CANADIAN FORCES CANADIENNES

National Defence / Défense nationale

MARITIME ENGINEERING Journal

MARE

Canada

WINTER 85 HIVER 85

MARITIME ENGINEERING JOURNAL OBJECTIVES

- To promote professionalism among Maritime engineers and technicians;
- To provide a forum for open discussion of major issues even if they may be controversial;
- To provide announcements on MARE programmes;
- To present practical engineering articles of interest to Maritime engineers;
- To provide personnel news of a type not covered by existing publications; and
- To provide historical perspectives on present situations and events.

WRITER'S GUIDE

We are interested in all subjects meeting one or more of the objectives stated above. The journal is published biannually in the winter and summer. Articles must be received at least two months before we go to press. Correspondence can be sent to the Editor, Maritime Engineering Journal, Directorate of Marine and Electrical Engineering (DMEE 5), National Defence Headquarters, Ottawa, Ontario, K1A 0K2.

NEXT ISSUE SUBMISSION DEADLINE

1 April 85

MARITIME ENGINEERING JOURNAL
ISSN 0713-0058
WINTER 85
EDITION
JANUARY 1985

The Maritime Engineering Journal is an authorized unofficial publication of the Maritime Engineers of the Canadian Forces. It is published biannually at National Defence Headquarters by the Director General Maritime Engineering and Maintenance. It is published to provide professional information, as a forum for the exchange of ideas and opinions, and as a common unifying influence through wide distribution to the Maritime Engineering Community. Views expressed are those of the authors and do not necessarily reflect official opinion or policy. Correspondence can be sent to the Editor, Maritime Engineering Journal, Directorate of Marine and Electrical Engineering (DMEE 5), National Defence Headquarters, Ottawa, Ontario, K1A 0K2.

JOURNAL DU GENIE MARITIME
ISSN 0713-0058
L'HIVER 1985
EDITION
JANVIER 1985

Le Journal du Génie maritime est une publication autorisée des ingénieurs maritimes des Forces canadiennes, à caractère non officiel. Edité 2 fois par an par le Quartier général de la Défense nationale, il bénéficie d'une large diffusion dans les milieux du Génie maritime. Les opions qui y sont exprimées n'engagent que la responsabilité de leurs auteurs et ne reflètent pas nécessairement le point de vue officiel. Le courrier doit être adressé au rédacteur du journal du Génie maritime, Directeur — Génie maritime and maintenance (DMGE 5), Quartier général de la Défense nationale, Ottawa (Ontario), K1A 0K2.

Contents

MARITIME ENGINEERING JOURNAL

Editor's Notes

This edition of the Journal features an article on HMCS BRAS D'OR written by Cdr Pat Barnhouse. As the author points out, many of the ideas that were embodied in the ship design remain as valid today as they were in 1959. The discussion concerning the decision milestones for the FHE-400 project is particularly conclusive, and from that it is interesting to note the lessons that can be learned from the history of the project.

Also in this issue, Cdr Jack Scholey et al point the way ahead beyond TRUMP for the DDH-280 waste-heat recovery system, and LCdr Bill Dziadyk discusses the performance considerations of the SHINPADS data bus. Mr. W.A. Reinhardt of DMEE 6, and Mr. C.A.W. Glew of the Naval Engineering Test Establishment complete this edition with their discussion of the use of vibration and rundown-time norms as a quality control tool for overhauled electric motors.

We are always eager to receive your letters and articles because the Journal is published as a forum for discussion. If you are unsure of what to write about or where to send it, you might find it helpful to refer to the Journal objectives and writer's guide on the inside of the front cover.

As a final note, congratulations go out to Cdr David Faulkner who, in recognition of his performance on the C.F. Command and Staff College course, was presented with a membership in the United States Naval Institute.

Letters to the Editor

I am a Preparatory Year student at Collège militaire royal de Saint-Jean and have classified as a Maritime Engineer. Your Summer 84 edition of the Journal was very interesting and informative, and I would like to express my congratulations on a fine job.

Richard G. Sullivan

MARE GET-WELL PROJECT

I have just had the pleasure of reading, cover to cover, your summer edition of the Journal. I am pleased to see that your group has seen fit to create the MARE Get-Well program and all its relevant spin-offs. The various articles are, as the opening page indicates, the views of the author and not necessarily policy. In this context, it is often noticeable where opinions and policy will differ. You are, indeed, fortunate to have the facility and means to publish such a text. Your overall branch with its various classifications has, indeed, suffered in the past decade. It may interest your readers to know that this is recognized by the concerned **Other Ranks** as we serve at sea with EO, after EO, and that some of us strive to assist A/EOs and EOs in their training and certifications.

Your readers are, no doubt, aware of the tremendous conflict of interests, soul searching and dissatisfaction with the state of the MAR ENG **Other Ranks** Community. We who are genuinely concerned for all aspects of the system and its future seem seldom to be heard, or else our comments appear to be disregarded. Since your journal is not restricted to the Officer Corps, and since the branch that supports your community on the high seas is in turmoil, I trust you will allow me to expound some personal views at a later date.

J.L. McIntosh, CWO, CMCDSC
Naval Engineering Project TECH
Naval Engineering Unit (Atlantic)

Commodore's Corner

BY COMMODORE J.A. GRUBER

The MARE Journal has provided me with my first opportunity as DGMEM and Naval Operations Branch Co-Adviser (MARE) to comment upon our profession, the people who practice it and the framework in which it is practiced. I have found the Journal to be of such a quality and substance that I believe it represents a symbol of our emergence as a profession in the era of the new realities. To its editors and contributors we owe a debt of gratitude for their fortitude, insight and dedication. It should grow on this base, as I believe we will within the context of the Navy and the Armed Forces.

I believe that the long period of drought in Naval programs and the inevitable storms and conflicts we have encountered have toughened us in a way that we can now go forward with a real resolve and purpose. My optimism, and in some part awe, at where we are is derived from the "horizon full" of Naval programs I see before me. It was not easy to achieve given the pressures of restraint, attrition, process and culture change we have experienced.

The sustaining element has been our people, both new and less new. Despite much peer pressure to seek other careers, each has made a contribution, whether it be in the domain of the existing fleet, new programs or part of the training or support process. It is the people element which is very much at the core of the Branch Adviser role (as undefined as it may be). In this regard I would like to acknowledge my two immediate predecessors: Commodore Ball, who spent untold energy and courage in laying out the essence of our profession during an era of extreme pressure from every quarter; and Commodore Ross who re-established the Branch Adviser as a follow-on to a number of unique contributions to the Navy.

We have a proud heritage and a real future in which to practice our profession as Naval Officers. In our Anniversary Year as a Navy I will seek your support in the continuation of the improvements to our Classification.

The Canadian HYDROFOIL PROJECT

AUTHOR COMMANDER P.D.C. BARNHOUSE

Cdr Barnhouse entered the RCN as a Cadet(L) in 1952. He is a graduate in Engineering Physics from RMC and obtained his BSc in the same discipline from Queens University. He later completed an M.S. in Engineering Electronics (Underwater Acoustics and Sonar Systems) at the USN Post-Graduate School, Monterey, California. He also attended the Long Electrical Officers Qualifying Course and the Canadian Forces Staff College. Service appointments have included: instructor in HMC Electrical School, Electrical Officer in HMCS HAIDA, Staff Officer (Directorate of System Engineering) in Naval Headquarters, Assistant Project Officer and later Project Officer (Fighting Equipment) for the FHE-400 Hydrofoil, Electronic Maintenance Officer in HMCS BONAVENTURE, Weapons System Engineering Officer HMC Dockyard Halifax, and MARE Career Manager; then, successively, Section Head DMCS 2 (Surface and Air) and DMCS 6 (Comm and EW) in DGMEM, and DGMEM/MAT. He presently occupies the Weapons and Mechanical Systems desk in the Directorate of Technology Application (Maritime), a unit of the Research and Development Branch.

ABSTRACT

Recent publication of "The Flying 400: Canada's Hydrofoil Experience" by Thomas G. Lynch has sparked renewed interest in the details behind the conception, design, trials, lay-up and final disposal of HMCS BRAS D'OR. This paper is essentially one that was presented to the Minister of National Defence in response to his request for a comprehensive brief on the subject.

INTRODUCTION

Conventional surface warships suffer fundamental limitations in performance precisely because they operate on the ocean surface. For example, a ship's maximum speed is limited by hydrodynamic drag associated with the sea surface and by the slamming effect of the seaway. The operational and technical problems introduced by sea surface effects can be reduced simply by getting away from that surface, either above it or below it.

The submarine solved the problem by going below the sea surface. The submarine, however, still suffered from fundamental limitations in endurance and speed until the advent of nuclear power transformed it into a true submersible. The other solution, of getting above the sea surface, may be achieved several ways and one of those ways is to use a hydrofoil. The hydrofoil ship, by lifting its hull above the sea surface, enjoys greatly reduced hydrodynamic drag and, at the same time, greatly improved sea-keeping characteristics.

The Canadian contribution to the search for an economical open-ocean patrol ship, effective against the modern submarine, was the design, construction and trials of HMCS BRAS D'OR (FHE-400). It was an ambitiously conceived ship which demonstrated in sea trials that it could meet its design objectives. At 200 tons all-up weight and 150 feet length it was a very big hydrofoil ship for its day -- as it needed to be to meet its operational role. Its top speed of over 60 knots has not been matched by any other commercial or military hydrofoil to this date. Many of the ideas embodied in the ship are as valid today as they were in 1959 when the programme was conceived. But there were many difficulties which introduced delays and these finally led to discontinuance of the trials and development in 1971.

HMCS BRAS D'OR foilborne during trials in 1969. With her surface-piercing foil system she achieved an incredible top speed of 63 knots.

HISTORICAL BACKGROUND

The conceptual beginnings of the FHE-400 hydrofoil can be traced back to the work of Alexander Graham Bell and F.W. "Casey" Baldwin during the period 1911-1920 at Baddeck, Nova Scotia. That work culminated with the breaking of the, then, water-speed record on the Bras d'Or Lakes using their HD4 hydrofoil. The ideas of Bell and Baldwin were further developed after World War II by the Defence Research Board at its Naval Research Establishment in Dartmouth, Nova Scotia. Three craft were built to test hydrofoil concepts: the 8-ton "Massawippi", the 17-ton "Bras d'Or" (renamed "Baddeck" with the commissioning of the FHE-400) and the 3-ton "Rx" research craft.

What these craft all had in common was the fixed surface-piercing type of hydrofoil system where the foils themselves are very much like aircraft wings. But because they operate in seawater having a density many times that of air, the area required to support a given weight is much less and, consequently, the foils are comparatively small. The faster the speed, the smaller is the area required to support the hull. The result is that the craft rises in the water as unneeded foil area emerges, continuously matching the immersed foil area at a given speed to meet the lift required to balance the load.

A fully-submerged foil system developed in the USA contrasts with the surface-piercing system by having constant immersed area. Lift is varied by moving flaps, or sometimes the entire foil, at the command of an auto-pilot much like an aeroplane. The system is relatively complex, requiring, as an example, a height-sensing system capable of "flying" the vessel at a very low altitude above the water. Its appeal lies in its inherent capability for better foilborne seakeeping, a very important consideration for the operational applications preferred by the USA which emphasize continuous high-speed running.

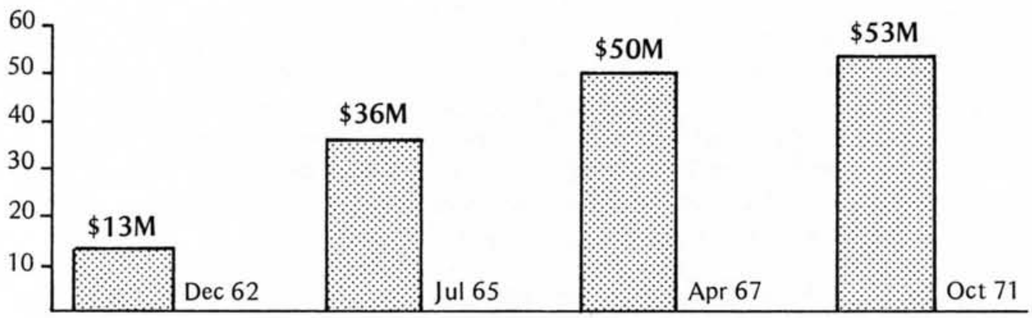
The appeal of the Canadian surface-piercing system lies in its essential simplicity. The system can be made inherently stable, so there is no need for moving lift-surfaces, auto-pilot or height-sensing components. In addition, the hydrofoil-section shapes themselves can be tailored to their particular speed regime. The thicker, more highly cambered, "low-speed" sections emerge to leave thinner, more efficient sections to operate at higher speeds, making possible the comparatively high speeds attainable with the surface-piercing system.

The Canadian R&D programme at the Naval Research Establishment (now the Defence Research Establishment Atlantic) led to the development of a concept for a 200-ton open-ocean ASW hydrofoil; that being the minimum size that could be expected to give a useful operational capability as a warship. For ASW an extremely versatile vehicle can be a decided advantage. Initial detection calls for long endurance at slow speeds with underwater radiated noise kept to a minimum, whereas interception of high-speed underwater targets requires short periods at high speeds. With its specialized design that achieved a high maximum speed, but which emphasized good displacement endurance and seakeeping capability, the conceptual hydrofoil was well suited to the ASW task.

In January 1960, the 200-ton ASW hydrofoil concept was studied in detail at a meeting of British, American & Canadian scientists, engineers and naval officers held under the auspices of the Technical Cooperation Program. The proposal was judged to be technically sound and it was also considered that the unique performance characteristics of the suggested ship promised a significant improvement in ASW capability.

The group recommended that "a program leading to the construction of an anti-submarine hydrofoil craft of about 200 tons should be set up in the near future, with design studies and model testing as initial steps. Such a program would complement in a very essential way the US programs now underway and its initiation should not await the completion of these programs". This is a concrete indication of the degree of cooperation which then existed (and continues to exist) at the technical level between the USA, Britain and Canada in the field of what has become known as advanced marine vehicle development. In fact, Canada's active participation in hydrofoil development and experimentation resulted in the accummulation of a very large amount of information on the broad spectrum of advanced marine vehicle technologies; data which Canada could not hope to have gathered on its own. The tacit agreement at that time was that the USN would concentrate on hydrofoil ships equipped with the fully submerged type of system, the British would concentrate on hovercraft, and Canada would investigate the potential of the surface-piercing system.

FHE-400 PROJECT – COSTS



Original estimate

First estimate based on "realistic technical data".

Based on better estimates, cost of technical improvements, and costs resulting from engine-room fire.

Total expenditure at time HMCS BRAS D'OR laid up.

Subsequent to the Tripartite meeting, the Canadian hydrofoil concept was critically investigated by De Havilland Aircraft of Canada Limited who followed up with the submission of a design proposal to the Royal Canadian Navy. Then in April 1963, De Havilland was given a contract to design and construct a development prototype hydrofoil ship, the FHE-400.

In mid-1964 the RCN requested and received approval to continue the ship programme, and to proceed with the design and construction of the fighting equipment suite for FHE-400 under separate contract with Canadian Westinghouse Company Limited.

The project, as approved at that time, had the following objectives:

a. To establish the feasibility of open-ocean operation of small surface-piercing hydrofoils, and to test the validity of the design predictions used in determining the characteristics of the developmental prototype ship; and

b. To develop a fighting equipment system that would be attuned to the characteristics of the ship design and would permit a thorough assessment of the ship's capabilities in ASW operations.

It was planned that the entire project would be completed by mid-1968.

FHE-400 DESIGN, CONSTRUCTION & TRIALS

Since a surface-piercing hydrofoil of the size of FHE-400 had not been built before, a great deal of modelling was used to verify the theoretical design. Analogue computer simulation, and tests at various scales of the foil arrangements (and even of the complete ship), were both used extensively. The most comprehensive of all the model trials were carried out using the Rx craft with a representative 1/4-scale foil system.

The foil design itself was in the canard configuration which meant that 90% of the weight was carried on the after, or main, foil while the remaining 10% was apportioned to the steerable bow foil. This particular configuration, besides allowing for good seakeeping, had the additional advantage of allowing convenient installation of the engines and propulsion system, and was eminently suitable for the proposed stern-mounted variable depth sonar handling gear. Although the bow foil was a small unit carrying only 10% of the load, it served the vital function of controlling the ship's trim stability and pitch response in addition to its function in steering.

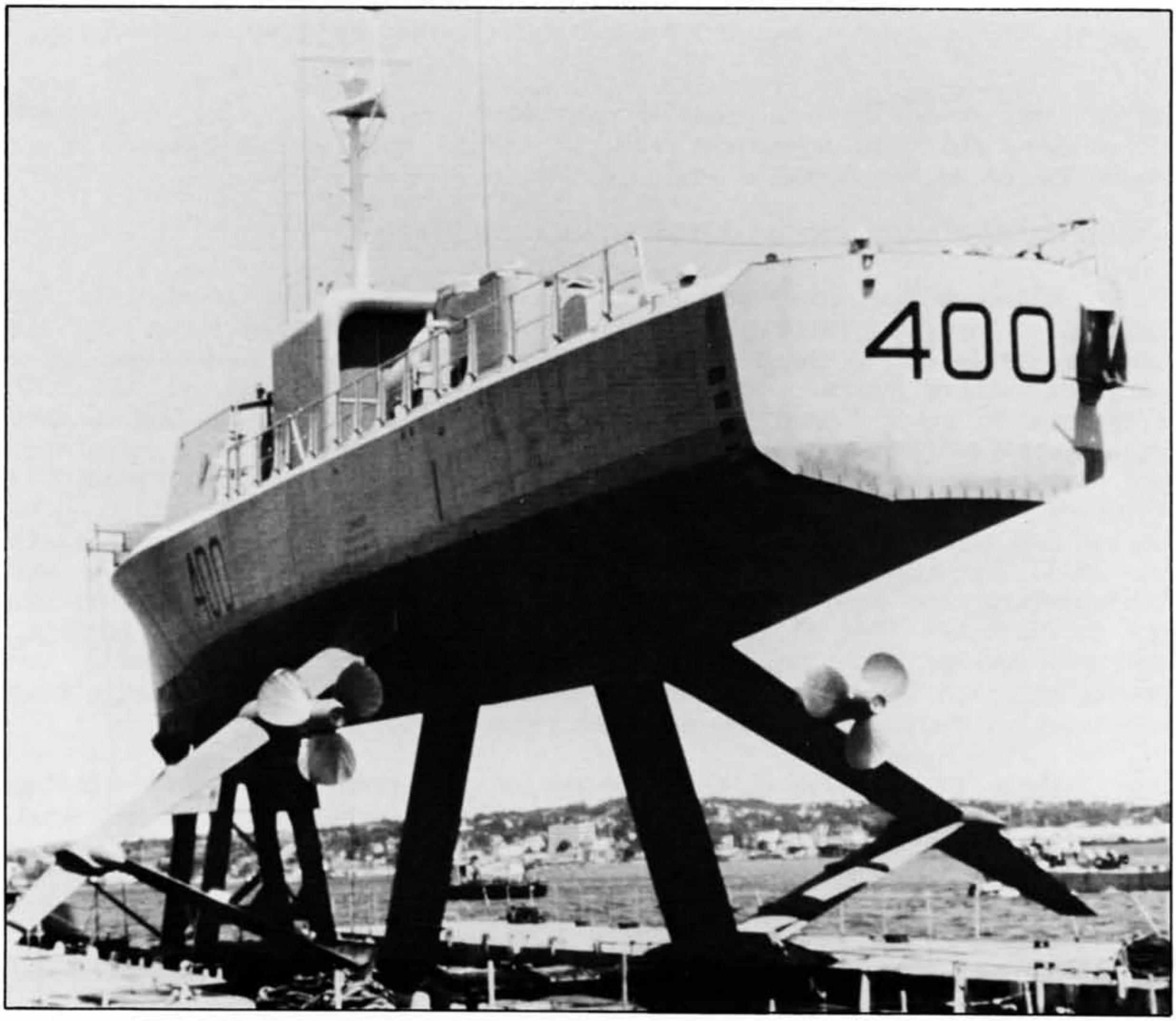
The hull shape, governed by the requirement for low-displacement resistance and ability to withstand wave-impact loads, was exceptionally slender and the appropriate use of aluminum alloy led to an efficient volume to weight ratio. Internal arrangements included a bridge and operations room superstructure, carefully thought out accommodation and messing for a crew of 20, and a machinery space located above and abaft the main foils. Propulsion itself was provided by a gas turbine for foilborne operation and a diesel for hullborne operation. A full suite of auxiliary systems was provided, designed to give complete electrical and hydraulic service.

The aim of the Royal Canadian Navy to design FHE-400 as an integrated ASW weapon system made it necessary for the development of specialized fighting equipment to proceed in parallel with the ship design and construction. The combat suite comprised a lightweight towed sonar for submarine detection, homing torpedos, and an integrated complex of navigation, radar, fire-control and communications equipment.

In November 1966, while the ship was under construction at Marine Industries Limited at Sorel, Quebec, a major fire occurred during tests of the auxiliary gas turbine engine installation. Extensive structural damage was done, principally in the engine-room, and repair necessitated the removal of all installed engine-room equipment and systems for overhaul and inspection.

In July 1968, still without its foilborne transmission but otherwise ready for launch, the ship was transferred to Halifax on the slave dock which served as its maintenance base. There it was launched for alongside systems activation. In September a brief spell of hullborne sea trials was undertaken as a continuation of the systems activation, and later in the month the ship was redocked to fit the foilborne transmission. In March 1969, the ship was finally relaunched for foilborne trials. A variety of engineering problems arose, but all were eventually overcome. They involved principally the displacement transmission, the bow-foil pivot-bearing, the tip and steering actuators, the electrical system and the hydraulic pumps. Then a large crack was discovered in the lower surface of the main high-speed foil. With the removal of the neoprene layer, with which the foils were coated, an extensive network of cracks was found entering the spar and rib members of the substructure. This disastrous development, thought to be due to leakage of seawater into the foil interior (past a supposedly sealed plug), led to stress corrosion at the welds with significant residual stresses.

A new centre-foil was fitted in October 1970 and foilborne trials resumed. When the system was inspected after a Halifax-Bermuda-Norfolk round trip, it was discovered that this foil too had developed major cracks and that extensive cracking was also present in other foil systems. The unmistakable inference from this was that a major redesign and rebuild of the foil system would be necessary before trials could continue. Thus it was that in October 1971 a decision was made by the Department of National Defence not to proceed with trials and to lay the ship up.



The main foil of the FHE-400 surface-piercing system supported 90% of the vessel's weight while only 10% was supported by the steerable bow foil. This canard configuration gave the hydrofoil an impressive seakeeping capability.

From September 1968 until July 1971 when trials terminated, the ship logged 648 hours of sea time of which 96 were foilborne. The highest speed attained was 63 knots in three-to-four-foot waves, whilst 42 knots was achieved in 12-foot seas. The ship also made a 2500-mile round trip from Halifax to Bermuda and Norfolk, Virginia. The hullborne range at 12 knots proved to be approximately 2500 miles and, foilborne at 45 knots, ranges varied from 900 miles in calm water to 600 miles in 12-foot seas. Hullborne seakeeping and manoeuvrability were excellent with rough-weather pitch and heave motions comparable to those of a 3000-ton St. Laurent-class destroyer. Foilborne motions in high sea states were similar to aircraft motions in turbulence, making it difficult for the crew to move about, although seated personnel had no difficulty. Overall, both hullborne and foilborne performance coincided with predictions. In the end, though, the combination of delays, and cost increases resulted in the main weapon systems never being fitted for performance evaluation.

VIABILITY ASSESSMENT AS AT 1971 PRESERVATION DATE

Although the immediate reason for terminating the trials was the failure of the foil material, there were other contributing reasons. First and foremost, in 1970 the Department had been placed on a fixed budget for a period of three years. The combination of this cash squeeze and cost increases in other higher priority ship-construction projects was a most significant factor in the decision, as were the high fuel-consumption rates and high operating costs of the hydrofoil itself. In addition, instead of a three-year design and construction period and six months of trials, the design and construction had taken six years and the first phase of trials was still incomplete after a further 3 years. The hydrodynamic design was fundamentally the same as originally proposed, but the overall design was now so different that it really represented a complete change in concept. The ship had evolved from a simple, relatively cheap vessel suitable for construction in large numbers, into a highly sophisticated vessel requiring construction techniques of the greatest refinement.

There is no doubt that the degree of development and sophistication essential to a 60-knot warship had been underestimated. It reflects great credit on the design team that they were able to meet the many technical challenges that arose. Far from working within the state-of-the-art, the designers had to extend the state in many areas. The problem was that too much technical innovation was required and, despite the success of most aspects of the design, the collective technical risk was very high.

SUBSEQUENT EVENTS

In October 1971, with the agreement of Treasury Board, FHE-400 was placed in a state of preservation for a period of five years. In October 1976 this was extended a further five years in view of the then current stage of the Ship Replacement Programme which saw a possible long-term option for non-conventionally hulled ships. Given the ongoing development in non-conventional hulls, and the relatively small amount of preservation funds required, it was considered prudent to retain FHE-400 as a possible useful platform for future trials and development at the least expense.

Subsequently, as a result of the evolving proposed future maritime force composition, it was concluded that the military requirement for FHE-400 no longer existed. In addition it was estimated that more than $6 million would be required to activate the ship as a research vessel even if the requirement did exist. Consequently the VCDS recommended that the vessel be disposed of as soon as possible.

Given official approval for disposal, FHE-400 was first offered "as is" to other government departments and industry. There were no takers, so it was determined that the ship should be offered to a museum after removal of all equipment useful to DND. Finally, with the aid of the Museum of Science & Technology, the Bernier Maritime Museum obtained HMCS BRAS D'OR in 1983.

DISPOSITION OF TECHNOLOGY ACQUIRED FROM THE PROJECT

The computer-based command and control Action Information System (AIS) developed for HMCS BRAS D'OR required the formation of a naval programming team at the program generation centre established at Canadian Westinghouse Company Ltd. in Hamilton. This expert team later developed computer programs for the naval tactical data Command and Control System (CCS) for the DDH-280-class ships. Thus, the CCS system currently at sea in the DDH-280s owes part of its existence to the hydrofoil project.

A variable depth sonar was designed and built for FHE-400 with Canadian Westinghouse responsible for the electronics and Fleet Industries Ltd. supplying the over-the-stern handling gear. Since then, Fleet Industries Ltd. and Fathom Oceanology Ltd. have, between themselves, produced a dozen sets of handling gear derived from that developed for the hydrofoil. The sets have been sold to Raytheon as part of their sonar sales to the Italian navy, and Westinghouse Canada Ltd. has sold one sonar system based on the hydrofoil system to the Swedish navy.

The hull structure of HMCS BRAS D'OR was designed to aircraft standards. By appropriate instrumentation of the hull for sea trials, the strengths and weaknesses of this technology vis-a-vis conventional ship design practices for hydrofoils were ascertained.

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

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

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

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

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

e. the completely new crew-habitability design to cater to the small crew, the operating environment and the limited accommodation space available.

SUMMARY/CONCLUSIONS

From a technical point of view, experience gained in the design and building of FHE-400 and in the exchange of information with the USA & Britain, both during the project and since its termination, leads to the following conclusions:

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

b. the fully-submerged foil system pursued in the USA has been developed to the point where its practicality and outstanding foilborne seakeeping cannot be doubted;

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

d. use of aircraft technology in hydrofoil construction is a mixed blessing. On the one hand it undoubtedly results in weight saving, but on the other hand leads to a less robust ship that costs more because of the use of tight aircraft tolerances which require expensive jigs & fixtures; and

e. USN experience has shown that there are expensive infrastructure and support costs peculiar to the operation of a fleet of hydrofoils; costs which are over and above the support base required for conventional warships.

Undoubtedly, the most valuable contribution of FHE-400 has been the footing gained for Canada in the general field of advanced marine vehicle technology. The effort and contribution made are fully recognized by the USA and Britain, and the tripartite cooperation which developed during the period continues today with DREA continuing a watching brief on hydrofoil and other advanced marine vehicle research. Continued cooperation and information interchange enables Canada to build on the fund of knowledge gained from FHE-400, and to be in a position to reassess continuously, on a technical basis, the potential for advanced marine vehicles to meet future needs.

FHE-400 PROJECT – DECISION MILESTONES

January 1960	Tripartite conference recommends extension of Naval Research Establishment work to construction of a 200-ton ASW hydrofoil.
March 1961	De Havilland feasibility study authorized.
December 1962	Naval Board approves construction of FHE-400.
August 1964	Procurement of fighting-equipment suite from Westinghouse approved.
April 1967	Decision made to continue project despite set-back from engine-room fire of 5 November, 1966.
October 1967	Decision made to defer cutting of variable depth sonar well and fitting of fighting equipment.
December 1969	Decision made to procure a replacement centre-foil and to continue trials.
October 1971	Decision made to lay up HMCS BRAS D'OR.

ACKNOWLEDGEMENTS

An invaluable source of technical information was the draft copy of "A Development and Trials History of HMCS BRAS D'OR (FHE 400)" by Mr. E.A. Jones of the Defence Research Establishment Atlantic. Without this information, the author would no doubt still be floundering in search of both facts and framework for his own paper. In National Defence Headquarters, both Dr. F.A. Payne of the Directorate of Technology Application (Maritime) and Cdr D. Cogdon, Director of Maritime Force Development, provided timely and incisive comment.

DDH-280 WASTE-HEAT RECOVERY SYSTEM

Commander J.R. Scholey
Mr. J.P. Neri
Lieutenant Commander G.W. Mueller

AUTHORS

Commander Scholey joined the RCN in 1966. During his career he has had shore appointments in SRU(A), NEU(A), RNEC Manadon, and NDHQ. He has also served as MPO in HMCS PROTECTEUR and as EO in HMCS ASSINIBOINE. He is currently the Section Head of DMEE 4 in NDHQ.

Mr. Neri joined the Public Service in 1972 and served with MOT before joining DND in 1975. Since then he has served as a Project Engineer in PMO CPF and is now the Senior Engineer in DMEE 4.

Lieutenant Commander Mueller joined the RCN in 1966. Since that time he has served as MPO in PROTECTEUR and EO in NIPIGON. His shore appointments in NDHQ have been with DPCOR, DMEE 3 and DMEE 4. He is currently the Sub-Section Head, DMEE 4-3, responsible for Diving Systems.

ABSTRACT

The history of the DDH-280 Waste-Heat Recovery System is reviewed and the way ahead formulated in light of developing technology. This article is based on a paper which is serving as the basis of Design Authority staff action in NDHQ.

INTRODUCTION

The waste-heat recovery system (WHRS) in the DDH-280 class continues to suffer from both design problems and maintenance shortcomings. Extensive efforts have been made to overcome the design faults but they have been piecemeal in approach, tending to solve the symptoms rather than dealing with the root causes of the problems. A complete re-engineering of the system, including the re-evaluation of the basic assumptions and design goals on which the current design was based, will be required to fully solve the problems currently being experienced. This problem may also be approached in another manner and solved by the removal of the WHRS from the DDH-280 class.

AIM

The aim of this paper is to summarize the history of the WHRS, and to outline considerations which will now determine the case for the retention or removal of this system for the DDH-280 class.

HISTORY

During the design evolution of the DDH-280 class, a great deal of effort was dedicated to making the ship an "all-gas-turbine ship". This push for gas turbines was partly due to the desire to incorporate advanced technology as well as to make the ship quiet. As far as electrical power generation was concerned, in order to compete with diesel-generator specific fuel consumption, a waste-heat recovery package was specified for the gas turbine generators.

In 1967, the Garrett Corporation of Canada was awarded a contract for the DDH-280 main generator package incorporating the total energy concept, and encompassing the responsibility for the development and supply of a fully engineered system to meet specific performance requirements. The main equipment in the Garrett package included not only the electrical power generators, but auxiliary steam generators, three 750 KW Solar Saturn gas turbine generator sets, two waste-heat boilers (WHB), two Vapor auxiliary boilers, two 35-ton/day flash-effect evaporators, and a 500 KW harbour service diesel generator.

The two waste-heat boilers were located one on each of the two generators in the auxiliary machinery room. The third generator set located forward was to serve only as an emergency set. The WHBs were designed for automatic operation after manual start up, with an interlocking pressure control system causing the automatic "fire up" of a preselected auxiliary boiler on insufficient steam pressure in the auxiliary steam range. The concept was to maximize the use of waste heat and minimize the use of the auxiliary boilers.

The heart of this total energy system was the WHB which, in the case of the DDH-280, was an unproven design developed by AiResearch Manufacturing Company of California. It operated in hot exhaust gases and was originally designed to produce 4800 lbs/hour of dry saturated steam at 50 psig when supplied with 49,200 lbs/hour of exhaust gas at 427°C (800°F). This output was to be achieved at a generator output of 750 KW and with a clean heat-exchanger. There were two heat-exchanger cores through which water entered, leaving in a 90% water -10% steam mixture. The steam was extracted through a two-stage separator and the remaining water recirculated. The mass balance in the boiler was automatically controlled by pumping feedwater into the steam separator to make up for the steam output. The circulating pump recirculated the water at ten times the rate of steam generation, thus helping both to maintain nucleate boiling in the heat-exchangers and to assist heat transfer.

A louvre arrangement controlled the steam pressure by directing hot exhaust gases through the heat-exchanger or through a bypass depending on the steam demand. With exhaust gas fully directed to the WHB, a reduction of steam pressure to 46 psig would cause an auxiliary boiler to start automatically. With a 750 KW electrical load carried by two generators (which is the preferred practice) the WHBs should produce a combined steam output of about 6000 lbs/hour. This would be sufficient for the operation of two evaporators as well as other ship services in most of the ship's operating environments.

The only part of the system considered novel was the waste-heat boiler module. The cores for this module were designed, with some optimism, for maximum output at minimum volume. Each core consisted of 650 vertical 3/8" stainless steel tubes closely spaced and welded into top and bottom headers. Continuous plate fins of chromized steel were fitted with a 10-fin/inch spacing.

The complete WHB system was initially tested on a natural-gas-fired gas turbine using distilled water as feed at the AiResearch test facility in Arizona. The tests were successful, although in retrospect one might wonder at the realism of the test conditions when compared with shipboard conditions; however, the thermal and mechanical properties were proven and a complete generator was set up and tested at the Naval Engineering Test Establishment (NETE). The main purpose of this test was to obtain and verify noise and vibration criteria. After 36 hours of testing no serious problems were revealed.

The system was installed and set to work in the lead ship, and all at once there was no shortage of problems. The significant shortcomings included an instability of the control system, rapid soot accumulation on the cores, core tube blockage and failure, and system instability. A brief description of each significant problem follows:

a. Soot Accumulation

Soot accumulation was fouling the cores at such a rate that in 48 hours the back-pressure on the gas turbines was 6 "W.G.". Several methods of cleaning were tried and eventually a system of manual cleaning with a high-pressure air lance was found to be the most effective. This, however, involved a significant shutdown period for the system.

b. System Instability

An unfortunate situation arose where the steam demand was greater than maximum WHB production, but less than the sum of the WHB production and the minimum auxiliary boiler production. This caused a rapid on-off cycling of the auxiliary boiler and the attendant increases in maintenance.

c. Feedwater Treatment

The original design had no provision for feedwater treatment or mechanical de-aeration. The common feed system with its open feed-tank allowed the ingress of large quantities of oxygen, which when combined with the initial use of hard water caused problems in both the waste-heat boiler and the auxiliary boiler. This problem was attacked in traditional ways through the use of trisodium phosphate and Naval Boiler Compound. Although these treatments helped the auxiliary boiler, problems with the WHB were increased. With no automatic or regular blowdown the closed recirculation system of the WHB collected and concentrated the additives in the steam separator. The water in the steam drum soon became more solid than liquid causing tube blockages, overheating and eventually core failure.

d. Corrosion

In addition to the soot accumulation problem, the tube fins of chrome-plated mild steel proved very susceptible to corrosion by the exhaust gases. Up to half an inch was found to be fully wasted. This was further exacerbated by feedwater leakage near the tube-to-tube-sheet welds. This leakage resulted in heavy deposits of a carbonized cornstarch on the fins which was virtually impossible to remove.

SYSTEM RE-ENGINEERING

In an attempt to reduce some of these problems two new core designs were tried. A revised AiResearch design reduced the number of tubes from 650 to 400 and doubled the fin spacing. Its net effect on steam production was to reduce it to 3800 lbs/hr. Another design based on traditional boiler experience was developed by Dominion Bridge. This design used 42 1¼" carbon steel tubes, with fins spaced at 6 to the inch, and had a rating of only 2800 lbs/hr.

The redesigned AiResearch cores failed after 1500 hrs. The Dominion cores survived for 3000 hrs before falling prey to oxygen pitting, but their lower steam production required that at least one auxiliary boiler be used at all times.

A number of other modifications were also engineered into the original steam system in an attempt to limit corrosion and erosion within the boilers and their associated subsystems. These modifications or SHIPALTS included:

a. fitting an additional, larger capacity, drain cooler to supplement the original;

b. re-routing the high-velocity drains through a cyclone separator-type flash-tank;

c. changes to piping material and size;

d. changes to the control system with a pneumatically actuated servo-controlled steam dump-valve;

e. changes to the blowdown arrangements; and

f. installing a system for automatically injecting an oxygen scavenging chemical (sodium sulphite) directly into the boiler during operation.

The sum total of these modifications was marginally successful. The hardware changes, particularly that of the larger drain cooler, permitted greater usage of the system, but the corrosion/erosion problems remained unresolved. It was obvious that the entrained oxygen levels were much too high to treat effectively with chemicals alone. A mechanical de-aeration method would have to be incorporated into the system before sodium sulphite or any similar chemical could become effective.

The problem of having a common feed-tank for the waste-heat boilers and the auxiliary boilers was also readily apparent. The WHBs required extremely pure de-aerated water, and the auxiliary boilers were returning large amounts of dissolved solids to the tank. But the use of Naval Boiler Compound, and more frequent blowdowns, kept the levels of dissolved solids at, or near, acceptable limits. The only expense was an increased usage of feedwater.

Finally, four new sets of austenitic stainless steel cores were ordered from Dominion Bridge. The SANICRO 28 cores will replace the existing mild steel cores which are all showing advanced internal corrosion.

OPERATIONAL EXPERIENCE

At the present time one DDH-280 has WHBs which have never been operational. Another ship uses the waste-heat boilers extensively, albeit at the expense of extensive maintenance and a dedicated maintainer. A third ship uses the waste-heat boilers only if an auxiliary boiler is out of commission due to corrective/planned maintenance of components. The fact that non-standard operating procedures have evolved is a tribute to the engineering ingenuity of the ships' personnel. But it also emphasizes the degree of difficulty presented by the auxiliary steam system design in that it has not functioned as intended.

The system was designed to be operated with the WHBs in constant operation, and supplemented by the auxiliary boilers as required. In most cases the WHBs produce, at best, 2500 lb/hr each at maximum generator output. This results in a requirement for one auxiliary boiler to be kept cycling between low- and high-fire. In many cases it has been found to be easier to keep the auxiliary boiler running at maximum output and meeting the variation in load by using the pneumatically operated bypass dampers of the WHBs and dumping the excess steam.

As a result of considering the factors associated with steam production in the DDH-280s, it was concluded that all normal steam requirements could be met with the two auxiliary boilers. However, to ensure the satisfactory availability of domestic steam a third, redundant, source (that is to say the WHB) would be required. Certain changes are being considered, however, which will reduce the steam requirements.

CHANGES TO THE STEAM REQUIREMENT

The development of reverse osmosis desalination (ROD) has changed the design authority perspective on domestic steam systems and has also generated discussion concerning the replacement of steam with electric heating throughout the ship. Currently three ROD units are being evaluated in the fleet, and the information thus far provided has been used to specify an advanced development model for final evaluation. ROD plats are widely available and utilized in the commercial world, and were used by the Royal Navy in ships taken up from trade during the Falklands conflict. Based on the foregoing, it is therefore believed that a ROD plant suitable for naval use will be available within the next three years.

In anticipation of this, a SHIPALT package is being staffed to remove the existing DDH-280 evaporators and replace them with ROD units. Ships using reverse osmosis will have a significantly reduced steam demand, and will be able to operate on one auxiliary boiler instead of two in all but the most extreme conditions. In this configuration, availability of domestic steam can be assured with two auxiliary boilers without a third source of steam being required.

THE WAY AHEAD

The logical solution to the maintenance and operating problems inherent in the DDH-280 WHRS would be to remove the system once the ROD units are fitted. With ROD the two auxiliary boilers would provide the required quantity of steam with sufficient availability as to ensure a continued and redundant steam supply, and existing levels of spares' support and training would not require upgrading. There would also be obvious improvements in space and weight in the auxiliary machinery room and a significant reduction in maintenance man-hours dedicated to the WHRS.

In formulating the way ahead it must be realized that all the problems with ROD have not yet been solved, and that the ships must be kept running in the interim. Any plan to be implemented must therefore recognize the following requirements:

a. the two auxiliary boilers must continue to be supported at their current levels;

b. the WHBs, as a third source of steam supply, must be retained until ROD is fitted; and

c. ROD may not be ready in the time frame planned for the DDH-280 Tribal Class Update and Modernization Program (TRUMP).

With these requirements in mind the following interim support measures are deemed necessary for the WHRS:

a. survey each ship to check system completeness, integrity, and implementation of previously engineered SHIPALTS;

b. fit new stainless steel waste-heat boiler cores;

c. write particularized refit work specifications for each ship in support of TRUMP refits; and

d. issue operating and maintenance manuals so that standard procedures are created.

TRUMP REFITS

The timing of ROD evaluation and SHIPALT engineering does not dovetail well with the TRUMP refits. The package will not be ready for the first TRUMP ship and is unlikely to be ready for the second. It is therefore envisaged that improvements to the WHRS will be included in the refit portion of the first two TRUMP ships, and that the fully engineered ROD SHIPALT, evaporator removal, and WHRS removal will be implemented in the last two TRUMP ships. The first ships would then get the ROD SHIPALT at the next opportunity.

CONCLUSION

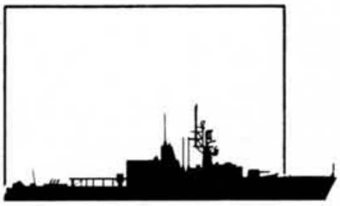
The WHRS has had a troubled history. Aside from having a dismal record of reliability, the design has completely failed to function as planned or to achieve the intended fuel savings. The cost of operating the WHBs has been very high, both in terms of repair parts and ships' staff man-hours. Limitations imposed on system weight and space have precluded any question of adopting the major WHRS redesign necessary to fully attain the required system performance with respect to steam output, fuel saving, reliability and maintenance workload.

In the current DDH-280 configuration three sources of domestic steam are necessary, however with the fitting of reverse osmosis desalination this will change. Steam requirements will be adequately met by the two auxiliary boilers and the WHRS can be removed. This occurrence is planned for the last two ships in TRUMP and will do much to ensure that, for the second half of their lives, the DDH-280s will have less trouble producing steam.

REFERENCES

1. Cheney, P. "Marine Waste-Heat Boiler in the Canadian Forces", presented at the Fifth Symposium on Gas Turbine Operations and Maintenance, Sep 1983.

2. Nicholson, D.K. "DDH-280 Gas Turbine Waste-Heat Recovery", presented at the Commonwealth Engineer Officers' Conference, Bath, England, May 1979.



SHINPADS DATA~BUS Performance Considerations

THE AUTHOR

Lieutenant Commander William Dziadyk joined the RCNR in 1965 and transferred to the RCN in 1967 as an ROTP cadet. He subsequently received his Bsc (Physics) from the University of Victoria in 1971. His appointments have included: positions under training at sea, management systems analyst in the Maritime Forces Supply System, systems analyst for the Mobile Command and Maritime Command operational information systems, senior government monitor at the Burroughs SAMSON development site in Pennsylvania, and senior test and acceptance engineer for the Canadian Supplementary Military Network. LCdr Dziadyk recently received his MSc (Computer Systems) from the Royal Military College, Kingston. His thesis topic was "Performance Optimization of the SHINPADS Data Bus".

INTRODUCTION

The Shipboard Integrated Processing and Display System (SHINPADS) is the chosen combat system architecture for the Canadian Patrol Frigate, and it will likely be implemented in further shipbuilding and modernization programmes. SHINPADS will also be used by the United States Marine Corps Air Traffic Control and Landing System (MATCALS).

SHINPADS uses a Local Area Network (LAN) architectural concept where the loosely coupled processors do not share access to a master main memory. All exchanges of common information between as many as 256 distributed processors are made by a single interconnected serial 10 Mbps data bus.

This paper describes the SHINPADS data bus and its protocol, and discusses some factors which influence its performance. The results of simulation of bus access delays are also presented and discussed.

SHINPADS ARCHITECTURE

The Shipboard Integrated Processing and Display System (SHINPADS) uses a distributed loosely coupled naval combat systems architecture. This multiprocessor network is distributed by:

a. LOCATION - The SHINPADS design allows up to 256 processors (and their appropriate software and hardware) to be distributed throughout the ship. The ship's combat system processing power is thus spacially distributed for survivability.

b. FUNCTION - The various combat system application functions (i.e. navigation, sensors, weapons, fire control, etc.) are distributed to dedicated application processors. These application processors are loosely coupled (i.e. they do not share access to a master memory). The application functions are interfaced by the SHINPADS data bus (SDB). This traffic is sufficient to allow some processors to monitor and maintain the status of non-resident applications (i.e. those assigned to other processors) and to take over the application functions of damaged processors.

c. CONTROL - The application processors are interfaced to the data bus via "nodes". The capability of controlling the SDB is shared by some of the nodes. (These particular nodes, with bus controller capability, have additional hardware and firmware.) There is a hierarchy among these controller nodes: "primary", "first alternate", "second alternate", etc., such that when the primary bus controller fails the first alternate will automatically become the primary bus controller.

SHINPADS DATA BUS

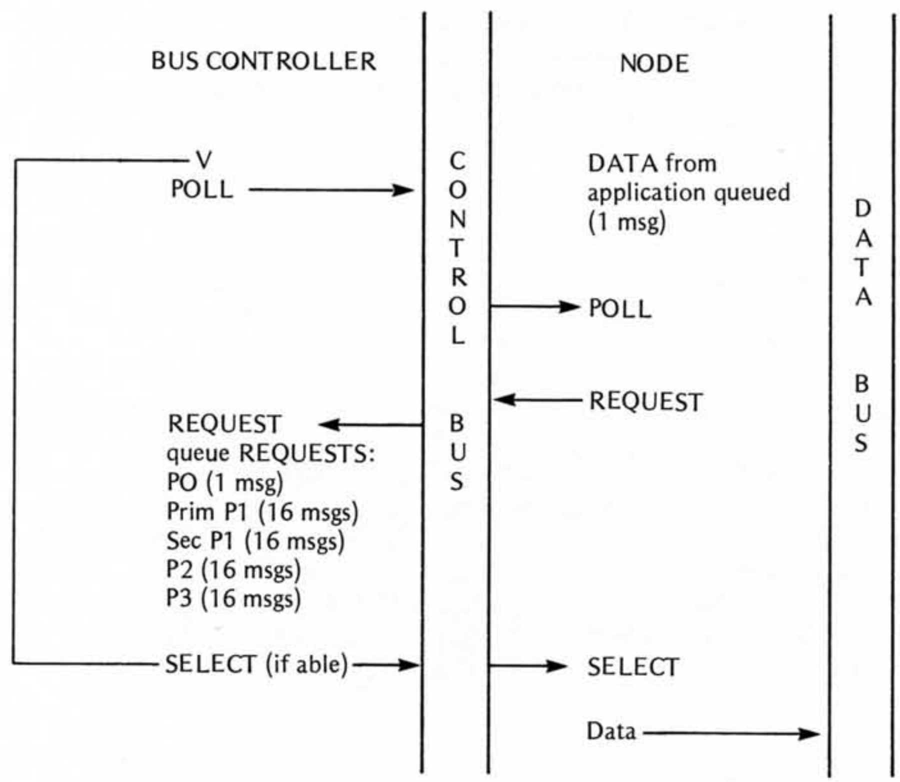
The main component of these distributed networks is the SHINPADS data bus. Using the bus analysis techniques of Thurber (Thurber 1972), the SDB, which can be thought of as a number of parallel channels, can be briefly described as follows:

a. TYPE AND NUMBER - The SDB consists of a functionally dedicated "control" channel, a functionally dedicated "data" channel and four spare channels. For redundancy the spare channels can be used for either of the two bus functions: control or data. Upon failure of an operational channel, the "data" or "control" function will automatically be assigned to one of the redundant spare channels. Each node is interfaced to each of the six triaxial channels via a bus access module (BAM). While a node is utilizing the two active channels, it is also monitoring the four redundant spare channels for activity.

b. BUS CONTROL TECHNIQUE - Centralized bus control is used to poll the nodes. (Upon the failure of a bus controller, the bus controller function is automatically assumed by a surviving node according to a preset hierarchy.) The bus controller utilizes a two-level POLL/SELECT algorithm. The nodes are categorized as being "primary" or "secondary" users. All primary nodes and a subgroup of the secondary nodes are polled once on the control channel during each poll cycle. After it is polled, each node sends a RESPONSE to the bus controller on the control channel indicating either a REQUEST or NO-REQUEST for the data channel. The bus controller maintains the "requests" by priority in five internal "response queues". (The five internal priorities, in order of significance, are: priority 0 (P0), primary user priority 1 (PP1), secondary user priority 1 (SP1), priority 2 (P2) and priority 3 (P3).) The bus controller will issue a SELECT on the control channel to the node with the highest priority request when a previously selected node starts transmitting on the data channel. (There can only be one outstanding SELECT in the system.) This protocol is more fully described in a later section. Figure 1.1.a shows the bus control technique relative to one node.

POLL SELECT

(figure 1.1.a)



SHINPADS DATA-BUS ARCHITECTURE (Sperry 1982)

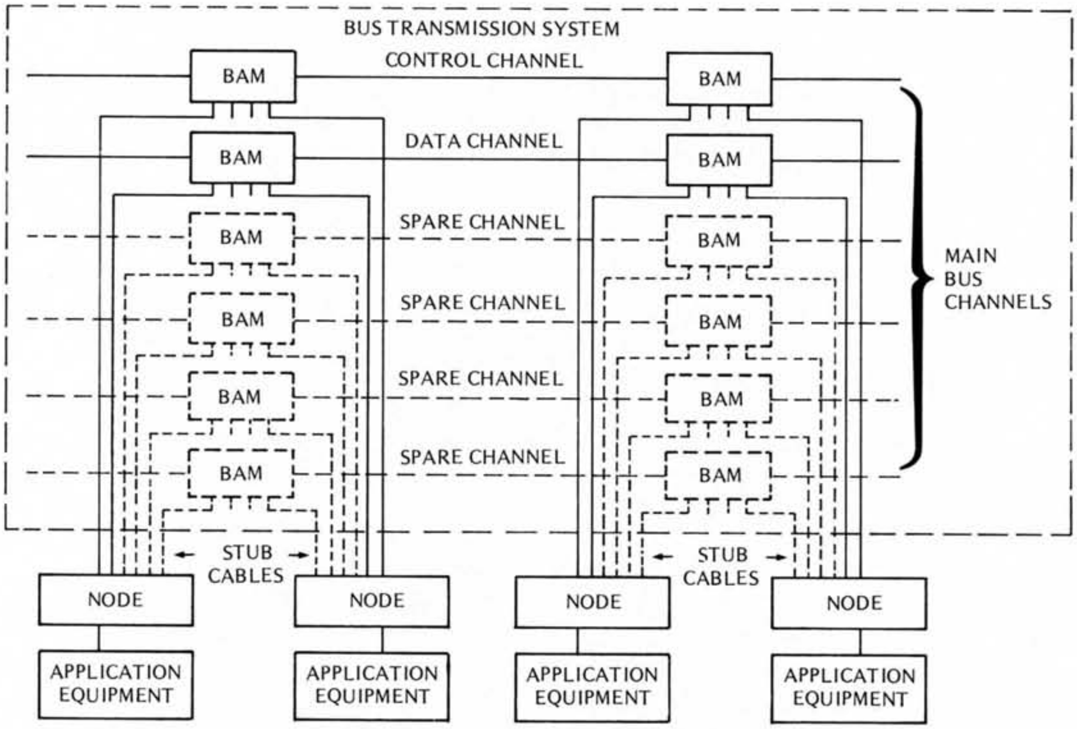


Figure 1.1.b shows the SDB network relative to its user subscriber processors.

c. BUS COMMUNICATION TECHNIQUE - There is no handshaking (i.e. Request/Acknowledge, One-Way Command, ... etc.) between the nodes. Any handshaking would have to be accomplished at a lower level between the application processors.

d. DATA TRANSFER METHOD - The SDB can transfer messages of single 32-bit data words or variable length blocks containing up to 125 data words. In addition to the data words, each message has a 32-bit application processor header, a 32-bit logical address header (Anderson 1984), a 32-bit SDB header and a 16-bit CRC trailer associated with it. The SDB header contains the message's destination address, message length, etc.. All subscriber nodes read the data channel at all times and only accept traffic routed to their resident application processors.

e. BUS WIDTH - 10 MHz Manchester encoded serial channels are used for both the control and data channels. The effective maximum data throughput is expected to approach 8 Mbps for average message lengths of 5 words.

SHINPADS PROTOCOL

The bus control technique is fully described in Sperry documentation (Sperry 1982, Sperry 1983) and the protocol will be summarized herein. Each of the discussed protocol commands consist of 16 bits of control information and 8 bits CRC.

POLLING ORDER

The bus controller will poll nodes in sequence as follows:

a. Poll all np primary nodes, ($np \leq 16$).

b. Poll ns of Ns secondary nodes, ($ns \leq 256$) and ($Ns \leq 256$).

c. Poll all np primary nodes.

d. Poll next ns of Ns secondary nodes.

e. Repeat c. and d.

The variables np, Np, ns and Ns are defined below:

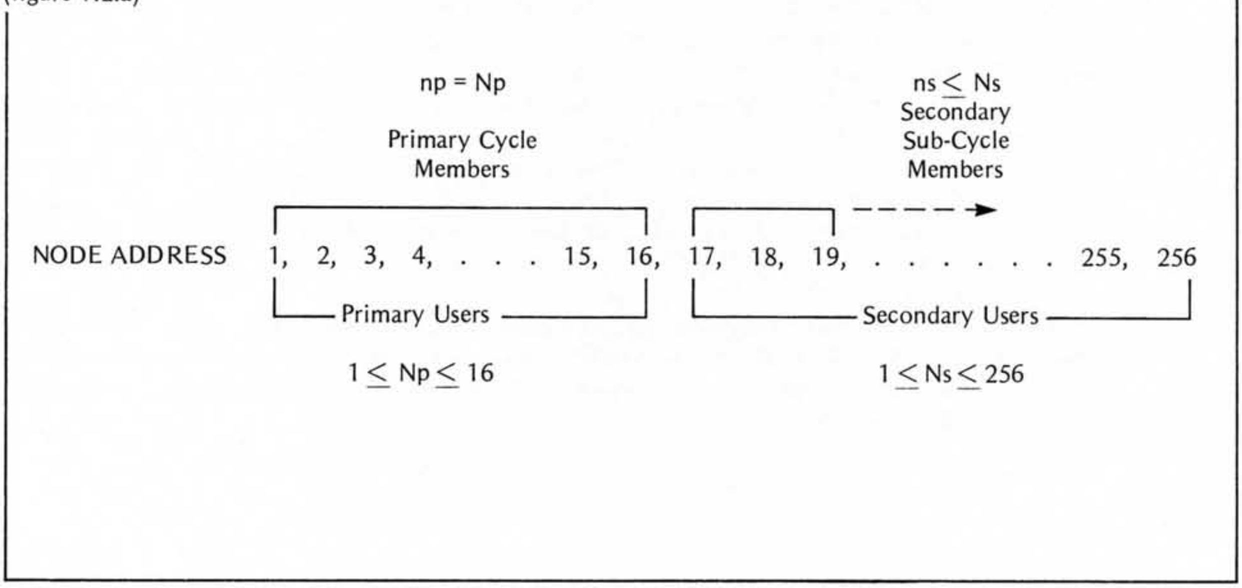
Np - total number of primary users, (range: 1 to 16 nodes).

np - number of primary users in poll cycle, (np = Np).

ns - number of secondary users in poll cycle, (range: 1 to 256 nodes).

Ns - total number of secondary nodes (range: 1 to 256 nodes).

(figure 1.2.a)



POLL RESPONSES - The polled node will respond as follows:

a. Transmit a NO-REQUEST if the node has no message to send or has already made a previous request to send a message which is in its output buffer queue (1 entry deep).

b. Transmit a priority P0, P1, P2, or P3 REQUEST if the node has a message to send.

c. A node will respond with a REQUEST to a POLL only once for a given message with the following exceptions:

(1) If the node is polled 256 times after sending a REQUEST without receiving a SELECT from the bus controller, the node will make another REQUEST.

(2) If the node receives a REQUEST-DENIED it will send another REQUEST after next POLL.

(3) If the node receives a TERMINATE after being SELECTED and before the message has been completely transmitted, the node will make another REQUEST after the next POLL.

NO REQUEST - This response indicates that the requesting node has no messages to send or is waiting for a SELECT due to a previous REQUEST. The bus controller performs no action on the receipt of this command.

PRIORITY 0 REQUEST - This response indicates that the requesting node has a P0 message to send. Upon receipt of this command, the bus controller will take action as follows:

a. The P0 REQUEST will be placed in the internal P0 RESPONSE QUEUE (1 entry deep) and the following will occur:

   (1) If no other node has been SELECTED, the bus controller will send a SELECT to the requesting node.

   (2) If a node is transmitting a P1, P2 or P3 message on the data channel, the bus controller will send a TERMINATE command to pre-empt any message traffic. The bus controller will then send a SELECT to the requesting node when the data channel reaches the quiescent state. If the last selected node had a P0 message to transmit, it would be allowed to complete transmission. (i.e. P0 cannot pre-empt P0).

b. If the PO RESPONSE QUEUE already has one entry in it, the bus controller will send a REQUEST-DENIED to the requesting node and a new REQUEST will be generated after the next POLL.

c. If three PO REQUESTS have already been received in the current poll cycle (primary group and secondary subgroup), the bus controller will send a REQUEST-DENIED to the requesting node and a new REQUEST would be generated after the next POLL (Anderson 1984).

PRIORITY 1 REQUEST - This response indicates that the requesting node has a Pl message to send. Upon receipt of this command the bus controller will take action as follows:

a. If the requesting node is a PRIMARY user, the request will be placed in the PPl RESPONSE QUEUE (16 entries deep). If the PPl RESPONSE QUEUE is full, the bus controller will send a REQUEST-DENIED to the requesting node.

b. If the requesting node is a SECONDARY user, the action by the bus contoller is identical to that in subparagraph (a) except that a separate SPl RESPONSE QUEUE (16 entries deep) is utilized.

PRIORITY 2 REQUEST - This response indicates that the requesting node has a P2 message to send. Upon receipt of this command the bus controller will take action on it as follows:

a. The request will be placed in the P2 RESPONSE QUEUE (16 entries deep).

b. If the P2 RESPONSE QUEUE is full, the bus controller will send a REQUEST-DENIED to the requesting node.

PRIORITY 3 REQUEST - The bus controller will take action on this request in the same manner as for the P2 REQUESTS, with the exception that a separate P3 RESPONSE QUEUE (16 entries deep) will be utilized.

SELECT - This command is sent by the bus controller to authorize a requesting node to transmit a message on the data channel at the next quiescent period. The five FIFO response queues are used by the bus controller to identify the highest priority requesting node to SELECT. The SELECT is issued immediately after a previously selected node has begun transmitting on the data channel.

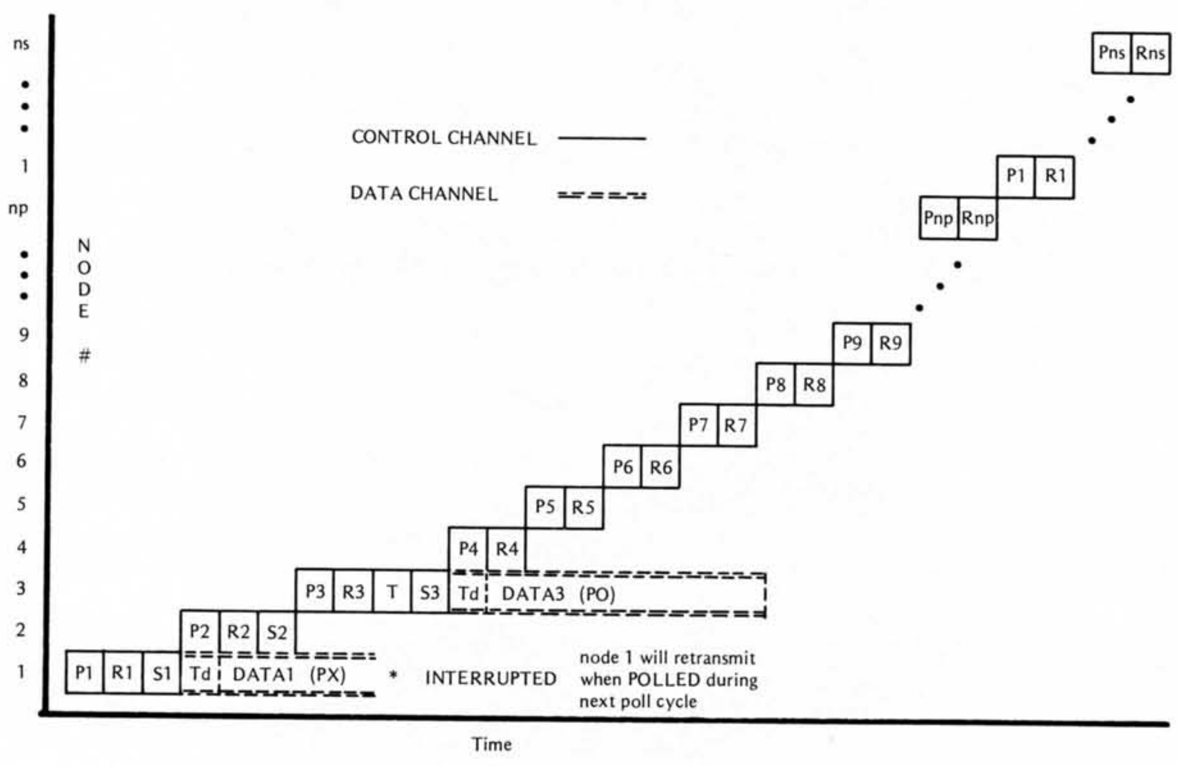
REQUEST DENIED - This command is sent by the bus controller when the corresponding response queue is full. When a node receives a REQUEST-DENIED, it will make another REQUEST after its next POLL.

TERMINATE - This command is sent by the bus controller to pre-empt any messages being sent on the data channel. It is only sent when a P0 REQUEST is received. All nodes in the system will receive the TERMINATE. A node transmitting a P0 message on the data channel or a node SELECTed and waiting to transmit a P0 message will ignore the TERMINATE. Nodes transmitting P1, P2, or P3 messages or SELECTed and waiting to transmit P1, P2 or P3 messages will be pre-empted and the pre-empted nodes will re-submit REQUESTS after their next POLL.

Figure 1.2.b is a "space-time" diagram which shows some typical protocol activities on the control and data channels. The abscissa represents time and the ordinate represents the subscriber nodes associated with the bus activities. The concurrency of the control and data channel activities is highlighted through the use of single lines (——) and double lines (====) to delimit the control and data channel activities respectively. The symbols which are used to label the activities are:

CONCURRENT ACTIVITY ON DATA CHANNEL AND CONTROL CHANNEL

(figure 1.2.b)



P n	POLL node n
R n	RESPONSE from node n
T	TERMINATE to all nodes
S n	SELECT node n
Td	Quiescent time on data channel
DATA n	node n on data channel

To proceed through a possible poll cycle, follow the activities from left to right in the space-time diagram. (Space-time diagrams can be utilized to describe various SHINPADS protocol scenarios)

BUS ACCESS DELAYS

Delays in information transfer are an important consideration in the design of a combat system that must operate in a real-time environment. The particular delays associated with the bus access are especially important with SHINPADS because of its time-critical applications. The SHINPADS LAN is a new architectural concept and, to date, it has been implemented by the contractor (Sperry Univac) only in limited test configurations of fewer than a dozen nodes with low-traffic loading. Forthcoming operational networks will serve much larger numbers of application processors with heavy data rates, and simulation is needed to determine what delays can be expected. What follows are the results of such a simulation of a theoretical system application.

The anticipated peak traffic rates (Carruthers 1980, Ironside 1983) for the loosely coupled applications in a theoretical frigate-class distributed combat system are summarized below:

a. number of subscribers = 68

b. peak raw traffic = 1387 Kbps

c. system message data word probability distribution:

DATA WORDS = L	p(L)	
1 word	.221	probability
2 words	.434	
3	.011	
4	.030	
6	.007	
12	.022	
20	.001	
32	.022	
50	.001	
100	.015	
125	.235	
	.999	

d. expected data words in message = E(L) = 33.197 words.

e. expected throughput = (1387 Kbps)/[E(L)*32 bits/word] = 1305.78 msgs/sec.

f. expected time between arrivals = 1 msg/1305.78 msg/sec = 766 usec.

This theoretical distributed network can be considered a benchmark system against which the performance effectiveness of the SHINPADS data-bus protocol can be measured.

The SDB uses two classes of users (PRIMARY and SECONDARY) and four message priorities (P0, P1, P2, and P3). Thus, there are effectively eight message precedence categories:

a. primary user, priority 0 (PP0)

b. secondary user, priority 0 (SP0)

c. primary user, priority 1 (PP1)

d. secondary user, priority 1 (SP1)

e. primary user, priority 2 (PP2)

f. secondary user, priority 2 (SP2)

g. primary user, priority 3 (PP3)

h. secondary user, priority 3 (SP3)

There are two variables which application developers and system managers must consider if the SDB is to simultaneously provide "reasonable" bus access delays for all eight traffic precedence categories. The two variables which can be used to optimize the bus access delays are:

a. The probability distribution of the P0, P1, P2, and P3 message priorities which are generated by the application programs.

b. The length of the poll cycle within the bus controller's polling algorithm.

For the benchmark system described above, software simulation (Dziadyk 1984) has indicated that reasonable bus access delays for all eight precedence categories can be obtained if:

a. The P0 traffic is restricted to less than 5% of the total traffic with the remaining three priorities having equal likelihood of occurrence; and

b. Sixteen "primary" users (those with the shortest mean time between arrivals of messages) and nine of the "secondary" users are polled in each poll cycle.

If these variables were selected without due forethought, some of the mean bus access delays would be much greater (by a factor of ten). These optimal values of the two variables are only directly applicable to the investigated benchmark network. To optimize the performance of any future operational Canadian Forces or United States Marine Corps system, further analysis would be required. These networks would have their own unique system configurations and data rates. The techniques developed in the author's Masters degree thesis (Dziadyk 1984) could be used in the optimization of these future networks.

A simulation run with the optimal variables yielded the following overall mean bus access delay and the mean bus access delays for each of the eight precedence categories. (The primary user bus access delays have almost exponential distributions, and the secondary user bus access delays have almost uniform distributions.)

	MEAN VALUE	STANDARD DEVIATION	MINIMUM VALUE	MAXIMUM VALUE
SYS BA DELAY	132 usec	198 usec	15 usec	6455 usec
PMY PO BA DELAY	118	155	25	2805
SDY PO BA DELAY	634	383	38	1329
PMY P1 BA DELAY	114	149	15	5018
SDY P1 BA DELAY	680	366	19	1465
PMY P2 BA DELAY	118	162	15	4483
SDY P2 BA DELAY	679	352	25	1944
PMY P3 BA DELAY	120	186	15	6445
SDY P3 BA DELAY	715	465	19	2707

The optimum bus access delay performances for the eight precedence categories are compared below:

	PRIMARY USER: Percentile of Bus Access Delay 300 usec	SECONDARY USER: Percentile of Bus Access Delay 1200 usec
P0	96	95.7
P1	94.9	93
P2	94.5	93.7
P3	94.3	91.2

The overall system bus access delay for all priorities of messages and types of users has a mean value of about 130 usec. The approximate breakdown of this mean delay is:

Node output QUEUE (msg waiting for POLL)	100 usec
REQUEST waiting for CBUS	0
REQUEST on CBUS	5
RESPONSE QUEUE average wait time	15
SELECT waiting for CBUS	0
SELECT on CBUS	5
Node output QUEUE (msg waiting for DBUS)	5
mean =	130 usec

CONCLUSION

SHINPADS is considered by many to be the way ahead in combat systems integration. The potential advantages of standardization, flexibility and, perhaps foremost, survivability are evident, but the limitations of its performance and application must be clearly understood.

The performance of the SHINPADS data bus can be optimized to provide reasonable bus access delays for all eight message precedences simultaneously. Control over two variables in particular makes this possible. The poll-cycle length can be controlled in real time by the bus-controller software, and the probability distribution of message priorities can be controlled by system design and, where possible, by providing guidelines to the application programmers.

It is considered that bus access delays in the order of 500 usec (Anderson 1983, Kuhns 1979) will be acceptable. In this respect the simulation results are encouraging as the majority of the primary user delays fall well within this figure for the benchmark application and choice of variables. Other networks will of course have their own unique system configurations and traffic requirements, but with the techniques described in the author's Masters thesis it will be possible to optimize them.

BIBLIOGRAPHY

Anderson, Steven C. and Jeffery V. Marshik (Sperry Univac). DRAFT TASK-TO-TASK MESSAGE DELAYS FOR SUBSYSTEMS INTERCONNECTED VIA THE SHINPADS SERIAL DATA BUS. Prepared for Director of Maritime Combat Systems, Dept. of National Defence, Ottawa. March 1983.

Anderson, Steven C. (Sperry Univac) Personal Interview. 5 January 1984.

Carruthers, James F. Commander C.F. "SHINPADS A New Ship Integration Concept" NAVAL ENGINEERS JOURNAL, April 1979, pp 155-163.

Carruthers, James F. Commander C.F. SHINPADS DATA RATES analysis paper. Ottawa. August 1980.

Computing Devices Company. CPF POST-CD PERIOD REVIEW MEETINGS ONE notes and overhead projections, Ottawa. 3 March 1983.

Dziadyk, William G. Lieutenant Commander C.F. PERFORMANCE OPTIMIZATION OF THE SHINPADS DATA BUS, Masters degree thesis. Department of Electrical Engineering, Royal Military College, Kingston, Ontario. May 1984.

Ironside, J.E. Commander C.F. SHINPADS TECHNICAL SEMINAR notes and overhead projections, Ottawa. 31 May 1983.

Ironside, J.E. Captain (Navy) C.F. Personal Interview. 22 September 1983.

Kuhns, Richard C. "The SHINPADS Serial Data Bus" NAVAL ENGINEERS JOURNAL, April 1979, pp 164-172.

Sperry Univac Defence Systems. SERIAL DATA BUS SYSTEM USERS MANUAL FOR THE SHINPADS ENGINEERING DEVELOPMENT. Prepared for Director of Maritime Combat Systems, Dept. of National Defence, Ottawa. March 1983.

Sperry Univac Defence Systems. PRIME ITEM PRODUCTION FUNCTION SPECIFICATION FOR THE SHINPADS SERIAL DATA-BUS SYSTEM. Prepared for the Director of Maritime Combat Systems, Department of National Defence, Ottawa. September 1982.

Thomas, D.M. "The SHINPADS Standard Display" NAVAL ENGINEERS JOURNAL April 1979, pp 179-184.

Thurber, K.J. "A Systematic Approach to the Design of Digital Bussing Structures" AFIPS CONF. PROC. Vol 41, pp 710-740, 1972.

Williams, Paul F. and John M. Anderson "The AN/UYK-502(V) Microcomputer" NAVAL ENGINEERS JOURNAL, April 1979, pp 173-178.

THE DEVELOPMENT OF

VIBRATION AND RUNDOWN-TIME NORMS

AS A QUALITY CONTROL TOOL FOR OVERHAULED ELECTRIC MOTORS

BY: C.A.W. GLEW AND W.A. REINHARDT

C.A.W. Glew served with the Royal Air Force as an engine fitter and flight engineer for 12 years after completing an aircraft engineering apprenticeship in 1943. He subsequently obtained a B Sc in Mechanical Engineering at London, England in 1957 and a Master of Engineering degree in McGill in 1964. In between university spells, he worked on free-piston engine development, and tested Pt 6 gas turbine engines for Pratt and Whitney of Canada Inc. In 1964 he joined the Naval Engineering Test Establishment as a project engineer specializing in heat transfer, and later worked in the areas of machinery vibration monitoring and gas turbine engine health monitoring. He is currently the Special Projects Engineer at the Establishment.

W.A. Reinhardt graduated from the University of Toronto in 1962 with a BA Sc degree in Electrical Engineering. For three years after graduation he worked for Computing Devices of Canada as a design engineer on the design and development of airborne navigational aid equipment. In 1965 he joined the Maritime Engineering and Maintenance Division at National Defence Headquarters where he has held various engineering specialist positions. Initially, he served as a navigation-aid engineer responsible for shipborne radiating (transmitting and receiving) equipment. In 1968 he was promoted to the position of Electro/Mechanical Instrumentation Engineer, responsible for ships' machinery instrumentation and monitoring systems. Then, in 1979, he transferred to the position of Power Distribution System Engineer where he was responsible for ships' electrical distribution systems. Currently, he is a senior design engineer responsible for shipboard electrical motor-drive and propulsion systems.

ABSTRACT

Research at the David W. Taylor Naval Ship R&D Center during the 1960s indicated that the mechanical reliability of electric motors could be greatly improved. In the early 1970s the Naval Engineering Test Establishment at Montreal applied the results of this work to several failure-prone critical motors and greatly improved their service life. The quality of mechanical overhaul of the motors was gauged by the octave-band vibration spectrum and rundown-time measurements during the post-overhaul motor tests.

This quality control concept was extended to all integral-horsepower electric motors, and a vibration control specification was established which is a significant improvement upon those presently used commercially. A refinement to the specification to include the dependency between the motor-speed and the normal vibration spectrum is being studied, and rundown-time norms for different types of electric motors are being established.

INTRODUCTION

The mechanical reliability of electric motors in the Canadian navy has progressively improved over the last 10 years by using vibration analysis and rundown-time (RDT)[1] measurements as quality control checks after overhaul, and by modifying the overhaul procedures on ball-bearing-mounted motors. It was realized in the 1960s that the standard industrial practice of fitting anti-friction ball-bearings into their housings with a press fit, caused the balls to skid in their tracks under zero-thrust load and excessive-thrust loads at other times because of differential expansion between the motor rotor and the casings during normal operation (Ref. 1). It was also realized that measurement of rundown times and bearing temperatures could give an indication of satisfactory bearing installation (Ref. 2).

Measurements of motor axial movement, bearing skidding and temperatures were published in a paper by G. Philips of the David Taylor Naval Research Center in 1978 (Ref. 3) from which Figure 1 was produced. The upper graph compares the axial movement of the free end bearing relative to the casing of a motor built, first with a standard bearing fit (0.000" to 0.0023" interference) and then with a pre-load spring and a sliding fit between the bearing and its housing. The middle graph compares the bearing temperature of the two installations. The initial temperature overshoot with the sliding bearing occurred whilst the grease was channelling. On subsequent starts no overshoot would occur, whereas with the standard bearing some temperature overshoot would occur after every start due to high-thrust loads at some time in the warm-up period. The lower graph shows that there was much less ball-skidding with the sliding bearing than with the standard-fit bearing.

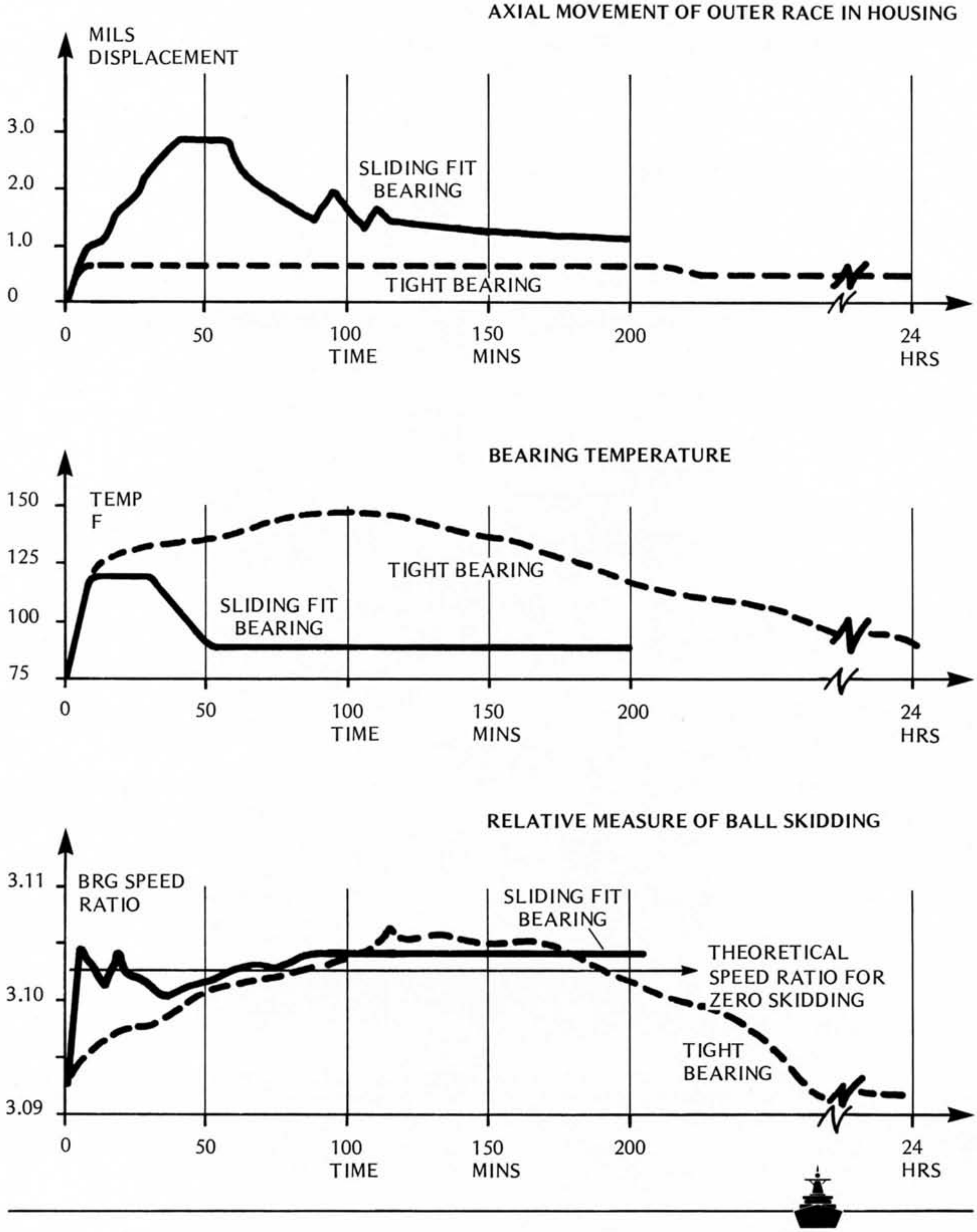
THE IMPROVED OVERHAUL METHOD FOR LARGE CRITICAL MOTORS MOUNTED ON BALL-BEARINGS

Based upon the US research the Canadian navy in 1966 began a quality improvement program on certain critical shipboard motors which were experiencing low mean-time between failures (MTBF). The results of this program were described in two papers by Watson and Xistris (References 4 and 5). In summary, the Canadian navy's solution to the motor-bearing

[1] Rundown time is the time taken for a motor to coast to a stop under no-load conditions when the power is switched off.

FIGURE 1

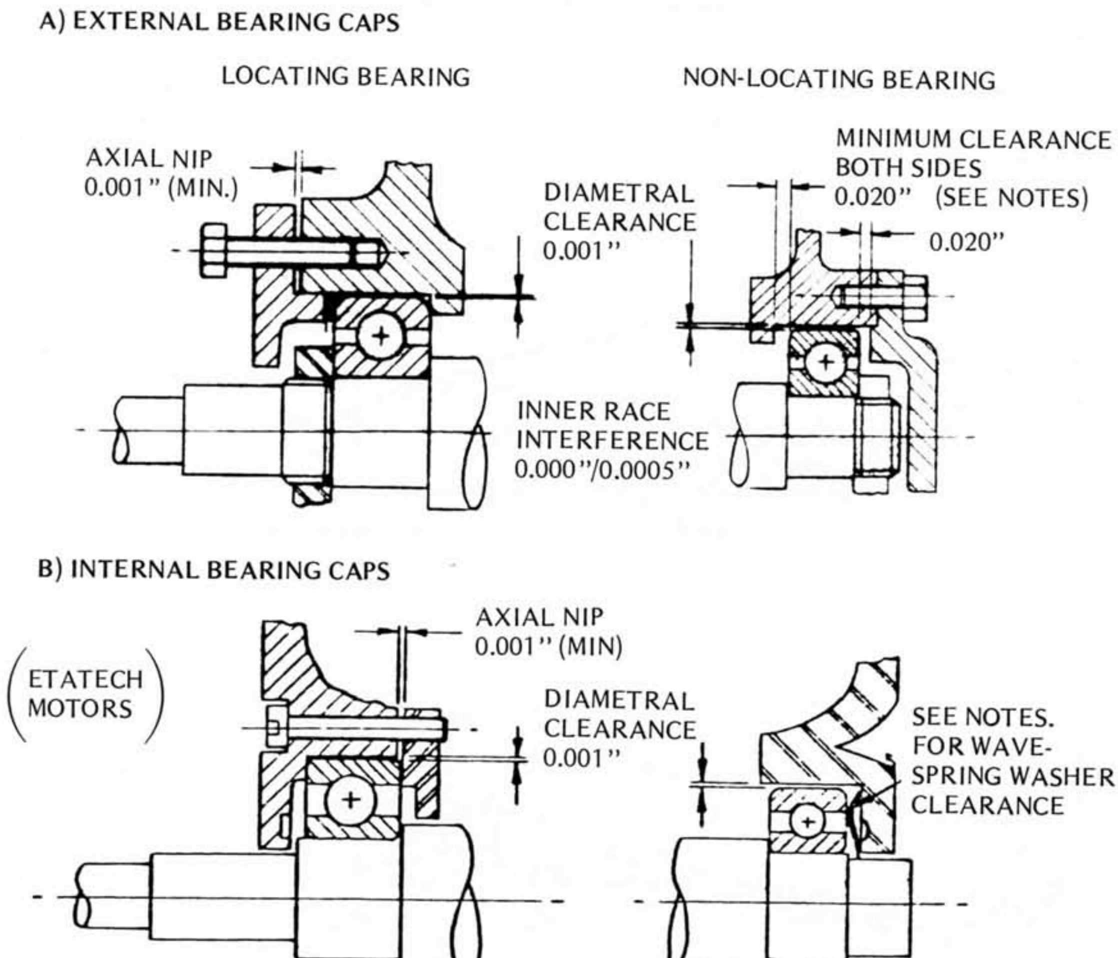
COMPARISON OF AXIAL MOVEMENT, BEARING HOUSING TEMPERATURE AND BALL SPEED RATIO (SKIDDING) OF A MOTOR BEARING, INSTALLED WITH A STANDARD FIT AND WITH PRELOAD WASHER AND SLIDING FIT



reliability problem was to fit the bearings so that they would slide smoothly in their housings, and to install a wave-spring washer on the non-locating bearing to act as a pre-load spring and to minimize ball-skidding as shown in Figures 2 and 3. Improved casing concentricities and fits, and upgraded rotor-balancing procedures were also implemented. A post-overhaul motor test (POMT) was introduced consisting of six runs: 1, 5, 10, 20, 30 and 60 minutes. The motor RDT and bearing temperatures were

FIGURE 2

TYPICAL BEARING ASSEMBLIES FOR MOTORS WITH BEARING HOUSINGS MACHINED IN THE END BELLS



NOTES

1 MANY NEW MOTORS HAVE WAVE SPRING WASHERS FITTED. CHECK MASTER DWG. CFTO D-03-002-006/SG-000 APPENDIX 3 LISTS THE CLEARANCE REQUIREMENTS FOR WAVE SPRING WASHERS.

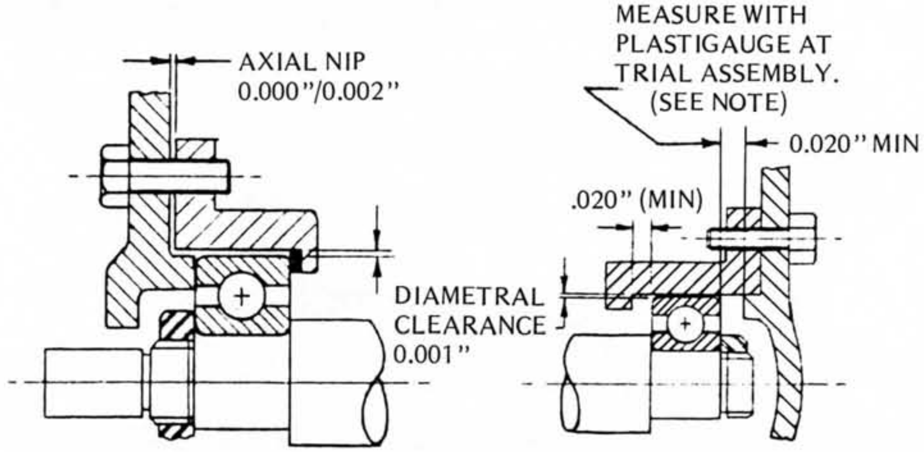
2 SHIM OR MACHINE AS REQUIRED TO OBTAIN CORRECT AXIAL CLEARANCE AT NON-LOCATING BEARING.

measured at the end of each run, and octave-band vibration surveys (measuring vibration velocity decibels Ref. 10^{-6} cm/sec rms (VdB)) were conducted during the 20-minute and 60-minute runs. Figure 4 shows three discrete frequency vibration spectra from a critical electric motor: after overhaul, but without the wave-spring washer; with the washer fitted; and after "in situ" trim-balancing the motor to 0.03 mils pp displacement. (Nowadays it is not considered necessary to balance to this degree.) This

FIGURE 3

TYPICAL BEARING ASSEMBLIES FOR MOTORS WITH BEARING HOUSINGS BOLTED IN THE END BELLS

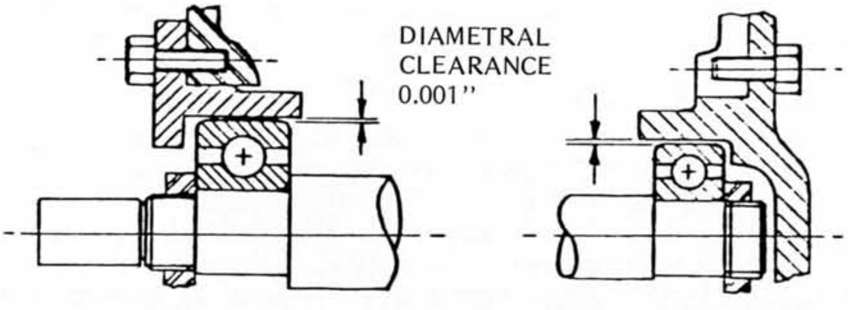
A) BEARING HSG BOLTED INSIDE END BELLS



NOTE:

MANY NEW MOTORS HAVE WAVE SPRING WASHERS FITTED. CHECK MASTER DRAWINGS. CFTO D-03-002-006/SG-000 APPENDIX 3 LISTS THE CLEARANCE REQUIREMENTS FOR WAVE SPRING WASHERS.

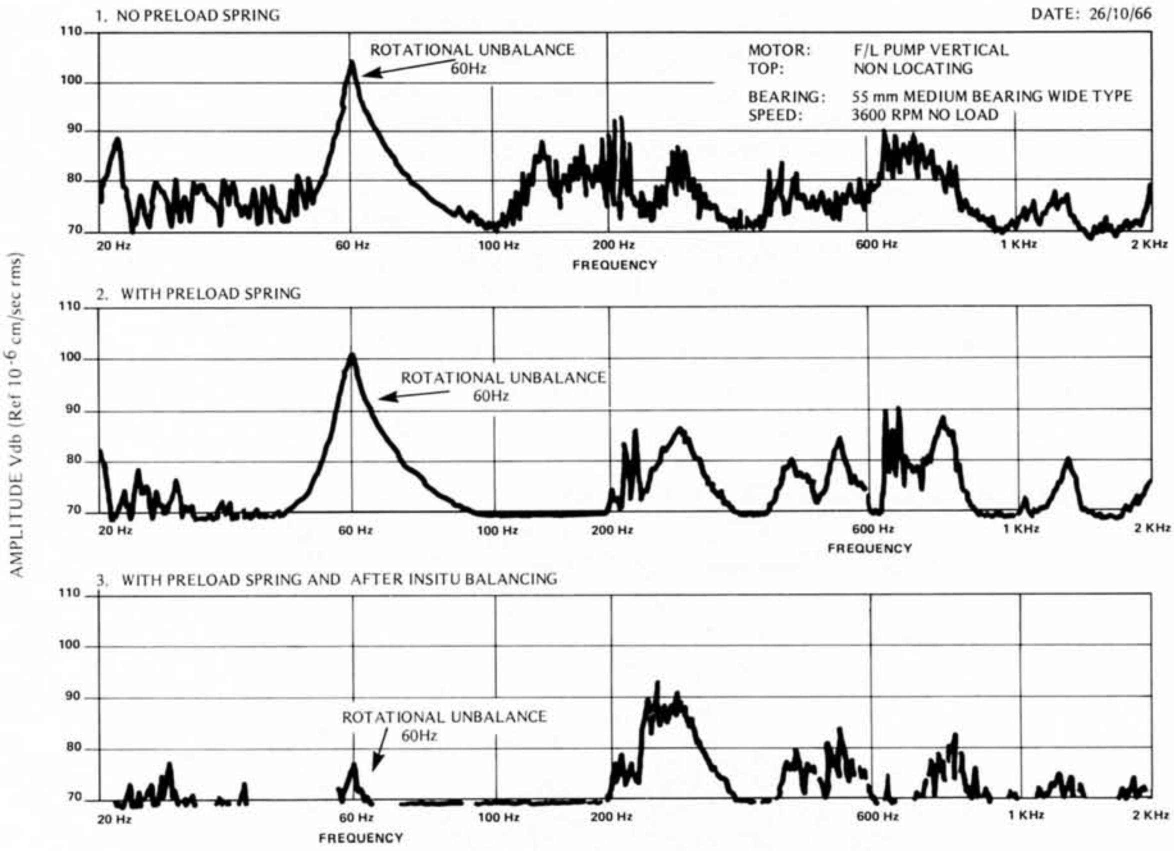
B) OPPOSED SHOULDER LOCATION



NOTE:

AXIAL END PLAY AFTER ASSEMBLY MUST BE BETWEEN 0.020" AND 0.045" (0.5mm AND 1.1mm) SHIM AND MACHINE AS NECESSARY.

FIGURE 4 **COMPARISON OF VIBRATION SPECTRA ON MOTOR WITH SLIDING FIT BEARING**



program resulted in a great improvement in the service life of these electric motors. For example, on one type of motor, the motor MTBF was increased from 500 to 5,000 hours.

APPLICATION OF THE CRITICAL-MOTOR POST-OVERHAUL TEST TO OTHER MOTORS

The motor repair-and-overhaul facilities (dockyards and ship repair contractors) were advised of these techniques, and it was decided to introduce the POMT to all motors of greater than 5 HP. Problems arose implementing this policy because the test requirements were not completely defined.

The requirement for satisfactory rundown time was that it increase during each of the six motor runs of the POMT, with a maximum permissible bearing housing temperature of 80 degrees centigrade. The maximum acceptable vibration level was a curve which was approximately a factor of four (12 VdB) greater than the average VdB levels of the critical motors overhauled at NETE. (See Figure 5.) It was thought that this would give an adequate margin for the vibration levels of general-purpose motors in service, however the overhaul shops were unable to meet these levels. The vibration curve was set up by another factor of two (6 VdB) as shown in Figure 5, but the storm of protests from the motor repair-and-overhaul facilities continued, and increased when the POMT was applied to motors of 1 HP and up. It was found that 50% of the motors had to be accepted without meeting these requirements.

A review of the existing commercial and military vibration control specifications for electric motors was then conducted. The principal ones are shown in Figure 6. The NEMA specification is antiquated, as it simply calls up discontinuous first-order vibration limits (e.g. for motors with speeds from 1500 rpm, up to and including 2999 rpm the permitted vibration is 0.0015" peak/peak, but at 3000 rpm the vibration allowed is 0.001"). The US Navy Submarine Service adopted limits of 1/5 of those above in the 1950s, and in 1980 the US military specification MIL-M-17060E halved the NEMA limits for surface-ship electric motors. With regard to the ISO 2372 recommendations, the naval motors come under machinery Classes 1 or 2, and the limiting discrete frequency vibrations recommended for their quality B machines are 105 and 109 VdB respectively. Thus it can be seen that, except for the first-order vibration on US navy submarines, these specifications were all much less stringent than the vibration level permitted by the POMT. What had happened was that in the quality improvement programs on critical electric motors at NETE, aircraft engine standards of accuracy had been specified and these motors ran much more smoothly than normal industrial motors.

FIGURE 5 DERIVATION OF ORIGINAL NAVY SPECIFICATION FOR VIBRATION MEASURED ON THE BEARING HOUSINGS OF ELECTRIC MOTORS AFTER OVERHAUL

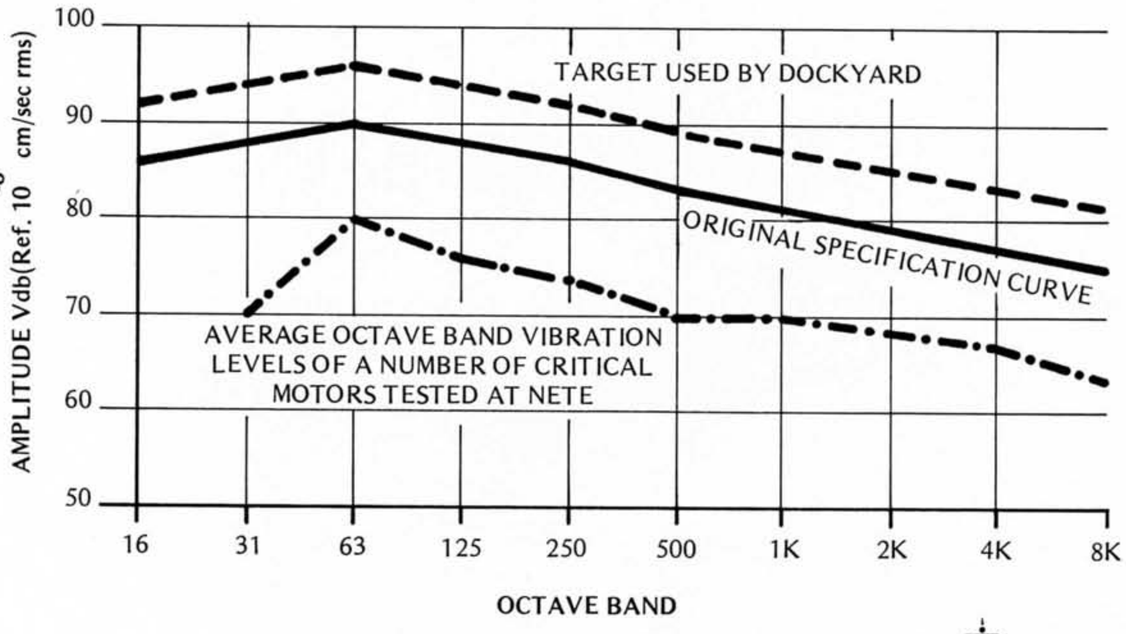
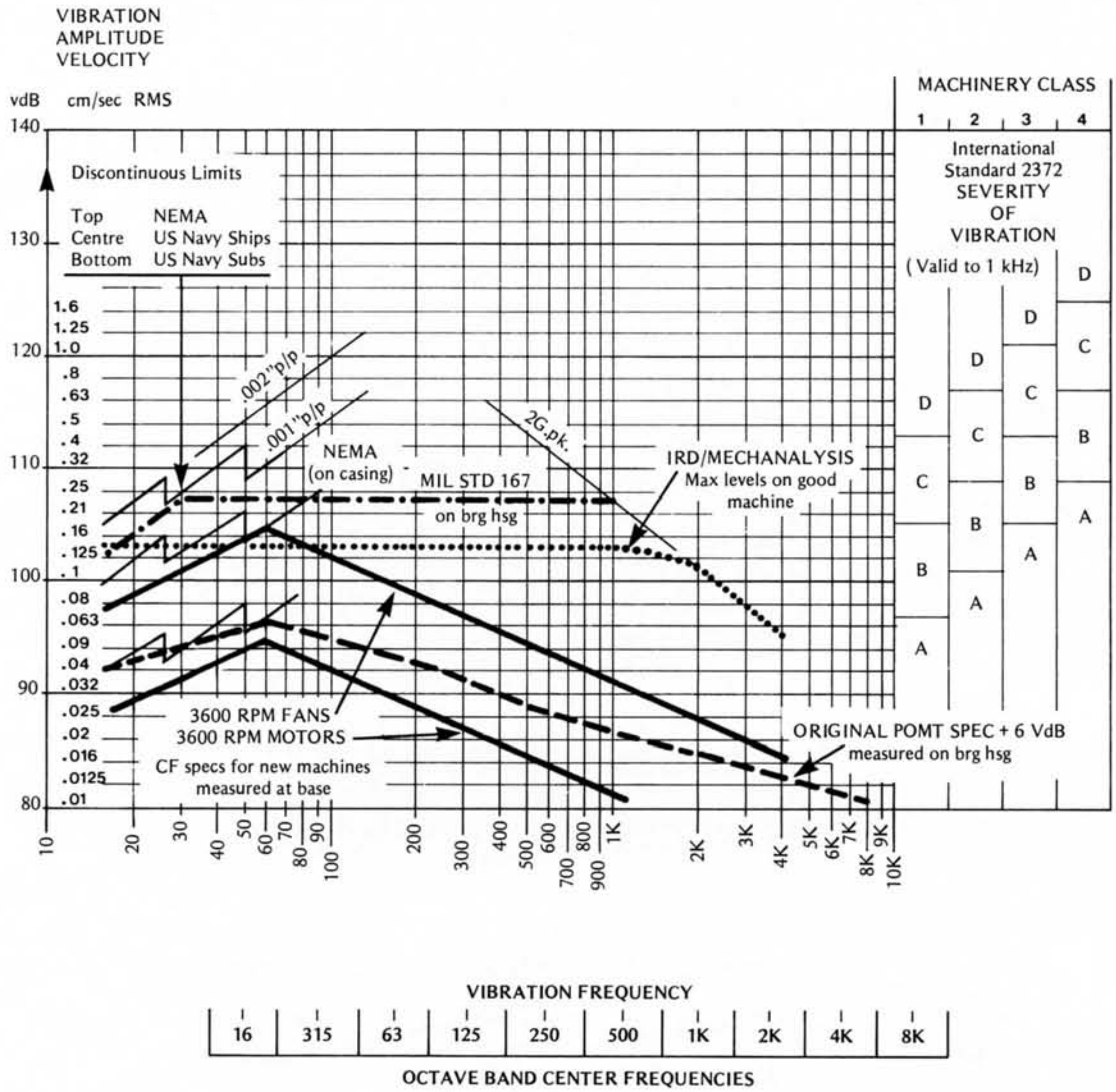


Figure 6

COMPARISON OF EXISTING VIBRATION SPECIFICATIONS FOR ELECTRIC MOTORS WITH THE POST OVERHAUL MOTOR TEST SPECIFICATION



ISO 2372

CLASSES OF MACHINES

CLASS 1: SMALL MACHINES, ELECTRIC MOTORS, ROTARY PUMPS, ETC. TO 15KW.
CLASS 2: MEDIUM ROTARY MACHINES, MOTORS UP TO 75KW SOFT MOUNTED, (300 KW. RIGID)
CLASS 3: LARGE ROTARY MACHINES SUCH AS TURBO GENERATORS ON RIGID BASES.
CLASS 4: LARGE ROTARY MACHINES SUCH AS TURBO GENERATORS ON SOFT MOUNTS.
CLASS 5 AND 6: RIGIDLY MOUNTED AND SOFT MOUNTED RECIPROCATING MACHINES, VARY WIDELY BUT MAY BE UP TO 10 dB HIGHER THAN EQUIVALENT ROTARY MACHINES.

DETERMINING ACCEPTABLE POST-OVERHAUL VIBRATION LIMITS FOR MOTORS

The Canadian navy now categorizes motors for overhaul purposes as follows:

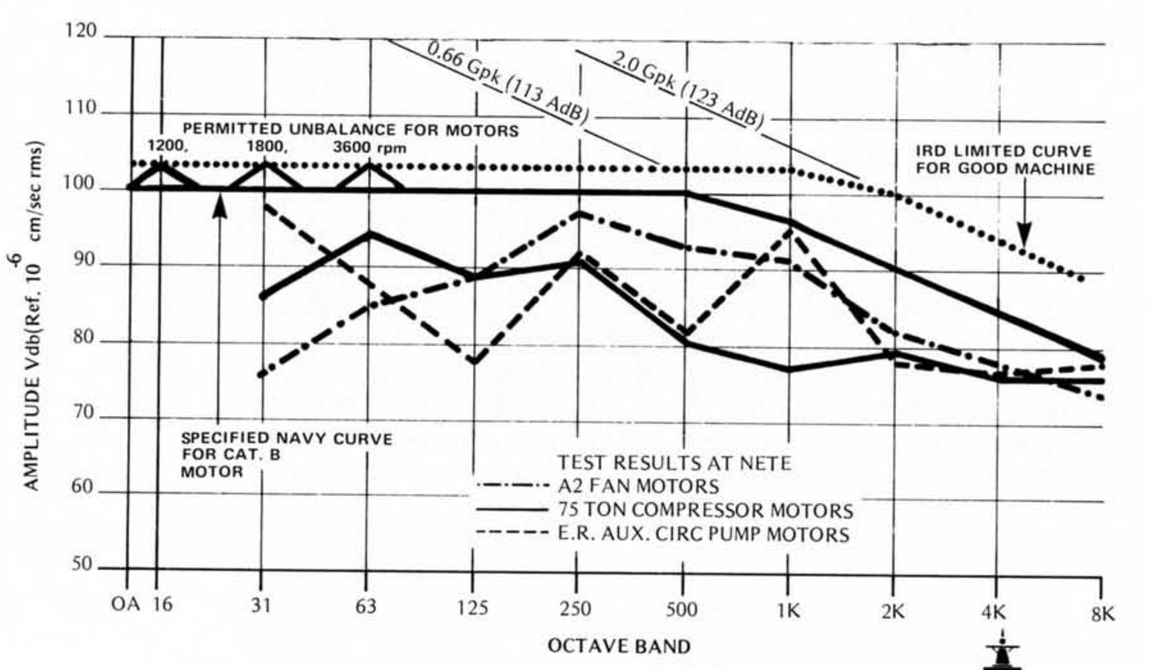
Category A: military specification motors greater than 5 HP and critical to shipboard operation and safety.

Category B: all remaining integral-horsepower military specification motors.

Category C: all commercial motors and fractional-horsepower military specification motors.

To determine normal vibration levels for Category B motors, 42 motors of three types of 3600-rpm machines were overhauled at NETE. The motors were given no special treatment except that the housings were opened to give a sliding fit (G6 limits) for the bearings, wave-spring washers were incorporated at the non-locating bearing and the motors were reasonably well balanced (to 0.2 mils pp displacement on a soft-bearing balancing machine). Figure 7 shows the maximum vibration levels from the three types of motors, and the limits for industrial machines in good condition taken from the IRD/Mechanalysis General Machinery Vibration Severity Chart. From this data a relaxed control curve, "The Vibration Limit for Category B Motors", was defined as drawn in Figure 7. This is now part of the POMT for non-critical motors.

FIGURE 7 DERIVATION OF PRESENT NAVY VIBRATION SPECIFICATION FROM MAXIMUM VALUES OF 42 TESTS AT NETE AND COMPARISON WITH LIMITING IRD CURVE FOR 'GOOD' MACHINES



To study how effective this vibration specification was likely to be, the post-overhaul motor test sheets from six ships which have been refitted since 1980 were compared against it. In summary, of 566 machines for which test sheets were available from the contractors' yards, by the end of 1983 57 had been repaired because of mechanical defects. (Approximately the same number of failures had occurred through electrical faults.) Of the 566 motors:

> 393 had passed the Category B POMT, 34 of these had failed in service; and
>
> 173 motors did not pass the test and 23 of these had failed in service.

The six ships had together reached a total of 10 ship-years of service since refit, and since the total time between refits is 4 years, by extrapolating to 24 ship-years, the number of failures relative to the POMT can be assessed.

Of the 393 motors (69%) which passed the POMT,
the % of failures to be expected in 4 years' service is: $\frac{34}{393} \times \frac{24}{10} \times 100 = 20\%$

Of the 173 motors (31%) which did not pass the POMT,
the % of failures to be expected in 4 years' service is: $\frac{23}{173} \times \frac{24}{10} \times 100 = 32\%$

These figures suggest that the POMT is not sufficiently discriminating, and ways of improving this will now be considered.

DO NORMAL MOTOR VIBRATIONS INCREASE WITH MOTOR SPEED?

One proposal for improving the POMT vibration specification is derived from the Shipboard Machinery Vibration Analysis Program, where it has been found from experience that if the vibration level at any given point is more than 12 VdB (a factor of 4) above the average VdB level at that point, there is probably a fault in the machine. The global average levels plus 12 VdB for all the 1200-, 1800- and 3600-rpm motors on the 6 ships in the program are shown in Figure 8. It can be seen that these curves are bounded by lines decreasing by 3 VdB per octave, commencing from 103 VdB in the 16 Hz, 31.5 Hz and 63 Hz octave bands for the 1200-, 1800- and 3600-rpm motors respectively. However, it has been noted that the levels of some types of machines, even in good condition, exceed these curves in certain octave bands. This is because of structural resonances, aerodynamic noise or other machine characteristics, and so an alternative proposal has been studied.

FIGURE 8

GLOBAL AVERAGE OCTAVE BAND VIBRATION LEVELS PLUS 12 VDB FROM THE 1200, 1800 AND 3600 RPM ELECTRIC MOTORS OF 6 SHIPS (SHOWING PRESENT CAT B MOTOR VIBRATION SPECIFICATION & POSSIBLE CHANGES)

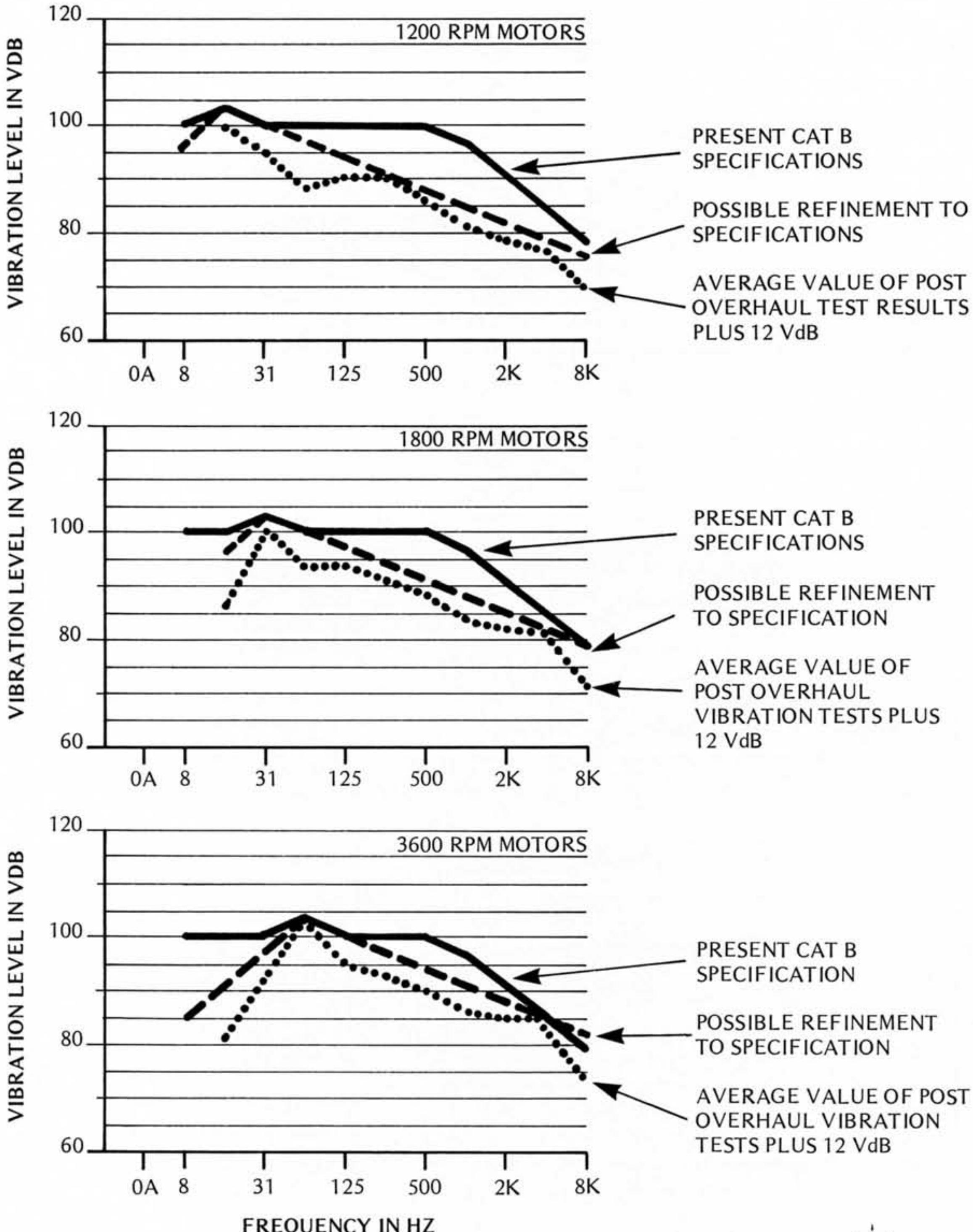
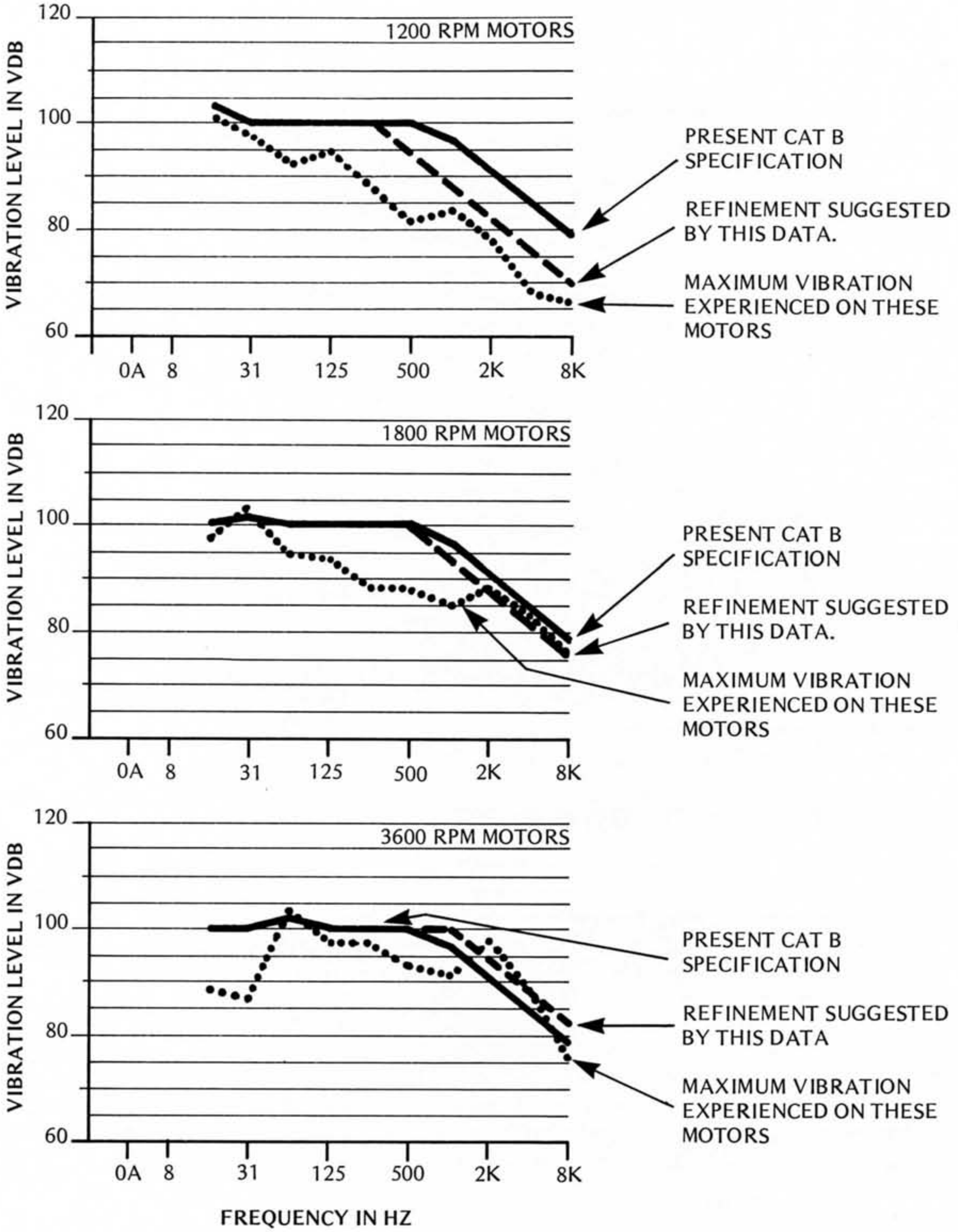


FIGURE 9

MAXIMUM OCTAVE BAND VIBRATION LEVELS FROM 1200, 1800 AND 3600 RPM MOTORS ON HMCS MACKENZIE (SHOWING PRESENT CAT B MOTOR VIBRATION SPECIFICATION AND SUGGESTED REFINEMENTS)



The global averages contained readings from several contractors, and it was noted that the west-coast yard was able to meet the POMT requirements much more readily than other contractors, and subsequent motor failures have correlated quite well with their test results to date. For example HMCS MACKENZIE had achieved $1\frac{3}{4}$ years' service since refit by the end of 83, and of the 73 motors overhauled at refit:

64 machines had passed the POMT, and 2 of these had broken down in service.

9 machines had failed the POMT, and 2 of these had also required repairs.

It was decided to use the maximum vibration levels from all the machines on this ship, grouped on the basis of motor speed, to verify the vibration specification of the POMT. The results are given in Figure 9, from which it can be seen again that in the higher octave bands, the slower motors have lower vibration levels. On the graph it can been seen that at 3600 rpm it may be necessary to relax the constant acceleration portion of the present vibration specification for Category B motors to 116 AdB (0.9 g peak), but the 1800-and 1200-rpm vibration levels are covered by the envelope of 110 AdB (0.45 g) and the 104 AdB (0.22 g) respectively.

At present these two sets of controls, which are shown in Figure 10, are being evaluated by comparing the machinery POMT results with the motor-failure information which is forwarded periodically to NETE.

IS A GLOBAL VIBRATION ENVELOPE ADEQUATE FOR CATEGORY A MOTORS?

Some types of Category A motors have not been modified in the manner discussed earlier in this paper. At present the targetted vibration acceptance level for the Category A motors is half that of the Category B motors, i.e. 6 dB below the specification envelope in Figure 7. This is easily met by the critical motors whose casings were reworked to the "aero-engine" standards specified by NETE in the early 1970s. However 3600-rpm Category A motors, which have not been accurately remachined, may have higher vibrations than these because of the effects of misalignment and because some motors have internal attachments which may affect the vibration levels. It is considered that ball-bearing motors falling in this category will be satisfactory in service provided that the non-locating bearings are fitted with wave-spring washers and have a sliding fit in their housings, and that the rotors are properly balanced.

As an example, the average plus 12 VdB of the 1800-rpm A10 fan and the 3600-rpm 75-ton AC compressor motors are shown in Figure 11 with the Category A vibration specification. Since the "75-tonner" average-plus-12 VdB curve exceeds the specified limits in several octave bands, excursions above this limit must be expected. In fact this occurred with two of the

FIGURE 10 **ALTERNATE GLOBAL VIBRATION CONTROL PROPOSALS FOR NON CRITICAL MOTORS PRESENTLY UNDER STUDY AT NETE**

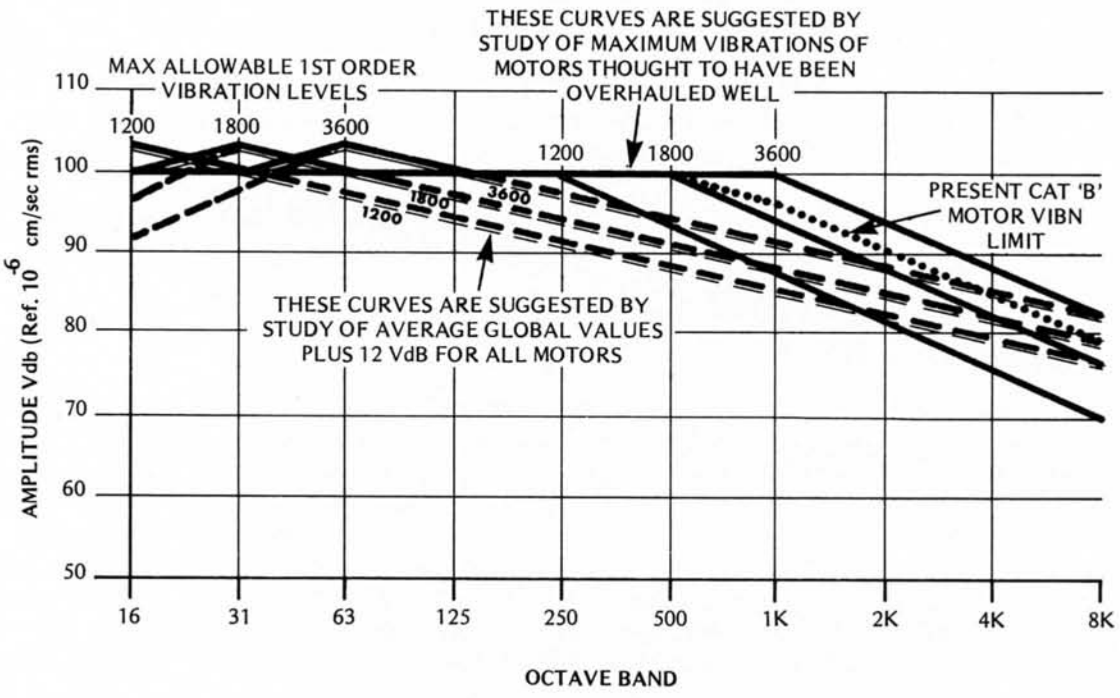
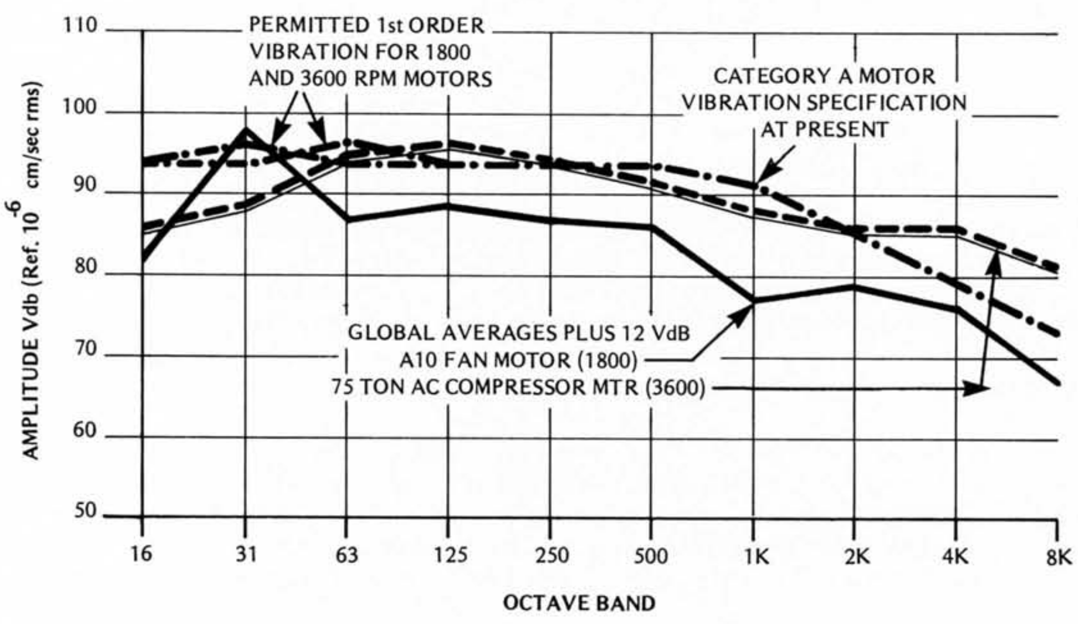


FIGURE 11 **COMPARISON OF THE CAT A MOTOR VIBRATION SPECIFICATION OF THE POST OVERHAUL TEST WITH THE GLOBAL AVERAGES PLUS 12 VdB FOR TWO CRITICAL MOTORS**



motor rebuilds at NETE. For these unmodified Category A machines it is recommended that norms consisting of the average plus 12 VdB be prepared for each type of motor.

IS THERE A NEED FOR POST-INSTALLATION MOTOR VIBRATION TESTS?

Three hundred and ninety-three motors passed the Category B POMT, of which 34 motors failed. Ten of them were recognized as having defects such as coupling misalignment, pulley or fan unbalance etc. which may have occurred during the installation of the motor to its driven unit onboard ship. Vibration control tests are not generally called up on the shipboard post-installation runs at present, and the data suggests that this is a significant weakness in the refit procedure. An experimental post-installation vibration survey will be conducted on the motors coupled to their driven units on a ship leaving refit to evaluate the effectiveness of this additional control.

HOW RELIABLE IS THE RUNDOWN-TIME INDICATOR?

To round out the paper, the present status of RDT measurement will be discussed briefly. Two of the four motors which failed on HMCS MACKENZIE to the end of 1983 had very short RDTs, however the motor rundown times did increase during the runs and so they were accepted. On the other hand, 50 of the 566 motors tested from the six ships had an irregular RFT/running time pattern, but their final times were fairly close to the group average, and none of these motors has yet failed because of bearing problems. It is thought that these irregularities are associated with minimum clearance fits between the bearing outer-races and housings. When the minimum clearance (approximately 0.0005") exists, a temperature difference of 8°C is sufficient to eliminate this and cause the race to be locked. It is thought that fitting wave-spring washers will reduce this effect and produce more uniform RDT figures.

FIGURE 12

MACHINE NO. 29235A DESCRIPTION: A2 FAN

		RUN DOWN TIME (SEC) AFTER (MIN)						FINAL TEMP (C)		
SHIP	LOC	1	5	10	20	30	60	DE	ODE	
SAGUENAY	1D1	9	11	12	15	16	16	50	57	BEARINGS FAILED: JUN 81, OCT 82. (SHORT RDT)
SAGUENAY	1F2	15	30	34	39	50	75	33	36	BEARINGS FAILED MAR 82, SEP 83
SAGUENAY	1G8	12	15	18	22	24	27	43	42	
SAGUENAY	1G9	12	18	24	28	33	36	37	40	
SAGUENAY	3H3	12	15	45	72	87	100	30	36	
SKEENA	1D1	8	12	21	24	22	25	42	56	
SKEENA	1F2	9	20	22	28	31	33	41	51	FAILED SEP 82
SKEENA	1G8	10	13	14	20	21	24	50	47	
SKEENA	1G9	14	23	34	38	49	58	39	47	
SKEENA	3H3	9	22	24	31	33	37	38	47	
MACKENZIE	2F1	14	21	23	28	29	30	33	39	
MACKENZIE	2G1	17	20	24	26	31	33	41	41	
MACKENZIE	2D8	12	15	17	20	22	24	45	50	
MACKENZIE	3J3	20	22	26	28	31	34	31	37	
OTTAWA	1D1	14	21	28	36	47	53	51	62	
OTTAWA	1G8	13	18	19	20	22	24	35	58	
OTTAWA	1G9	42	54	62	62	74	78	37	39	
OTTAWA	3H3	44	53	99	118	155	158	35	45	
NIPIGON	2D5	23	29	35	45	47	49	25	25	
NIPIGON	O1E1	0	0	0	0	0	0	0	30	DATA NOT AVAILABLE. TESTED WITH FAN
NIPIGON	1G6	34	34	43	50	58	67	35	35	
AVERAGE VALUES:		17	23	31	27	33	39	28	43	

Tables of the individual and average RDTs and bearing temperatures have now been prepared and their usefulness is being evaluated at NETE. Figure 12 gives the results for the 2-HP axial flow fans. It appears probable that, when the average RDT for a given type of motor is well established, an RDT of less than 1/3 of this value will be a good indication of faulty bearing installation. The RDT data has also shown that some motors, running without their fans, have developed excessive bearing temperatures in the one-hour no-load run. And since the RDT trend is well established by the 30-minute run, the one-hour run has now been deleted.

SUMMARY

It can be said that the industrial electric motor vibration limits are inadequate. After a false start, the Canadian Forces have established a vibration and RDT control for Category A and B motors which has improved the quality of overhaul, and which filters out many motors with severe defects from a group. Category C motors are at present only subjected to the motor run-in procedure, with measurements of RDT and bearing housing temperatures, and it is planned to investigate and establish suitable vibration controls on these units where it is considered cost effective.

It is considered that the refinements to the vibration specifications discussed in this paper, and the publication of the RDT and bearing temperature norms for each type of motor will further improve the quality control exercised during overhaul of Canadian navy motors.

ACKNOWLEDGEMENTS

Thanks are due in particular to Mr. Banford and the NETE office-staff who typed the manuscript, to Mr. Watson for a valuable critique, and to Mr. Costis, Manager NETE, for support during preparation of the paper.

LIST OF REFERENCES

(1) Handbook for Maintenance of Aeronautical Anti-Friction Bearings. U.S. Bureau of Naval Weapons Publication NAVWEP 01-1A-503 Aug 65.

(2) Interaction of Lubricating grease with Ball-Bearing Vibration in Quiet Running Electric Motors. Layn R.P. and Warren K.H. Journal of American Society of Lubricating Engines Aug 66.

(3) Bearing Performance Investigations through Speed-Ratio Measurements. Phillips, G.J. Transactions of A.S.L.E. Vol. 22.4; pps 307-314.

(4) Redesign and Assembly of Anti-Friction Bearing Housings for Improved Life. Watson D. G. and Xistris G. 21st Seminar of Mechanical Failures Prevention Group. Gaithersburg Md; Nov 74.

(5) Improved Anti-Friction Bearing Life using Rotor Rundown Time as a Quality Control Indicator. Watson D.G. and Xistris, G. ASME paper 75-DE-6.

Standing at the Threshold

Photograph by WO V. Johnson

Marc Garneau sat at home one night
with the quite peculiar thoughts
of replying to a want ad
for Canadian Astronauts

How little did he then expect
selection from the mass
but still . . . why not?
An Astronaut
is someone with great class!

So penning deeds and merits
he'd accomplished to that day
he scripted all
"Marc's Marks in Life"
in Curriculum Vitae

Then
astounded by achievements
now displayed in printed script . . .
hope sprang that his successes
might indeed
not be eclipsed

The numbers soon depleted
as the tests all took their toll
then the interviews
and more exams
again reduced the roll

The short list was established
and my friend was of the few
Then finally . . .
the chosen six
were presented for our view

And there stood Marc
with beaming grin
"quite handsome" some would tell
but more important
he was good
and would do the job
damn well

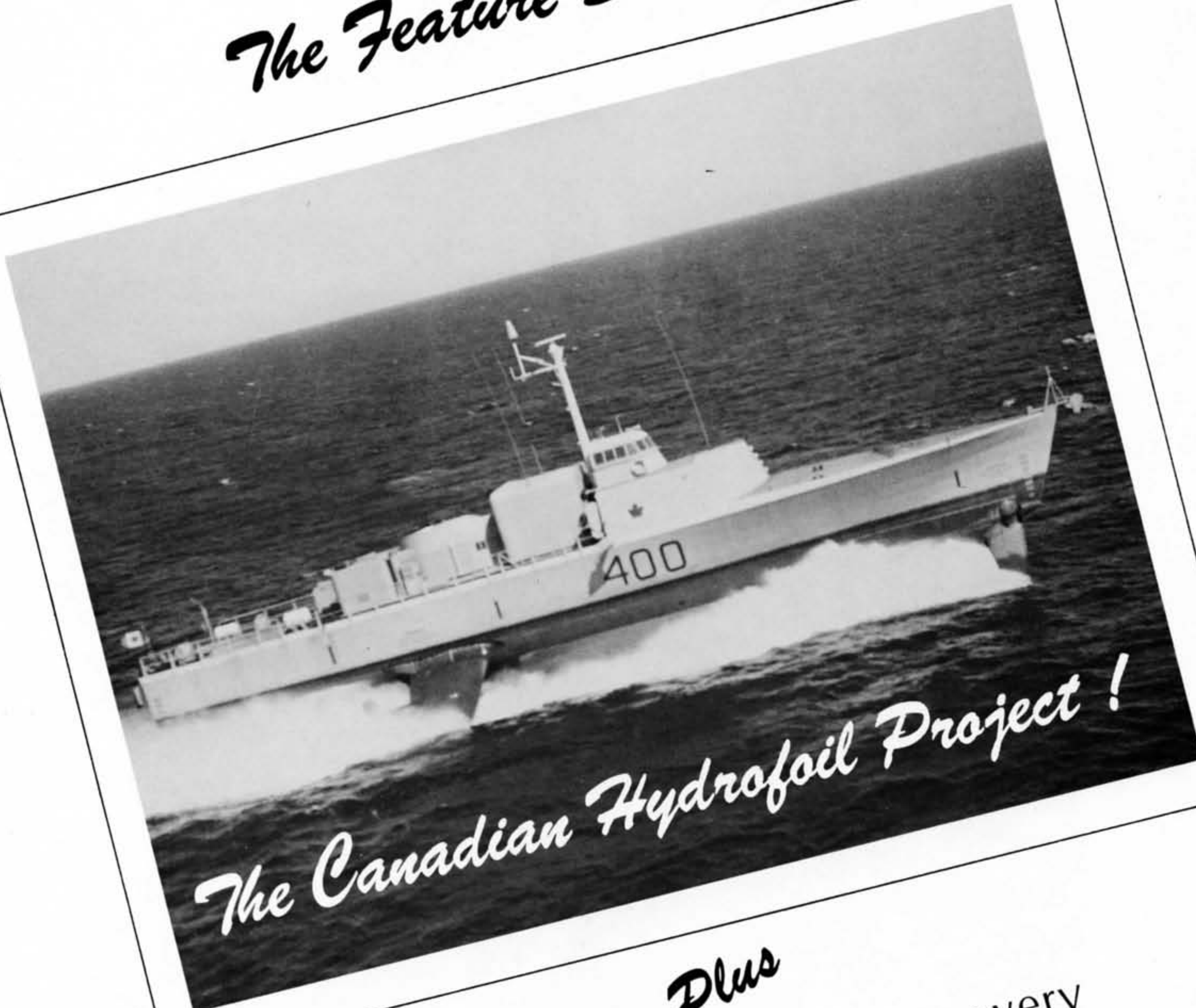
The training process then commenced
from six could come but one
to perform the varied scheduled tasks
required to be done

Again Marc was successful
standing now alone . . . unique!
Ambassador . . . to all the World
His stature at new peak

Then standing at the threshold
for the step out into space
Marc reaffirmed our Country's role
and secured Historic Place.

Larry J. MacLeod

The Feature Story



Plus

DDH-280 Waste-Heat Recovery

SHINPADS Data Bus

Vibration and Rundown-Time Norms