*. The zone painting process also capitalizes on the practicality and cost-effectiveness of performing work as early as possible in the construction process.

The PWBS Matrix

Construction of the CPF involves an army of planners, engineers, purchasers, accuracy control technicians, quality control experts, cost-account managers, supervisors and tradesmen. These players must all team up in a highly coordinated effort to bring the CPF into being. The game plan for the execution of this task is



SPECIAL INSTALLATION. **Shafting is one of 26 special installations in the CPF. Here a Saint John Ltd accuracy control technician prepares for the final line-of-sight measurement required to bore out the starboard intermediate A-bracket.**

PRODUCT		WORK CENTRE									
		1000	1100	1200	1300	1400	1500	1600	1700	1800	1900
UNITS											
4410	LOWER FUNNEL	*	*	*		*		*	*		
4420	UPPER FUNNEL	*	*		*	*		*	*		
4410	FUNNEL	*								*	
OUTFIT ZONES											
1600	WEATHER DECK	*	*							*	*
2260	FER UPTAKES	*	*			*			*	*	*
3134	#2 GYRO ROOM	*	*						*	*	*
4114	CCR	*	*						*	*	*
SPECIAL INSTALLATIONS											
6110	C5 SONAR	*	*							*	*
6230	CRUISE DIESEL	*	*			*				*	*
6580	MASKER BELT	*	*			*				*	*
MODULES											
7210	FEED TANK	*	*				*			I	
7239	AUX MACHY FLAT	*	*				*		I		
MANUFACTURING JOBS											
7609	VENTHOLE COVERS	*	*								
7939	FIRE HOSE RACKS	*	*								

Figure 1. The PWBS matrix represents the basic framework on which to plan, coordinate and execute all CPF construction activity. The complete matrix consists of 262 interim products under five categories.

MANUFACTURING JOB. **Cable hangers utilized throughout the ship are manufactured in batches. The items are then kitted by unit for installation at the hot pre-outfit stage of construction.**

the matrix of the product work breakdown system. As previously outlined, the *product* has been carefully analyzed and subdivided into 262 interim products. Furthermore, the *work* required to build and assemble these 262 products has been assessed and delegated to ten well-defined work centres. These two elements, product and work, now form the basic framework of the PWBS matrix. Figure 1 represents a sampling of the matrix, which in its entirety consists of the 262 interim products versus the ten work centres.

Each intersection of product and work centre constitutes a 'cell' of activity, or a job. These jobs in turn signify various requirements to the different participants in the construction activity.

Planners will use the PWBS matrix primarily as a scheduling tool. Their objective is to determine start and finish dates for each job, and to coordinate the work in order to achieve an efficient production run with a relatively constant workforce. When at full production, CPF construction activity at Saint John Shipbuilding will require a workforce of approximately 1200 tradesmen. The planning department is also responsible for promulgating the necessary work orders, depending on the number of trades involved and the scope of work required to accomplish the task.

The engineering department also uses the matrix, primarily as a schedule for the development and issue of production drawings, but also as a guideline for the promulgation of unique procedures. Field engineers must also possess a working knowledge of the PWBS.

The material purchasing group uses the PWBS matrix extensively. Their responsibililty is to procure the right material at the right time, thereby feeding construction activity without interruption while maintaining the warehouse at a manageable and cost-effective stock level. The CPF requires an endless amount of logistical support, from nuts and bolts to sophisticated weapon installations. The ideal procurement plan for this type of project calls for an item to be on hand eight weeks prior to it being required at the first work centre.

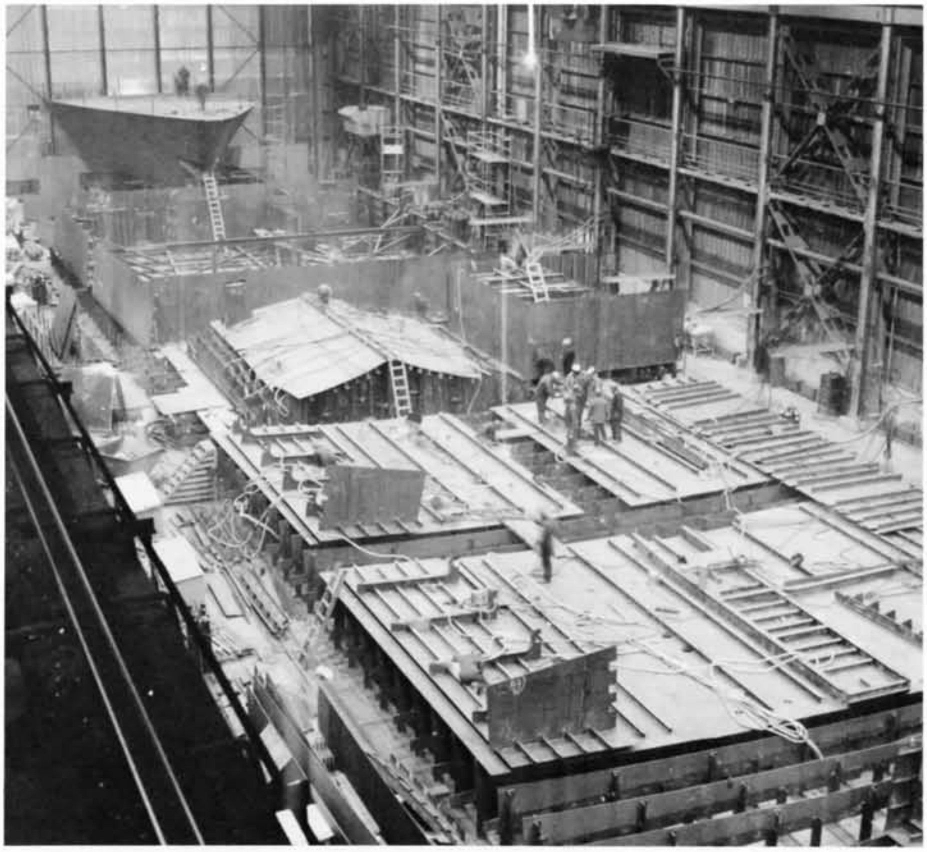
The Quality Assurance Manager can also benefit enormously from the PWBS matrix. The matrix provides the framework on which to formulate the master inspection and test plan (ITP). For example, an ITP can now be developed for each product at each work centre. This ITP will include receiving inspections, in-process inspections, accuracy control and NDE requirements, and the all-important final inspection prior to releasing the product to the next work centre. Many of the jobs are repetitive processes for which a common ITP can be developed. Therefore, the task of designing an integrated master ITP for the CPF construction program becomes a relatively easy assignment.

To the senior managers the PWBS matrix becomes an invaluable yardstick for measuring production, cost and schedule performance. Each activity cell represents a finite amount of the budget and therefore has a weighted value in comparison to the whole project. Consequently, a true measure of physical progress and man-hour costs can be determined as the various interim products are completed in each work centre.

Conclusion

A technological task such as the construction of a Canadian patrol frigate demands the expertise, and more importantly the cooperation, of a variety of talent. Not only must the ship be built to specification, but the job must be accomplished within the ever-present constraints of cost and schedule. The PWBS matrix provides the framework on which this complicated task can be successfully completed. The Product Work Breakdown System itself provides the common language necessary for its success.

LCdr Richard Payne recently served for three years in Saint John, first as the Annapolis *DELEX refit project officer and subsequently as the marine systems quality assurance officer in the CPF leadyard detachment. He is currently attending the Canadian Forces Command and Staff College in Toronto.*



WORK CENTRE 1400. **This is the work centre where flat and curved sub-unit components are assembled into assembly units. The assembly units also undergo hot pre-outfit work here. The bow section seen at the far end of the work centre is assembly unit 1150.**

DRYDOCK. **Approximately one quarter of all work required to construct a CPF takes place in this work centre. Here, erection unit 1250 is lowered into position.**

New frigates a shipbuilding success story

By LCdr Brian McCullough
Journal *production editor*

The Canadian navy was ceremoniously launched into the 21st century in Saint John, New Brunswick last May with the "float-up" and christening of HMCS *Halifax*, lead ship of the 12 new patrol frigates promised to the navy, and the "placing in the dock" of the first modular unit of CPF 02 -- the future HMCS *Vancouver*.

Thanks to the unit construction of the new frigates, gone were the more traditional methods for launching down the ways and laying a keel, but in their place was the remarkable evidence of a shipbuilding success story.

On the day the newly named *Halifax* was towed out of the Saint John Shipbuilding drydock and secured alongside the wall to complete her fitting-out, the ship was 55 percent complete. That, say some, is the highest percentage completion at launch for a lead ship of any naval combatant construction program in the West.

With the champagne still wet on her bows, all of *Halifax*'s welding and main hull-steel painting was complete, she was insulated throughout, the main generators, main engines, gearbox and shafting were installed and compartment completion below the third deck had begun -- all barely 14 months since her first pre-outfitted unit was lowered into the dock.

To get a better idea of the extensiveness of the pre-outfitting being used in the frigate construction process, consider this. Moments before *Halifax* was christened the first erection unit of the future *Vancouver* was lowered into an adjacent drydock. As the 50-tonne unit came to rest on the blocks and Defence Minister Perrin Beatty declared the keel of CPF 02 "well and truly laid", five more pre-outfitted erection units sat off to one side ready to be joined to the first. The vessel was already 21 percent complete.

There is no question that the shipyard is benefitting from the construction learning curve. The erection units for 02 are being more fully pre-outfitted than were the 01 units, and the degree of pre-outfit work on the follow-on ship (*Toronto*, now in the fabrication/assembly process) will be even greater.

According to Shipbuilding Director Matt Reid the second vessel is much farther advanced in terms of pre-outfitting than was CPF 01 at the same point in the schedule. By May, 33 of the 57 assembly units had been completely assembled, fabrication was 85 percent complete and seven of the 26 erection units had been completed and painted. "We are about one month ahead of schedule on CPF 02," Reid said. Float-up is scheduled for March of next year.

"I name you HMCS Halifax. *God bless this ship and all who sail on her." — Mila Mulroney*

Software and the MARE

By Cdr Roger Cyr

Presented at the MARE Seminar in Ottawa, 20 April 1988

Introduction

Computers have found applications in most modern systems. They guide torpedoes and missiles, tune radios, track and evaluate targets, and control propulsion machinery. Embedded computers have become a critical component of all shipboard systems, with their power stemming from their flexibility, via software, to readily adapt systems to changing requirements. However, experience has shown that software is costly to produce and difficult to control. There is no question that software has contributed to the realization of military systems of unparalleled sophistication and potential, but this software revolution has unfortunately come accompanied by its own peculiar and growing problems — problems which affect all systems, and as such have become the purview of all MARE officers.

Background

The Canadian navy entered the age of Automatic Data Processing with the arrival of the DDH-280 Tribal class destroyers in the 1970s. With these ships came the navy's first command and control computers, and the navy's first encounter with software and its associated problems. Programming for the system was for the most part relegated to a few naval officers who started coding after taking a short course in programming. As a result, the software was highly unreliable and program crashes occurred frequently; a situation which continued to exist ten years after the system was brought into service. When these catastrophic failures occurred, the Tribals became virtually disabled and were easy prey to any attacking unit.

Systems of the '90s

The ships of the '90s, the Canadian Patrol Frigate and the upgraded Tribal class destroyers, represent considerable technological advance with respect to computer power. In the CPF virtually all systems and subsystems (including propulsion machinery subsystems) will rely on fully integrat-

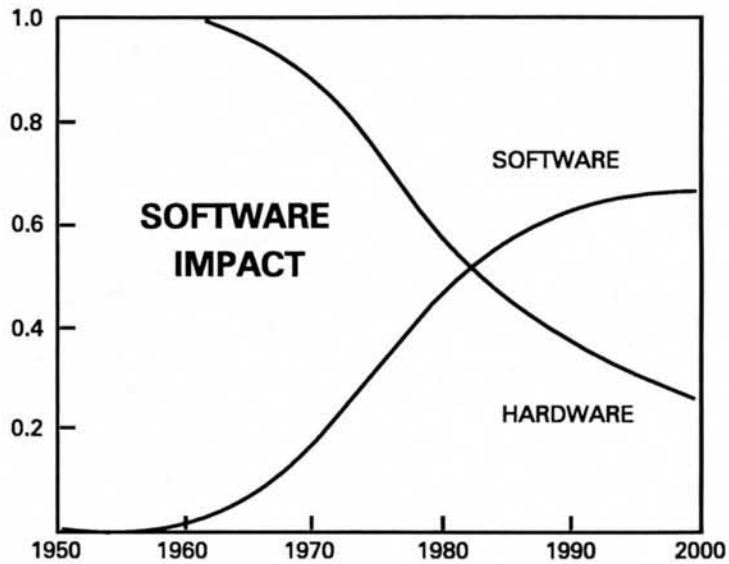


Fig.1. The Relative Influence of Software on System Design and Development

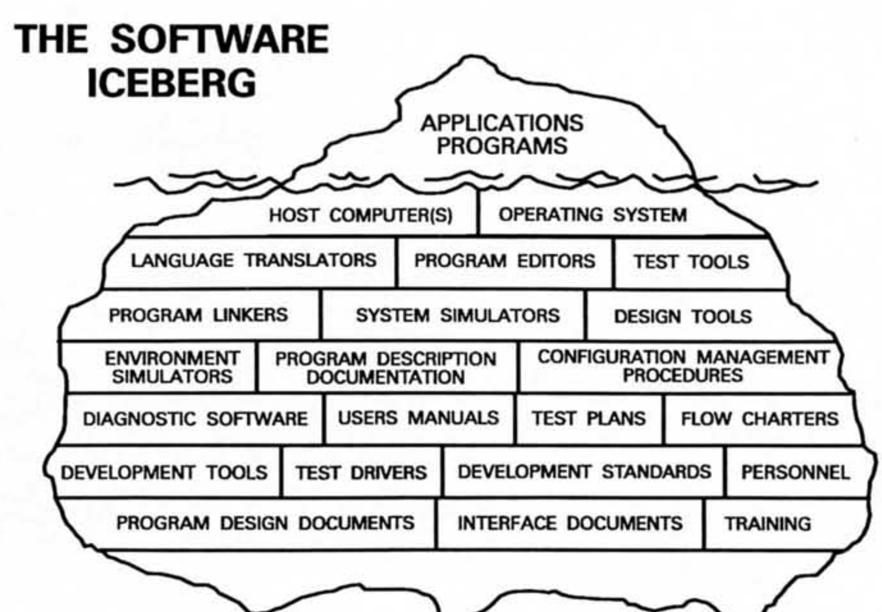


Fig.2 The Software Iceberg

ed embedded computers for data processing. This is advancement, to be sure, but at a price. For with these myriad embedded computers which are about to enter service comes an extremely large software inventory, one which will require considerable attention from the MARE community in the years ahead.

The Software Crisis

Software has become the dominant component of modern systems and subsystems (*Fig.1*) because of the integration function it performs. In some cases it has actually dictated both the system and its architecture. It is important to note that software does not consist only of applications or operational programs. Far from it. Application software normally comprises only about ten percent of the total software in a system (*Fig.2*).

Software requirements for embedded computers are growing at an alarming rate. But where technological developments have kept hardware costs down, the costs for software have skyrocketed. In 1980 alone the U.S. military spent $4 billion on embedded computer resources, 65 percent of which was taken up by software (*Fig.3*). For 1990, of the $38 billion planned to be spent on embedded systems, the portion allocated to software will increase to 85 percent.

The U.S. Department of Defense now estimates that the number of embedded computers in use by 1990 will reach 250,000 from the 10,000 in 1980 — a 25 times increase that is being accompanied by significant perturbations. Recent rules of thumb for estimating software costs indicate that, whereas the total cost per line of delivered code in 1975 was $75, today each line of code is estimated at costing close to $200 to develop and $4 000 to maintain over a ten-year life cycle. But what is even more alarming is that even at these costs flawed code in mission-critical systems is the norm rather than the exception. The U.S. National Bureau of Standards estimates that delivered software for large systems typically has errors (which affect system performance) at a rate of one in every 300 program statements, or 3.3 errors per 1 000 lines of source code.

The problems of high software product costs and low software reliability are still very much with us. This is not a failing in the development of software engineering ideas, but a reflection of the fact that improvements in software production technology have been unable to keep pace with the rapidly increasing demand for complex software products.

A recent study estimates that the demand for new software is increasing at a rate of 12 percent, but that the growth in programmer productivity is growing by only four percent annually. Moreover, in 1985, the Electronic Industries Association calculated that the shortage of programmers in North America (then estimated at 100 000) could reach one million by the early 1990s. This number did not take into account such massive development projects as the Strategic Defense Initiative (SDI), which is expected to require programming services of unprecedented size and complexity. There are even fears that the major stumbling block to SDI will be the lack of personnel resources to complete the software program, which is estimated at 25 million lines of code.

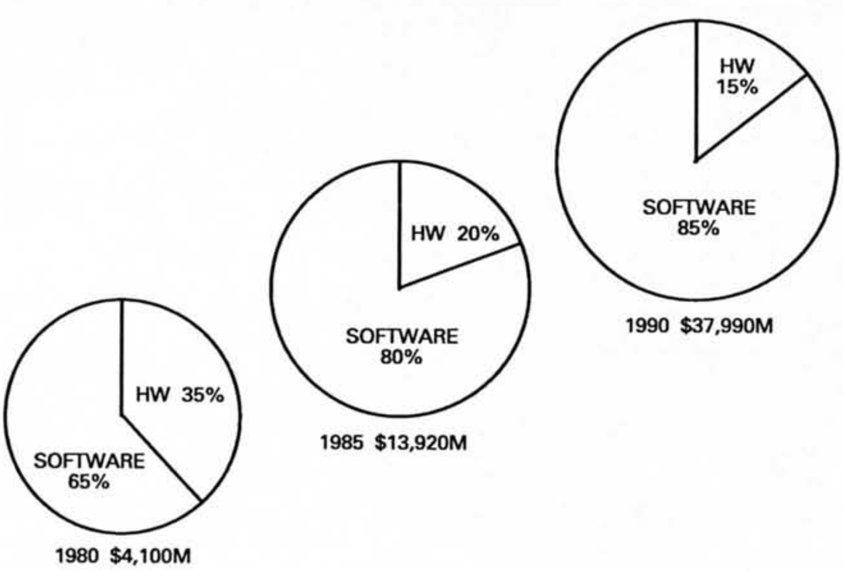


Fig.3 Embedded Computers — Hardware vs. Software

Canadian Naval Software

With the advent of CPF and TRUMP the software support requirements of the Canadian navy will grow to about a million lines of code. This means that a great proportion of the navy's limited personnel resources will have to be directly employed on in-house software maintenance as programmers, analysts and software engineers. In addition, since all systems will rely on embedded software, every MARE involved in system management will have to be "software literate."

Based on the National Bureau of Standards average, the number of errors remaining after a real-time system such as CPF becomes operational could be around 3 000. And these would be catastrophic errors affecting performance. When we apply the rule of thumb regarding the maintenance cost per line of software, the navy likely faces a $4 billion bill for embedded software support in the years ahead. This is the estimated labour cost for the life-cycle maintenance of CPF and TRUMP software.

Future Software Support

Mission-critical systems must be maintained regardless of the cost and volume of the activity. Since software has become the dominant element of most systems, the requirement to possess software skills will no longer be the domain of a few officers employed directly in software maintenance tasks. It will be the concern of all who are involved with systems, be it designing, implementing or maintaining them. System designers, for example, will have to consider such issues as whether more hardware may modify the need for software, the potential trade-offs between hardware and software and the interfacing requirements between hardware and software.

The U.S. Defense Science Board task force on military software concluded that today's major problems with software development are not technical, but stem rather from managerial shortcomings. Another authority, the Software Productivity Consortium representing the 14 major aerospace industry corporations in America, argues that the problems stem from the use of the traditional software management model — the so-called waterfall model (Fig.4) which calls for formal specification, design, coding and maintenance phases. The consortium states that this document-driven approach may not be ideally suited for embedded systems, and that an evolutionary model (Fig.5) should be adopted to permit incremental software development, using prototyping and design iterations in an overall system perspective.

Given the nature of naval requirements, embedded software is redeveloped several times after the initial version is delivered. With the development process shown in Figure 5, redevelopment is carried out throughout the life cycle of the system. The point of reentry for redevelopment is determined by the scope and magnitude of the intended change. It is then determined if a complete or partial rebuild is needed. It is now considered cost-effective to adopt a philosophy of discarding prototype software, as is done with prototype hardware.

Industry experience has shown that despite the use of traditional system development methods, users of the system regard the resulting applications as neither correct nor complete. This occurs because the traditional methods were unable to accurately capture the user's true needs.

Ada Language

Software has been described as too expensive, always behind schedule, never working according to the specifications and

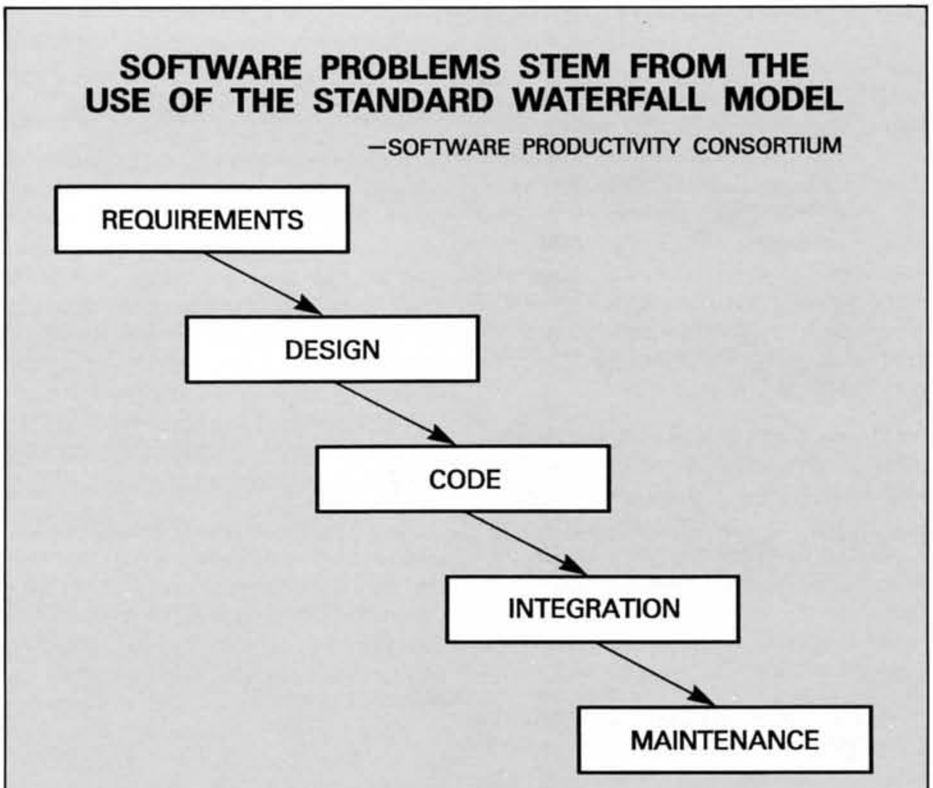


Fig.4. The Waterfall Model for Software Management

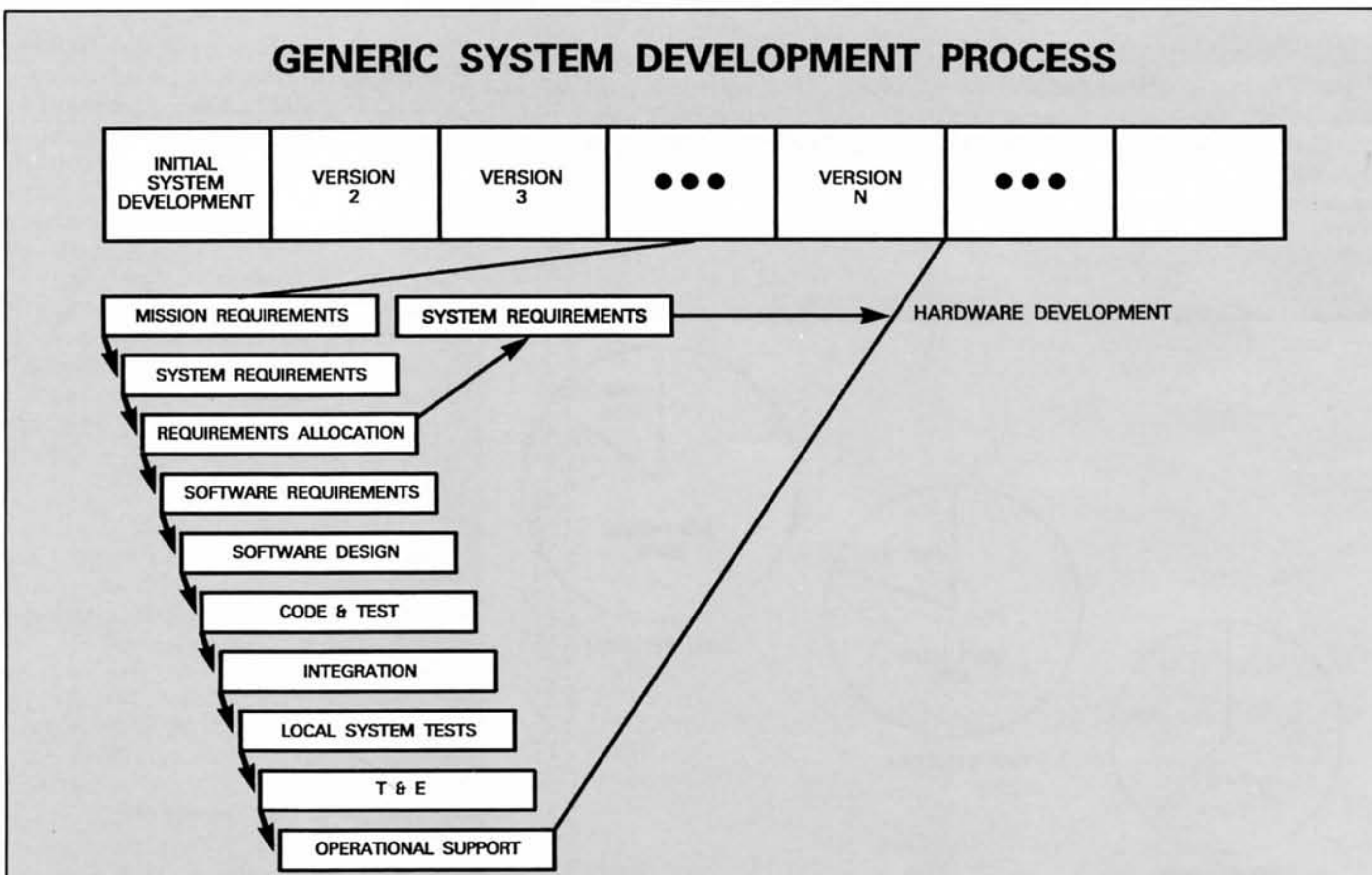


Fig.5. The Evolutionary Model

impossible to modify. These attributes define the software crisis which led the U.S. defense department to fund development of the Ada language. Language proliferation was a major cause of their software difficulties, and it was found that over 450 different computer languages were being used for mission-critical systems, with none of the languages dominating the others as far as frequency of use was concerned.

Other than providing the single common language, Ada's major advantage is in providing the means to achieve the benefits of modern software engineering methods. A key element in the Ada concept is the existence of a complete Ada programming support environment comprising all the tools required for the production of embedded systems. Ada has been mandated as the single, high-order language in the United States* and NATO, and in Canada a recent policy directive established Ada as the mandatory language for capital projects.

Early experience with Ada suggests that the promise of increased software productivity and reliability will be fulfilled. However, many problems remain, such as the need for validated and efficient compilers targeted to embedded systems, and software development environments built around Ada. The technology supporting Ada is evolving rapidly and validated compilers for embedded systems are now emerging in the marketplace.

The use of Ada alone will not guarantee the generation of better software. Good, modern principles of software engineering are needed for software design, and Ada will enforce those principles better than any other language.

Software in the Future

In the years ahead systems will make use of supercomputers, consisting of a large number of parallel processing systems composed of clusters of processors dedicated to activities such as artificial intelligence, number crunching, graphics or database manipulation. These super-knowledge-based systems will have memory space of hundreds or thousands of gigabytes, data-transfer rates of tens of gigabytes per second and large software programs capable of processing data with incredible speed and accuracy. With these supersystems it is hoped that vast improvements in the way we produce software will be forthcoming.

In this era of automated mass production of chips, memory and other hardware elements, it is totally incongruous that the art of programming will remain unchanged from its earliest days. It is expected that industrialized programming — the "software factory" — will emerge. Just as hardware systems are assembled with standard boards and circuits, so the software program for naval systems of the future will likely be assembled from standard software components which have been recycled from other systems or procured from off the shelf.

Conclusion

It has become quite fashionable to complain about software and the processes and organizations that produce it. The problems of software continue to manifest themselves, and their effect is growing as systems become more complex and more dependent on software. The software process is difficult to control, estimate, schedule or track. It is both a technical and managerial problem. Since all systems now depend on embedded processors and software, it behooves all MAREs to become proficient in structured software/development methodologies if the software crisis is to be conquered.

Commander Cyr is the DMCS 8 section head for naval computer technology at NDHQ.

* The U.S. DOD spent $700 million in 1987 on software written in Ada, and it is expected that a further $16 billion will be spent on Ada by 1990.

Panic!

On the spur of the moment, the Naval Overseer for *Assiniboine*'s Montreal refit, a Chief Hull Tech, decided to check the cleaning of #1 ballast tank. Entering the tank alone and not noticing the hose lines hanging from the manhole, he crawled to the forward end of the tank, a very tight fit. To his horror, the tank started to fill with water. Panic-stricken and unable to dislodge himself from between frames, he screamed for help. With luck, the tank tester understood his scratchy Scottish accent, shut off the water and the rescue began. With the aid of one Pusser, two haulers and a charge hand, the Contractor managed to extricate him from the tank ... but not his predicament. He was later presented with a (hoax) Form 1379 Bill of Arisings totalling $2500 for "the removal of Naval Overseer from tank."

Ed McSweeney, Senior Hull Inspector,
NEU(A)

Do you have an amusing anecdote?
See page 1 for our address

Looking Back: 1986

The Nipigon *Bow Fracture*

By Cdr John Edkins, Naval Architecture Officer, NEUA
Lt(N) Mark Gray, Ships and Submarine Services Officer, NEUA
Mr. Clyde Noseworthy, Chief Hull Inspector, NEUA

Editor's Note — *When cracks were discovered in* Nipigon's *stem back in 1986 there was little hard evidence to indicate what had caused them. A certain amount of conjecture was made at the time, but nothing definitive was ever put forward to explain the probable cause of the damage. Until now. When these photographs by chance resurfaced at NEU(A) last spring, they sparked a renewed interest in the problem. With the help of the photos, the authors felt a hypothesis could be made which would explain the stem structure failure in* Nipigon *and in other steamers where similar type damage has been occurring since the mid-1970s.*

We all know that our ships take a pounding out in the Atlantic. Probably the most visible and disturbing sign of the wear and tear they endure is the presence of cracks. In the spring of 1986 ship's divers discovered extensive hull damage in the forefoot and stem sections of HMCS *Nipigon*. The opening (*Fig.1.*) permitted flooding in the forepeak and significantly reduced the structural rigidity in this area. Further evidence of the problem was illustrated by more cracking observed in the plating over several transverse and longitudinal stiffeners in the lower bow area.

To prevent further damage to the ship while she fulfilled her operational commitments, interim repairs were made in April 1986 by FDU(A) alongside in Halifax. The opening was closed using bolts and flat bars, and the cracks were arrested by drilling out the ends (*Fig.2.*) A month later, *Nipigon* was docked and the entire stem assembly was rebuilt (*Fig.3.*).

CFB Shearwater photo

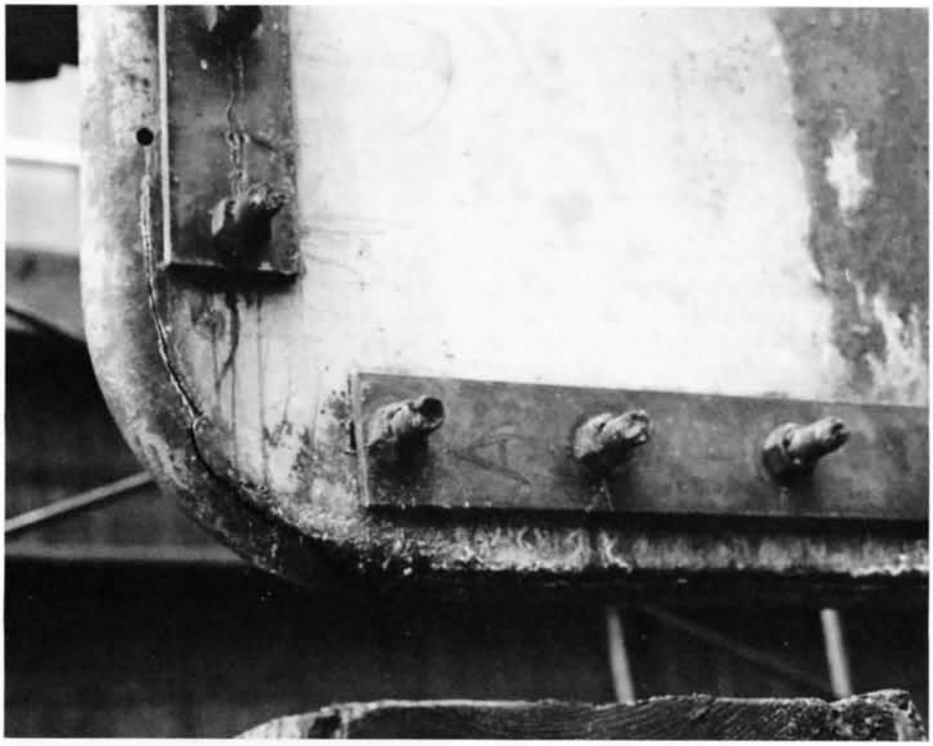
Fig.1.

In an attempt to determine the cause of the problem the DREA Dockyard Lab was asked to analyze the damage. Unfortunately, the crack "history" had been erased by corrosion and by the stop-gap repairs. It is, however, still possible to hypothesize a failure mechanism and possible causes based on the clearly visible evidence.

The propagation of the cracks along the stem bar is largely confined to the weld beads (*Fig.1.*), suggesting that the crack growth was controlled by material characteristics within the heat-affected zone. The cracks may have been started by long-term corrosion in the inaccessible forepeak void space, or by a defective weld, but it is fairly certain that a large force would have been required to open the hull.

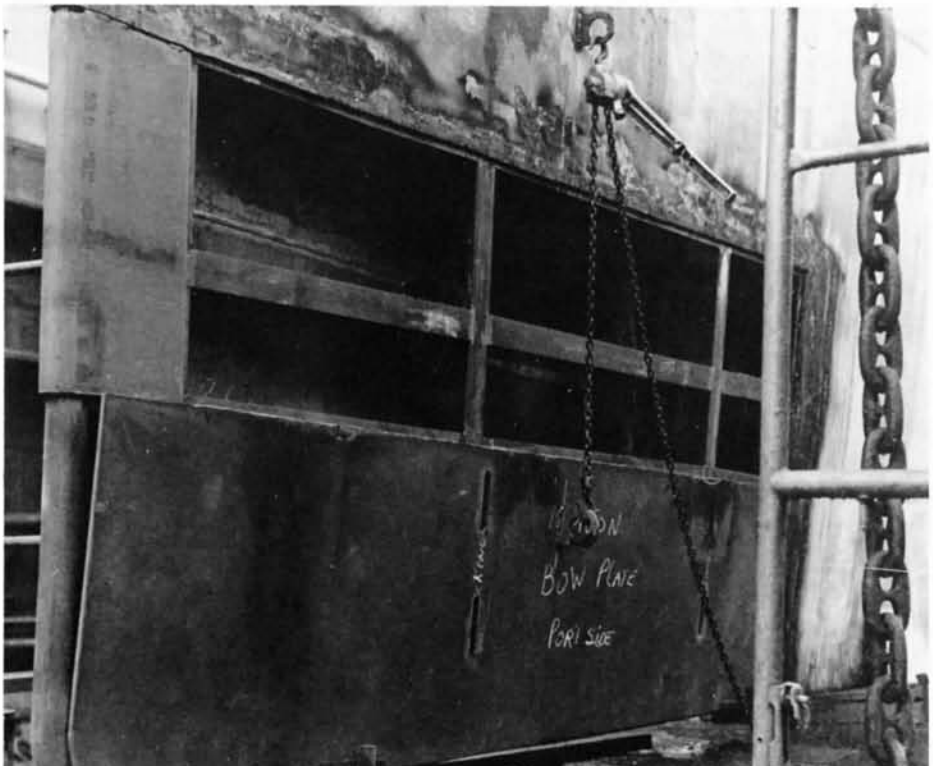
Since there was no evidence of collision or docking damage it is felt that the damage was caused by slamming. The stem structure in our steamers is extremely slender and flexible, and thus it is very likely that the structural damage in *Nipigon* was due to fatigue failure under repeated flexing of the stem.

Given the age of these ships, their operating conditions and their stem and forefoot design, this type of failure will likely continue to occur. (A longitudinal crack discovered in *Margaree's* forefoot this year may well have been the start of such a problem.) However, awareness of the situation should result in early recognition of the problem and a concomitant reduction in repair time.



DREA Dockyard Lab photo

Fig.2.



CFB Halifax photo

Fig.3.

News Briefs

Bravo Zulu

Congratulations go out to Commander Peter McMillan and Lieutenant Commander Brian Staples. Their article "Saint John Shipbuilding Ltd and CPF Construction", which appeared in the January 1987 issue of the *Journal*, was recently selected as background reading to the Canadian Studies program at National Defence College in Kingston.

Sonar production contract awarded

Computing Devices Company of Nepean, Ontario has been awarded a $21.3-million contract for the production of AN/SQS-510 sonar equipment for the Canadian and Portuguese navies.

Under the terms of a contract let last April, Computing Devices will furnish two sets for HMC ships *Nipigon* and *Annapolis*, and a further three sets for Portugal as part of a NATO military assistance program to that country.

Nipigon should receive the AN/SQS-510 late in 1989 and delivery to *Annapolis* is expected to follow a year later.

The first delivery to Portugal is scheduled for March 1990. The 510 sonar will become the primary underwater sensor on three MEKO-200 anti-submarine frigates now under construction in West Germany.

TRUMP officers receive awards

LCdr Alex Rueben and Lt(N) Noel Purcell, both of whom were employed in the TRUMP PMO from 1986 until this summer, have received awards for excellence from the Canadian Institute of Marine Engineers.

LCdr Rueben was honoured for achieving the highest mark in the naval engineering certificate of competency (marine systems) Part I exam for 1982, and for the highest mark in the Part II exam for 1985.

Lt Purcell was honoured for achieving the highest mark in the combat systems C of C Part II exam for 1985.

The awards were made in Ottawa last April 26.

Bravo Zulu to both officers!

Pictured at the awards ceremony are TRUMP Project Manager Capt(N) R. Preston, Lt Purcell, LCdr Rueben and C.I. Mar E. Ottawa Branch Chairman Gerry Lanigan. (N. Martin photo)

CANTASS...

Coming up in our January issue