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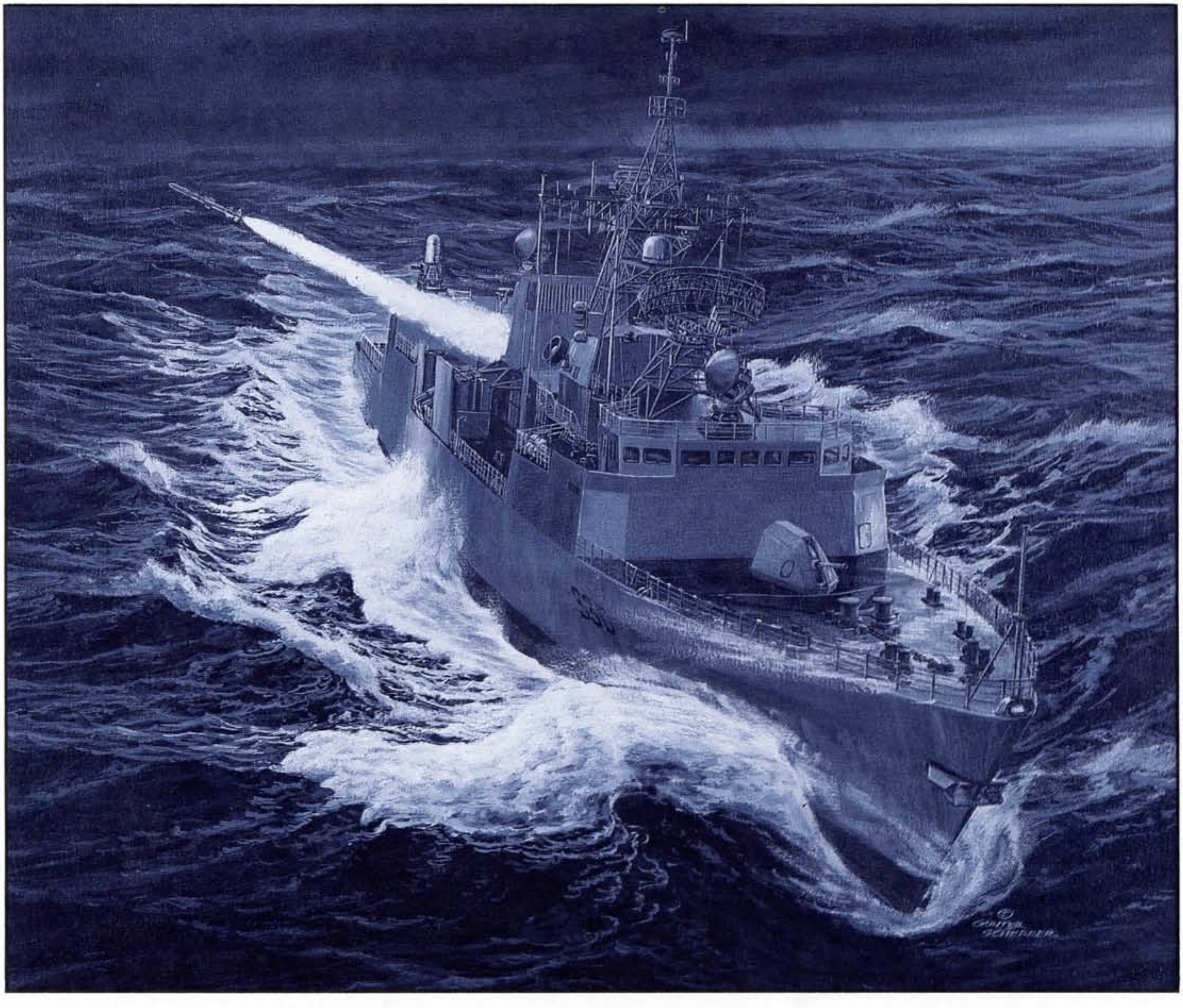
MARITIME ENGINEERING Journal du GÉNIE MARITIME



Canada

January 1987 Janvier

Full Speed Ahead on Trump

Athabaskan

Find out what TRUMP means for the Tribals — in our News Briefs section starting on page 27

MARITIME ENGINEERING
Journal
du GÉNIE MARITIME

DIRECTOR-GENERAL
MARITIME ENGINEERING and
MAINTENANCE
Commodore D.R. Boyle

OUR COVER

An artist's conception of the Canadian Patrol Frigate HMCS *Halifax* by Gunter Scherrer. (This painting was commissioned by Paramax Electronics, Inc. of Montreal and is used here with their kind permission.)

JANUARY 1987

DEPARTMENTS

FEATURES

MARITIME ENGINEERING JOURNAL
ISSN 0713 - 0058

The Maritime Engineering Journal (ISSN 0713-0058) is an authorized unofficial periodical of the maritime engineers of the Canadian Forces, and is published three times a year by the Director-General Maritime Engineering and Maintenance. Views expressed are those of the writers and do not necessarily reflect official opinion or policy. Correspondence can be addressed to **the Editor, Maritime Engineering Journal, DMEE, National Defence Headquarters, Ottawa, Ont., K1A 0K2.** The Editor reserves the right to reject or edit any editorial material. Journal articles may be reprinted with proper credit.

JOURNAL DU GÉNIE MARITIME
ISSN 0713 - 0058

Le Journal du Génie maritime (ISSN 0713-0058) est une publication autorisée et non-officielle des ingénieurs maritimes des Forces canadiennes. Elle est publiée trois fois l'an par le Directeur général du Génie maritime et de la maintenance. Les opinions exprimées sont celles des auteurs et ne reflètent pas nécessairement les politiques officielles. Le courrier doit être adressé au **Rédacteur en chef du Journal du Génie maritime, DMGE, Quartier général de la Défense nationale, Ottawa, Ont., K1A 0K2.** Le Rédacteur en chef se réserve le droit de rejeter ou d'éditer tout matériel soumis. Les articles de ce journal peuvent être reproduits tout en tenant compte des mérites de l'auteur.

Editor's Notes

Much has been written about the Canadian Patrol Frigate in terms of its performance capabilities, equipment and concept of operations, but very little has been written about how the CPF will be built. In our lead article, authors Cdr Peter McMillan and LCdr Brian Staples walk us through the CPF construction process at the Saint John Shipbuilding Limited facility in Saint John, N.B., and highlight SJSL's advanced construction techniques for steelwork and unit assembly. (This article is the first of what we hope will be a series of CPF construction articles.)

Also in this issue, an article by L.T. Taylor; this time he considers the stratified charge, omni-fuelled rotary engine (SCORE) as an alternative to the gas turbine as a prime mover for electrical power generation. And in a "joint-service" article, LCdr Bill Dziadyk, LCol Brian Nix and Maj James Mackenzie describe the system architecture of the AN/AYK-502(V) general-purpose digital computer — the central computer on board the CP-140 Aurora Maritime Patrol Aircraft.

We complete the article line-up with an intriguing look into the world of Artificial Intelligence. Rather than the usual descriptive style of article, though, LCdr Paul Senechal provides us with what is best described as a structured glossary cum reference to the salient activities, concepts and terminology of AI. He precedes the "glossary" with a brief history of what one authority calls this "science of making machines do things that would require intelligence if done by men".

We ask that you make special note of the News Briefs section towards the back pages of this issue. This will be a regular feature of the *Journal* where we throw the spotlight on project announcements and updates, news of upcoming events, and on other short items of interest. If you have news of developments in your area that you would like to pass along, please let us know so that we can include them in an upcoming issue.

Three new technical editors have joined the magazine staff — LCdrs Peter Lenk and Bill Miles are now looking after the combat systems editing, and Lt(N) Michel Bouchard has taken up the reins for marine systems editing. Regrettably, we must say farewell to two other of our technical editors. Lt(N) Bill Vandinther, who has been covering the naval architecture side of things for the past year, has been posted to the CPF detachment in Saint John; and LCdr Dave Jacobson, our combat systems technical editor for more than two years, has been posted to Staff College in Toronto. Our thanks and best wishes go with them.

And finally, we have included a questionnaire with this issue to find out what you do and don't like about the *Journal*. Your comments and suggestions are always welcome, but please take the time to complete and return the questionnaire as soon as possible. In this way we hope to get a snapshot opinion of the magazine from the entire readership so that we can do something about making the *Journal* better for everyone.

WRITER'S GUIDE

We are interested in receiving *unclassified* submissions on subjects that meet any of the stated objectives. Manuscripts and letters may be submitted in French or English, and those selected by the Editorial Committee for publication will be run without translation in the language which they were submitted.

Article submissions must be typed, double-spaced, on $8^{1}/_{2} \times 11$ white bond paper and should as a rule not exceed 6,000 words (about 25 pages double-spaced). Photographs or illustrations accompanying the manuscript must have complete captions, and a short biographical note on the author should be included in the manuscript.

Letters of any length are welcome, but only signed correspondence will be considered for publication. The first page of all submissions must include the author's name, address and telephone number.

At the moment we are only able to run a limited number of black and white photographs in each issue, so photo quality is important. Diagrams, sketches and line drawings reproduce extremely well and should be submitted whenever possible. Every effort will be made to return photos and artwork in good condition, but the **Journal** can assume no responsibility for this. Authors are advised to keep a copy of their manuscripts.

GUIDE DE RÉDACTION

Nous désirons recevoir des textes non classifiés qui répondent à l'un ou l'autre des objectifs mentionnés précédemment. Les manuscrits et les lettres peuvent être présentés en anglais ou en français, et les textes choisis seront publiés dans la langue d'origine, sans traduction.

Les articles doivent être dactylographiés à double interligne sur feuilles de papier à lettre de 8-1/2 sur 11 et, en règle générale, ils ne doivent pas dépasser 6,000 mots (environ 25 pages à double interligne). Les illustrations et les photographies doivent être accompagnées d'une légende complète, et le manuscrit doit comprendre une brève note biographique sur l'auteur.

Les lettres de toutes longueurs sont les bienvenues. Cependant, seules les lettres signées pourront être publiées. La première page de tout texte doit indiquer le nom, l'adresse et le numéro de téléphone de l'auteur.

À l'heure actuelle, nous ne pouvons publier qu'un nombre limité de photographies en noir et blanc dans chaque numéro. C'est pourquoi la qualité des photos est très importante. La reproduction des diagrammes, des croquis et des dessins est d'excellente qualité et nous vous encourageons à nous en faire parveir lorsque c'est possible. Nous ferons tout en notre possible pour vous retourner les photos et les présentations graphiques en bon état. Cependant, le Journal ne peut assumer aucune responsabilité à cet égard. Les auteurs sont priés de conserver une copie de leurs manuscrits.

Letters to the Editor

Dear Editor,

The April 1986 edition of the *Maritime Engineering Journal* presented an article by P01 F.B. Kirke, entitled "Marine Engineering Training in Spectrometric Oil Analysis". It is felt that the concerns expressed in this article should be addressed.

The main thrust of the article was the assertion that SOAP training is initiated too late in an individual's career to convince him of the value of the program. The point that must be clarified here is that SOAP is one of many Equipment Health Monitoring (EHM) techniques that is used by the Canadian Forces. The concept of EHM is that, by using a combination of techniques, the performance of systems and equipments is constantly monitored so that impending failures may be diagnosed. It is awareness of the value of EHM as a whole, therefore, that must be encouraged. With the implementation of the New Naval Maintenance Policy, this reliance on EHM has increased and an updating of existing training as well as the development of new course packages has been initiated.

The specific problem areas in SOAP training are not unknown. One of the main problems in instructing SOA is the complexity of the testing process. The test equipment currently in use requires the skill of a qualified technician and the interpretation of an engineer, not to mention a laboratory environment. This is hardly encouraging for the ordinary seaman who is at the first level of career training. NDHQ is attempting to circumvent this problem by investigating new types of equipment that require little or no training to operate, and provide a computer program which interprets the data in comprehensive terms. At present, one such piece of equipment is under consideration that will undergo a Naval Techval to determine its suitability for sea duty.

Another important factor is the development of advanced technology that can alter the effectiveness of EHM procedures. Due to recent improvements in filter design, for example, the continued effectiveness of SOAP has been questioned. When SOAP was first developed, the analysis provided was based on wear metals which passed through filters ranging from 10 to 50 microns. Today a large number of equipments are using 5-micron filters which obviously decreases the effectiveness of SOAP for those units. The answer to this problem is to develop techniques specific to equipments with 5-micron filters and continue SOAP on those with 10-micron filters. There are currently two programs under study at the Naval Engineering Test Establishment and with private contractors which may provide alternative methods of oil analysis. The feasibility of a formal Filter Debris Analysis Program is being considered, and an Oil Condition Analysis Program is now being tested on diesels for effectiveness and reliability.

With the realization of Equipment Health Monitoring as a viable method of predicting failure, the re-evaluation of programs such as SOA has become a prime concern for the Navy. Established alarm levels are no longer considered static, development of alternative programs has become essential, and education and training in all new and existing EHM techniques is necessary.

A complete article on EHM will be prepared for a future edition of the *Journal*.

Cdr J.R. Sylvester
DGMEM/DMES 6

MARITIME ENGINEERING JOURNAL OBJECTIVES

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

LES OBJECTIFS DU JOURNAL DU GÉNIE MARITIME

— promouvoir le professionnalisme chez les ingénieurs et les techniciens du génie maritime.

— offrir une tribune libre où l'on peut traiter de questions d'intérêt pour la collectivité du génie maritime, même si elles sont controversées.

— présenter des articles d'ordre pratique sur des questions de génie maritime.

— présenter des articles retraçant l'historique des programmes actuels et des situations et événements d'actualité.

— annoncer les programmes touchant le personnel du génie maritime.

— publier des nouvelles sur le personnel qui n'ont pas paru dans les publications officielles.

Commodore's Corner

by Commodore D.R. Boyle

As this is my first opportunity to address you in the *Journal* since relieving Cmdre Gruber as DGMEM and MARE Branch Adviser, I thought it appropriate to use this space to review briefly where we are and where we're going. This is a challenging time for the MARE profession as we work our way toward a future full of promise; we have brought about significant personnel changes in the last few years and are entering a period of consolidation, and our fleet modernization is underway with even more projects in the planning stages. I am extremely grateful to my predecessors for their foresight and hard work, and I certainly intend to continue the effort.

The MARE "health" has been a significant concern for the last five years. Our attrition was high, our recruiting low, and the requirement for MARE officers was growing with each new acquisition project approval. Further, the classification was not structured to meet the needs of the '80s and beyond. Two parallel programs were undertaken, and both have borne fruit. The MARE Study, which culminated in 1983, yielded a revised structure and new personnel specifications for four subclassifications. Training has been extensively revised, and new course training standards are in the final stages of publication.

Concurrently, the MARE Get-Well Program was launched to address the numerical shortfall. Beginning in 1983, recruiting was more than doubled and training staffs have applied a superhuman effort to cope with the increased student flow. As a result, the number of junior officers has increased by 50% since 1983, and there has been a 115% increase in the number of officer cadets in the ROTP. We're still short, especially in the Lt(N) and LCdr ranks, but we're getting there. The major outstanding concern is our inability to attract sufficient combat systems candidates, and a special effort will be needed to address this problem. In this regard I want to make a plea to you: the situation is too serious simply to rely on "the system" to resolve, and we all need to act as unofficial recruiters. Use your initiative — talk to students, your cousins and nephews, service clubs, anyone who will listen — and find CS recruits! If we can get them to the recruiting door, "the system" can take it from there.

Perhaps less obvious to you is a renewed interest in the state of the naval reserve. The roles and missions of this relatively unseen portion of our wartime force have been redefined, and a considerable effort is being applied to examining the needs and training of reserve personnel. As part of this process, DGMEM and COS MAT have been working with the involved staffs to establish a firm place for MAREs in the reserve structure. As well, CMDO is well-advanced in a proposal to improve the reserve minor warship fleet. Only time, and the state of future capital budgets, will attest to the success of these endeavours.

Looking at the status of the major crown projects, the situation seems promising indeed. CPF's steel problems have been resolved and several construction units have been completed; pre-outfitting has commenced and detail design is progressing. TRUMP is also progressing well, with the first ship, *Algonquin*, due to start her shipyard phase in the fall of this year. SRP II is currently in the initial stages of project definition. The feasibility study for the NATO Frigate has been completed, and documentation for the project definition phase is being prepared for the participating nations' approval. CASAP has received approval to proceed with project definition and is undergoing Source Qualification now. And finally, the New Shipborne Aircraft Project is on schedule, with an RFP having been released to industry last year leading to the eventual selection of the prime contractors later this year.

So, overall, there are exciting times ahead. They will require a continued, extensive effort from all of us as we work to re-build the navy and at the same time continue to meet our operational commitments. This effort will place many demands on all of you. I cannot promise any relief — only more work and more fun. The reward lies in the achievement of a modern navy of which we will all be proud. As your Branch Adviser I am pleased to be a part of the process, and I will do my utmost to foster the responsiveness of our profession to meeting the challenges which arise.

Finally, I would like to draw your attention to this journal. It is the publication of our profession, and it can serve us well as a professional journal. Use it to advance concepts and exchange ideas that will both generate and enhance the cause of the maritime engineering profession. The editor has few constraints on the type of article he can print, and controversial subjects are not forbidden, so I urge you to support the *Journal* with your articles and letters.

Boyle

Saint John Shipbuilding Ltd and CPF Construction

by Cdr P. McMillan, CD, P. Eng., and
LCdr B. Staples, Ph.D, P. Eng.

Introduction

The Canadian Patrol Frigate Project represents Canada's commitment to re-equip the navy and prepare our fleet for the 21st century. Since the original statement of requirements was developed in 1977 much has been written about the CPF performance capabilities, equipment and concept of operations, but very little has been written about how the ship will be built. The CPF construction method is as progressive and exciting as the ship itself. While a cursory view would indicate that the CPF and the DDH-280 have employed the same construction philosophy, that similarity is only applicable to the basic steelwork assembly. CPF construction will see shipbuilding techniques never before used in Canada, and equal to or an improvement upon the methods being employed by major United States naval shipbuilding programs. The adoption of advanced construction methods cannot be instituted in isolation and therefore there has been a corresponding revolution in the disciplines of engineering drawings, material control and quality assurance. These issues will be discussed only to the extent of their direct impact on construction.

Historical Background

Saint John Shipbuilding and Drydock, now Saint John Shipbuilding Limited, was founded in 1923 with the construction of a large graving dock, and during the Second World War produced both commercial vessels and naval corvettes. The shipyard was sold to its current owner (Mr. K.C. Irving) in 1959 and has since undergone several significant modernizations. In 1960 a large steelwork assembly building was completed, thus allowing SJSL to approach ship construction with a production-line methodology. In 1982 the graving dock was lengthened from 198 to 423 metres, providing an inner section of dock and an outer section, each capable of handling large construction programs. SJSL's involvement with naval work since the Second World War has included the refits of several warships and the construction of the two AORs, HMCS *Protecteur* and *Preserver*. The CPF program is the largest activity undertaken by the SJSL shipyard.

Canadian Patrol Frigate Program

Following competitive bids for the CPF, Saint John Shipbuilding Limited was awarded the $3.5 billion contract on 29, July 1983. The government's procurement strategy delegated total program responsibility and risk, for the first time in Canadian naval history, to a civilian contractor. The scope of the CPF program includes: the design, construction, trial and delivery of six fully supported, operationally capable warships; training facilities and programs; logistical support requirements and support spares; and program management. All procurements are governed by a comprehensive industrial benefits program.

At contract signing, SJSL consisted of a small nucleus of program management personnel, an engineering affiliate (Saint John Marine Consultants Ltd.) and a relatively large shipyard work-force

The Saint John Shipbuilding Ltd. facility in Saint John, N.B. SJSL operates the largest drydock in Eastern Canada.

of 1500, much of which was completing work on the semi-submersible oil rig *Bow Valley III*. Now, three years into the program, SJSL's Program Management, Engineering, and Integrated Logistics Support staffs have grown to over 500. The shipyard work-force, which was laid off following the completion of the oil rig, has gone through requalification courses and a CPF-specific training program, and is now building up in strength as the construction requirements diversify towards the various trades. SJSL has reorganized their CPF program management and corporate organization on several occasions since contract signing, restructuring between functional and matrix responsibility, and corporate versus program alignment. Initially the CPF Program Office, corporately responsible to the Shipyard Management Office, was by far the larger and more influential group. Gradually, however, with the start of construction, the shipyard's identity enhanced within the total project group such that the present matrix management structure can function in a balanced environment.

The Shipyard

Saint John has the largest drydock in Eastern Canada, serviced by four heavy cranes capable of lifting 200-tonne units onto the building blocks. Apart from the drydock, the heart of the shipyard is the main steelwork assembly building, a facility extending 285m in length (see photo). It has modern material handling facilities, plate-cutting, forming and rolling equipment, as well as good cranage and ample work space. To support the steelwork fabrication, a modern blast-and-paint facility sized to handle large construction units is located adjacent to the assembly building. Since contract signing, SJSL has undertaken the further enhancement of the assembly and outfitting buildings, including improved lighting, heating, ventilation, tooling and interior cranage. To support the CPF construction and logistics requirements, a 10,000 m^2 central receiving warehouse has been constructed. In the future it is planned to build a jetty-side outfitting building and improve the shipyard's electrical power and dockside services. These facility improvements, along with an energetic employee training program and implementation of advanced shipbuilding techniques, are intended to dramatically improve the overall efficiency of SJSL with consequential benefits to the CPF Project.

Ship-Construction Philosophy

SJSL will employ a "unit construction" methodology with a high degree of "pre-outfitting", termed a "zone-by-stage" methodology. This technique will organize the total production effort into manageable-sized products that are progressed through specific stages of construction. This "production line" method can then use proven construction techniques such as repeating work stations, extensive pre-outfitting and module fabrication. This zone-by-stage approach, however, requires the total integration of design, planning, material procurement and production operations. In order to understand the procedures employed, it is necessary to review the terminology.

The main "products" of this system are:

a. *Assembly Units* (Figure 1) — the product of steelwork assembly and hotwork outfitting, they are a specific area of the ship, a block, consisting of a deck, bulkhead and two side-shells, or a deck, bulkhead and bottom-shell assembly;
b. *Erection Units* (Figure 2) — the product formed by the welding together of two to four assembly units, normally two or three decks high. Once blasted and coated, they become the focal point for pre-outfitting or load-out of equipment. It is the erection unit that is lowered into the drydock as a segment of the ship; and
c. *Outfit Zones* — areas of the ship defined from bulkhead to bulkhead and deck to deckhead, used to control material installation and labour charging for the finish outfitting while the unit is in the dock or afloat.

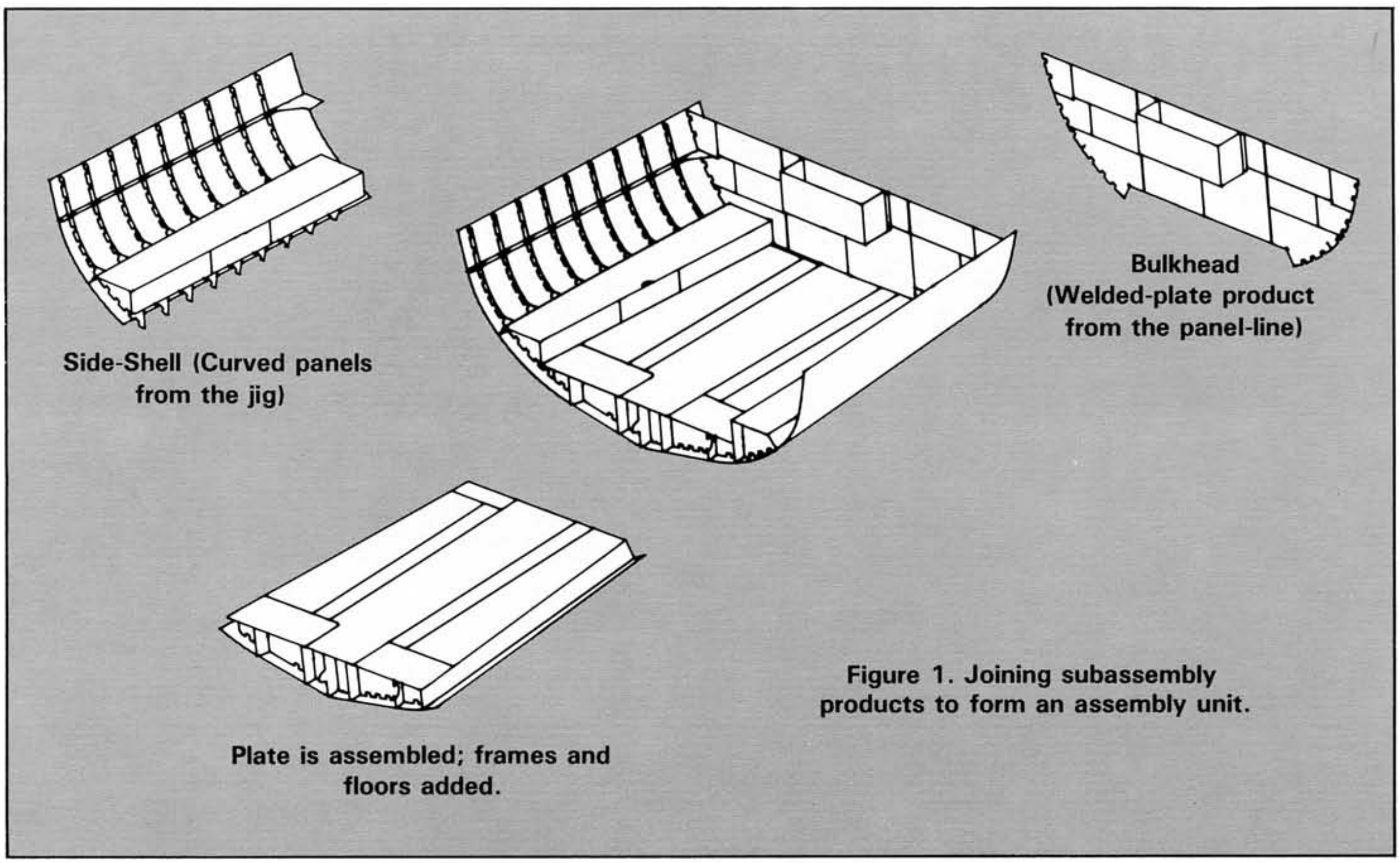
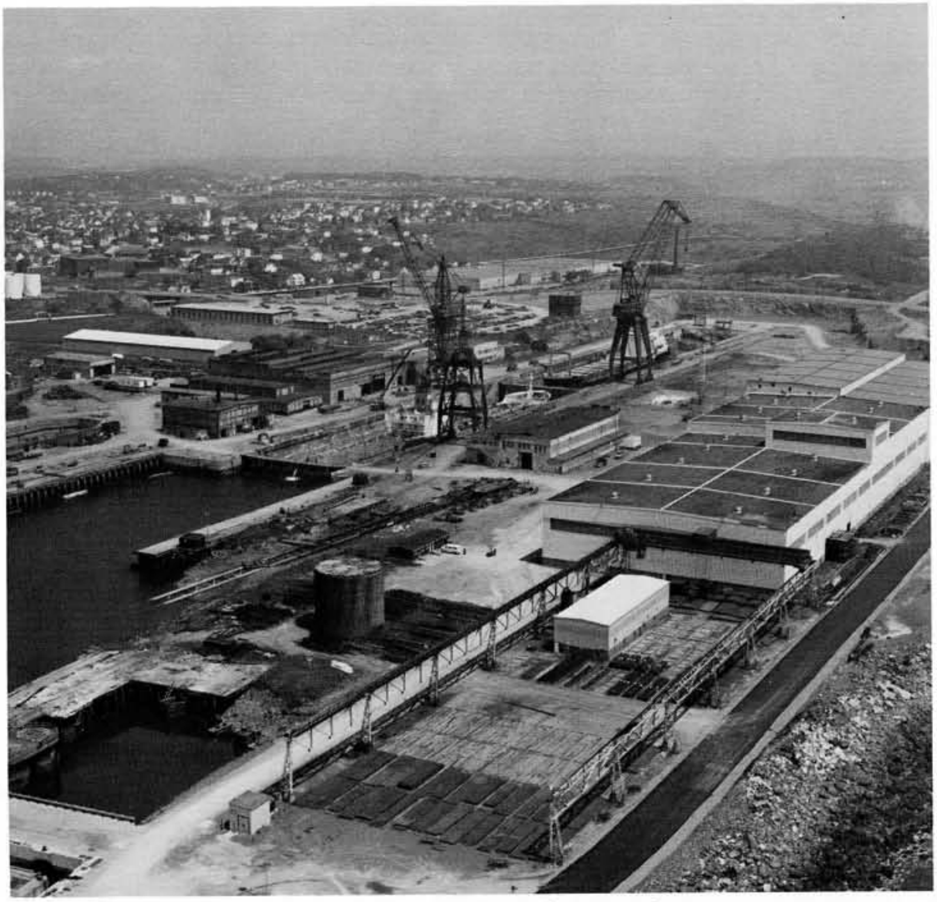


Figure 1. Joining subassembly products to form an assembly unit.



The assembly building with plate stockyard in the foreground.

(There are three other products of lesser magnitude; namely: modules, special installations and manufacturing jobs. These products support the overall advanced pre-outfitting concept, but are conducted in parallel to, and in support of, the main ship-construction activity.)

The stages of construction that are required to produce the Assembly Unit, Erection Unit and Outfit Zone are:

a. *Steelwork Assembly* — consisting of several substages including:

   (1) *fabrication* — the sorting, marking, cutting and shaping of steel plates and structural members;
   (2) *subassembly* — the welding of fabricated parts to form decks, frames, floors and side-shells; and
   (3) *assembly* — the fitting and welding of subassembly components to form complete assembly units.

b. *Pre-Outfit* — the process of fitting internal systems and equipment into the units prior to erection in the graving dock. This is done in two stages — Pre-outfit One, a "hot" work outfitting which employs welding, burning or grinding for the installation process; and Pre-

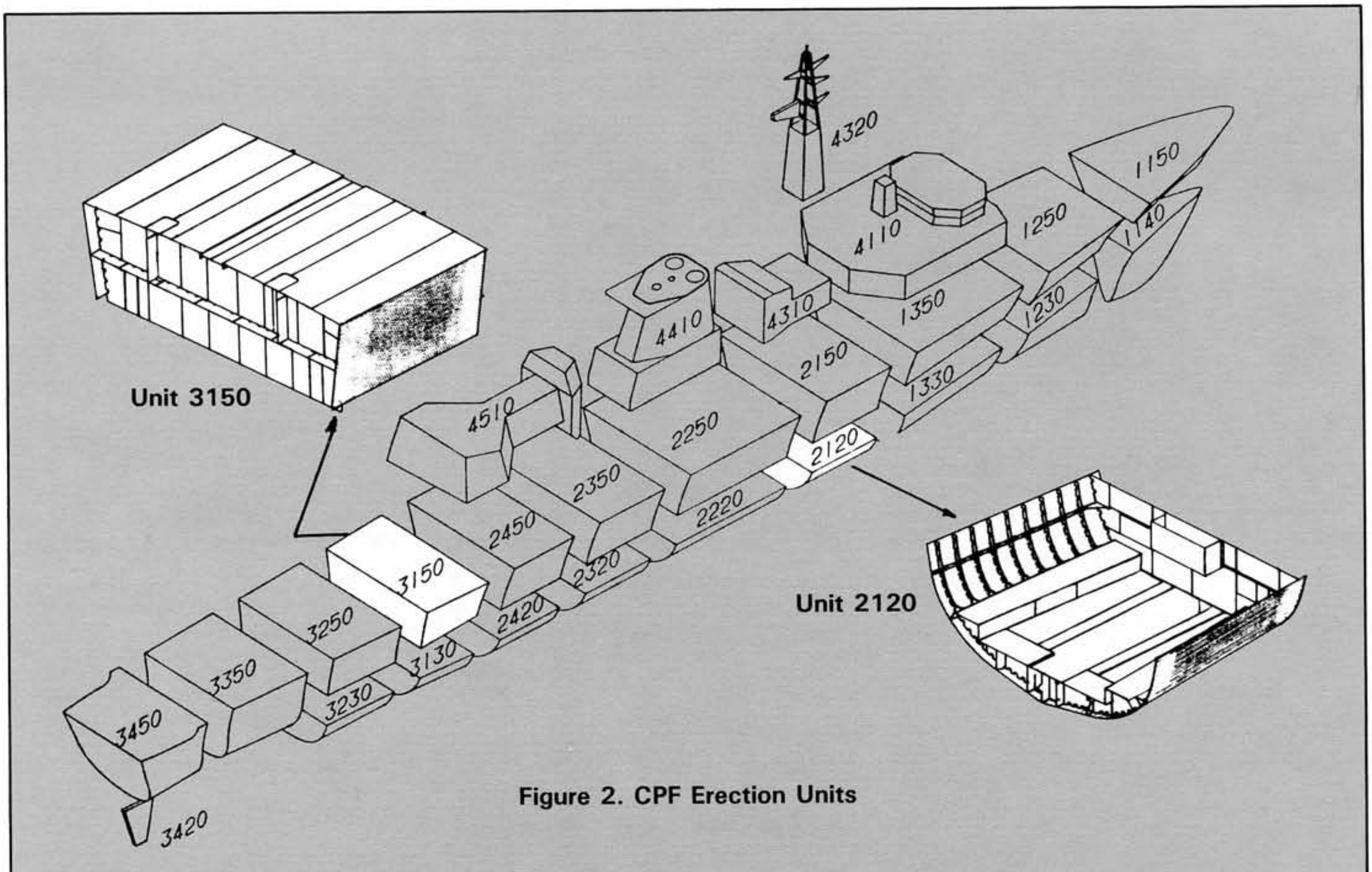


Figure 2. CPF Erection Units

outfit Two, a "cold" work or equipment installation stage;

c. *Blast and Paint* — the cleaning to bare metal and priming of the erection units (normally occurring between Pre-outfit One and Pre-outfit Two);

d. *Erection* — positioning the pre-outfitted erection units into drydock and joining them together by fitting, trimming and welding;

e. *Overboard Outfit* — installing equipment into the ship while in the drydock or afloat, leading to the final painting, close-out and acceptance of each finished compartment; and

f. *Test and Trials* — checking out and verifying the performance of all equipment and systems.

The entire process from the stockyard to overboard outfit through the various work areas is shown in Figure 3.

In order to assist in the development of production drawings and to identify the products in the construction process, each has been given a unique and specific identification number based upon its location in the ship. There are four major sections: Frame 20.5 forward (Section 1), Frame 20.5 to 43 midships (Section 2), Frame 43 aft (Section 3), and the superstructure (Section 4). These sections are further divided into erection units (typically six to eight per section), and finally into assembly units (typically two to four per erection unit). These unit divisions, or "unit and erection butts", have been carefully chosen to ensure, firstly, that the contained structure is self-supporting and therefore transportable, and secondly that the size and weight of the units is within the volume and lift capacity of the shipyard facilities. The identification numbers for the various components of the CPF can be seen in Figure 2.

Construction Details

Steelwork Assembly

The process of steelwork assembly commences with specific plates and rolled sections being "called up" by manufacturer's plate numbers as referenced in the production drawings. Steel plate is processed through a shot-blast ("wheelabrator") facility to remove all millscale before being loaded onto the numerically controlled plasma burning machine. This electrical-discharge cutting device not only cuts the plates to size and shape, but also marks the locations for longitudinals, bulkheads, beams, etc. Once cut, each piece is marked with a colour-coded (according to steel type) identification code, indicating the hull, assembly unit and part number. For example, a steel part marked in blue with the number 1222-3130-219 indicates the hull number to which it belongs (i.e. 1222 for CFP 01), its unit number of 3130, and its individual part number (219). The blue marking paint indicates the type of steel to be used — in this case, 350 WT. This coding provides positive control and material traceability throughout the entire construction process, as these numbers remain with the parts throughout the process.

Following the cutting operation the plates are channelled either to the flat-

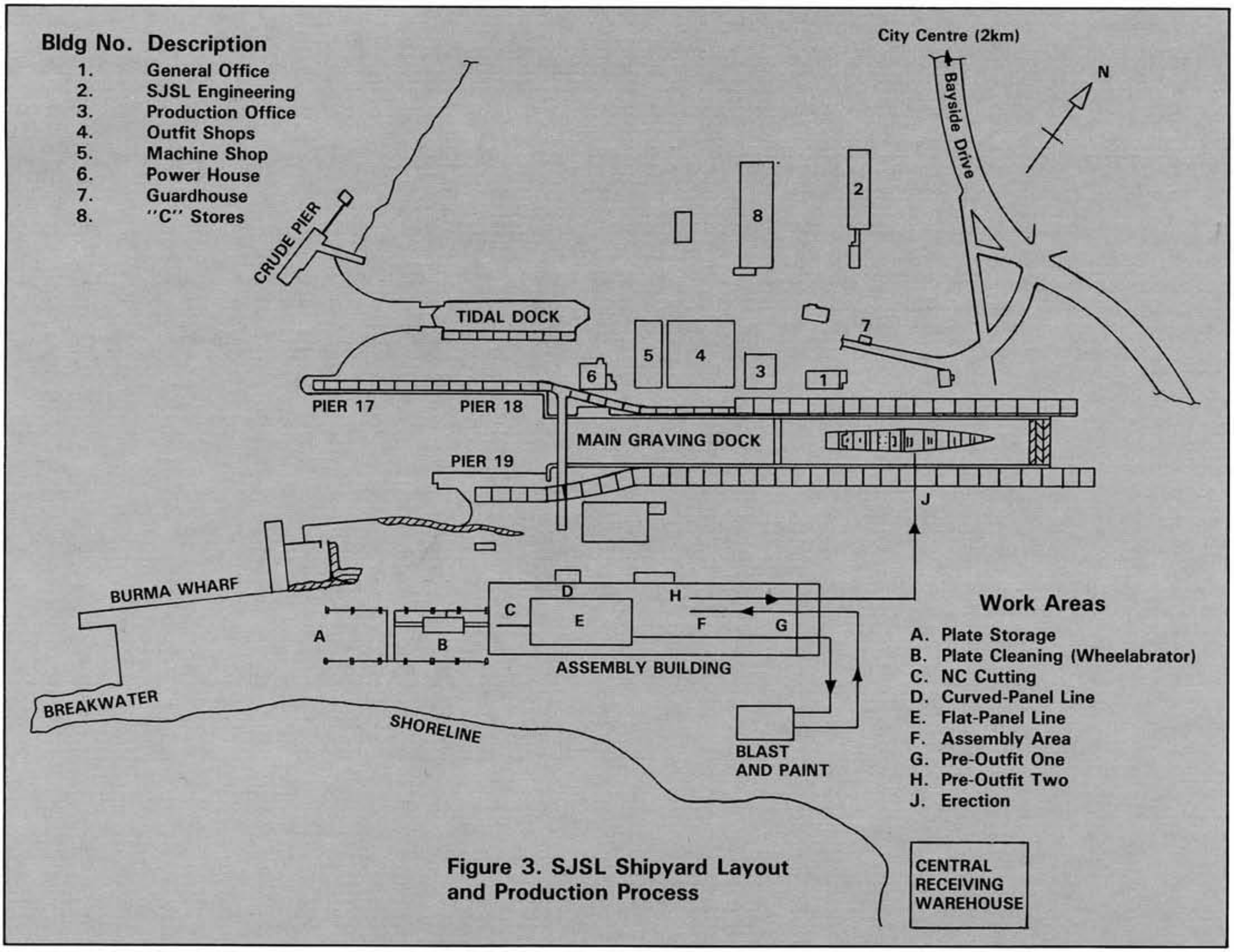


Figure 3. SJSL Shipyard Layout and Production Process

panel line for decks and bulkheads, or to the curved-panel line for side- and bottom-shells. The products of these two lines, the subassemblies are brought together in the assembly areas where they are joined to form assembly units (Figure 4). Assembly is conducted on laser-leveled beds with the units inverted to maximize the use of the more efficient "downhand" manual and semi-automatic welding procedures. Throughout the assembly stage the work is continuously monitored by the SJSL Quality Control staff and Accuracy Control group. Quality Control verifies that the products or units are constructed within the allowable tolerances and workmanship standards, with a "go, no go" result. Accuracy Control, a branch of the Production Department, determines the amount of variation in dimensional parameters at each stage of assembly in order to quantify changes resulting from the process (e.g. plate shrinkage). This data can then be fed back into the process in the form of offsets or additional stock requirements. Upon completion of all assembly work, the Quality Control staff conducts a final acceptance inspection of each unit prior to it leaving the assembly stage. A typical assembly unit at this stage of construction is shown in Figure 5.

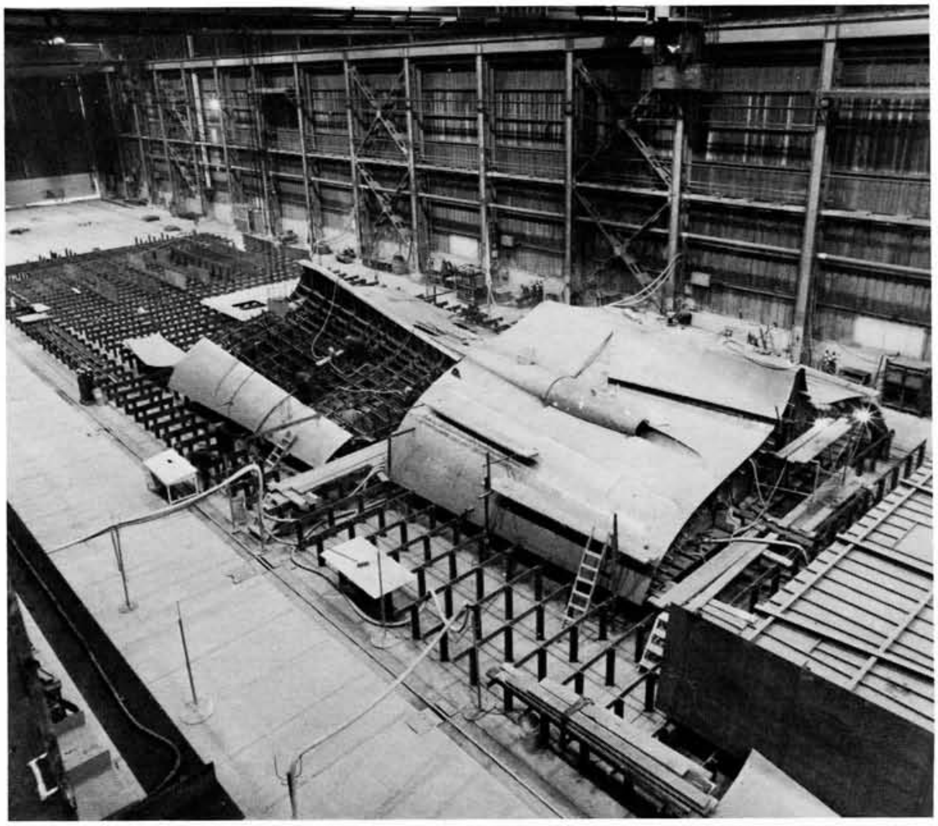


Figure 4. Assembly units under construction — (L to R) Units 3220, 3120 and 3240.

Pre-Outfit One

Following steelwork assembly the units are processed through Pre-outfit One, or "hot" pre-outfit. This stage is dedicated to the installation of substructure, equipment supports and penetrations which require welding, burning or grinding. Items include pipe and cable hangers, minor bulkhead curtain and toe plates, foundations, seatings, hatch coamings, and pipe and cable penetration pieces. To support this type of pre-outfitting, Engineering must produce specific outfit drawings including an "inventory and bill of materials" for each assembly unit, the Material Control group must batch the material by assembly unit and provide it at the scheduled time, and the Production Division must ensure that the manufacture of pre-outfit components is completed in advance of the installation schedule. All aspects must be controlled and coordinated in order to match the overall production schedule. Pre-outfit One is divided for planning purposes into two phases. The first phase is accomplished while the units are in the inverted position, thus taking maximum advantage of the efficiency of downhand fitting, dimensioning and welding. Once the downhand outfitting of deckhead components is complete, the assembly units are turned upright and joined to other units to form erection units, and Pre-outfit One continues.

Figure 5. Assembly unit 3120 prior to Pre-outfit One.

Blast and Paint

With all scheduled welding, grinding and burning completed, the erection units are transferred from the assembly building to the blast-and-paint facility where they are grit-blasted to a near-white-metal finish and given a primer coat of paint. Following painting, the units are transferred to the outfit side of the assembly building and positioned upright on cradles to await the start of Pre-outfit Two.

Pre-Outfit Two

This phase, known as the "cold" pre-outfit, is the stage at which the erection units are outfitted to the maximum degree possible with total unit weight being the only limiting factor. Again, at this phase, Engineering must provide specific outfit drawings, the Materiel Department must batch the components and material, and Production must have the piping, ventilation trunking and cabling prefabricated and ready for installation, all on a unit by unit basis. Outfitting at this stage includes piping, electrical controllers, cabling, lighting, pumps, furniture, valves, ventilation trunking, motors and machinery.

Outfitting at this early stage of construction enables the work to be progressed within the controlled environment of the assembly building, takes advantage of the building services (cranes, ventilation, etc.) and ensures good work-force control. The load-out of equipment is further aided by the ability to side-load into these open-ended units.

As some outfit areas within units may be open-ended or without a deckhead, the engineering drawings and installation procedures must be referenced to the available structure. Equally, the designer must be aware of the interface requirements between units and zones, so that when the units are finally joined, piping and cable runs will line up, bulkheads and passageways will match, and the components will be properly positioned.

Unit Erection

Erection is a process of moving a unit to the drydock and joining it to an existing portion of the ship. When each erection unit has been outfitted it is moved to the drydock onboard a 200-tonne transporter. Then, using the combined lift of three dockside cranes, it is positioned in the dock according to the erection plan. The units are then jacked together and welded (shell plating, longitudinals, decks and beams), thus becoming part of the ship. While as much as 70% of unit outfitting is completed before erection, there is still much that is impractical or impossible to fit until after the unit is in the dock. Owing to the weight of much of the propulsion equipment, its load-out can only be accomplished when the units are in their final position in the dock. The diesel generators, propulsion diesel, propulsion raft, gearbox and gas turbines will all be loaded after erection. Most erection units are designed such that the seams between units are located 600mm above the deck. Therefore, when the unit is placed in the open dock, this deck forms a protective cover over the outfitted components. In the case of the machinery spaces the units are constructed without a covering deck to enable outfitting to continue. Therefore, until the upper units are positioned to cover the machinery spaces, a temporary and portable roof will be used to protect the components from the weather.

Outfit Zones/Drydock

Outfit zones are used to detail and schedule the installation of outfitting materials after the erection of units in the drydock. Thus the drawings are structured to fully define all outfitting installations and material on a compartmental basis. Care again must be taken to ensure inter-zone connections are properly engineered and arranged. At this stage, outfitting material consists of trunking, piping, machinery, furniture, etc. which could not be fitted earlier due to its interference with erection butt-welding. Loading material on board the ship while it is in the drydock is much more cumbersome and labour intensive as equipment/components must be manoeuvred along planned (but more restrictive) routes, down hatches and along passageways, before being slung into position.

During the drydock outfitting many special installations and alignments are done in order to take advantage of the dockside cranes and the stability of the ship on the blocks. The most critical item to be completed at this stage is the alignment of the gearbox, shafting and A-brackets, and the fitting of the propellers and rudder. While there are advantages to continuing the outfitting work while the ship is in the dock, the cost of tying up the dock requires that the ship be floated and moved to the outfitting pier as soon as practicable. The float-up is thus scheduled for as soon as the hull integrity is obtained and the external hull work complete.

Overboard Outfitting

Overboard Outfitting consists of the installation of the combat systems equipment and weapons hardware, the finishing work required in each outfit zone, and the close-out inspection of each compartment following its final paint-out. The combat systems operations room and communications equipment represents a special outfitting installation. These will be assembled, groomed and given full system verification at Paramax Electronics Inc. in Montreal before being moved by special transport to the shipbuilding site and virtually walked onboard and installed. Perhaps the most time-consuming and somewhat uncontrolled aspect of any shipbuilding activity is the finishing operation. While the programmed pre-outfitting will reduce many last-minute finishing operations, finishing and compartment close-out is a notoriously painstaking process. The final phase of the overboard outfitting stage is the completion of the testing and trial of all equipment and systems such that the ship can proceed safely on sea trials.

Conclusion

The "zone-by-stage" approach to ship construction and outfit will result in a higher quality product. In adopting this approach, SJSL has made many significant changes to the manner in which they build ships. Engineering, material control, quality assurance and project planning have all been tailored toward meeting the objectives of "zone-by-stage" construction. The product will be governed by a rigorous configuration control system that will result in a ship that can be constructed within the constraints of cost and schedule while meeting the performance requirements. The CPF will be a product of modern technology, not only in her operational capability but also in the manner in which she will be built.

Commander P. McMillan graduated from the Royal Military College at Kingston in 1970 with a degree in mechanical engineering. He has served as engineer officer of HMCS Margaree *and* Qu'Appelle, *and has been employed in staff positions in SRU(A) and DGMEM. He was posted to the CPF detachment in Saint John in 1983 as the Marine Systems Officer, and following promotion to his present rank assumed the duties of leadyard commander for CPF construction. Cdr McMillan has been posted to command the CPF detachment at Marine Industries Limited, Sorel P.Q. for followship construction.*

LCdr Staples graduated from the University of British Columbia with a B.A. Sc. (metallurgical engineering) in 1969, and received his doctorate from Imperial College, London in 1974. Since joining the navy in 1977 he has held staff positions in NEU(A) and has served as engineer officer of HMCS Margaree. *He is currently the leadyard marine systems engineer and quality assurance representative for the CPF Project in Saint John.*

Aurora Combat System Computer Architecture

by LCdr W. Dziadyk, LCol B. Nix and Maj J. Mackenzie

Introduction

The AN/AYK-502(V) General-Purpose Digital Computer (GPDC) is the central computer on board the Canadian Forces CP-140 Aurora Maritime Patrol Aircraft. The processor is one of a family of Sperry processors designed in the late 1960s for military applications and is virtually identical to the AN/AYK-10 computer of the American S3-A Viking, a carrier-based anti-submarine aircraft.

This paper will describe the GPDC system architecture, with particular emphasis on the bus architecture. This airborne system architecture is of interest to naval combat systems engineers in that it provides a benchmark against which shipboard computer systems and architectures may be compared. Such comparisons are of use when analyzing the effectiveness of the chosen distributed SHINPADS architecture with the AN/UYK-502 and AN/UYK-505 computers. While the GPDC and SHINPADS system architectures are very different from each other, each is well suited to its respective combat environment.

This paper is based upon material produced by the authors during their post-graduate studies at the Royal Military College, Kingston.

General System Description

The AN/AYK-502(V) computer is designed to meet the stringent volume and weight restrictions imposed upon avionic systems by the limitations of aircraft structures and powerplants. For this reason, although it embodies considerable redundancy in its design, all GPDC system components are housed in a single enclosure. Similarly, the use of serial I/O is dictated solely to reduce the weight of the wiring to the peripherals. The internal architecture of the GPDC is consistent with the state of the art in the 1960s for mainframe processors. Many of its features, such as protected register sets and multiport memories, have only recently been made available in commercial mini-computers.

System Hardware Overview

The standard GPDC system configuration consists of two Central Processors (CP), two Input/Output Controllers (IOC), two Input/Output Interfaces (IOI) and two 32,768-word (32K) memory units. The GPDC mainframe will accommodate a third memory unit. However, the third memory is not installed for normal operations, but is used only to support extended executive functions such as

software debugging and system performance analysis during software development and system integration. Figure 1 illustrates GPDC component location in the Aurora airframe.

The CPs function independently in multiprocessor fashion. They are composed of a 32-bit architecture which includes the control, arithmetic, logic and timing circuitry required to realize the necessary data-processing and system control functions.

The GPDC processes flight and mission data. Input data is entered into memory, and output data and commands are routed to associated avionic and display devices via the Input/Output Interface (IOI) and Input/Output Controller (IOC). Arithmetic and logic operations directed by the stored programs are performed by the left and right processors. Each processor is capable of independent operations, and each processor can communicate with either of the two IOCs. In addition, access can be gained to any 16K memory bank by either of the processors or IOCs. Discrete control signals between units provide asynchronous (REQUEST/ ACKNOWLEDGE) operation.

Input/output (I/O) functions are controlled and executed by the IOC and IOI. The IOC receives high-level I/O direction from the CP, gains access to memory for the specified I/O program, directs the logical execution of the I/O program instructions, furnishes I/O timing and directs the IOI. The IOI provides the interface between the IOC and the peripheral avionic subsystems for transfer of peripheral control words and data via serial data channels. Each CP can direct each IOC which, in turn, can direct each IOI. Each peripheral, however, is interfaced to only one IOI.

Each memory unit operates independently of the other(s), and may be accessed by any one of six channels which comprise the instruction and operand busses for each of the CPs and single busses to each IOC. Memory accesses are arbitrated by each memory unit on a fixed priority basis.

A major, closely integrated peripheral of the GPDC is the OL5004 Acoustic Data Processor (ADP). It is interfaced to the GPDC via serial data channels to the IOIs. The primary functions of the ADP are the storage and analysis of acoustic sensor data. A 64K section of each of the ADP's two data storage drums has also been allocated as secondary storage for the GPDC, raising the GPDC's standard program storage capacity to 192K.

Two additional essential peripherals of the GPDC are the Digital Magnetic Tape Units (DMTU). The system software is loaded from, and mission data recorded onto, magnetic cartridges via the DMTUs.

Figure 2 illustrates the functional relationships between the GPDC modules, the ADP drums and the DMTUs.

System Software Overview

The GPDC system software consists of three distinct, separately loadable programs: the System Test Program (STP), the In-Flight Training Program (IFTP) and the Operational Program.

The System Test Program stimulates GPDC and peripheral component built-in test circuits, and analyzes the component response to provide both a preflight component-level System Readiness Test and a more detailed card-level Diagnostic Test.

The In-Flight Training Program uses stubs of the Operational Program and extensive simulation to provide controllable training scenarios for aircrews while in flight.

The Operational Program is the largest, most complex and most critical of the three GPDC system software programs. The Operational Program subprogram modules, which are written in CMS-2Y, are:

a. system-level modules:

(1) Executive,
(2) Loader,
(3) Keyset Processing (KEYPAC),
(4) Display Processing (DISPAC),
(5) Data Extract and Recall (DEAR),
(6) Initialization,
(7) Recovery,
(8) In-Flight Performance Monitor (IFPM), and

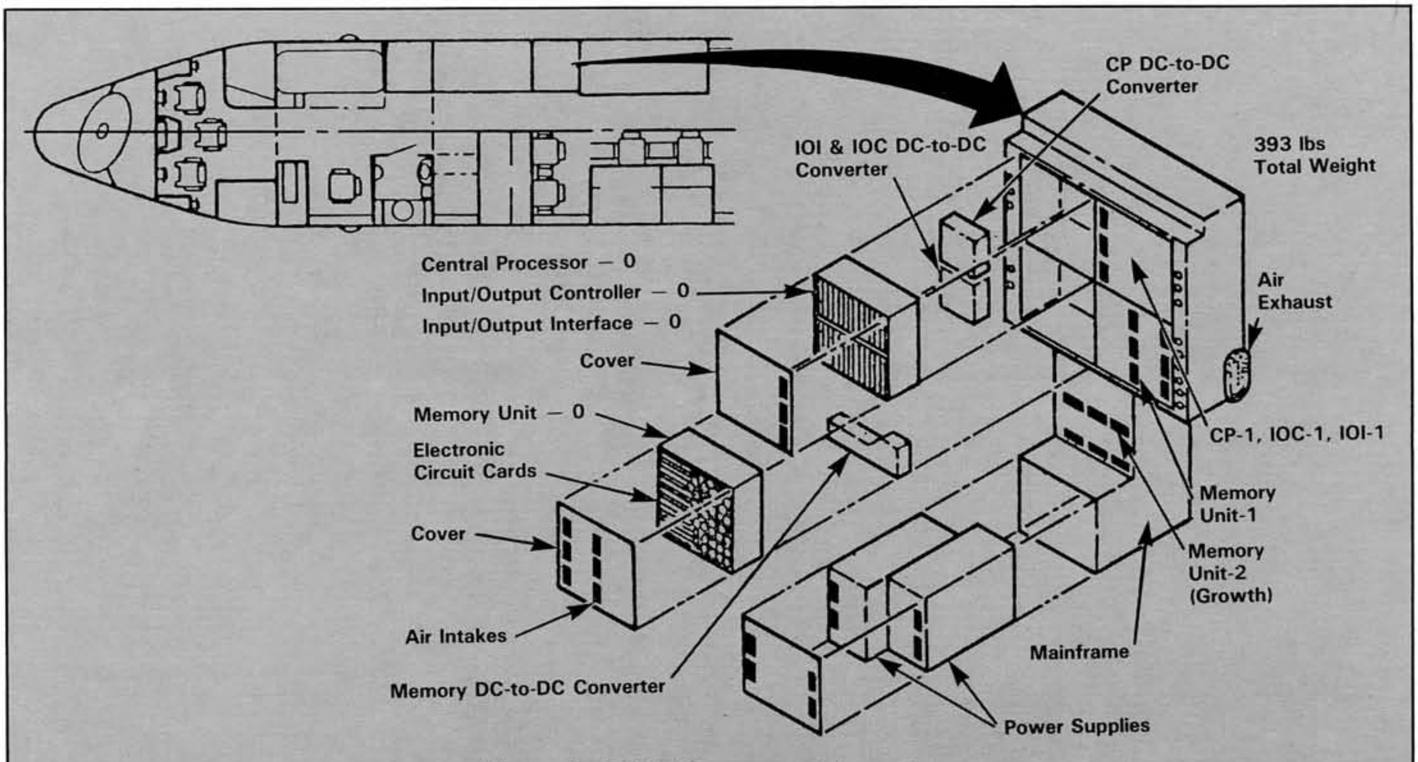


Figure 1. GPDC Component Location

COMPONENT	CHARACTERISTIC
GPDC	Multiprocessor Shared memory Memory overlap Task and interrupt modes Multiple index registers Multiple base registers Multiple accumulators Fractional word handling Indirect and character addressing Full-, half- and quarter-word operands Memory protection Fully buffered I/O Built-in test equipment (BITE) Degraded mode operational capability
Processor	133 basic instructions Fixed- and floating-point operations Double-precision capability 512-word non-destructive readout (NDRO) memory, containing Bootstrap program for initial load, automatic recovery routine, and diagnostics. Control memory, providing fast access to index, base, accumulator, and memory protection registers. Typical instruction execution times: Add: 1.3 usec (overlapped) Multiply: 12.1 usec (overlapped) Divide: 12.1 usec (overlapped)
Memory	65,536 36-bit words (32 data and 4 parity bits) with growth to 98,304 words. 750 nsec cycle time Memory protection, selectable in variable-length increments. Unit independent operational capability
Input/Output	25 basic IOC command repertoire 14 serial buffered I/O channels (plus 2 growth) Two 32-bit parallel I/O channels (167 kHz rate) Command- and data-chaining capability Control memories for buffer control-word access Data word-transfer rates at 667,000 words/sec

Table 1 GPDC Operating Characteristics

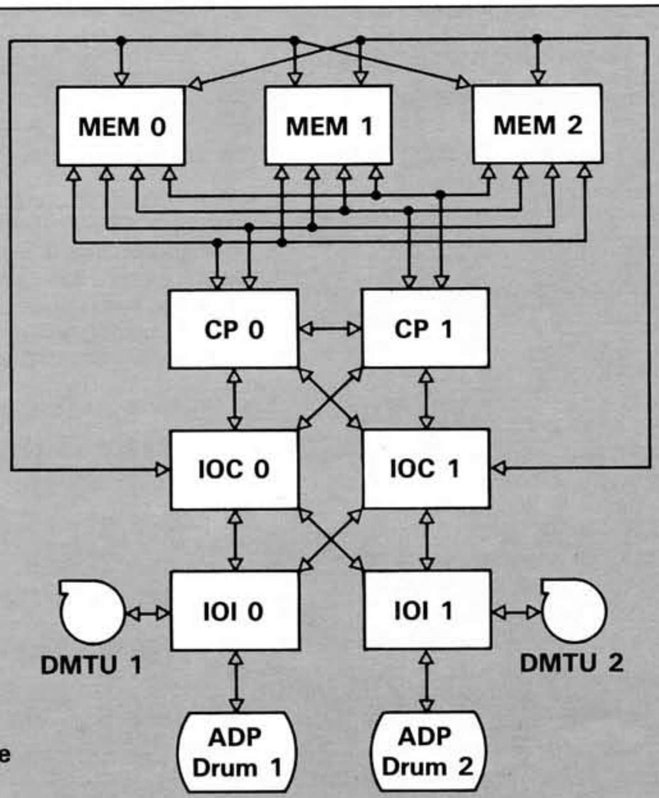


Figure 2. GPDC System Architecture

(9) Error Analysis Routines (EAR);

b. application modules:

(1) Navigation,
(2) Sonobuoy Reference System (SRS),
(3) Steering,
(4) Ballistics,
(5) Radar,
(6) Magnetic Anomaly Detection (MAD),
(7) Forward-Looking Radar (FLIR),
(8) Electronic Support Measures (ESM),
(9) Armament Control (ARMCON),
(10) Search Stores Control (SESCON),
(11) Radio-teletype (RATT),
(12) Data Link,
(13) Tactics,
(14) Passive Acoustic Data Processing (PADP),
(15) Active Acoustics (ACTIVE), and
(16) Acoustic Control (ACCON).

During the software System Generation process, the load addresses of each segment of the program are specified. The executive subprogram as well as common routine and common data segments are loaded directly into primary memory. The rest of primary memory is designated as transient memory. The remaining Operational Program modules are stored on the ADP drum segments reserved for such use. As drum-resident segments are required, they are read into primary memory and executed.

If a memory unit or a drum fails, a degraded Operational Program load is performed. That is, the least essential subprograms are automatically truncated or omitted during the program reload to permit the remaining, more crucial software to be loaded in the memory space available. This facility, combined with the redundant hardware of the GPDC, provides a graceful degradation capability under most component failure conditions.

GDPC Operating Characteristics

Specific operating characteristics of the GPDC and its components are listed in Table 1.

General Processor Architecture

Each processor consists of a Control Section and an Arithmetic Section. The Control Section of the processor contains:

a. registers and control logic to procure, modify and execute instructions;

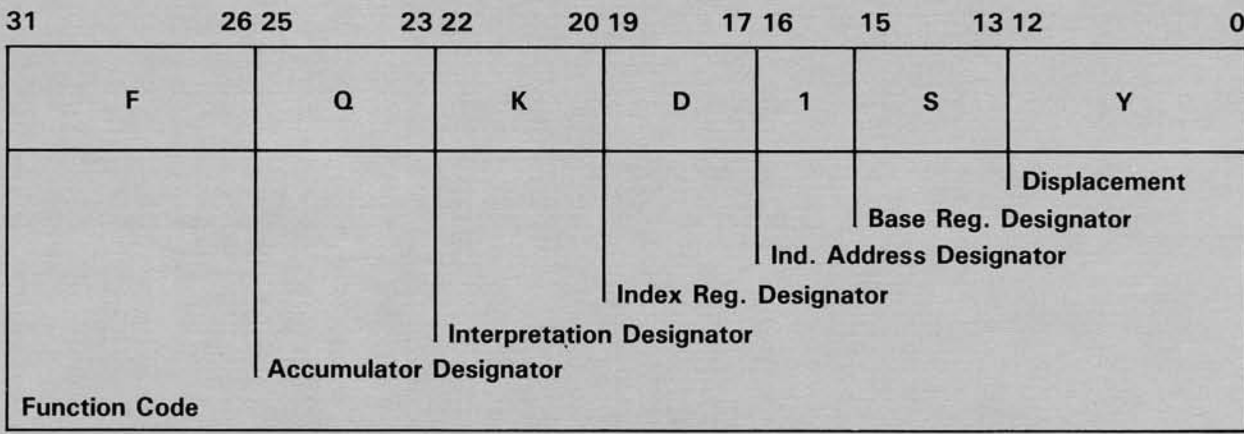


Figure 3. General Instruction Format

b. registers to store hardware and software status; and

c. timing and sequencing circuits to direct the operations required to address instructions and operands, to initiate arithmetic and logical operations, and to initiate input/output operations.

The Control Section uses single-address, self-modifying logic. A relative address (Y-displacement) is specified in the instruction. The address is modified during the instruction execution sequence by the contents of an index register (D) and a base register (S) designated in the instruction word (see Figure 3). The Control Section also supports indirect addressing as specified by bit 16 of the instruction.

Control Memory is divided into two sections; task and interrupt (executive). System control functions such as interrupt handling, initiation of I/O and task assignment are performed in the executive mode. The task mode performs the functions assigned by the executive mode. When a processor switches from the task to the executive state, the hardware automatically switches to the other set of registers, preserving the task environment.

Control Section timing circuits consist of the control clock and the main timing chain. The control clock generates the primary timing pulses which, in turn, are used to generate secondary timing signals via the main timing chain. Signals from the main timing chain provide the fundamental timing signals for the general control operations such as requesting memory for acquiring instructions and operands, interpreting instructions, and initiating arithmetic and I/O operations.

The control clock consists of a delay-line oscillator and associated logic circuits. During each cycle of the oscillator, three clock pulses are generated.

Processor operations are controlled by six timing sequences. Each timing sequence issues a series of commands to perform a particular instruction or operation. Each timing sequence uses at least one master timing cycle (1.2 microseconds). The six possible sequences of an "instruction cycle" are as follows:

a. Instruction (I) sequence;

b. Indirect Address (IA) sequence;

c. Operand 1 (OP1) sequence;

d. Operand 2 (OP2) sequence;

e. Console (CON) sequence; and

f. Interrupt (INT) sequence.

All instructions executed by the processor require at least two sequences — an I sequence and an OP1. The main purpose of the I sequence is to fetch the instruction, while that of the OP1 is to fetch the operand and execute the instruction. Certain types of instructions require additional sequences. The indirect address instructions require one or more IA sequences after execution of the first I sequence to permit cascading of the instruction until a direct address is found. Double-length instructions require an OP2 sequence to acquire the second half of a double-length operand from memory. The CON sequence is initiated when controlling processor operation by the Maintenance Control Panel (MCP). Interrupts are processed by an INT sequence.

The Arithmetic Section of the processor performs the arithmetic and logic functions as directed by the Control Section. Using one's complement subtractive arithmetic, the Arithmetic Section is capable of both fixed- and floating-point operations. The operands for fixed-point may be 32, 16 or 8 bits in length. Fixed-point arithmetic has full, double-precision capability for add, subtract, enter, store, test and branch operations. The floating-point arithmetic uses a 16-bit exponent and a 32-bit mantissa, and includes add, subtract, multiply and divide operations.

The Arithmetic Section is composed of a number of 32-bit registers and logic matrices. The registers in this section (excluding the accumulators) are not addressable and so are not covered in detail here.

Interrupt Processing

As stated previously, the processor Control Section operates in the task mode or the executive mode. In the task mode, the processor is limited in that it cannot perform privileged instructions.

The GPDC interrupts are divided into four different priority classes. Whenever an interrupt is honoured, the interrupt mode is enabled, the appropriate interrupt lockouts are set and an interrupt processing program is executed. The four classes of interrupts are:

a. Class I - Hardware interrupts;

b. Class II - Program Error (Software) interrupts;

c. Class III - I/O interrupts; and

d. Class IV - Executive Service Request interrupts.

Main Memory Organization

The AN/AYK-502(V) main memory is physically organized into three 32,768 X 36-bit word (32 data bits and 4 parity bits per word) "memory units" for a total of 98,304 words. However, the third (growth) unit is not installed for normal

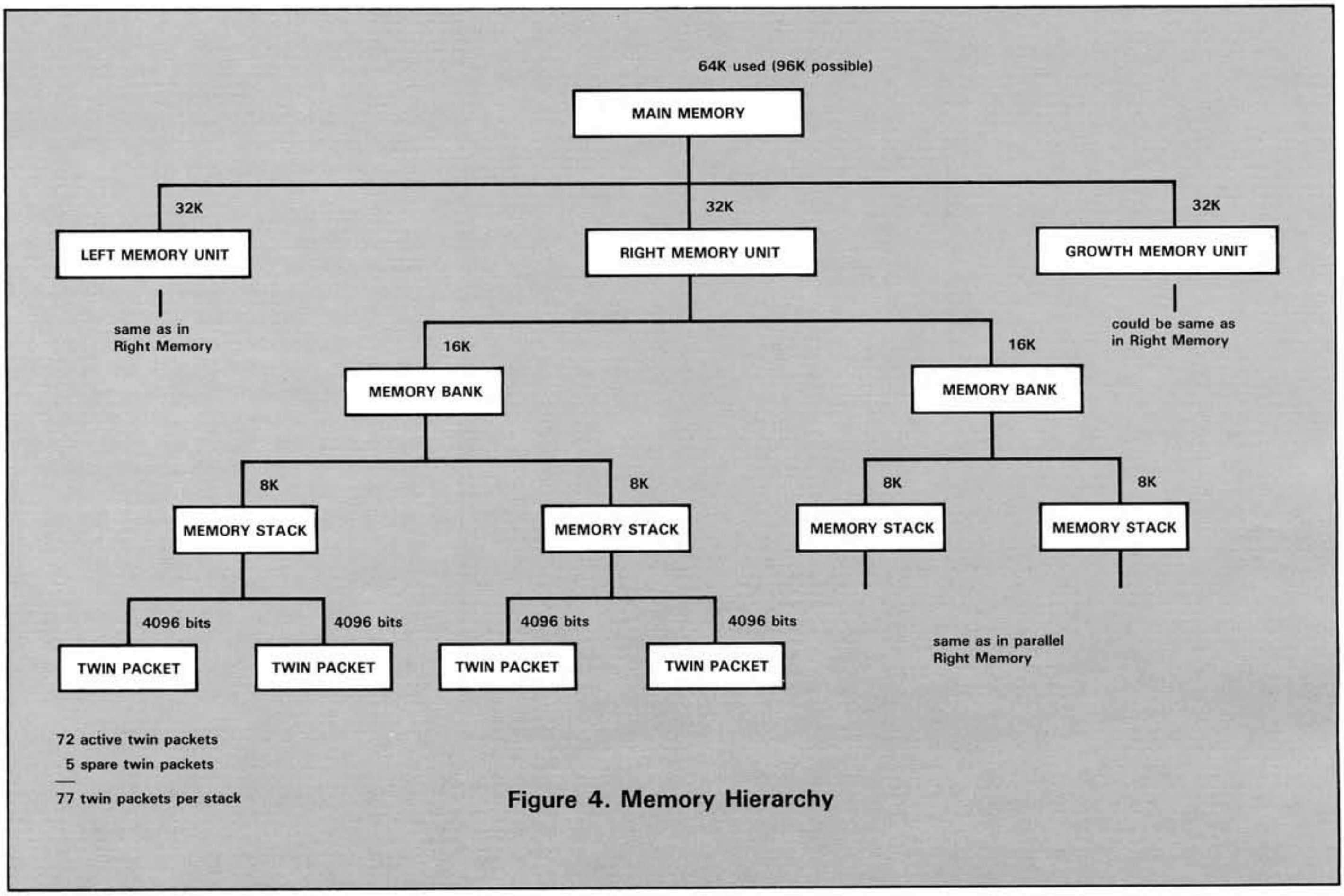


Figure 4. Memory Hierarchy

operations, reducing the available memory space to 65,536 words. Each unit has an independent operational capability since each has its own addressing and drive circuitry.

Each "memory unit" has two "memory banks" of 16K X 36-bit words. Access can only be gained to one "bank" of a "unit" at a time. The address received from the requesting user is interpreted by the memory unit's addressing circuitry, which directly accesses the appropriate memory location.

Each "memory bank" consists of two "memory stacks". The features of the "memory stacks" are:

a. they can be used to store 2,048 X 144-bit words or 8,192 X 36-bit words;

b. they utilize deposited magnetic film on silicon-glass substrates for storage elements. Thus, all reads are destructive and the data read must be replaced into memory; and

c. each "memory stack" consists of 77 "twin packets" of 4,096 bits per twin. Only 72 of the "twin packets" are required for the 8K X 36-word storage capacity. The five redundant "twin packets" are available as installed sparing.

The memory read-write cycle time is 750 nsec which can be effectively reduced to 375 nsec. The current operand and the next instruction can be retrieved in parallel from different memory banks. A graphical hierarchical description of the components of the AN/AYK-502(V) memory is presented in Figure 4.

Main Memory Bus Architecture

The AN/AYK-502(V) computer is built with small-scale and medium-scale integrated circuits mounted on six-inch-square circuit cards. Each processor accommodates one hundred of these cards which are interconnected by a wire-wrapped back plane. This back plane forms an internal bus which links the individual elements of the CPU, IOC, IOI and memory. These wire bundles constitute the internal busses of the computer. Each memory unit is accessible for storage and addressing via six serial ports or channels:

Channel	*Bus Name*
0	Left INPUT-OUTPUT CONTROLLER BUS
1	Right INPUT-OUTPUT CONTROLLER BUS
2	Left PROCESSOR OPERAND BUS
3	Right PROCESSOR OPERAND BUS
4	Left PROCESSOR INSTRUCTION BUS
5	Right PROCESSOR INSTRUCTION BUS

Thus, each "memory unit" has six access ports interfacing the memory's users to the two "memory banks". Each user has an assigned priority (channel 0 has highest and channel 5 has lowest priority), and each "memory bank" has a separate circuit to handle requests.

A "memory unit's" interface connections to the other components on the AN/AYK-502(V) system are presented in Figure 5.

Main Memory Bus Analysis

The AN/AYK-502(V) memory bus architecture was analyzed using Thurber's bus categorization techniques[1]. The results are summarized in Table 2.

Each main processor and each IOC can gain access to any of the "memory banks". The two processors each use two busses; one for instructions and one for operands. The two IOCs each use a dedicated, combined instruction/operand bus.

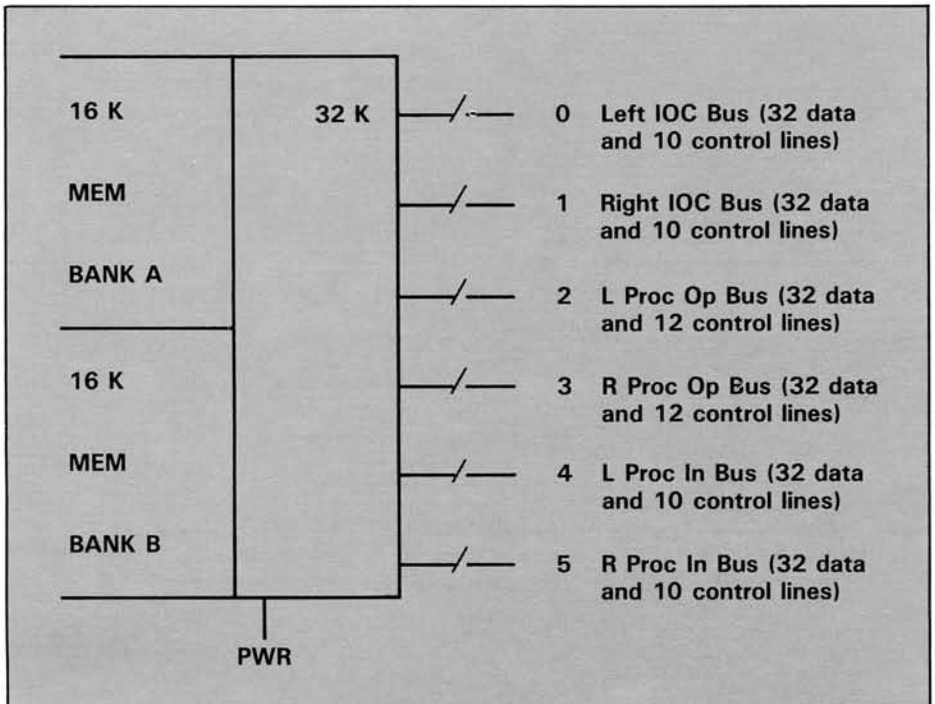


Figure 5. Memory Unit Interface

The memory is protected from unauthorized access by the processors. This memory protection prevents the main processors from gaining access to main memory outside assigned areas during read, indirect addressing or write operations. Within the Control Sections of the main processors, memory protection involves the eight task modes base (S) registers and their associated Storage Protection Registers (SPRs). This memory protection is implemented within the processors, not within the main memory.

General Input/Output Bus Architecture

I/O functions are controlled and executed by the Input/Output Controller and the Input/Output Interface. The IOC interprets the I/O commands from the processor, gains access to main memory for the specified I/O program, directs the logical execution of the I/O program instructions, furnishes I/O timing, and controls the IOI. The IOC requires only a single command from the processor to execute an I/O program since it has its own repertoire of 25 command codes, and can gain access to main memory.

The IOI provides interface between the IOC and the peripheral avionic subsystems for transfer of data and peripheral control words. Each IOI channel can perform four transfer functions: output data, input data, forced output (no peripheral request required), and external interrupt. Multiword buffers can be established for output data, input data and forced output. Data transfers are controlled by a request/acknowledge scheme, with control information coded into the word frame. The interface between the peripheral avionic subsystems and the IOI consists of type I, II and III serial channels. Type I and II channels transfer 32-bit words; type III, 288-bit words. The IOC handles data and instructions in parallel format. The IOI converts parallel information from the IOC or memory to serial format for transfer to the specified peripheral, and converts serial data from the peripherals to parallel format for transfer to the IOC or memory.

Data transfers from main memory to the IOC are carried out using Direct Memory Access (DMA). The data is transferred over the appropriate IOC/MEMORY bus, a 32-bit bidirectional bus which interfaces with the IOC memory address register and data interface register. The bus carries both data words and chain command instruction words to and from all memory banks.

The data transmissions over the serial channels occur at a nominal rate of six million bits per second, utilizing a biphase (Manchester) encoding scheme. The GPDC initiates all communication with the peripherals by sending a 4-bit control frame to which the peripheral responds by sending an appropriate response code. Depending on the type of response, this handshaking may then be followed by a single-word data transfer. A gap period follows each GPDC input or output. When a data transfer has terminated, this gap field is left open-ended. The rate at which the GPDC issues control codes is controlled by software and is generally a function of the peripheral's associated data transfer rate.

The 4-bit control frame transmitted by the GPDC consists of a control code followed by a GPDC self-test bit. The peripheral sends a response code only if the GPDC self-test bit is set (logical 1). The peripheral responds with its 3-bit response code after a gap time. If the response prohibits the sending of data, the GPDC will issue the control code again at a time T after the first transmission. When the control and response codes result in data transmission, the 36-bit data field follows a gap period.

Summary

The Aurora combat system computer architecture has been presented in terms which, we hope, will be of interest to combat system engineers:

a. hardware components and peripherals;

b. computer system architecture:
   (1) processor architecture,
   (2) memory architecture, and
   (3) bus and input/output architecture;

c. systems and application software.

The naval combat systems engineer can now make an engineering comparison between this air force system architecture and those of various naval combat systems. The areas where comparisons are worthwhile are performance and survivability.

We can learn from each other's systems.

Lieutenant Commander William Dziadyk joined the RCN in 1967 as an ROTP cadet. He received his BSc (Physics) from the University of Victoria in 1971 and his MSc (Computer Systems) from the Royal Military College, Kingston in 1984. LCdr Dziadyk's current posting is within the software section of the CPF Project. This is his second article to appear in the Journal. *His first, "SHINPADS Data-Base Performance Considerations", appeared in our January 1985 issue.*

Lieutenant Colonel Brian Nix joined the RCAF as an ROTP cadet in 1965. He received his B Eng (Engineering and Management) and his M Eng (Computer Engineering) from RMC in 1970 and 1984 respectively. He has served in numerous positions as an Aerospace

<table>
<tr><th>THURBER CATEGORY</th><th>AN/AYK-502(V) MEMORY BUS IMPLEMENTATION</th><th>COMMENTS</th></tr>
<tr><td>Type and Number</td><td>The busses are heavily "dedicated" by function and device. The physical and functional dedications on the SIX busses are:
<table>
<tr><th>BUS NAME</th><th>PHYSICAL DEDICATION</th><th>FUNCTIONAL DEDICATION</th></tr>
<tr><td>LFT P OPND</td><td>Left Proc to the pair of memories</td><td>Operands</td></tr>
<tr><td>RGT P OPND</td><td>Right Proc to the pair of memories</td><td>Operands</td></tr>
<tr><td>LFT P INST</td><td>Left Proc to the pair of memories</td><td>Instructions</td></tr>
<tr><td>RGT P INST</td><td>Right Proc to the pair of memories</td><td>Instructions</td></tr>
<tr><td>LFT IOC</td><td>Left IOC to the pair of memories</td><td>NIL</td></tr>
<tr><td>RGT IOC</td><td>Right IOC to the pair of memories</td><td>NIL</td></tr>
</table></td><td>The heavy dedication avoids many bus contention conflicts and permits interleaving the memory bank accesses (which reduces the effective access times). (It is important to note that on each bus the data and control signals are transmitted on different, dedicated parallel bundles of lines. Thus, on each bus, there is no contention between the control and the data functions.)</td></tr>
<tr><td>Bus Arbitration Technique</td><td>The bus-control technique for each of the six busses is "decentralized". The two memories share the control by arbitrating the "independent requests" of the processors and IOCs. (Each device has separate control lines.)</td><td>All BANK REQUESTS are presented simultaneously to the two memories. Thus the overhead times for allocating the bus would be shorter than for daisy chains or polling.</td></tr>
<tr><td>Bus Communication</td><td>The bus communication technique uses an ASYNCHRONOUS REQUEST/ ACKNOWLEDGE scheme. The precise timing relationships between the data and the request/acknowledge control signals are not yet fully known. However, it is possible to determine that these signals are functionally "fully interlocked" during the protocol.</td><td>The system operates in a noisy environment, so it was expected that the control signals would be either half or fully interlocked.</td></tr>
<tr><td>Data Transfer</td><td>The bus transfers are made using 32-data-bit "single words".</td><td>The overhead (acquisition, propagation, access, priority resolution, etc.) is significant for each word transferred.</td></tr>
<tr><td>Bus Width</td><td>The bus widths are:
<table>
<tr><th>BUS NAME</th><th>DATA WIDTH</th><th>CONTROL WIDTH</th><th>TOTAL WIDTH</th></tr>
<tr><td>Left Proc Opnd</td><td>32</td><td>12</td><td>44</td></tr>
<tr><td>Right Proc Opnd</td><td>32</td><td>12</td><td>44</td></tr>
<tr><td>Left Proc Inst</td><td>32</td><td>12</td><td>44</td></tr>
<tr><td>Right Proc Inst</td><td>32</td><td>12</td><td>44</td></tr>
<tr><td>Left IOC</td><td>32</td><td>10</td><td>42</td></tr>
<tr><td>Right IOC</td><td>32</td><td>10</td><td>42</td></tr>
</table></td><td>The busses are relatively wide, which is cost-effective over the short distances involved. These parallel busses would be much faster than one with the control lines combined in a serial fashion. However, the parallel control lines may result in some additional noise problems.

There is no parallel/serial conversion between devices, and no multilevel conversion. There is line combination based on direction but not function.</td></tr>
</table>

Table 2 Bus Analysis

Engineering Officer, including Air Vehicle Software Engineering Officer at the Aurora Software Development Unit. Currently, he is the Project Manager, Electronic Support and Training, for the Challenger Project.

Major James Mackenzie joined the RCAF in 1968 as an ROTP cadet. He graduated from RMC in 1973 with a B Eng (Electrical), and later returned to obtain his M Eng (Computer) degree in 1985. Major MacKenzie has served as an Aerospace Engineering Officer at several headquarters units and field units, including the Aurora Software Development Unit at CFB Greenwood. He presently holds the position of Avionic Projects Officer at the Aerospace Maintenance Development Unit, CFB Trenton.

References

1. K.J. Thurber et al., "A Systematic Approach to the Design of Digital Bussing Structures" (AFIPS Conference Proceedings, vol. 41, pp. 719-740, 1972).

2. C-12-140-0G5/MD-000 Data Processing System Aurora, 2 September, 1980.

3. ES 423708 AN/AYK-10 Display System Specification.

4. ES 423819D AN/AYK-10 Digital Computer Specification.

5. ES 423126D AN/AYK-10 Serial Interface Specification.

6. 11500-LRP-520 (ASDU) 25 November, 1982, GPDC Enhancement Study.

7. PX-5852-1-2 AN/AYK Study Guide Functional Description (Univac DSD Education, St. Paul).

8. AN/AYK-10 Instructors Guide.

Artificial Intelligence

by LCdr(R) Paul Senechal, c 1986

A Brief History

Artificial Intelligence (AI) has been in existence in research labs for the last 30 years. In the early fifties a small group of academicians was struggling with the problem of how to make computers solve problems more effectively. It was believed that within a quarter century computers would do most of the work, while humans would spend most of their time with leisure activities.

AI research remained an academic exercise for over 20 years, funded mainly by the Defense Advanced Research Projects Agency in the U.S. Over that time it became increasingly obvious that the visionary capabilities of computers were certainly not within easy reach. Not only were the problems more complex than anticipated, but the computer technology available was inadequate for AI technology to be practical for commercial use.

Scientists in the mid-fifties and early sixties had a notion that intelligent behaviour could be readily formalized. It was believed that "common sense" problems were simple enough to model on computers as opposed to inherently difficult problems such as medical diagnosis. Only after a few failures did it become apparent that human reasoning and problem solving were significantly more complex than had been originally envisioned. A rather popular example of this naivete was the translation into Russian, and back again into English, of the phrase "The spirit is willing but the flesh is weak". Translated back to English it became "The vodka is good but the meat is rotten". Nevertheless, the failures of the fifties and sixties laid the founda-

What is AI?

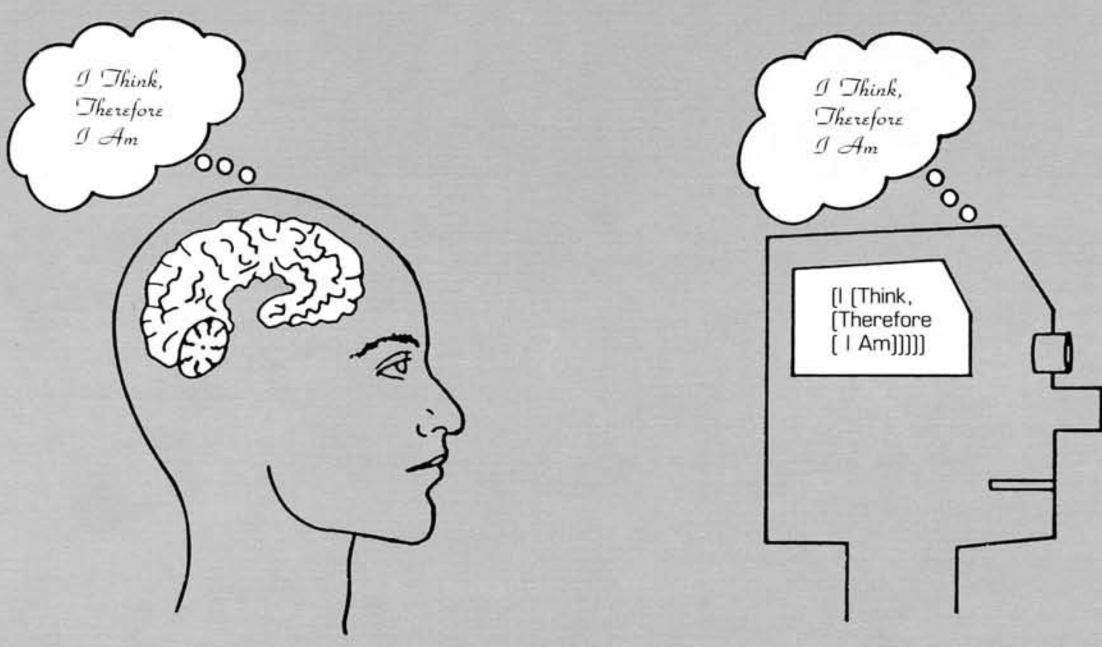
Artificial Intelligence is both a branch of computer science and a technology, becoming increasingly suitable for real-world applications. This technology, embodying concepts in computer science, cognitive science and linguistics, enables more effective use of computers to a broad range of activities heretofore considered impractical.

The following are a few examples of what some other people understand Artificial Intelligence to be:

Artificial Intelligence is the science of making machines do things that would require intelligence if done by men. (Marvin Minsky, MIT AI Labs)

Artificial Intelligence is the study of how to make computers more useful and to understand the principles that make intelligence possible. (Pat Winston, MIT AI Labs)

Artificial Intelligence research is that part of computer science that investigates symbolic, nonalgorithmic reasoning processes and the representation of symbolic knowledge for use in machine intelligence. (Bruce G. Buchanan and Edward A. Feigenbaum, Stanford University)



tions for future theories of machine intelligence.

The AI researchers of the seventies finally realized that perhaps the difficult problems (such as medical diagnosis) were more amenable to AI techniques than had been previously acknowledged. New methods of knowledge representation and search techniques began to appear in research papers. The approach was one of cautious, but sustained exuberance. AI researchers teamed up with other disciplines such as medicine, chemistry, and electronics to focus on specific problems. Various academic institutions worked on systems which included the capacity to solve problems within a narrow domain of knowledge. This approach was very successful and led to the future development of expert systems that imitated human reasoning capabilities.

In the eighties AI blossomed into a credible technology referred to as the "Fifth Generation". The concept of a Fifth Generation was revealed to the world in 1982 by the Japanese when they announced an ambitious 10-year plan aimed at developing a computer technology which would incorporate many human-like reasoning and functioning characteristics, as well as manage a great deal of information quite easily. Some countries responded to the Japanese challenge by announcing similar plans. Industry world-wide took notice of this evolutionary technology and is now trying to understand how to best apply it.

The Fifth Generation approach to computing will have a tremendous impact on our society, even greater than that of the personal computer revolution. Fifth Generation computing is becoming a reality of advancement in AI technology, the development of better computer tools, and advancements in both computer architectures and microelectronics (Very Large Scale Integration).

Characteristics of AI

AI can be viewed from three perspectives: research, knowledge engineering (tools) and applications.

Research

There are two views of AI from the research community — pure research and applied research. Pure research implies those activities related directly to computer science which endeavor to understand how to imitate human reasoning. This aspect of computer science is related to cognitive science, linguistics and neuroscience.

Applied research includes aspects of more traditional computer science (data structures, search paradigms, etc.) as well as the applicability of this research to solve very real, everyday problems. AI differs from conventional approaches of computer science in that this evolutionary technology incorporates concepts that diverge from the Von Neumann concepts of computer science.

Application of the results of AI research will, in the long run, be the determining factor for the success of the Fifth Generation. But there are many hurdles yet to be overcome. This technology is still, in many respects, in its infancy, having tremendous potential to change the very social fabric of the world.

Knowledge Engineering

Knowledge engineering is one of the most significant contributions to Fifth Generation computing. Knowledge engineering is a combination of tools, languages and techniques used to develop applications which incorporate the use of "knowledge". Knowledge engineers are those individuals who are capable of applying the tools and techniques of AI technology to specific problems. These individuals effectively perform the knowledge acquisition process. It is the knowledge engineer who scrutinizes the available AI tools to be able to implement a successful system.

AI Techniques

Part of the knowledge engineering function is the utilization of specific AI techniques. The three most important of these are: knowledge acquisition, knowledge representation and heuristic problem-solving paradigms. These techniques provide applications which can exhibit some intelligent characteristics such as simple inference and knowledge inheritance.

Knowledge Acquisition

Knowledge acquisition is the process of extracting information or knowledge from domain experts to be used by the expert system. Today, this area is still a topic of hot debate and research. There is no easy mechanism whereby knowledge can be extracted from the domain expert by the expert system. Today, a knowledge engineer provides the required knowledge to the expert system.

Knowledge Representation

Knowledge representation is a formal set of data structures which represents the relationships, procedures and descriptions of knowledge for a specific domain. It is similar in concept to that of specific data structures within the context of a traditional data base system. The actual knowledge represented is called the "knowledge base". Some of the more well known knowledge representation schemes include concepts such as production rules, frames and semantic nets. Each of these types of representations have characteristics which make them better for one type of knowledge or another. Production rules are the most widely used for commercial application today.

Heuristic Problem Solving

Heuristic problem solving is the application of "rules of thumb" or human reasoning mechanisms to unstructured, nonalgorithmic, nondeterministic and ill-defined problems. Chess is an example where the algorithmic approach is not practical because of the long search times involved in finding the optimal solution. (There are more chess moves to finish a chess game than atoms in the known universe.)

The role of heuristics in AI programming is to cut down on the time and memory requirements for search. A set of "rules of thumb", or "productions", guide the search-control mechanisms, altering the strategy if necessary, to arrive at a successful conclusion. Heuristic techniques are not foolproof; master chess players do lose a few games now and then. Expert systems do not necessarily generate the *best* solution, only a *good* solution; and due to the nature of the knowledge, occasionally a wrong solution.

An "inference" engine is the control structure of an expert system, separate from the knowledge. The task of the inference engine is to select the rules and mechanism to make deductions regarding the knowledge in the knowledge base. This contrasts with traditional programming techniques in which the programmer selects how the program is to execute at the time the program is written. Knowledge engineers are concerned with the relationship of the knowledge base as opposed to how that knowledge is deduced by the inference engine.

AI Tools

Since AI development is evolutionary, the tools required include interactive environments with built-in aids such as dynamic memory allocation, integrated debugging facilities, high-level symbolic processing languages, as well as many other programming aids essential to success.

Typically, languages such as LISP or Prolog have included an entire development environment around them. They have evolved as entire systems on their own, both as stand-alone dedicated AI workstations with sophisticated support hardware, and as a layered subsystem on general-purpose time-sharing systems. These tools are generally referred to as first-generation AI tools. Second-generation AI tools have now made their way to the marketplace. These represent an improvement in the built-in capabilities such as AI problem-solving methodologies and knowledge representation.

Commercial viability of this new-found technology is very much dependent on the availability, cost and reliability of those tools used to implement AI systems.

LISP

LISP (i.e. List Processor) is the most widely used AI language in North America. Considered to be the second-oldest programming language still in use today — it was invented by John McCarthy at MIT in the late 1950s — it is generally referred to as a symbolic processing language. After 20 years of use a standard called COMMON LISP has emerged. This standardization was developed in cooperation between educational institutions and industry. Now that a standard is recognized, the commercial implementation is possible.

Many other dialects of LISP have been developed over the years, the most notable being derivatives of COMMON LISP. They include MACLISP from MIT, ZETALISP (enhanced MACLISP) from SYMBOLICS, INTERLISP from XEROX and BBN, and PSL from the University of Utah.

PROLOG

Prolog is another AI language which gained its notoriety as a result of the Japanese commitment to it. Prolog (or, PROgramming in LOGic) is a logic-oriented language based on predicate calculus with very-high-level built-in features. It was invented in 1973 by A. Colmerauer and P. Roussel from the University of Marseilles based on earlier work which began at the University of Montreal before being moved to France.

OPS5

OPS5 was created by Dr. Charles Forgy of Carnegie Mellon University in the late '70s for the development of expert systems. It is a "rule-based" language, having three basic features: a rule memory where rules are defined; a working memory where facts about the world are defined and changed; and an inference engine, a mechanism to control the activity between working memory and rule memory. The execution of "rules" is dependent on the state of working memory (data dependent) as opposed to the order of the rules.

Object-Oriented Languages

Object-oriented languages are a class of programming tools that make use of "objects" rather than procedures to accomplish a task. Knowledge of what to do is inherently defined by the objects. For example, one can define graphic animation as a series of objects that communicate with each other to give the visual impression of continuous movement on the screen. Each specific object on the screen has procedures attached to do specific things such as move, rotate, turn color on/off, etc.

Object-oriented programming has been shown to be useful in graphics, animation, office applications, simulation and modeling.

Application Areas

The key application areas of AI can be grouped into the following categories:

- Robotics, including vision and manipulation systems
- Natural Languages (NL) processing
- Speech Recognition and Synthesis
- Expert Systems

These areas represent the types of problems where AI technology has been successful. The following is a summary description of the specific AI subdisciplines.

Robotics

Conceptually, robots are fairly simple to understand. The robots depicted in many of today's science fiction movies are a far cry from the capabilities of real robots available commercially or in research labs. Real robots in current use are simple machines with very limited capabilities in sensor recognition, sensor understanding and manipulator control. Developmental efforts in the lab are focused on imbuing the ability to solve problems in 3-D space.

Today's simple robots are pre-programmed to perform repetitive tasks, and have no awareness or knowledge of anything around them. These machines are used primarily for simple, predictable functions such as work on a production line, hazardous work in environments like nuclear power plants and other work that humans cannot perform because of inaccessible location.

Continued research in areas of vision systems, sensor systems and manipulation systems will make robots more versatile and useful to perform more complex tasks which we, as humans, would consider mundane. Perhaps within the next decade robots will be capable of doing those tasks envisioned in the early '50s, such as housework.

Natural Languages

This subfield of AI seeks to accomplish text and speech understanding by computers. The term "Natural Language" is considered a generic reference to the ability of computers to communicate in our native languages. Humans, unlike machines, have the capacity to recognize syntactic and semantic errors and still comprehend the intended meaning of the communication. We take communication for granted, understanding the idiosyncrasy, ambiguity and complexity of our native language. Computers, on the other hand, have a rather limited capacity to deal with these types of communications. The goal of natural language systems is to make the task of human communication with machines a lot simpler.

The problems with developing computer systems which can understand natural language are numerous. Humans can easily deal with language ambiguities. Take, for example, the phrase "I saw the Statue of Liberty flying over New York". To us this statement is quite normal and readily understood. A computer, however, not knowing that statues cannot fly, may interpret this quite differently. The same holds for metaphors like "Maria Garcia is a pillar of the community". A computer system would certainly need explicit instruction about the metaphor in order to properly interpret the meaning of the phrase.

While natural language understanding is not a mature discipline, there have been many successful attempts at developing applications which make use of some form of natural language processing. The most successful commercial natural language product is Intellect — a natural language front end for computer-based data base systems.

Natural language systems have a variety of practical uses such as machine translation (translate from one language to another), document understanding systems (enable computers to understand and summarize the points of interest) and native language "like" interfaces to data bases, operating systems, decision-support systems, robotics, etc.

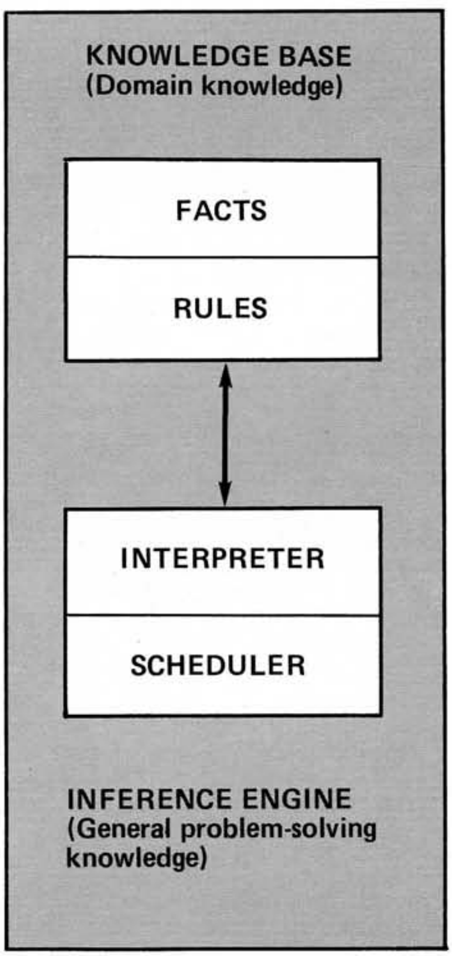
Natural language systems could potentially be of great benefit in many applications which require that untrained people use information systems and expert systems to their full capabilities.

Speech Recognition and Synthesis

Speech recognition and synthesis is primarily concerned with machines having the ability to recognize and generate continuous speech. This activity is an extension of the field of signal processing. Speech recognition differs from language understanding in that a computer must first recognize a particular sound as speech before it can even attempt to understand what was said. The ability of humans to recognize that someone is speaking in a foreign language, even though they might not understand what is being said, is an illustration of speech recognition.

Speech recognition is not a well-developed technology. There are many obstacles to be overcome before it is possible to have machines recognize continuous speech. Humans are rather good at discriminating speech from a series of unintelligible sounds, but it is not yet understood exactly how this is accomplished. For example, humans can recognize their name in the midst of a busy intersection in a large city. Hearing the correct sound not only implies the listener knows where the sounds originated from, but can discriminate sounds based on language understanding capabilities. Humans depend on several discrimination cues simultaneously in order to recognize what does, and does not, make sense. For example, "I scream, you scream, we all scream for ice cream" demonstrates the complexity of the human sound discrimination systems, something computers are not capable of doing.

EXPERT SYSTEM



Anatomy of an Expert System

Voice synthesis systems provide the ability to generate voice from textual information sources. Examples of useful applications include telephone answering systems and text-to-voice conversion (for the blind). Several voice synthesis products are available commercially at relatively low cost; for example, some personal computer vendors offer voice synthesis options for home use.

The ability of computers to recognize and generate continuous speech would be beneficial to a number of people. It would be possible to have automated offices with voice-activated typewriters and dictating machines, automated telephone answering services, voice-activated machines to perform designated tasks, as well as applications in education, industry and government. Today, speech recognition is still very much a research topic with limited commercial availability, but the application of the underlying technologies for continuous speech recognition/synthesis to other forms of signal processing is immense.

Expert Systems

Most people readily understand when someone is considered an "expert". Most experts solve problems (within such diverse domains as medical diagnosis, tax consulting, oil-drilling engineering, financial advice and machine repair). Typically, an expert is capable of applying experience and knowledge (expertise) to the solution of specific problems in an efficient and reasonably correct manner. The expert is able to reason and make inference from incomplete or uncertain knowledge, and explain and justify the reasoning. The expert is quite capable of learning new knowledge from the environment, as well as from other experts, to perhaps change an approach in solving a particular problem. The expert also knows when to break rules, when to consider information/knowledge not relevant to the problem and when the problem is outside the domain.

Expert systems are a set of AI software methodologies that apply some of the characteristics of human experts to solving problems of a specific nature. The robustness of an expert system is usually related to the amount of knowledge that can be provided to it. Despite the fact that no general-purpose reasoning formalism has yet been found, some simple inference methods have been developed which can demonstrate impressive results when applied to an adequate base of knowledge.

Expert systems differ from traditional data processing systems in many ways. Traditional systems require exact information, use numeric computation with well-understood algorithms, and, when complete, produce correct answers. Expert systems, instead, use incorrect or ill-defined information, manipulate information by symbolic reasoning methods without a specific algorithm, and produce information which is a satisfactory and useful approximation. As with human experts, the more complete the knowledge about the problem domain the better the solution will be. Expert systems, like humans, can also explain the reasoning mechanisms used to solve problems.

Most expert systems do not come ready to buy off-the-shelf because it is the knowledge extracted from domain experts by a knowledge engineer that makes up the "expert system". The knowledge engineer usually uses an expert system building tool to create an expert system tailored specifically to an organization's requirements. This is not a trivial process. The most significant problems with developing expert systems are: the lack of knowledge engineers; the difficulties in locating domain experts; and the obstacles necessary to overcome knowledge acquisition in general.

The applications most amenable to expert system concepts have the following characteristics:

- The solution to the problem has a high pay-off for the organization.
- The problem cannot be solved using traditional programming techniques.
- There is an available domain expert who is willing to participate.
- The problem definition is ill-defined.
- The problem may have many solutions, not one of them being necessarily best.
- The nature of the problem is such that there is continuous change to the knowledge about the problem domain (for example, new knowledge about a specific medical problem is continuously updated and changed).

Problems that can take advantage of expert system technology include: diagnostic problems like those in the medical and machine-repair fields; consultative problems like those in financial management; monitoring and management like those in resource planning and scheduling; configuration problems such as automatic computer configurators; military problems like those in battle management; and design assistance problems like those in VLSI design.

Expert systems are not a panacea for all problems, but are certainly an evolutionary step in solving many unique problems. There are limitations, but the overall benefits are proving to be worthwhile. For example, the most notable success being at Digital Equipment Corporation which uses expert systems (XCON) to configure VAX and PDP-11 computers, resulting in savings of millions of dollars.

Dr. Senechal, until recently, was Senior Engineering Manager with Digital Equipment Corporation's Research and Architecture group in Hudson, Mass. where he was responsible for advanced systems research. He is now Vice President, Engineering of Accugraph Corporation, responsible for developing intelligent CAD/CAE/CAM worksystems. A registered professional engineer in the Province of Ontario and Commonwealth of Massachusetts, and member of the IEEE and ACM, his technical interests include systems architecture, workstations, real-time computing and fault tolerant computing. As a naval reserve officer LCdr Senechal has been involved in a number of technical assignments principally related to combat systems. He currently resides in Ottawa.

References

1. Abramson, R., A. Beane and R. Alexander. *Artificial Intelligence Reference Manual*, Digital Equipment Corporation.

2. Charniak, E. and D. McDermott. *Introduction to Artificial Intelligence*, Addison Wesley.

3. Evans Research Corporation. *EDP In-Depth Reports: Artificial Intelligence*, Vol. 14 No 1. January 1985.

4. Feigenbaum, E.A. and P. McCorduck. *The Fifth Generation: AI and Japan's Computer Challenge to the World*, Signet.

5. Hayes-Roth F., D.A. Waterman and D.B. Lenat. *Building Expert Systems*, Addision Wesley.

6. Manning, E., N. Cercone, R. Holt, J. Mylopoulos and J. Vaucher. *Towards a Canadian 5th Generation Research Plan*, Canadian Artificial Intelligence Newsletter, March 1985.

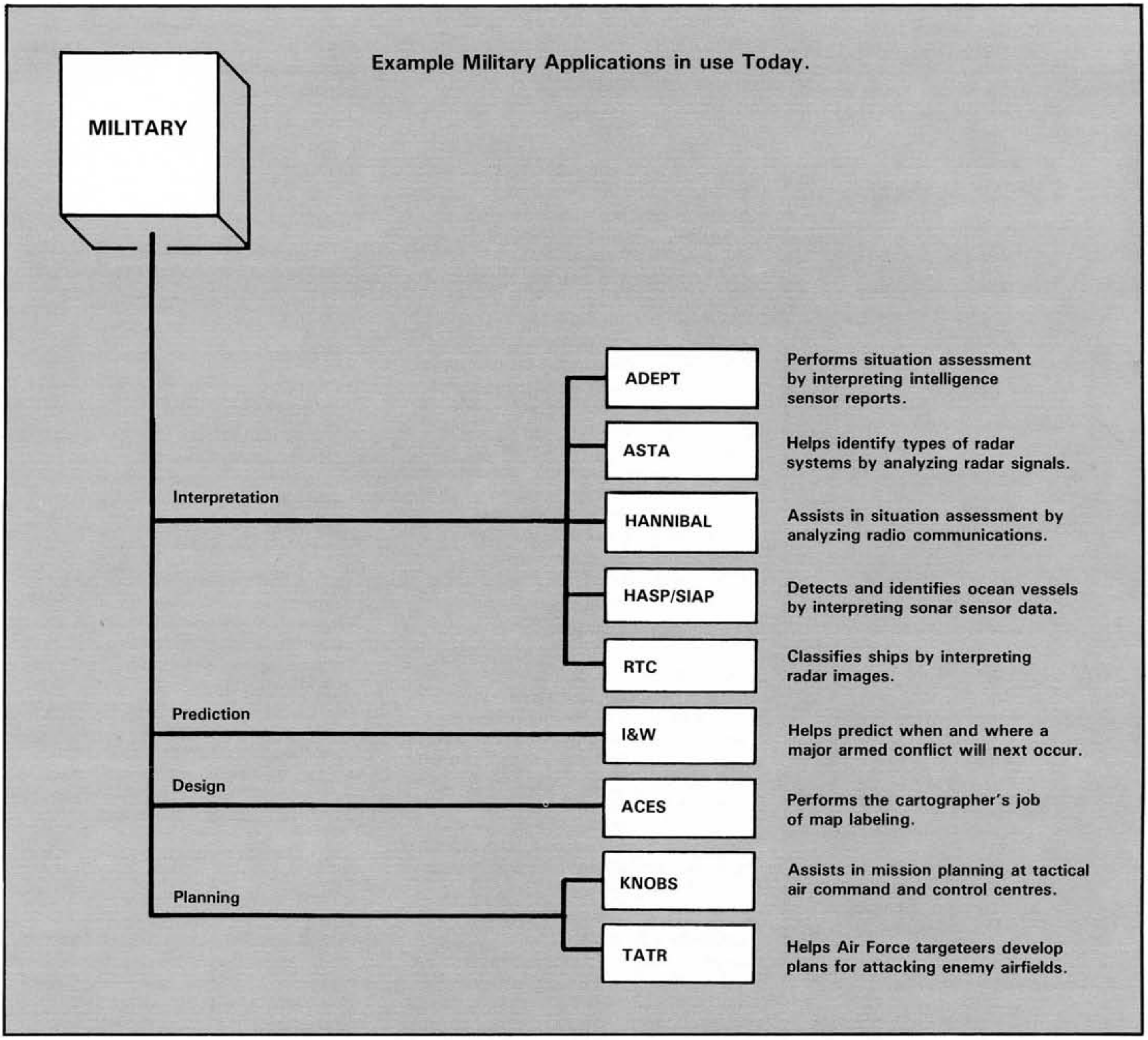
7. Michaelsen, R.H., D. Michie and A. Boulanger. *The Technology of Expert Systems*, Byte, April 1985.

8. Schank R. and L. Hunter. *The Quest to Understand Thinking*, Byte, April 1985.

9. Schlosberg J. *Almost Human*, Digital Review, May 1985.

10. Scown S.J. *Artificial Intelligence Experience: An Introduction*, Digital Equipment Corporation.

11. Winston P.H. *Artificial Intelligence*, 2nd Edition, Addison Wesley.



SCORE — An Alternative Generator Prime Mover

by L.T. Taylor

Background

The DDH-280 class-design decisions which led to the choice of gas-turbine prime movers for electrical power generation are not readily available; however, the following are some of the positive factors:

a. underwater noise — gas turbines create higher frequency noise for which it is easier to provide noise-isolation mountings;

b. small size and low weight — this eases installation of gas-turbine sets and also makes it easier to provide noise-isolation mountings; and

c. new technology — the aura of an "all-gas-turbine ship" with the arguments for gas-turbine propulsion carrying over to electrical power generation.

The major negative factor was the high fuel consumption; however, the addition of waste-heat boilers made the energy balance, fuel for both electrical power and steam, more competitive.

The expressed intent to remove the waste-heat boilers from the DDH-280s[1] will remove any energy effectiveness competitiveness that the original installation may have had. There will be a fuel consumption penalty which will appear as reduced endurance (range) for the ships.

Aim

The aim of this paper is to demonstrate that the stratified charge rotary engine as a prime mover for electrical power generation could reduce this fuel consumption penalty without paying the noise penalty of going to diesel alternators.

Discussion

Diesels are noisy by virtue of their intermittent combustion and the vibration of the components and interconnections involved in translating reciprocating motion to rotary motion. Gas turbines are continuous combustion, rotating machines and operate without the noisy elements of the diesel; the detonations of intermittent combustion, and the reversals and accelerations associated with changing reciprocating motion to rotary motion. The stratified charge rotary engine also produces power directly as rotary motion, but it uses an intermittent combustion process. Still, Mazda based a great deal of its advertising for the rotary (Wankel) engined cars on their quietness and absence of vibration. A comparison of the Wankel to a standard car engine would be directly analogous to a comparison between the stratified charge rotary and a diesel. The rotary should be superior to the diesel in terms of reduced noise and vibration, but not as good as the gas turbine.

The intermittent combustion aspect of the rotary is a double-edged sword: it does pay a noise penalty, but higher cycle temperatures are achievable. Thus the rotary can operate with maximum cycle temperatures similar to the Otto or diesel cycles which are well above Brayton cycle practical maximum cycle temperatures. This results in higher Carnot efficiencies, which in practice equates to better fuel economy.

None of this is meaningful unless there are practical engines in the power range which are suitable for shipboard use. The Mazda (Wankel) engine has too small a power output and is fuelled with gasoline making it unsuitable for shipboard use. Ingersol Rand markets a 500-b.h.p. single-rotor, and a 1000-b.h.p. twin-rotor industrial engine. The latter is in the correct power range, but they are both natural-gas fuelled and thus impractical for naval applications. The John Deere SCORE, or stratified charge *omni*-fuelled rotary engine (formerly the Curtiss-Wright SCRC), has multifuel capability; gasoline, diesel, JP4 or JP5.

There are two possible variants which would be of interest for a comparison with the Solar Saturn gas-turbine alternators in the DDH-280 class. The first is a four-rotor, naturally aspirated unit developed up to the production point for a class of United States Marine Corps landing craft. This engine, designated the SCRC 4-350 (Figure 1), was rated at 1500 b.h.p. at 3600 r.p.m. The other is a four-rotor turbocharged variant of the same rotating components designated SCORE 4231R. A USN-funded study uses a six-rotor, turbocharged SCORE driving a 1000 kW alternator, but the data available allows comparison with a 750 kW alternator driven by a SCORE 4231R.

Description of Operation

The John Deere patented stratified charge design is the technology which converts a gasoline-fuelled Wankel into an engine capable of burning a variety of fuels. A pilot injector located adjacent to the spark-plug injects a small amount of fuel to create a localized fuel-rich mixture to initiate combustion. This pilot flame then ignites fuel from the main injector at a lean fuel-air mixture (Figure 2)[2]. The action of the rotor sweeps the air charge past the main injector into the pilot flame creating a natural layered (stratified) charge. Turbocharging enables leaner fuel-air ratios and better efficiency.

The rotary engine has simplicity as a major design feature. The SCORE uses rotors with three combustion faces. The faces are equivalent to pistons in a reciprocating engine, but produce rotary motion directly. Figure 3 demonstrates the cycle[2].

1. The operation begins when the apex seal uncovers the intake port and unthrottled air from the turbocharger enters the combustion chamber.

2. Air continues to enter the chamber until the trailing apex seal closes the port. Air is compressed as the rotor continues its rotation.

3. As the air is compressed to its minimum volume the pilot-fuel charge is ignited.

4. Combustion is stratified. This is controlled by the main injector and air motion resulting from a specially designed rotor pocket. The power stroke is completed when the exhaust port is uncovered.

5. High-temperature gases then exit through the exhaust port. The

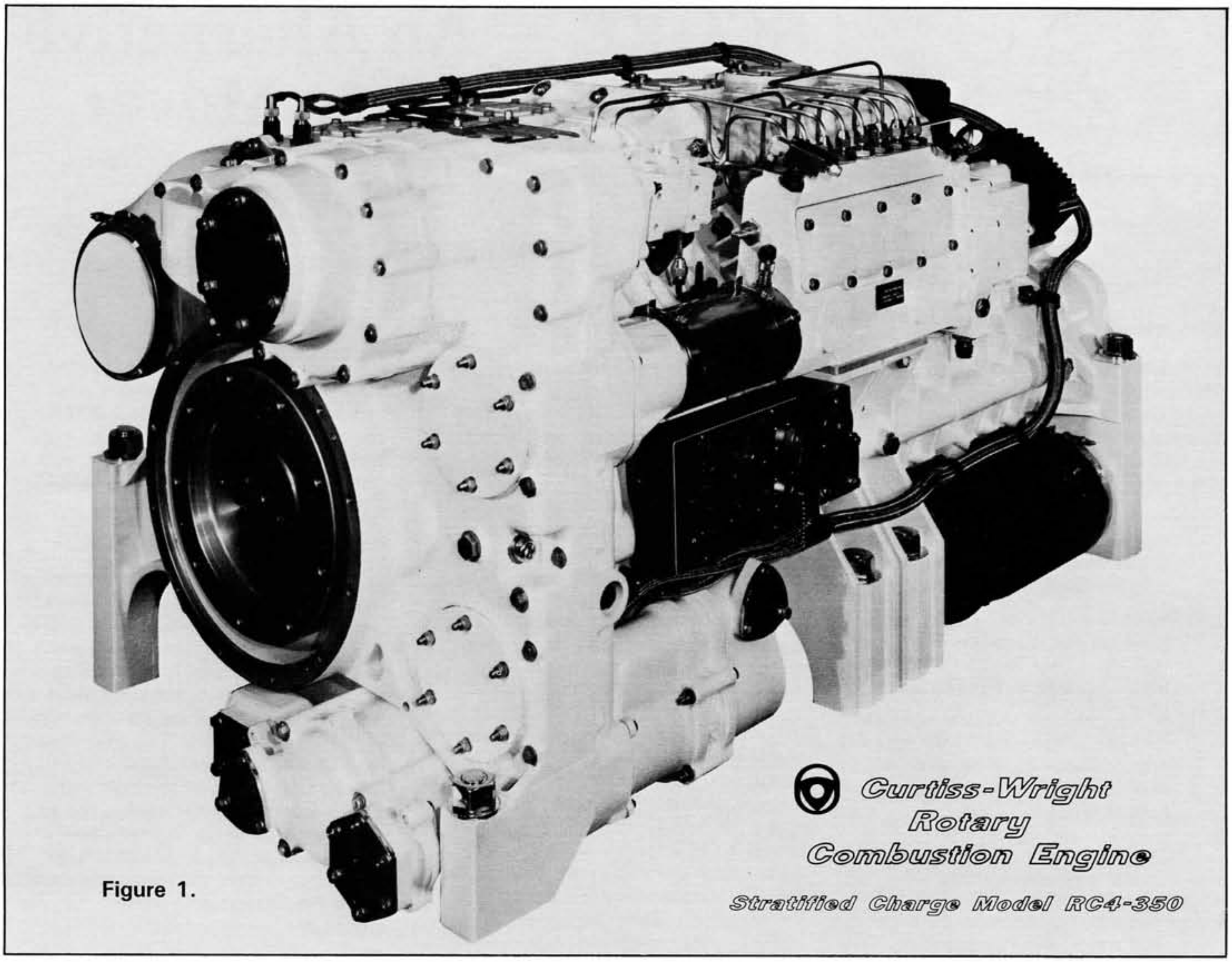


Figure 1.

exhaust turns the turbocharger turbine which in turn powers the turbocharger compressor.

Comparison

Size and Weight

Table 1 gives the principal dimensions and weight of the four prime movers being compared. The GM-149 series diesel engine is used in naval electrical power generation applications in this power range and will serve as a comparison. It is obvious from the table that the gas turbine does not have the size and weight advantage over the SCORE/SCRC that it has over the diesel. The rotary engine could require a gearbox (the gearbox is included in the length of the Solar) to optimize the speed for the power required rather than running at 1800 r.p.m with a four-pole alternator, or 3600 r.p.m with a two-pole alternator. This would increase both the length and weight of the SCRC/SCORE. These size and weight figures deal with the bare engine and do not include inlet ducting, exhaust ducting or off-engine auxiliaries such as pumps (cooling water, fuel) and heat-exchangers. The significant items among these are the inlet and exhaust ducting for the gas turbine which are very much larger than those required for the SCORE or diesel.

The weight of the unit becomes important when noise-isolation-mount systems are used[3]. The engine is mounted to a sub-base which is in turn mounted to the hull. The mass of the sub-base is important to the design of the mounting system, and the higher it is compared with the engine the better the design is for noise isolation. With the low weight of the SCORE compared to the diesel, a better noise-isolation design is possible for the SCORE at significantly less weight. The SCORE installation would probably be heavier than a Solar to achieve equal underwater noise signatures based on the SCORE being assumed to be noisier than the Solar.

Fuel Consumption

The SCRC specific fuel consumption (sfc) curve (Figure 4) is based on the

Engine	Length	Width	Height	Weight
Solar	80″	30″	27″	1,400 lbs
SCRC 4-350	61″	30″	29.5″	1,860 lbs
SCORE 4231R	61″	39″	30″	2,250 lbs
GM-149	101″	63.5″	70″	14,000 lbs

TABLE 1 Size and Weight

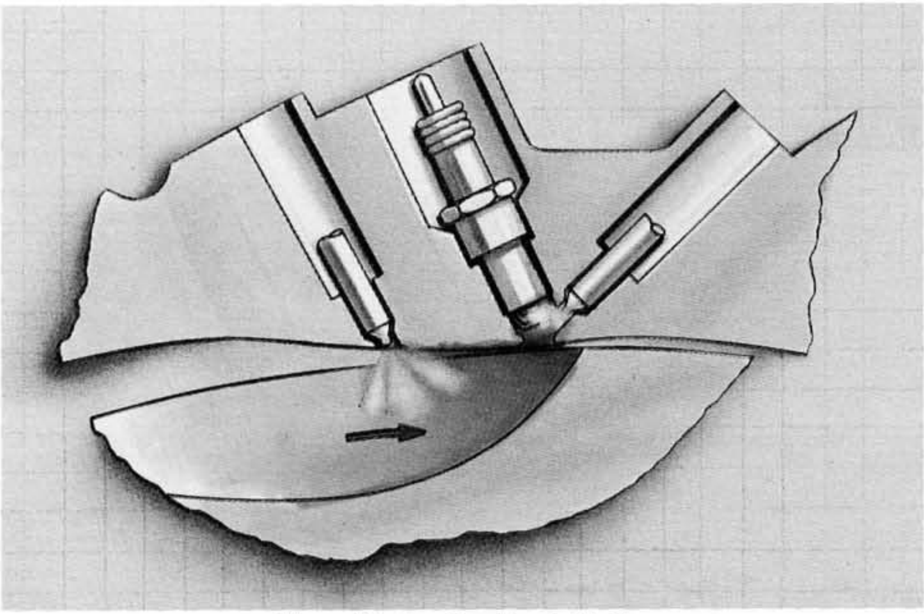


Figure 2. Combustion Initiation

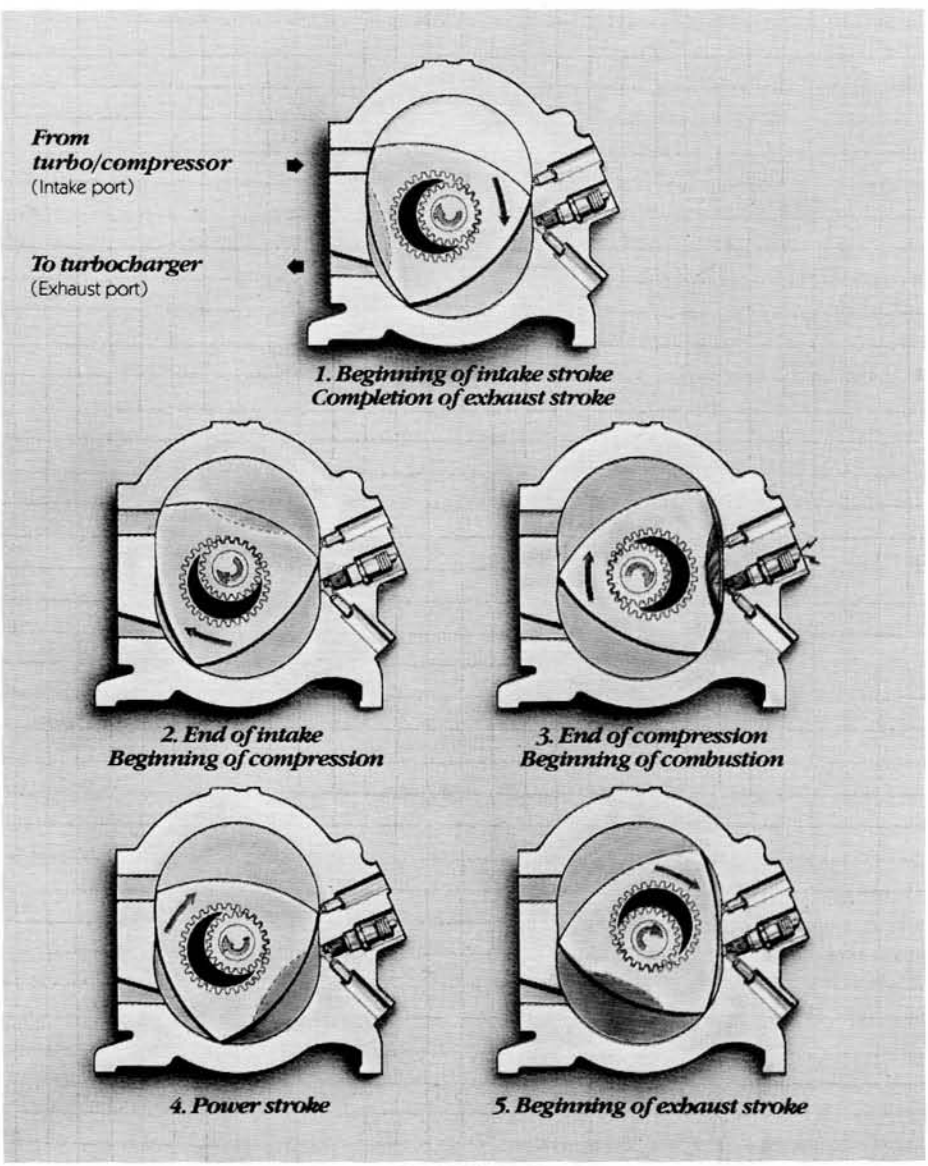


Figure 3. SCORE Cycle

RC1-350 naturally aspirated engine at 3600 r.p.m. The advantage of the diesel is immediately obvious, but the SCRC fairs much better in comparison than does the gas turbine. Table 2 compares the sfc of the SCRC and Solar to the diesel sfc, and the sfc of the Solar to the SCRC sfc for various loads. There is very little to choose between the SCORE 4231R and diesel with respect to sfc throughout this range. Although this comparison highlights the economy advantage of the diesel over the gas turbine and naturally aspirated rotary engines, there are also significant savings available utilizing the SCRC instead of the Solar. For example, 1000 kW of load (66% power level on each of two 750 kW alternators) would give a 2.8 ton/day fuel saving (i.e. 21 barrels/day or 3.3. cubic metres/day) once the waste-heat boilers are removed from the Solar gas-turbine alternator installations.

Maintenance

The existing Solar gas turbines utilize first-line maintenance only for accessory replacement and inspections. Beyond this, repair-by-replacement is the maintenance concept with contractor overhaul. The DDH-280 would require extensive modification to establish a removal route suitable for repair-by-replacement of a diesel using the GM-149 series for size. The SCRC would fit through a standard hatch provided it could be lifted on end. Thus it may not be necessary to remove soft-patch accesses. The SCORE would probably come out with soft-patch accesses removed, utilizing the access routes already available through the ship.

Conclusions

The SCRC or the SCORE would fit into the volume presently occupied by the Solar gas turbine and would save on ducting volume throughout the ship.

Both the SCRC and SCORE would create fuel savings compared with Solar alternators operating without waste-heat boilers. The SCORE fuel savings would be comparable to those of a diesel alternative.

A maintenance policy identical to the Solar could be applied to the SCRC/SCORE with accessory replacement in situ and engine removal for repair or overhaul.

Both the SCRC and the SCORE should be less noisy than a diesel, although probably noisier than a gas turbine. The additional weight of mounting and acoustic enclosure for the SCORE would be considerably less than the weight required to achieve the same underwater noise level for a diesel, but would represent a weight increase over the Solar gas-turbine installation.

Way Ahead

The noise and vibration levels of the SCRC and SCORE engines would have to be determined. This could be done by contracting with John Deere to obtain data from an engine running on their test bed, or by obtaining engines to test at NETE where a full range of tests could be carried out.

The U.S. Navy/Marine Corps experience from engine trials should be determined, particularly with respect to reliability & maintainability and to operating experience using diesel fuel.

A full study would have to be undertaken to evaluate SCRC or SCORE as a replacement prime mover for DDH-280 alternators. The study would start with a detailed underwater noise evaluation of the engine on designed mounting systems, and would compare anticipated pay-back time period for retrofits considering fuel savings and differences in capital, operating and maintenance costs.

Acknowledgement

The author wishes to acknowledge the assistance of the John Deere Rotary Engine Division staff who kindly provided the pictures of the SCRC 4-350 and the material to better explain the principle of operation of the stratified charge rotary engine.

L.T. Taylor served almost 22 years in the Canadian navy before retiring in 1983. He is a former engineering officer of HMC Ships Iroquois, Annapolis, Fraser *and* Bras d'Or. *Since his retirement Mr. Taylor has been on the MSEO staff at NEU(A). This is his third article to appear in this journal.*

Editor's Note: To put this article in perspective, it must be understood that the 1MW electrical power generation rotary engine is a "paper engine" only. A smaller unit is under development by the U.S. Marine Corps for use with landing craft. This R&D engine has a target Mean Time Between Failure of less than 1,000 hours, and a target life significantly below 5,000 hours. A rotary engine to follow the Solar Saturn is unlikely to be in production before 1995, which precludes its consideration as a replacement option at this time. The LCMM will continue to monitor rotary engine progress both at John Deere and elsewhere.

Power Level	50%	66%	80%	100%
Solar/diesel	1.87	1.83	1.795	1.69
SCRC/diesel	1.14	1.205	1.245	1.285
Solar/SCRC	1.64	1.52	1.44	1.315

TABLE 2 Specific Fuel Consumption Comparison

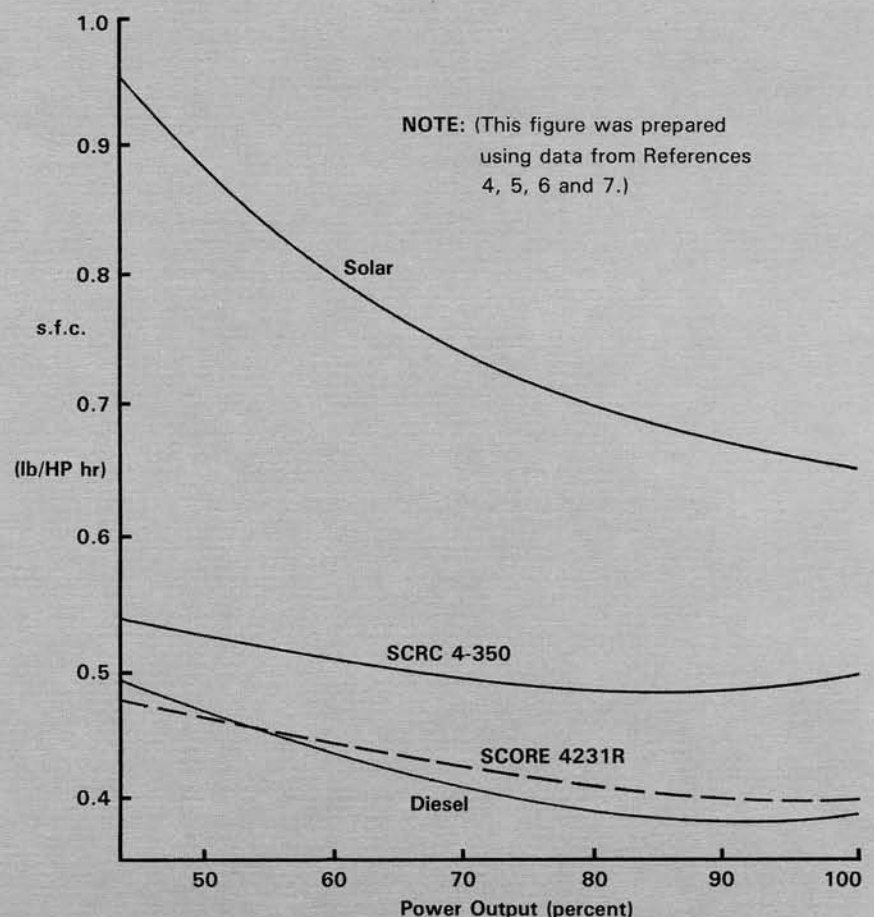


Figure 4. Fuel Consumption Comparison

References

1. Cdr J.R. Scholey et al., "The DDH-280 Waste-Heat Recovery System," *Maritime Engineering Journal*, January 1985, p.12.

2. SCORE ROTARY ENGINES, John Deere Government Products Division Brochure A-1892-85-6.

3. K.F. Schultz, "The Propulsion Machinery Installation of the Type F-122 Frigate," *Maritime Defence*, 4, 9 (September 1979), 342.

4. Charles Jones, "An Update of Applicable Automotive Engine Rotary Stratified Charge Developments" (SAE Technical Paper 820347, International Congress and Exposition, Detroit, Michigan, February 22-26, 1982).

5. R.L. Harrington, ed., *Marine Engineering* (Society of Naval Architects and Marine Engineers, 1980).

6. Charles Jones et al., "Advanced Rotary Engine Developments for Naval Applications" (SAE Technical Paper 851243, Government/ Industry Meeting & Exposition, Washington, D.C. May 20-23, 1985).

7. Handbook for Solar Saturn Gas Turbine Engine T-1020S-28A and 28B, (CFTO C-26-199-000/MS-000).

News Briefs

AN/UYS-501 Contract Awarded

Computing Devices Company of Ottawa has been awarded a $16-million contract for the militarization of the AN/UYS-501 Signal Processor for the AN/SQR-501 Canadian Towed Array Sonar System (CANTASS) and the AN/SQS-510 Active Sonar.

The AN/UYS-501 Signal Processor is an extremely powerful, general-purpose, programmable digital signal processor designed to analyze the large quantities of data received by modern sonar sensors. It can perform vector arithmetic and matrix operations in its eight arithmetic units, using floating-point complex operations at a sustained rate of 320 million floating-point operations per second (MFLOPS). This ranks the AN/UYS-501 as one of the fastest computers in the world.

The militarized AN/UYS-501 utilizes a 64-bit complex word format where each of the real and imaginary parts conforms to the IEEE standard, 754 32-bit floating-point format.

The militarization program is being managed by DMCS 3.

Full Speed Ahead on TRUMP

Last May, the federal government gave the go-ahead to a $1.2 billion (1986 dollars) project to modernize the navy's four Tribal-class destroyers. The modernization will significantly improve Canada's naval capability, particularly that related to air defence.

Treasury Board approval to proceed with the Tribal Class Update and Modernization Project cleared the way for the contract award. Litton Systems (Canada) Ltd. of Toronto, earlier selected as the prime contractor for the project, was awarded the TRUMP contract shortly after the May go-ahead announcement.

Under TRUMP, Litton Systems Canada Ltd. will upgrade HMC Ships *Iroquois, Huron, Athabaskan* and *Algonquin*, all of which entered service in 1972-73. While the Tribals will retain their considerable anti-submarine warfare capability, they will be better equipped to meet the challenge of modern missile warfare at sea.

One of the most significant improvements will be the installation of

The Tribal-Class Destroyers As They Are Today

The four DDH-280 Tribal-Class Destroyers: HMCS Iroquois; HMCS Huron; HMCS Athabaskan; HMCS Algonquin, were introduced into service between June 1972 and September 1973.

The primary role of the four DDH-280 Class Destroyers is anti-submarine warfare, for which they carry the following:

- 2 Sea King/CH-124A helicopters;
- Medium-range hull-mounted sonar;
- Variable-depth sonar;
- Anti-submarine warfare (ASW) mortars;
- Sea Sparrow point-defence missile system;
- 1 – 5''54 surface gun
- 2 triple-barrel torpedo tubes for MK44/46 torpedoes.

Features include:

- Integrated electronic warfare system;
- Computerized ASW data system;
- Automated Command and Control System.

Main Propulsion System:

- 4 gas turbines geared to 2 shafts with controllable pitch propellers;
- Direct control of all machinery from the bridge or the machinery control room;
- Acoustically-lined gas-turbine intakes and uptakes;
- Main machinery raft-mounted; all machinery shock-mounted.

Marine Architecture:

- Specially-rounded bow, for noise reduction in anti-submarine operations.

TRUMP Will Convert the DDH-280 Destroyers into Ultra-Modern Area Air Defence Weapons Systems.

New Combat Systems include:

- Mark 41 Vertical Launch Missile System;
- Standard Missile 2 Block 2;
- 76 mm Rapid-Fire Gun System;
- Phalanx Close-In Automatic Weapon System;
- Fire-Control Radars and Weapon Direction System;
- Torpedo Handling System;
- Plus: retention of 2 existing Sea King Helicopters and homing torpedoes, and removal of obsolete ASW Mortars.

New Command, Control and Communications Systems include:

- Integrated command, control, processing and display system;
- Dual Switch Redundant Interior Communications System, adapted for secure voice;
- Plus: retention and improvement of Secure Data Link (Link 11, Link 14) Systems.

New Electronic Warfare Systems include:

- Canadian Naval Electronic Warfare System (CANEWS™);
- SHIELD Chaff and Infra-Red Decoy Launching System;
- Inherent Electronic Counter Counter Measures (ECCM) in new radar and fire-control systems;
- Plus: retention of existing Electronic Warfare (EW) Systems.

New Surveillance and Detection Systems include:

- Long-Range Radar;
- Medium-Range Radar;
- Identification Friend or Foe (IFF);
- Auto-Track Radar Management System;
- Plus: integration of existing Sonar and Torpedo Countermeasure Systems into the Command and Control System.

New Navigation System:

- 2 Inertial Navigation Systems.

New Propulsion and Electrical Systems include:

- Gas-Turbine Cruise Propulsion Engines;
- Main gearbox improvement;
- Diesel generator;
- Propellers;
- Digital Integrated Machinery Control System.

Hull Improvements include:

- Major hull strengthening;
- New compensated fuel/ballasting system.

Outfitting and Refurbishing

Complete Integrated Logistics Support and Quality Control

- Training; shore support; spares; tools and test equipment; maintenance; documentation.

a supportive air-defence missile system capable of protecting ships against attacking aircraft and anti-ship missiles. New sensors will allow the ships to detect, at longer ranges, the threat generated by sophisticated weapons used in modern naval operations. They will also be fitted with new command, control and communications systems, as well as new propulsion and auxiliary systems that will give them improved speed, power and operability, easier maintenance, better energy effectiveness and lower detectability. As well, equipment and systems that are becoming incresingly difficult to maintain will be updated or replaced.

The conversion of these ships to the primary role of supportive air defence will give them the capability to detect and destroy air targets at a long range, enabling them to protect themselves and ships in company. This project will enable Canada to better meet its national and international naval operational obligations. The modern capabilities of the Tribal destroyers will complement those of the new Canadian Patrol Frigate, and the two classes of ships will form the nucleus of Canada's maritime force in the 1990s. To the maximum extent that is operationally and economically feasible, and wherever similar capabilities are required, systems are being procured that are common to both the CPF and the TRUMP projects.

The first of the Tribal-class destroyers is scheduled to enter the shipyard of Versatile Davie Inc., of Lauzon, Que., in November 1987. The Quebec shipyard, which originally built two of the Tribal destroyers, was nominated by the government as the shipyard for the updating work on the first two ships. A separate competition will be held by Litton Systems to select a shipyard(s) for the conversion of the last two ships. Each ship will require approximately 18 months of work, and the last ship is expected to be completed in early 1992.

As prime contractor, Litton is responsible for the design, conversion, refit, trials and delivery of the four fully supported ships and shore facilities, including the provision of a number of support items and an industrial benefits package.

The company has agreed to ensure that maximum benefits, of at least 100 per cent of the project's value, are passed on to Canadian industry. Approximately 70 per cent will be in the form of direct Canadian content. The balance will be offsets that have yet to be determined.

It is estimated that TRUMP will create 13,000 person years of direct and indirect employment.

CPF Construction Update

Unit assembly of CPF-01 (HMCS *Halifax*) is progressing rapidly, with five units (3140, 3230, 3130, 3240 and 2420) now assembled and thirteen others in various stages of construction.

The initial units are currently at the P01 stage, and some of the manufacturing jobs required to produce pipe spools have commenced. The production of the pipe spools (short pieces of pipe normally terminating in a flange) requires careful attention so that the components will match up with a minimum of wastage when installed in the ship during P01. SJSL is using numerically (computer) controlled pipe-bending machines to ensure accurate bend radii and lengths. Other items such as pipe penetration pieces and cover assemblies for manholes and ventholes are also currently being manufactured.

Planning for special installation such as plummer block seats and RAST gear manufacture has been completed, and it is anticipated that work on these items will commence shortly. A number of small items (e.g. flanges, valves, etc.) are now coming into the central receiving warehouse on a daily basis. None of the major components has yet arrived, but the main reduction gear and propulsion diesel have both just undergone factory acceptance trials and are expected to arrive sometime in the next few months.

LCdr B. Staples, PhD, P. Eng.

PD Phase Approved for CASAP

The Department of National Defence has given approval to proceed with the Project Definition phase of the Canadian Submarine Acquisition Project to replace the navy's aging fleet of Oberon-class submarines.

During this phase, fully costed options for four, six, eight and 12 submarines will be developed by potential Canadian prime contractors. DND has identified a need for a minimum of four new conventional submarines to replace the current fleet and restore a minimum submarine capability on the West Coast.

Companies in Britain, West Germany, Italy, France, the Netherlands and Sweden have been identified as potential design sources for the new submarines. The prime contractor, however, will be a Canadian firm, and as much work as possible will be done in Canada.

The Oberons were commissioned in the 1960s and will reach their designed life-expectancy by the early 1990s. If CASAP proceeds as scheduled, the first of the new submarines would join the fleet in 1995, and the remainder of the minimum four would be completed by 1999.

Index to Articles 1986

Photocopied reprints of articles appearing in the *Journal* are available on request. Please mention the title of the article and the month of publication in your request.

MARITIME ENGINEERING JOURNAL SURVEY

1. What is your occupation, rank, MOC?

2. Where do you work?
   Canada/Abroad
   Ship
   Dockyard
   Base
   Headquarters
   Training Centre
   University/Military College
   Other ____________________

3. How long have you been involved with naval engineering or the navy?
   less than 1 year
   1-5 years
   6-10 years
   11-15 years
   16-20 years
   20+ years

4. Which sections of the *Maritime Engineering Journal* do you usually read?
   a. Editor's Notes
   b. Letters
   c. Commodore's Corner
   d. News Briefs
   e. One article
   f. Two articles
   g. Three or more articles
   h. Cover to cover
   i. None. (Reason? ____________________
   ____

5. Which sections do you like best?

6. Which sections do you like the least?

7. How do you rate the technical articles?
   a. Too technical
   b. Too general
   c. Just right

8. How do you rate the *non-technical* and general interest articles?
   a. Too in-depth
   b. Too shallow
   c. Just right

9. Do you think there is a good mix of articles in each issue?
   Yes No

10. Which type of article would you like to see more of?
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11. Is there a particular subject you would like to see covered by an article?

12. Do you feel there is a place for humour in the magazine?
   Yes No

13. What do you do with your copy of the *Journal* when you finish reading it?
   a. Keep it
   b. Circulate it
   c. Throw it away

14. Do you ever refer to back issues?
   Yes No

15. How *useful* is the *Journal* to you?
   a. Very useful
   b. Somewhat useful
   c. Of little use
   d. Of no use

16. What is your overall impression of the *Journal*?
   a. Very favourable
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   c. Neither favourable nor unfavourable
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   e. Very unfavourable

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   d. Provide technical information
   e. Provide news of engineering programs — ____
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18. Generally, do you feel the magazine meets its stated objectives? (See p.2 of this issue.)
   Yes No (Why not?) ____________________
   ____

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20. Can you suggest a more appropriate title?
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   Yes No

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