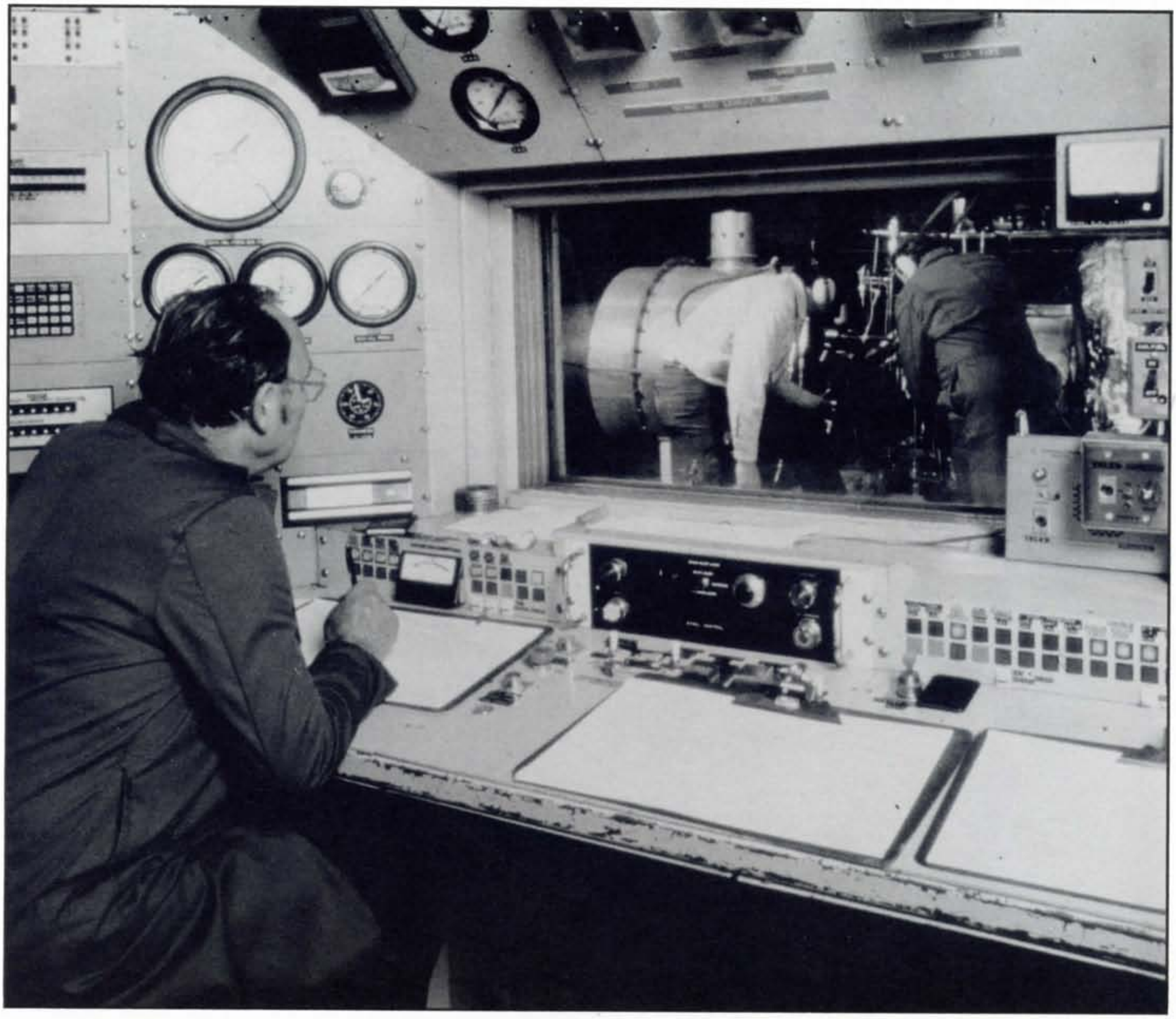
National Defence Défense nationale

MARITIME ENGINEERING Journal du GÉNIE MARITIME



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JOURNAL DU GÉNIE MARITIME
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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.

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.

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.

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MARITIME ENGINEERING

Journal

du GÉNIE MARITIME

DIRECTOR-GENERAL
MARITIME ENGINEERING and
MAINTENANCE
Commodore J.A. Gruber

JANUARY 1986

DEPARTMENTS

FEATURES

OUR COVER

View from the control room of the Solar gas-turbine/generator set installation at NETE for the evaluation of the TRUMP modifications.

Editor's Notes

The Naval Engineering Test Establishment has been in operation in the Montreal area for well over 30 years, providing a variety of services in support of the navy's ship-construction programmes and equipment life-cycle activities. In our lead article, the manager of NETE takes us on a familiarization tour of the test establishment's services and facilities, and walks us through a typical NETE tasking.

Also in this issue, Lt(N) Serge Garon provides us with a simple reference to the operational aspects of shipborne desalinators, LCdr Bob Gebbie discusses how the introduction of RCM into naval maintenance policy will eliminate some of the "madness" from preventive maintenance, and LCdr Derek Davis (promoted to his present rank just as this issue was going into production) gives us Part II of his comprehensive look at ship passive protection. We are especially pleased to be able to feature Captain(N) Reilley's reminiscence "On Being a Base Commander" in the Commodore's Corner.

The *Journal* is intended to be your professional forum where you can share your knowledge and ideas with the rest of the maritime engineering community. As always, we are looking for your suggestions for articles that you think should be written and, more importantly, for your article submissions.

There is no hard and fast rule for determining how long or short an article should be, other than it should be the length you feel is necessary to cover the subject properly as you see it — no more, and no less. A limit of 6,000 words is mentioned in the Writer's Guide only because, to be fair, we want to have space to run articles by a number of different authors in each issue. Of course, should an article run longer, we will certainly consider spreading it across two issues although we prefer not to have to do that.

The bottom line is that we need your articles, and there is an editorial staff, here, ready to help you get your ideas into print as quickly and easily as possible.

Finally, we would like to know what you think of the *Journal* in its new format. If you haven't already given us your thoughts after seeing the September 1985 issue, then please take the time now to tell us what you do or don't like about the magazine. Let us know how we can make the *Journal* better for you.

We at the *Journal* wish you all the very best for 1986.

Letters to the Editor

Dear Editor,

I read with interest Lt(N), now LCdr, Davis' article on Passive Protection (MEJ Sep 85).

Regarding the IR portion, the priority given to signature reduction measures depends on the type of missile or other sensor from which one is attempting to hide, but I believe that the importance of cooling or concealing the visible exhaust duct has been understated. A clean exhaust plume, for instance, will have a fairly low emissivity whereas the duct is an almost perfect black body.

An interesting point on hull insulation is that on a cold winter's day an insulated hull at ambient air temperature would stand out clearly in the IR band against the warmer water. It is difficult to beat a modern IR sensor.

My main reason in writing, though, is to point out that HMS *Sheffield* did *not* have an air-entraining funnel. *Sheffield's* funnel design, in fact, had the exhaust coming out the side — a disaster from the IR point of view! The ship in the p.15 sketch would be one of the later Type 42s. Their funnels are not air-entraining either but are still a big improvement.

Notwithstanding these minor points, I would like to compliment LCdr Davis on his article. Passive protection and survivability features in a ship design are unglamorous yet costly; when money gets tight they are often the first "requirements" to be cut back. We need to be reminded of their importance.

Yours sincerely,

Cdr R.G. Weaver
DMEM 4

Share your views. Your letters are welcome, and signed correspondence should be addressed to:

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In the News

Marc Garneau, naval combat systems engineer and the first Canadian astronaut to fly a mission in space, has been promoted captain (navy) effective Jan. 1, 1986.

Captain (N) Garneau, a native of Quebec City, enrolled in the RCN in 1965 and underwent studies at the Collège militaire royal de Saint-Jean and the Royal Military College of Canada.

He received a doctorate in electrical engineering from the Imperial College of Science and Technology in London, England in 1973.

A communications and electronic warfare specialist, his military assignments include: combat systems engineer aboard HMCS *Algonquin*; instructor of naval weapon systems at Fleet School, Halifax; NDHQ project engineer for naval weapon systems; engineering officer at NEU(A); and DMCS design authority for all naval communciations and EW equipment.

Following his selection for the Canadian Astronaut Program, Captain Garneau was seconded to the National Research Council in early 1984 and flew on the October 5, 1984 mission of the space shuttle *Challenger* as a payload specialist.

Interviewed by the *Maritime Engineering Journal* eight months before his spaceflight, Captain Garneau (then a commander) anticipated that being away from a naval environment for two years would be "pretty much business as usual" as far as his career was concerned. "When I return to the navy on completion of this work I will probably go back into a job where I can get my feet wet fairly fast again, just in case I've forgotten some of the things I've learned. So I don't think that there will be that much disruption to my career," he said.

"I hope when I return that I won't be out of date. Obviously I will be to some extent, but I hope that my usefulness as a naval officer will not have suffered in any important way."

Due to his experience with the astronaut program, Captain Garneau's original two-year assignment with NRC has now been extended until August 1987.

Commodore's Corner

The Commodore's Corner is usually reserved for the comments of Commodore engineers, but from time to time there comes an opportunity to use this space to spotlight the words and wisdom of other senior officers of captain or flag rank. Such is the case in this issue of the *Journal* with Captain (N) Reilley's thoughts "On Being a Base Commander". His account of his recent experience with commanding a non-naval base certainly makes the point that even a less traditional role can offer an interesting and worthwhile avenue in a MARE's career. Considering the grass roots theme of his reminiscence and the value of his message to all MAREs, I think it is entirely appropriate that we feature this introspective in the Commodore's Corner.

Commodore J.A. Gruber
DGMEM

On Being a Base Commander

by Captain(N) J. Dennis S. Reilley, CD

MAREs have tended to shy away from pure command roles, opting rather to pursue more traditional involvements. These traditional involvements are necessary, very rewarding and, indeed, embrace most aspects of command and leadership. In fact, the MARE leadership role is in many ways much more difficult than traditional command as so many diverse bureaucratic functions have to be pulled together and satisfied to achieve the objective. In command, the structure is more clearly defined, and most who work for you recognize you as the leader with ultimate authority and, indeed, responsibility. Thus, in many ways, a MARE who is a base commander has a less frustrating time than another MARE of the same rank who, for example, may be a director or project manager.

A base commander in my experience is held much more accountable than most officers across a broad spectum of activities and, as a result, can find himself "holding the can" in short order even if the issue resulted from a matter beyond his control. Also, both the Minister and the Chief of the Defence Staff become personally involved in matters very quickly when either politics or the press are central to an issue. I have seen it all during the past three years and, in a nutshell, the base commander is continually out on a limb. Yet that is one of the fascinations of the job.

The base commander at Cornwallis is responsible for the training of up to 7,600 male and female english-speaking recruits each year. The annual base budget is $43M and I have 450 military and 430 civilians working for me. The base is completely self-contained comprising: 250 married quarters; the usual administrative and lecture buildings; single quarters for 400 staff; a 200-bed hospital, a fully equipped 12-chair dental unit; three rifle ranges; a fire hall; four messing facilities; three indoor Olympic-sized swimming pools; a school (grades 1 to 9); complete inside and outside gymnasium, sports and recreational facilities; a fleet of 60 vehicles of all types ranging from two highway cruisers to snowploughs; a weekly base newspaper with a circulation of 2,500; a police force; repair and maintenance facilities; two churches, 95 small boats (whalers, 420s, etc. to support the 1,000 Sea Cadets from across Canada who descend on the base for training during the summer months); a very modern CANEX facility, and more, all on 3,700 acres of property.

The dependants very much look to the base commander for inspiration and leadership.

The base commander commands 450 military staff, and this translates into about fifteen hundred dependants who must be looked after. In this context the base commander has to ensure that housing, schooling, social and recreational programmes are well established. The dependants very much look to the base commander both for inspiration and leadership. It sounds like a tall order, and indeed it is. However, on an isolated base it must be done properly as the overall morale must remain as high as possible. If morale in one sector slips everyone is affected as there are few secrets in such a community.

Death must be dealt with from time to time and this adds yet additional stresses. The next-of-kin have to be notified, estates settled, burials arranged, the press dealt with, investigations initiated, etc. Never a pleasant task, but one nonetheless in which base commanders must become involved.

Being a base commander in a remote area demands the very highest standards of personal integrity.

In the same vein discipline and efficiency must be maintained. I have been very fortunate in not having had too many disciplinary problems to deal with. The act of reducing someone in rank or sending him or her off to jail is never pleasant but it must be done. Likewise, having someone released for reasons of incompetence is difficult enough. However, when one is very much aware that he or she may never find a reasonable second job, and one has met the spouse and young children, it is doubly difficult. This can be a very sobering experience and I have found such human decisions much more difficult to make than ones dealing with equipment.

Being a base commander in a remote area demands the very highest standards of personal integrity at all times. Furthermore, one must insist that the officers and NCOs do likewise. It is amazing how fragile the social fabric is, and the least deviation on the part of the leaders can have a very damaging effect on both the morale and efficiency of a base. An urban base is not nearly so critical in this respect as one's social inadequacies can be well hidden from the work place. Human Rights notwithstanding, there can be no compromise as the objectives of the base can be very seriously affected if one turns a blind eye.

Likewise, I have been very hesitant about accepting what I term "mixed marriages" on my base. An officer married to an NCO may not have a disrupting effect, but it does tend to limit the complete professional development of them both, particularly in the social sense.

One area that has struck me very forcefully is that, on my base at least, junior officers are given much responsibility very early in their careers. For example, captains and lieutenants (unified ranks) run sections such as Supply, Security, Personnel Selection, Transport, etc. My Base Supply Officer (a recently promoted captain) is responsible for a $5M budget, looks after 15,000 line items, has a monthly turnover of $700K and leads 85 people. I question how often young naval lieutenants are challenged with such responsibilities. In my experience junior naval officers are just as capable, but we tend to not challenge them in this way so early in their careers. The MARE Get-Well Programme will go a long way towards helping in this regard.

Another new experience was to be treated as a "somebody", not only on my base, which goes without saying, but also within the CFTS and ADM(PER) command structure. It may seem strange to naval officers to hear a captain say such a thing, but let me just state that the naval fraternity doesn't seem to attach quite the same importance to four stripes in command of a base as the other environments do.

Leading a ship/unit with all of the main actors belonging to one environment with one mission is difficult enough. Leading a "green" base is another matter. At one end of the spectrum are the army types with their well-defined sense of discipline and leadership. At the other end is the air force outlook which is somewhat more relaxed in such matters. The naval style falls somewhere between the two extremes. One also finds the green approach which is very difficult to define. Often the people who call themselves green relate to one of the three traditional environments. More often, however, the young "green" officer and man relate to nothing but their classification/trade.

Real animosities can arise over parochial matters on a base such as Cornwallis and motivational problems result.

One can very quickly detect that it is no easy task to meld these diversities into a whole. For example, naval NCOs always have great difficulty in calling a CWO "sir". To them a CWO is a chief. Nor do naval types take kindly to rank regimentation in the mess. However, in the army (and, indeed, in the air force tradition much to my surprise) this is expected. Another approach which is often embarrassing to naval and army types is the propensity for air force officers to call their NCOs by their first names. Real animosities can arise over parochial matters on a base such as Cornwallis and motivational problems result.

In this context a base commander must set his standards based on the highest traditions early in the game or forever be fighting a rearguard action. In short, leading a truly green base is in my view the biggest leadership challenge existing in the CF today. I have found during my career that operational matters always tend to bring people in uniform together. Thus I have placed much emphasis on Base Defence Force matters, and I also played BOLDSTEP to the hilt involving all my staff in real time. This approach has paid handsome dividends in bringing all the diverse groups together as a team.

There are many similarities between commanding a base and programme management. Resources have to be gathered and dispersed, material objectives must be set, conflicting guidelines have to be followed, budget/approval levels must be adhered to, political considerations recognized and schedules met. Yet there is one major difference. The base commander normally has the design, technical and construction resources working for him. In this sense the tasks of a CO SRU and a base commander are very much alike.

Dealing with labour has been a real eye-opener and I can now readily claim to be an expert in labour/management relations. Furthermore, I am now through osmosis very knowledgeable about civil service regulations. I quickly learned early in the game that civil servants march to a very different tune than does the military. One may not like it, but the fact must be accepted as to do otherwise is to court disaster.

In this respect, I have learned that MAREs are better equipped than most to lead a base. Not only are we well up on pure military matters but we have all worked with civil servants during our careers. Furthermore, our technical training and backgrounds allow us to provide the required leadership to the technical services function. I have taken great pleasure in periodically internally and externally inspecting the boilers at the central heating plant. This one action has helped to motivate labour as they can see that the boss isn't afraid to get dirty, he knows their business and that he appreciates what they have to go through.

There have been many other parallels during my tenure here. The message is: get down to the working level and show an interest. MAREs are trained to do this. Most other classifications (with the exception of Combat Arms) are not, and the officers don't seem to be sensitive to what their people are really having to go through.

The loneliness of command at sea is well documented. The same phenomenon exists ashore at bases which are remote from metropolitan centres. In fact, in many ways the loneliness of command can be more pervasive ashore than at sea in this context. The captain of a ship has the opportunity of escaping to the suburbs in a private sense when not afloat. He can also get away from it all in foreign ports. This luxury does not exist at Cornwallis. The base commander's residence is surrounded on three sides by barrack blocks, and staff and troops are continually marching by. The natural focus, of course, is the residence and one must be on his best behaviour even in his own backyard.

The base commander is very much on the firing line and he alone is held accountable for the success or failure of the entire operation.

This total involvement extends to the surrounding communities as the base commander is well known there as well. I have often had people approach me in a store or restaurant and say something to the effect "Aren't you the base commander at Cornwallis?". In this context I have practically been accorded star status when off the base. At the very least I have been regarded as the paternal benefactor as the base influences the local economy to a very great extent.

The surrounding economy is not the most vibrant and jobs are scarce. As a result, politicians are very anxious to help their constituents. Being by far the largest employer in the area, interesting pressures have been brought to bear on me. I can remember a situation not too long ago where federal and very senior provincial politicians descended on me at a social function to discuss employment policies. The point is that a base commander never knows when or where he will be confronted, and it follows that he must be both current and vigilant.

Considering that my contacts have included the Lieutenant-Governor of Nova Scotia, the Premier of Nova Scotia, one local federal MP, two local MLAs, four mayors and the president of Ste Anne's University, it almost goes without saying that media and community relations have been an important dimension to the job. The base commander is both expected and funded to entertain in his official residence, and my family and I have had to be continually sensitive to the age-old requirement of "noblesse oblige". The experience has been delightful and we have been flattered, yet personal privacy has been absolutely nonexistent. Having had to cope with the loneliness which this entails has not been easy.

I have very much enjoyed my time at Cornwallis but I must admit that protocol has taken a toll on my family life. I often wonder how senior officers such as the Commander of MARCOM cope in this respect if my experience here is any indication of the accelerated social pace he must endure. One quickly learns to adjust, but I must admit that after three years I am ready to spend much more time with my children.

Command of Cornwallis will likely be the last service job I have where my boss is 1,839 kilometers away and with whom I speak about once a month or so. Nor have I had the luxury of a large adjacent military infrastructure to associate with the way COs of SRUs and naval bases do. The complete isolation of Cornwallis in this sense has been both a blessing and a frustration. A blessing because I have been very much master in my own domain, yet a frustration as one often wonders whether the main stream still knows you exist. Nonetheless, the autonomy afforded me has been a delightful and refreshing experience, and I wouldn't have missed it for the world.

The base commander is very much on the firing line, and he alone is held accountable for the success or failure of the entire operation. Complete responsibility is the key and I have loved every minute of it. The past three years have not been easy but they have been extremely rewarding. There is no doubt that naval engineers can command such an establishment, and, indeed, should seek to do so. I am a changed man and, without question, am much stronger for my experience. Finally, I think I have proven to MAREs and others that a naval engineer can do the job. The door is open for other MAREs, and I would like to think that one will soon again command a base, be it naval or green.

Captain (N) Reilley graduated from the Royal Military College at Kingston in 1962 with a Bachelor of Science degree. Prior to his appointment as Base Commander of CFB Cornwallis in 1982, he served three years in NDHQ as the Director of Marine and Electrical Engineering. Captain Reilley was selected to attend the National Defence College in August 1985.

The Naval Engineering Test Establishment

An Introduction to its Role, Services and Facilities

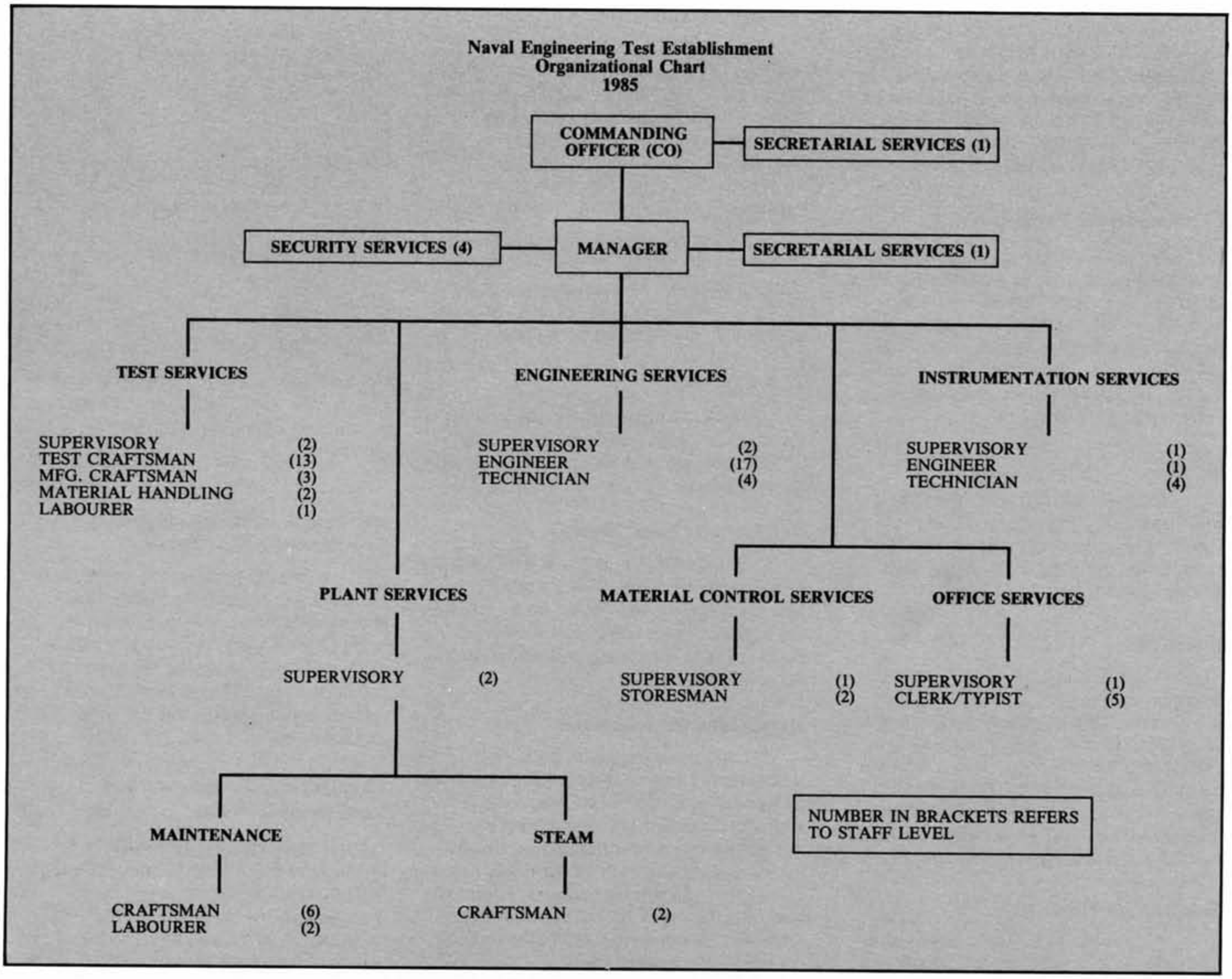
by Mr. J. Costis

History and Role

The Naval Engineering Test Establishment (NETE) was established in 1952 with the issuance of a contract by the, then, Department of Defence Production (DDP) to Peacock Brothers Limited (now Peacock Inc.). Peacock was contracted to modify a Crown-owned building and property in LaSalle, Quebec in order to provide appropriate test facilities for the majority of the steam and electrically powered prototype and production auxiliary machinery and systems of the DDE-205/257/261-class ships. On completion of the modifications and provision and installation of the test facilities, Peacock Brothers was contracted to manage and staff NETE in support of the naval shipbuilding programme.

In 1968 the administration and control of NETE was transferred to the Department of National Defence. NETE became a unit of the Canadian Forces and was allocated to National Defence Headquarters under the Assistant Deputy Minister (Material). NETE's role was defined as a third-line engineering service by Canadian Forces Organization Order No. 1.23, dated 16 September, 1974.

As such, with its staff of 78, NETE provides in-house and field-engineering services and facilities to support, princi-



pally, the navy's main and auxiliary machinery and systems. Specifically, the service is provided to test, investigate, evaluate, qualify and develop mechanical, fluidic (i.e. steam, air, water, fuel and oil), electronic and electrical equipment and systems and their related controls and life-cycle maintenance needs. Its role under DDP and DND has involved NETE in supporting the navy's major ship-construction programmes and their life-cycle maintenance and operational needs since 1953. Experience with the DDEs, DDH-280s, and now the Canadian Patrol Frigate, has resulted in the evolvement of a broad spectrum of expertise and facilities at NETE in support of system and equipment testing, some of which are unique in Canada.

NETE's facilities in LaSalle are located conveniently close to NDHQ and to some of the principal suppliers, designers and maintainers of naval equipment. The location has thus optimized NETE's ability to keep abreast of related developments, and to respond expediently to requests for its services.

The site itself occupies a lot of some 96,700 square feet, with the main building and numerous annexes accounting for over 4,000 sq. ft. of floor space. Roughly half of this is devoted to test facilities, with the remainder being occupied by the various support services.

Environmental Facilities

These facilities subject equipment and systems, in a static and/or operating mode, to simulated marine and other adverse environments. This permits their performance to be assessed under these conditions and, if required, modifications can be incorporated and evaluated to achieve the desired results.

Shock

Medium- and light-weight shock machines apply high-shock pulses at controlled displacements to equipment and systems weighing up to 3,409 kg and 113 kg respectively. See Figure 1.

Vibration

A 2,722-kilogram-force electrodynamic shaker (Fig. 2) and a 11,340-kilogram-force mechanical shaker produce vibrations at frequencies and displacements up to 3,500 Hz and 2.54 cm (peak to peak) and up to 60 Hz and 0.35 cm (peak to peak) respectively. The former accommodates equipment weighing up to 1,361 kg and the latter up to 136 kg.

Temperature/Humidity

Chambers with inside dimensions up to 3.96 m × 3.66 m × 2.44 m high provide combined and controlled temperature conditions ranging from −62°C to 77°C and humidity from 20% to 95%.

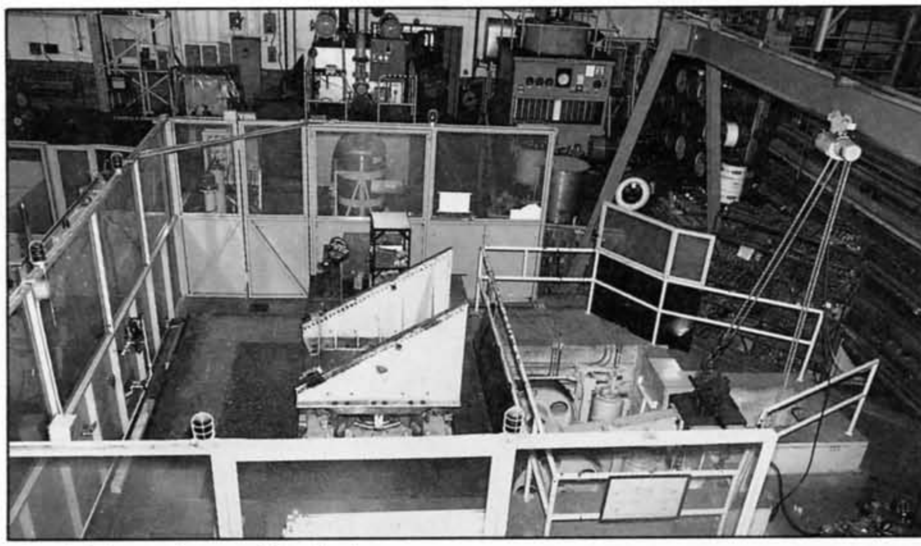


Fig. 1. The medium-weight shock-test facility.

Oscillation Motion

An oscillating platform (Fig. 3) provides a simulated ship-roll condition up to ±45°, at periods ranging from 8 to 20 seconds. Equipment weighing up to 1,361 kg can be installed on the platform.

Salt-Fog Chamber

A chamber with inside dimensions of 3.05 m × 3.05 m × 2.44 m high generates a salt fog, at temperatures up to 35°C, to permit accelerated evaluation of equipment resistance to corrosion.

Test Facilities

These facilities permit equipment, systems, controls, concepts, etc. to be tested under normal or abnormal operating conditions.

Gas Turbine/Diesel Engine

Gas turbines and diesel engines up to 5,220 kw and 2,982 kw respectively, and their respective services and monitoring and control systems can be tested under various operating and environmental conditions.

Steam-Operated Equipment

High-pressure/high-temperature steam-supply test circuits (10,886 kg/hr at 42 kg/cm² and 427°C) in conjunction with other related test circuits permit the testing of steam-operated or steam-driven equipment such as turbines, heat-exchangers, pumps, generators, compressors, etc. Figure 4 shows a steam-driven feedwater pump installed in a test circuit for performance evaluation.

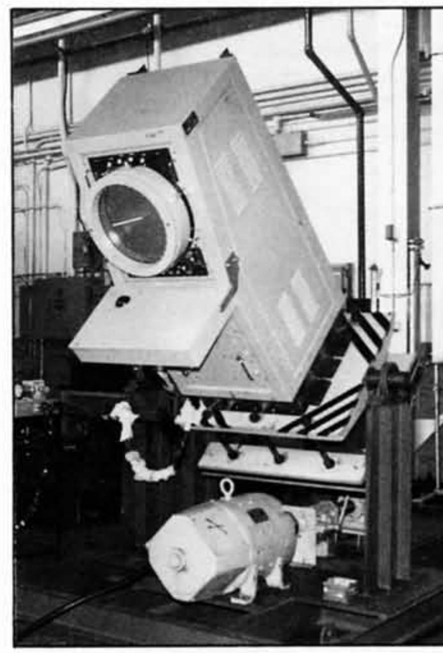


Fig. 3. The oscillation unit with an air-control indicator mounted on the platform.

Mechanical/Electrical Equipment, Components and Materials

A broad spectrum of test circuits designed to optimize flexibility can accommodate the testing of compressors, pumps, generators, rectifiers, hydraulic motors, heat-exchangers, air-dryers, pollution-control equipment, electric motors, cable glands, valves, controllers, monitors, etc.

Engineering, Technician and Craftsman Services

These services are available for in-house and field work, and include the full spectrum of functions from the inception to the completion of a "TEST" program. A brief outline of some of the principal functions is provided.

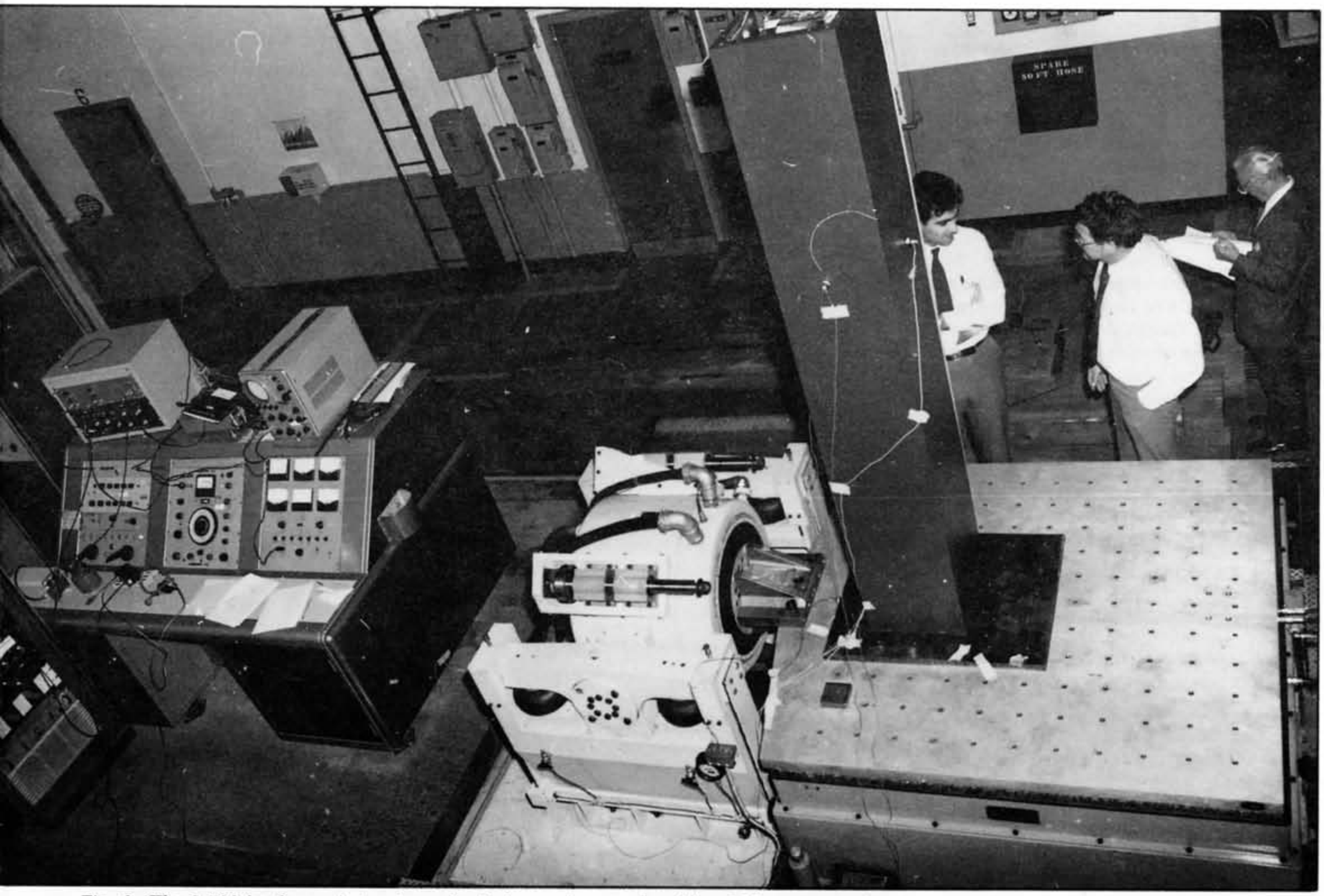


Fig. 2. The 2,722-kg-force electrodynamic shaker and controls with a 200-ampere cabinet mounted on the horizontal shaker table.

Engineering Services

a. Prepare, engineer and cost "TEST" programs.

b. Engineer and supervise "TEST"-program implementation, including design, construction and installation of test fixtures, circuits etc., selection and installation of data collection and processing equipment; maintain test schedule and keep testing and costs within budget.

c. Analyse test data and results and, if required, provide consultation services to achieve the objective of a program or the desired performance, and prepare a report with appropriate conclusions and recommendations.

Technician Services

a. Provide drafting, inspection and laboratory services in support of, or to satisfy, the principal requirements of a "TEST" program.

b. Design, install, operate and maintain data collection and processing instrumentation packages in support of, or to satisfy, the principal requirements of a "TEST" program.

Craftsman Services

a. Manufacture and construct test circuits, and install, operate and maintain the principal test equipment, systems and services employed in conducting tests and being tested.

Support Services

These services complement and enhance the control and assessment of the operations of the environmental and test facilities, condition of equipment and systems undergoing testing.

Inspection Services

A comprehensive array of inspection, destructive and non-destructive tools (operated by qualified inspectors) provides the means to measure, observe and assess the physical and operational condition of equipment, systems and components before, during and after testing.

Instrumentation Services

Qualified technicians work with a wide variety of instruments to measure, control, record and analyse static and dynamic conditions such as temperature, vibration, displacement, flow, force, shock, moisture level, pressure, and load of equipment and systems. Stand-alone computers in conjunction with a central computer provide a high-density acquisition and analysis capability. The majority of these services can be provided in the field.

Laboratory Services

Facilities and services are available to conduct various chemical, metallurgical, bacteriological and environmental tests to measure water, fuel and oil quality; to detect and measure trace quantities of metals in aqueous solutions and wear metals in lubricating and hydraulic oils; to sample, by isokinetic means, and analyse effluents of air-compressor, air-purifier, combustion-engine and incinerator-exhaust emissions, and to measure bacteria in water.

Computer Services

A GOULD/SEL 32/77 32-bit minicomputer with a time-sharing multiple user capability, 1.75-MB main memory and three 80-MB disk drives for data storage, in conjunction with configured peripherals, permits data entry, retrieval, processing, printing, plotting, high-speed, simultaneous on-line data acquisition of up to 16 channels of shock- and vibration-related signals, and up to 1,000 channels for low-speed data acquisition requirements. The capability to develop software and design and fabricate interfaces in-house ensures that optimum data acquisition and processing services are provided to satisfy particular needs.

Manufacturing and Material Handling Services

The variety of weld/sheet-metal, machine-shop and woodworking equipment provides the flexibility and capacity to manufacture and construct (to close tolerances) the various and special types of fixtures, test circuits, components, etc. needed to interface the item being tested with the environmental and test facilities, or to modify items being tested according to prescribed requirements. Material handling facilities with a lifting capability of up to 13,608 kg and height clearance up to 7.3 m are available where the principal environmental, test and manufacturing facilities are located to facilitate the handling of heavy or bulky equipment and systems.

General Services

General services are distributed throughout the various test areas. The capacities of the principal ones are:

a. Electrical
   (1) 1,300 kW (500, 440, 220 and 110V, 60 Hz, 1- & 3-phase).
   (2) 5 kW (120V, 400 Hz, 3-phase).
   (3) 3 kW (270 and 110V DC)

b. Cooling Water
   (1) 11.4 m^3/min flow, 3.2×10^{10} J/hr heat dissipation.

c. Fuel Storage
   (1) one 68.1 m^3 tank.
   (2) two 54.5 m^3 tanks.
   (3) two 22.7 m^3 tanks.

d. Water Storage — up to 45.4 m^3 tank.

e. Electrical Load-Bank
   (1) 500 kW, 440V, 3-phase, or
   (2) 200 kW, 550V, 3-phase

f. Steam Supply (for testing)
   (1) main boiler: 10,886 kg/hr, 42 kg/cm^2, 427°C.
   (2) auxiliary boiler: 2,268 kg/hr, 42/cm^2, 427°C.

NETE Activities

The combination of NETE's involvement since 1953 in work associated with naval ship-construction programmes and life-cycle needs, and technical staff experience and service averaging over 13 years, has kept NETE in the forefront of a broad spectrum of activities such as:

(a) Evaluation, development and implementation of health-monitoring techniques.

(b) Development and provision of on- and off-line instrumentation packages and data acquisition and processing systems.

(c) Technical evaluation and assistance in the development of diesel engines, gas turbines, pumps, compressors, pollution-control equipment, electric motors, generators, fuel-, oil-, and water-contaminant control equipment, etc. and their related control and monitoring systems.

(d) In-house and field investigation and qualification of shipboard equipment and systems.

(e) Technical evaluation of general techniques, materials and equipment in support of maintenance requirements.

(f) Design, manufacture and construction of test circuits in support of testing.

Some of these activities are best illustrated by following through a typical NETE tasking. At the time of writing the tasking selected has not been completed, but has progressed sufficiently to highlight the principal functions involved.

Functions Associated with a Typical NETE Tasking

NETE was tasked to evaluate a reverse-osmosis desalination plant that was manufactured by Seagold Industries Corporation for the DDH-280 class. Prior to the issuing of the project, a substantial amount of liaison was required between the NETE Project Officer (NPO) and the OPI in the NDHQ Project Office. It had to be established, initially, that NETE had the resources available (or could provide them at an acceptable cost) to perform the evaluation requirements within the target date.

Once it was established that the work could be undertaken at a reasonable

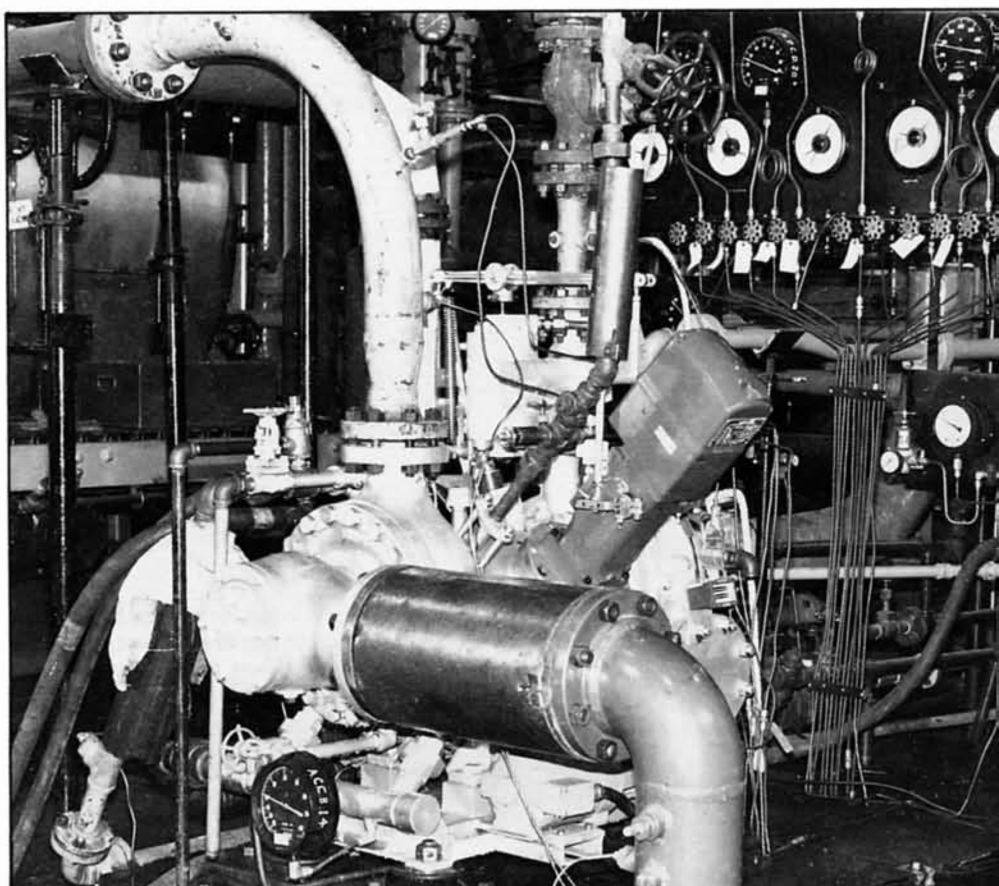


Fig. 4. A Pacific TBA-12 feedwater pump installed in a test circuit for performance evaluation.

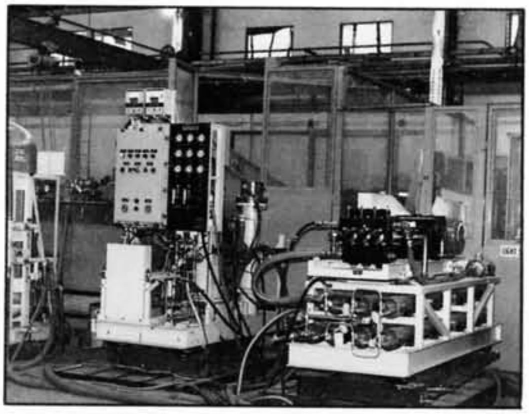
cost, further liaison was required to establish the tasking description in adequate detail. This was done to develop an evaluation cost-estimate and to optimize the schedule and minimize costs. At this stage a visit was made to the manufacturer's plant in British Columbia to obtain information on the reverse-osmosis plant construction and operation, and to establish the optimum method for testing it.

The plant comprised three major sections:

1. The filter media tank;
2. First-stage pump and the membranes;
3. Second-stage pump, control panel, heater, second filter, and boost pump.

It was determined that NETE would test the three sections individually

Fig. 5. The reverse-osmosis desalination plant set up for performance, noise and structureborne vibration measurements.



as the plant's total size and weight exceeded NETE's shock and vibration test facility capability. (The plant, fortunately, was also designed to be split temporarily into three sections to facilitate onboard installation.)

Once the aforementioned was completed, the OPI prepared a Proposed ADM (MAT)/CEM Project Tasking Directive (in accordance with CFTO-C-02-006-006/AG-001, dated 21 June, 1978) and forwarded it to NETE for comments and preparation of a cost estimate. The Tasking Directive, complete with NETE's comments and cost estimate, was submitted to the OPI's Director for acceptance and forwarding to the DGMEM Resources Management Section (DGMEM/RM) for approval and formal tasking of NETE. (NETE employs a cost-accounting system which accounts for all of the actual service, labour and material costs associated with a given project.)

The principal services to be provided by NETE were:

(a) Engineer, procure and install the interconnections between the three sections to permit each one to be operational while undergoing testing;

(b) Engineer and construct the necessary test circuit, and provide the related support services (i.e. electrical power, cooling water and a simulated saltwater recirculation system) to permit the plant to be operated;

(c) Engineer and provide the necessary measurement instrumentation to monitor the critical parameters of the plant and related support services provided under (b);

(d) Make the plant operational;

(e) Engineer and implement a SOAP and vibration analysis health-monitoring programme for the specified items of the plant;

(f) Conduct the prescribed tests (i.e. shock, vibration, 200-hour performance run, noise and structureborne vibration measurements);

(g) Provide assistance to the manufacturer, as requested, on a cost-recovery basis to achieve the specified performance from the plant;

(h) Prepare a report including appropriate conclusions and recommendations.

A general view of the NETE laboratory facility.

A summary of the tests and results up to the time of writing is as follows:

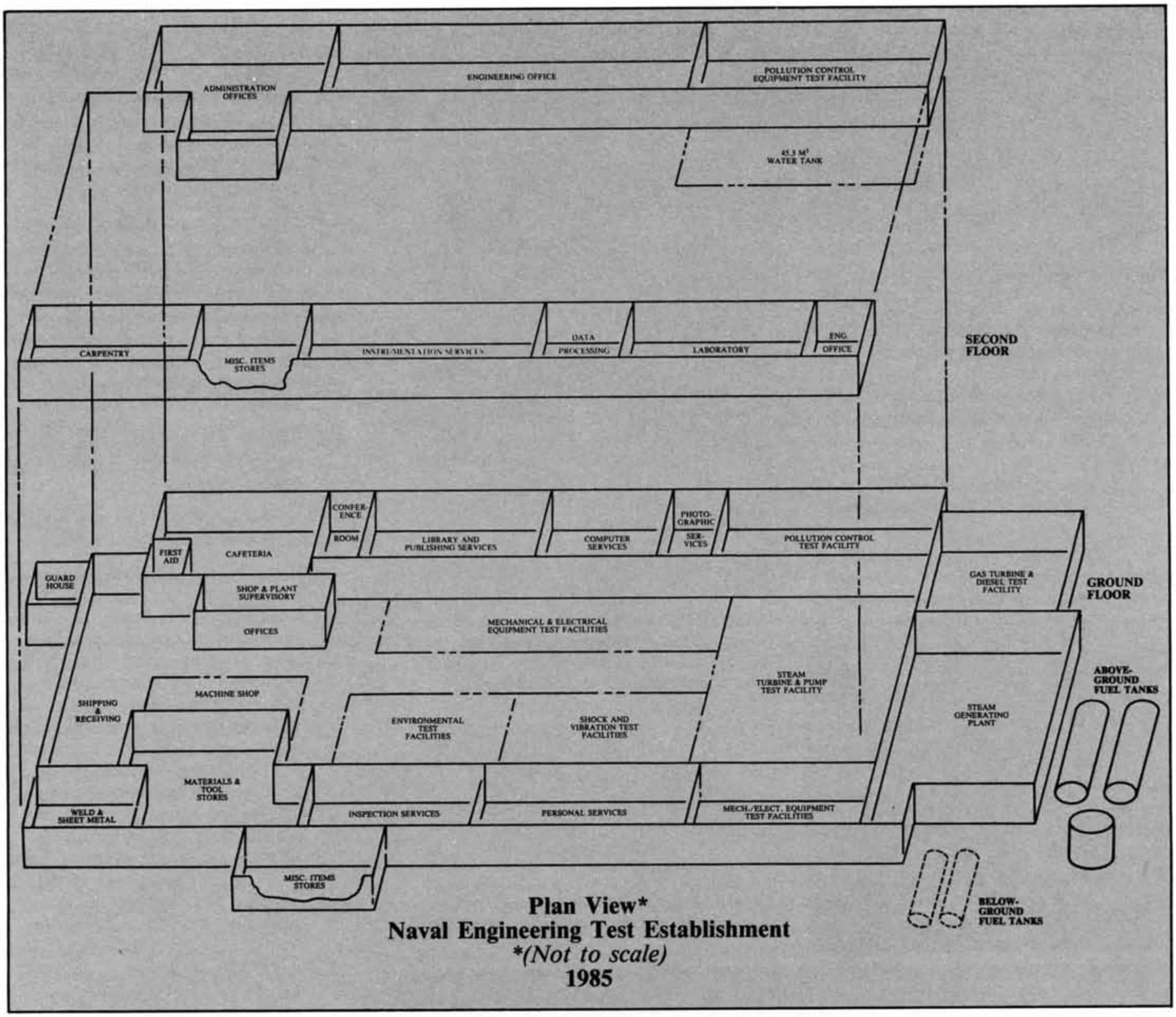
(a) The 200-hour performance run of the plant was satisfactorily completed. (Figure 5 shows the plant's three sections interconnected for the operational test.) However, an undesirable operating condition was brought to light early in the 200-hour run which permitted the boost pump in Section 3 to continue operating even in the event of no flow, which would surely damage the pump. NETE modified the plant-control design to preclude the pump operating without flow for the balance of the 200-hour run, and will recommend that it be incorporated in the plant design. Numerous leaks of a minor nature were observed and corrected in the course of conducting the operational run.

(b) Section 1 satisfactorily completed the shock test.

(c) The noise levels of the plant sections were borderline, yet acceptable to the OPI. The structureborne vibration levels of Sections 2 and 3, however, exceeded the acceptable levels.

The manufacturer has contracted the services of a consultant to propose modifications to the mounting and/or equipment installation arrangement of Sections 2 and 3 to reduce their structureborne vibration levels. NETE is being considered for implementing the modifications.

Once the modifications have been completed, the noise and structureborne vibration tests will be repeated and the outstanding tests conducted. The retests and additional costs involved necessitate a revision to the original tasking and



Plan View*
Naval Engineering Test Establishment
**(Not to scale)*
1985

authorized expenditure. NETE will be required to obtain the OPI Director's acceptance of the retests and additional costs.

On the basis that the retests and outstanding tests are satisfactorily completed, NETE will be responsible for preparing a test report. Once the report is issued, NETE submits a project closure request to the OPI's Director for acceptance, and he in turn forwards it to DGMEM/RM for approval and formal closure.

In view of NETE's involvement and familiarization with the reverse-osmosis desalination plant, the OPI may request NETE's assistance in setting the plant to work once it has been installed onboard. If this does happen, a new project tasking would have to be promulgated.

Summation

The intent of this article is to familiarize readers with the services and facilities of NETE for the purpose of optimizing their utilization by interested parties. Further information on NETE is available from an audio-visual slide presentation, and from the Report On Proceedings (issued every six months) which reviews the project work in progress. Requests to acquire the services of NETE, loan of the audio-visual slide presentation or Report On Proceedings should be made to DGMEM/RM in NDHQ.

J. Costis graduated from the North Carolina State College in 1956 with a degree in Mechanical Engineering. During the three years following his graduation, he worked as a design engineer in the field of material handling for the Aluminum Company of Canada and in powerplants for the Power Corporation. He joined NETE in 1959 and held the position of Project Engineer until 1965, specializing in the testing of mechanical/electrical equipment and systems. He was Chief Test Engineer up to 1967, being responsible for the administration and technical supervision of the engineering department. Since 1967 Mr. Costis has been the Manager responsible for the administration, operation and maintenance of NETE.

Reliability Centred Maintenance

How to Put the Method into Preventive Maintenance Madness

by LCdr R.J. Gebbie

Introduction

On 26 July, 1984 a new *"Naval Maintenance Policy"* was promulgated by DGMEM and endorsed by CMDO and MARCOM (ref 1), which in part stated that:

"The requirements for preventive maintenance (PM) will be determined by use of the analytical techniques called reliability centered maintenance (RCM) which establish:

a. *Whether PM will be done at all;*
b. *If so, whether it will be time-based or condition-based;*
c. *What the PM tasks will be."*

The above statement represents a major shift away from conventional maintenance planning which is heavily reliant on historical data. The introduction of this new maintenance policy will apply to maritime engineers and technicians whether they are maintaining current equipment or designing new ships. Therefore, it is the purpose of this paper to provide the naval engineering community with some of the important concepts of RCM, and to emphasize the support that will be required by all levels of the branch if RCM is to become a viable maintenance programme. (A more detailed introduction to RCM can be found in the January 85 and June 85 editions of the NAMMS Newsletter.)

History of RCM

In the late 1950s the successful emergence of jet-powered commercial flight requiring increasingly complex equipment with growing maintenance costs warranted a new look at maintenance philosophy. It became obvious that maintenance had to be geared to the achievement of the highest reliability for the least cost.

In 1967 airlines first applied RCM techniques to the problem of optimizing safety and reliability versus cost of preventive maintenance tasks. It provided an efficient approach since it directly faced the primary question of the impact of unreliability of operation. In 1968 RCM formed the basis for the design of the initial maintenance programme for the Boeing 747. Since then, similar methods have been used on the DC-10, L-1011, Concorde and Boeing 767 and 757 (ref 3).

In the early 1970s the work attracted the attention of the United States Navy which applied this new preventive maintenance programme to both newly designed and in-service aircraft. The prototype application to surface ships was initiated in the USS *Roark* (FF-1053) in 1978. In mid-1979, as a result of favourable evaluations of RCM in four additional FF-1052-class ships, an ongoing programme for application of RCM to both new and in-service naval ships was implemented in the USN (ref 4).

Aspects of RCM are already being used in the Canadian Forces to varying degrees. In the Canadian navy RCM is an integral part of the CPF design and construction process, TRUMP and CASAP, and in the land forces, RCM

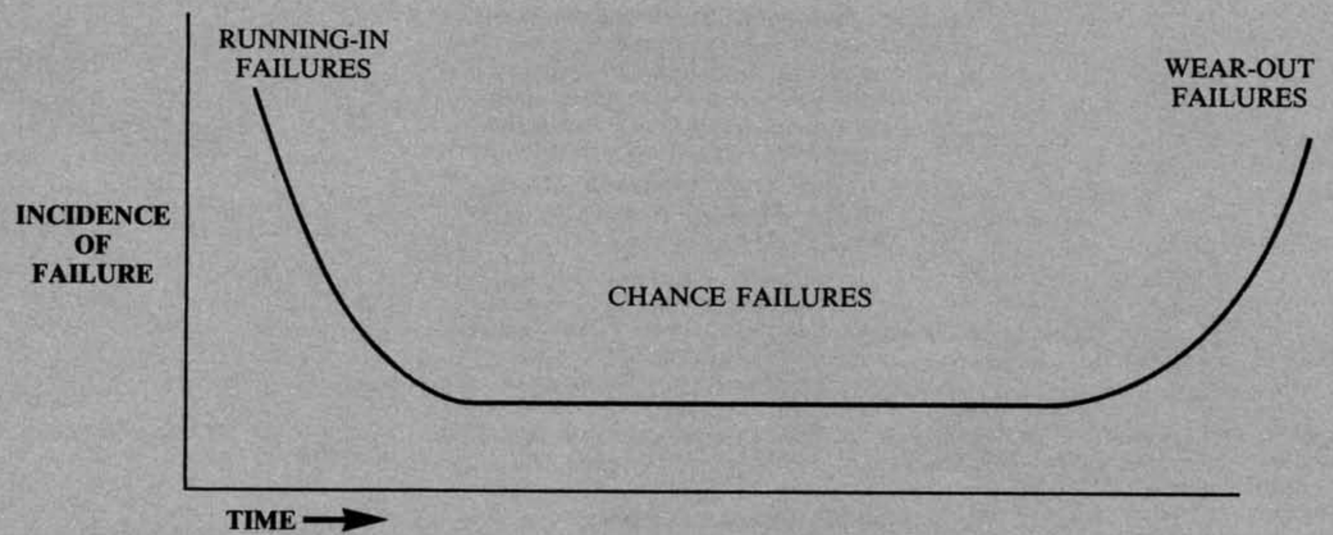


Figure 1. The Bath-Tub Curve

techniques were used in the high-mobility, multi-purpose wheeled vehicle acquisition programme. At present, though, RCM is used the most extensively on the air side. At the Aircraft Maintenance Development Unit (AMDU) at CFB Trenton, RCM techniques are applied in all planned maintenance programmes for fixed-wing and rotary wing aircraft in the Canadian Forces.

Objective of RCM

The objective of RCM is to achieve and retain the inherent reliability which has been designed into equipment. However, RCM does not presume that hardware requires preventive maintenance in order to achieve this inherent reliability, but uses knowledge about systems and their failures to identify applicable and effective preventive maintenance tasks. In other words, preventive maintenance must be matched to the inherent reliability of the equipment.

Some Common Misconceptions

In order to determine the right match between an equipment's reliability and its required planned maintenance, several factors must be considered. First, each component, subsystem and system has a tendency to fail. This tendency can be reduced to some minimum level by maintenance activity, however there may be some failures which are unpreventable regardless of the frequency of inspection or replacement. This may come as a surprise to many who believe that the risk of failure increases only with age. In fact, just the opposite may occur during the "running-in" period of an item. To illustrate the different failure rates which can be exhibited by a complex system, the "bath-tub" curve is presented in Figure 1.

If replacement of parts is the only form of preventive maintenance available, then replacement during the item's "running-in" and "chance-failure" stages will be wasted effort since it *will not* reduce the probability of equipment failure. On the other hand, preventive replacement during an item's "wear-out" stage *will* reduce the probability of equipment failure in the future.

Secondly, it is necessary to be able to quantify the current reliability characteristics of the equipment. This requires some form of failure tracking (i.e. SMMIS) and an understanding of the modes of failure that may occur. Also, the inherent reliability of the equipment cannot be improved by maintenance activity, but only attained. The item's reliability can only change through modification or redesign.

Finally, it is usually not sufficient to base the PM periodicity for equipment on mean time between failure (MTBF) since MTBF only gives the average age at which failure might occur. By recalling the bath-tub curve, it will be evident that MTBF does not take into account the effect of increasing age upon risk of failure. Thus, PM for equipment in the chance-failure stage will not be applicable if the equipment enters a wear-out phase. As an aside, the latest revision to the Maintenance Action Form (CF 1304) includes the equipment's operating hours which can be used to determine the equipment's location on the bath-tub curve.

RCM Terminology

Before proceeding further, the reader should be familiar with the following terminology used in RCM:

Hard Time: Maximum interval for performing an overhaul or replacement maintenance task. Usually applies to items requiring periodic overhaul or items having specific life expectancy (through age or usage) which dictates scheduled replacement. Also referred to as "time-based maintenance" (ref 1).

On-Condition: Inspections or tests scheduled on a recurring basis to determine the condition (deterioration) of an item. Also referred to as "condition-based maintenance" (ref 1).

Condition Monitoring: Condition-monitoring maintenance requirements are unscheduled tasks. Condition-monitored components are those that are allowed to fail, or those for which impending failure can be detected by the operator or crew through routine monitoring during normal operations.

Maintenance Significant Item (MSI): Items which have an immediate impact on safety or operational capability or those that have non-operational consequences but are expensive to repair or have hidden failure consequences.

Failure Mode Effects and Criticality Analysis (FMECA): An FMECA identifies the following for each MSI:

a. Function — the normal, characteristic actions of an item;
b. Functional Failure — how an item fails to perform its function;
c. Failure Effect — the results of a functional failure;
d. Failure Cause — why the failure occurs.

RCM: New and In-Service Equipment

The required input data for both in-service and new systems is approximately the same. However, the sources of such data are different, causing the RCM analyst to approach these types of systems in varying ways.

a. **New Systems**
A failure mode, effects, and criticality analysis (FMECA) is a very valuable tool in the engineering of a new system under development. The FMECA identifies the specific conditions that are the dominant causes for functional failures — the conditions that a PM task is intended to prevent or discover. This analysis, together with the system partitioning (i.e. system, subsystem, component), can be the major source of information for identifying candidates for planned maintenance. In fact, since there is no field experience information on development systems, this predicted information is the primary source of input for future RCM analysis.

b. **In-Use Systems**
Most in-service systems have not had FMECA performed (usually due to the high cost), so the best sources of information for input to RCM analysis consist of field experience contained in the Ships' Maintenance Management Information System (SMMIS), unsatisfactory condition reports (UCR), and pre-installation failure (PIF) reports.

Decision Logic — The Heart of RCM

Decision logic is the vital link in transposing FMECA data, or field-maintenance records, into specific maintenance tasks designed to attain inherent equipment safety and reliability levels at the lowest life-cycle costs. It has been defined as a "process to reduce a complicated problem to a number of simple questions to obtain definitive answers that lead to a reasonable and justifiable resolution" (ref 6). For RCM, the decision-logic process is applied to a failure mode of an MSI to determine what maintenance action will most significantly avert such a failure mode.

Several variations of decision-logic diagrams are currently available (refs 3, 4, 5, 9). However, regardless of their format, their objective is to assist the RCM analyst in determining the best maintenance activity for each MSI. The analyst works through the logic diagram by answering the questions in each of the columns of Figure 2 (i.e. operational and safety criticality, regulations, economics, and detection methods potential). In this manner the analyst is led through the decision-logic diagram to a recommended maintenance action for the item based on the answers he has supplied to the questions.

Determination of Inspection Interval

After the RCM decision logic has identified the best maintenance activity for a candidate, it is then necessary to determine the optimum inspection interval. At the same time, intervals for other items under consideration for planned maintenance should be combined in order to minimize equipment downtime.

For certain U.S. Army aviation equipment on which tests have been conducted, or field experience for which data have been compiled, optimization of maintenance intervals is being accomplished through the use of computer software packages. For example, "Mavis" (ref 6) is a computer simulation of aircraft inspection, usage, and repair which significantly reduces maintenance costs and improves mission reliability. Use of "Mavis", however, requires an extensive and comprehensive base of reliability and maintainability data concerning the system or equipment. Also, the system or equipment must exhibit failure modes characterized by the failed item entering a deteriorated state at some measurable interval prior to total (catastrophic) failure.

The age-reliability data used in "Mavis" is usually not available for ship systems and associated equipment. Therefore, the RCM analyst is required to determine planned maintenance periodicity based on his own careful analysis. The "LSA Analyst's Guide to Preparation of LSA/MP Documents for the Canadian Patrol Frigate Program" (ref 5) recommends that when there is a threat to safety, and the associated failure is time-related, a conservative approach based on past experience is required to ensure a very high level of effectiveness. A non-safety related failure mode requires a careful evaluation of the impact of failure, the effectiveness of the task, and the resources required to perform the task. Generally, failures which have little impact on the ship's missions and which require significant resources should have tasks assigned as infrequently as possible. It should also be remembered that in most maintenance tasks a risk exists that failure will be induced through improper performance of the task. Thus, selection of any periodic tasks means that the analyst believes, after careful consideration of the available information, that the user will be better off by performing the task than by not performing it.

The U.S. Navy's *"Reliability Centered Maintenance Handbook"* (ref 4) recommends that if there is a lack of current information about the effect of age on reliability, then the best action to take is to pick a periodicity that seems logical. Subsequently, this period can be reviewed and possibly extended without adverse results.

RCM — An Example

The following example illustrates the need for higher mathematics in many RCM problems. It also illustrates the important role an effective maintenance information system plays in the collection of failure data for RCM analysis.

The item under analysis is the main transmission in a helicopter (say, a Sea King) that has the function of transmitting engine power to the main rotor, tailrotor, and various accessory drives. After the RCM analysis it was determined that the failure modes of the transmission required either condition monitoring, on-condition monitoring (i.e. oil analysis) or hard-time replacement. After performing an FMECA on the transmission, the RCM logic chart (Fig. 2) was applied to determine the best maintenance task. In this case it was determined by the RCM analyst that a Spectrometric Oil-Analysis Program (SOAP) should be implemented for the transmission.

The next step was to determine the optimal interval for taking the oil-analysis samples. For safety considerations, an inspection interval must be established which gives an acceptably low probability of failure during the period when an impending failure would go undetected. This time period is the time from the end of the last inspection to the time of the next inspection, minus the time from detectable failure onset to failure. The probability of a failure occurring during this time period is represented by the following expression:

$$\mathrm{PNTI} = \int_{(N-1)\,TI}^{NTI - TOS} f_{NTI}(t)\,dt$$

where:

- **TI** = time between inspections
- **N** = positive integer
- **TOS** = time from failure onset to failure
- $f_{NTI}(t)$ = failure distribution for the transmission

By performing statistical analysis techniques on data obtained from the equipment's maintenance information system, it was possible to determine the probability of a failure occurring and not being detected in the time between any two inspection points during the service-life of the equipment.

The following list is the average probability of going to failure without detection (PNTI) for selected times between inspections (TI). The interested reader is directed to Reference 6 for a more comprehensive explanation of the mathematics used in this example.

TI	PNTI
25 hrs	.003636
50 hrs	.0247
100 hrs	.0575

For this example, the design authority set the maximum allowable PNTI at 0.025. Based on this criterion the RCM analyst recommended an inspection interval period of 50 hours to be scheduled for oil sampling in order to ensure that this component of the helicopter would have at least a 97.5% probability of completing its mission in a 50-hour time frame.

Can We Meet the Challenge?

The application of RCM requires personnel from three areas of expertise. Firstly, RCM analysis should have input from engineers who understand the intended use of the equipment. Secondly, this should be complemented by experienced individuals who know how the equipment actually performs at sea. Finally, there must be someone with an understanding of reliability analysis.

In the new Naval Maintenance Policy (ref 1) it stated that "LCMMs are to apply the analytical techniques of Reliability Centred Maintenance to determine the maintenance requirements of their systems". While it is quite reasonable to expect the LCMMs to implement the policies of Reference 1 (i.e. repair by replacement, on-condition maintenance versus hard-time maintenance, etc.), it is perhaps unreasonable to expect them to be responsible for "applying the analytical techniques" without the support of a cell specializing in reliability analysis. Who will they turn to for assistance while performing "multi-mode Weibull Analysis" or "regression analysis" which are some of the fundamental mathematical tools used in equipment failure analysis? Albeit LCMMs can be introduced to these techniques on "short courses" (such as the 3-day Engineering Maintenance Management Course, or the 3-week Reliability & Maintainability Engineering Course), they may need to consult with experts when attempting to apply these newly learned techniques to real-life problems. (See the boxed example of an RCM problem which in practice required support from a cell of expertise.)

In a report from the USAF Air Command and Staff College (ref 7), it was stated quite clearly that wholehearted endorsement and support of the RCM programme is needed for it to be effective. A piecemeal approach with insufficient support from the higher levels of management in the USAF caused serious problems in the effective application of RCM in that service, which resulted in a seven- to ten-year delay in its general acceptance and implementation.

In order to avoid the failures experienced by the USAF, it will be necessary to implement RCM in a manner which will ensure its success. Since RCM is not new to the CF, the navy can benefit from the experience gained by other branches. For example, the Maintenance Analysis Branch (MAB) has been involved in the RCM process for over ten years and has begun to create the foundation of a true RCM programme for the CP-140 and CF-18 aircraft (ref 8). By liaising with the AMDU and other government agencies, the learning curve in the areas of policy, planning and evaluation may become somewhat less steep.

The Reliability, Availability and Maintainability (RAM) section in DMES 6 was manned in April 1984 in order to provide some statistical analysis capability for SMMIS data. Notwithstanding the fact that it is a new section, significant increases in resources and expertise must occur in order to develop a standard comparable to its equivalent section at the AMDU at CFB Trenton. In light of this statement it is interesting to note the following observation from a recent review of SMMIS by the Director of Management Consulting Services:

"Once RAM experience has been acquired, then these personnel should teach LCMMs, ships' staffs, fleet-school instructors and other key technical personnel how to analyze SMMIS data using whatever statistical methods are necessary. A RAM analytical capability must be finely developed if the swing to on-condition maintenance and reliability centred maintenance is to happen."

Summary

The introduction of RCM into naval maintenance policy will provide a more rational approach to the maintenance of naval systems. Instead of assuming that preventive maintenance is required, equipment health monitoring and analytical techniques as well as common sense will determine the equipment maintenance needs (if any are required at all). As a result, maintenance activities will tend to move away from more or less arbitrarily scheduled inspections, or

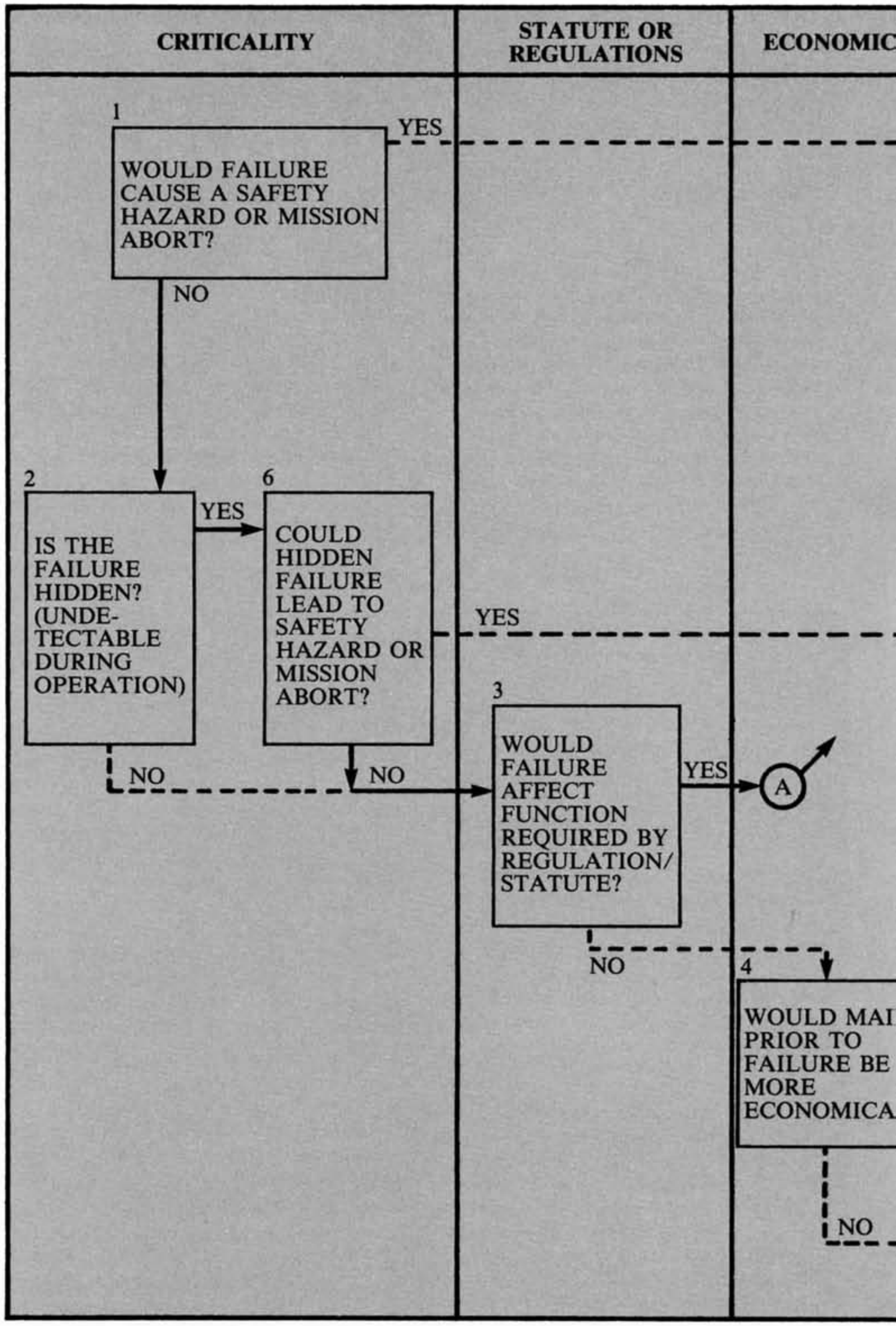
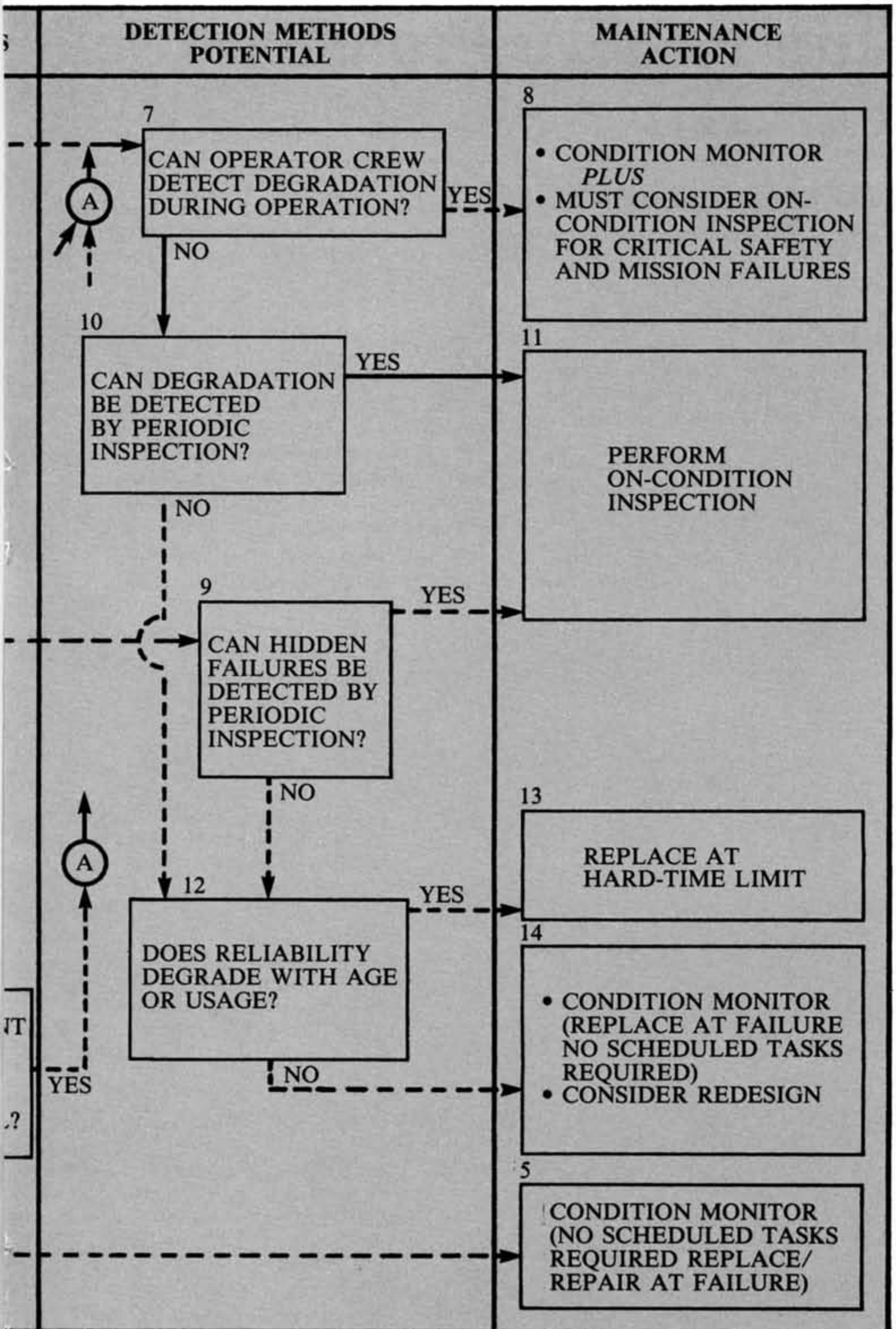


Figure 2. Decisi



n-Logic Diagram

overhauls based on a fixed time, to a variable schedule based more often on the condition of the item.

RCM is not new, as it has been vigorously practiced in the commercial airlines industry since 1967. And it was not long before the U.S. Navy recognized the critical link between operational reliability and maintenance of equipment. In the Canadian Forces, the AMDU at CFB Trenton has taken the lead in applying RCM techniques in the determination of all aircraft maintenance schedules However, the navy is equally committed as the RCM policy forms an integral part of the CPF, TRUMP and CASAP programmes.

The success of this new maintenance policy will depend upon the amount of support given it by the naval engineering community. More expertise in the techniques of RCM will be required as the new maintenance policy grows to fruition. This can only be obtained through in-service courses and post-graduate training. As the field of naval maintenance becomes more sophisticated and challenging, we can look forward to eliminating some of the "madness" from preventive maintenance.

LCdr Gebbie graduated from the Royal Military College of Canada in 1976 and spent the next several years training in Marine Systems Engineering. In 1979 he was posted to SRU(P) where he worked in the areas of advanced planning, contracts and destroyer-refit scheduling. He went back to sea as the MSEO in HMCS Terra Nova *from 1981 to 1983, and afterwards returned to RMC to obtain a Master of Engineering in Industrial Engineering, specializing in Reliability and Maintenance Information Systems. LCdr Gebbie is currently with the Industrial Engineering Division of SRU(A).*

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Ship Passive Protection (Part II)

by LCdr Derek W. Davis, P. Eng.

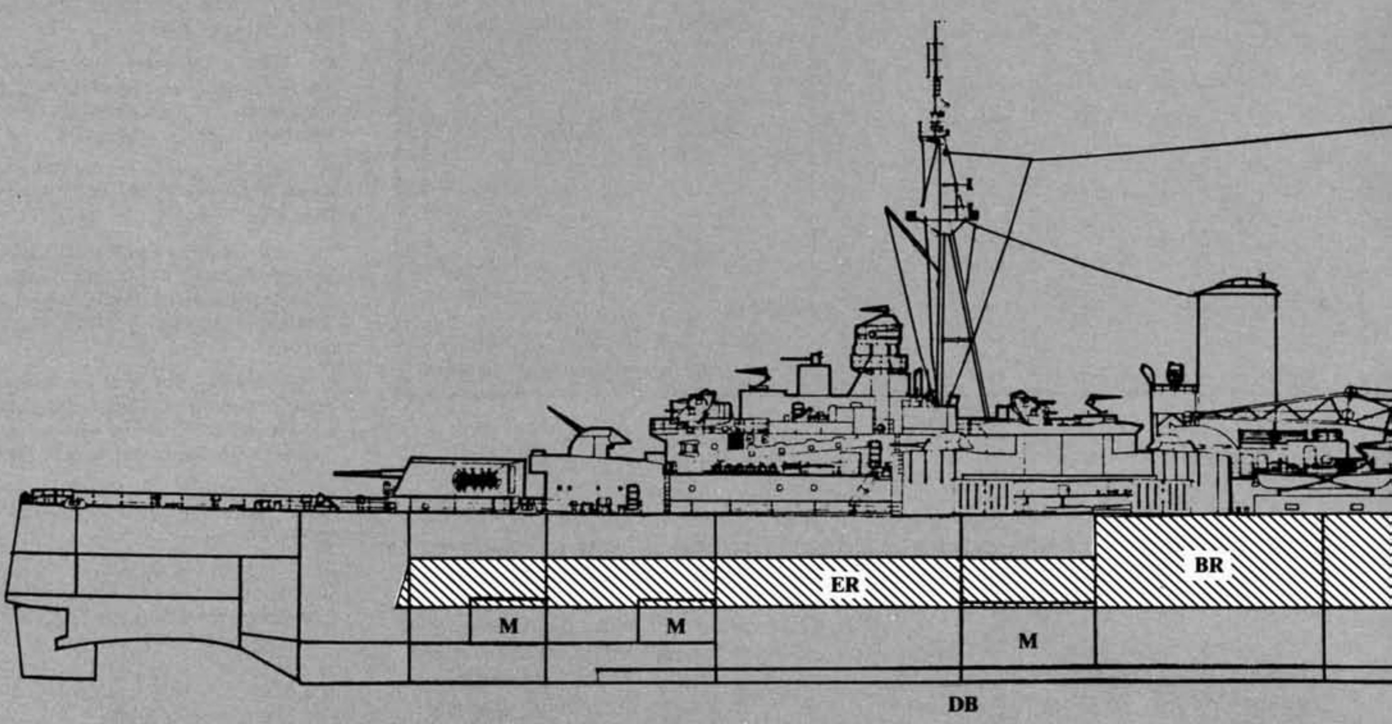
Editor's Note: Part I of this article which appeared in the September 1985 issue discussed measures that can be taken to reduce the risk of a ship being detected and to enhance the capabilities of one's own ship's sensors. The second and final part of this comprehensive look at ship passive protection examines features that can improve a ship's ability to survive damage and weapon effects, and discusses the rationale for the degree to which passive-defence features are incorporated in ship design.

Introduction

Historically, ship designers have always built in features to minimize the effects of enemy weapons upon their ships. Much of the time this simply meant adding greater thicknesses of wood, iron or steel to defeat the latest form of projectile. Gradually, with the introduction of new technology such as the self-propelled torpedo and the airplane, things became more complicated as additional features (i.e. spaced armour, redundant systems and damage-control features) came to play an important part in a ship's ability to survive an attack. With the development of the atomic bomb, though, many of the reasons for fitting certain passive-defence features were thrown into confusion because no system of protection could save a ship from the power of such an awesome weapon.

The emphasis on countering the threat of nuclear weapons during the post-war era gradually led to the construction of warships today that are

Figure 1. WW II Cruiser Compartment Location and Protection



sometimes referred to as "eggshells armed with hammers". To some extent certain aspects of warship survivability have been compromised in the process.

Recent events in the Falklands and the Middle East, however, have indicated that navies today must still be fully prepared for conflicts involving conventional weaponry. Even then, many of the claims that certain weapons are capable of "one shot — one kill" have been seen to be overrated in combat situations. As a result there now seems to be a reawareness of the value of incorporating survivability features in warship design.

This resurgence of interest in ship survivability is no doubt due also to the realization by most navies that their once relatively inexpensive frigates and destroyers are being replaced by fewer and significantly more expensive ships. The loss of a vessel is relatively more costly today than it was 20 to 30 years ago. Thus, it is worth investigating any measures which can reduce the risk of a vessel being lost, or increase a ship's ability to withstand weapon effects. The overriding criterion, though, is to incorporate features that will allow maximum operational capability for a given amount of damage to the ship.

LIMITING DAMAGE

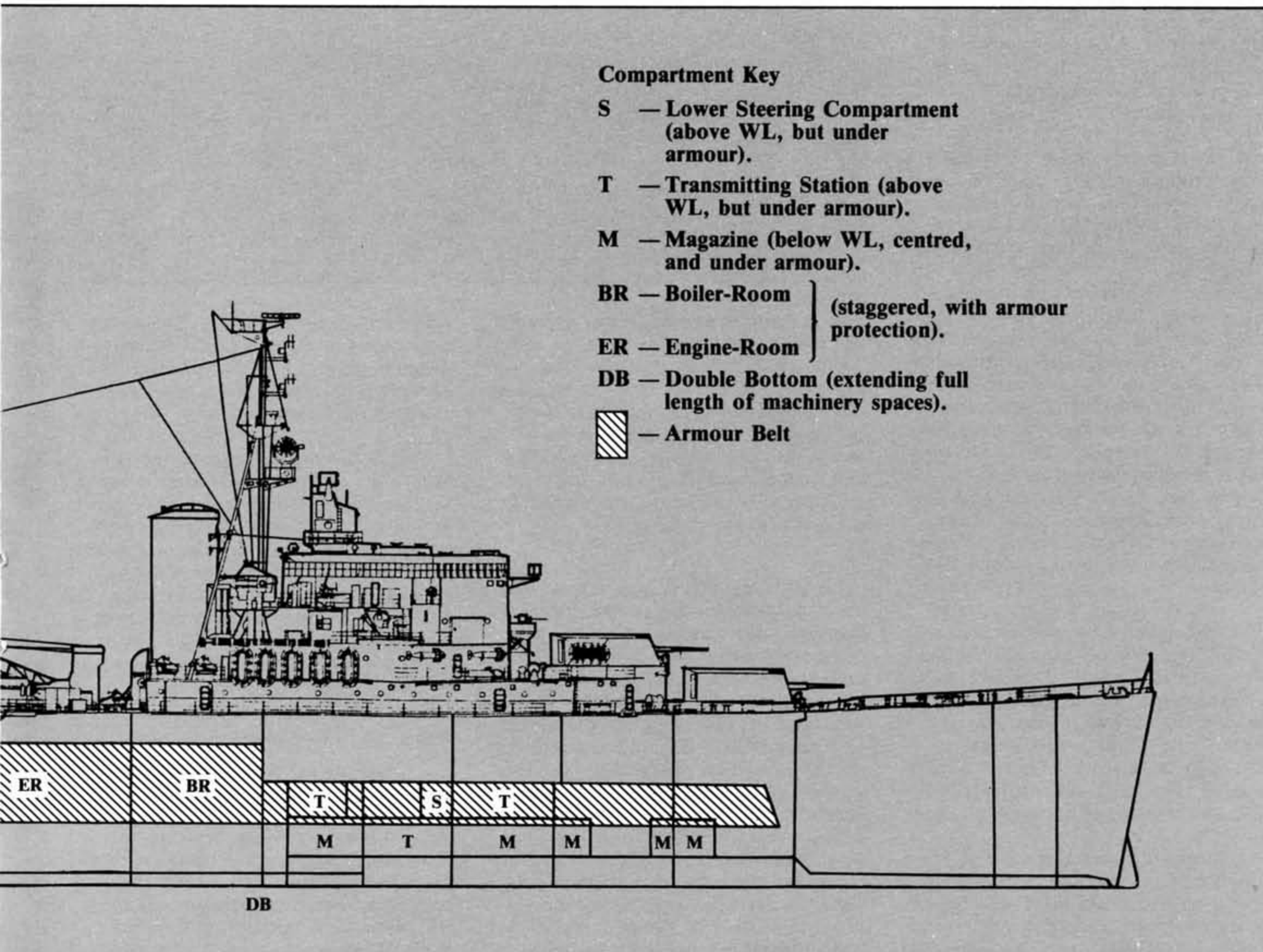
The aim of course is to employ measures that can prevent weapon effects from damaging the ship's structure and/or reaching her interior systems. The simplest (and oldest) way is to make the ship's outer skin impenetrable, but not all modern threats take the form of projectiles or explosives. Besides which, the weight of structure needed to protect against the entire gamut of conventional threats is almost impossible to achieve in all but the largest vessels. One must rely not only on thicker hull-plating, but also on the intelligent use of the ship's structure and system/equipment/compartment location (see Fig. 1) to counter the typical threats.

Underwater Threats

Contact Explosions

The invention during the last century of the mine and the self-propelled torpedo created new problems for the ship designer. The effect of a large explosion adjacent to a ship's hull, where it's force is amplified by the water around it, cannot be resisted by any reasonable amount of thickened hull-plating or strengthened framing. Instead, one can only attempt to reduce the effects of such an explosion by creating distance between it and the system being protected.

An early method was to install anti-torpedo nets on booms projecting from the ship's side. This system worked well while the ship was in harbour or operating at slow speeds, but was totally impractical when the ship was operating at speed in the open sea. Thus, "torpedo bulges" came to be incorporated in most large ships. The bulge typically consisted of a thin outer skin to detonate the warhead, a space into which the explosive



could vent its force, and a thicker backing plate to withstand the explosive destruction of the outer plating. Over time these bulges came to be incorporated within the main hull-structure, as we now find in contemporary capital ships.

To increase the efficiency of these systems, the space between the outer and inner plates was often subdivided by several longitudinal bulkheads. The enclosed volume between some of these bulkheads was then filled with oil or water to help defeat the explosion by spreading its force over a wide area of resistant plating. However, if all of the voids were filled with fluid the shock would be transmitted directly to the interior bulkhead, so at least one of the intervening spaces was always left empty.

Unfortunately, problems with asymmetric flooding can occur when these spaces are breached, and any ship fitted with such anti-torpedo features must have very good inherent stability and adequate counterflooding systems. The stability factor results in vessels that are fairly beamy relative to their length, while the counterflooding systems place extra demands on the ship's pumping capabilities with their attendant increases in the amount and complexity of auxiliary systems.

Another aspect of this method of protection is that the use of such a system often affects the vessel's underwater form. As the depth of water increases, so does it's backing effect on an explosion next to the ship's hull. Therefore, to maintain a similar degree of protection, the distance between the ship's vitals and her outer skin should increase the closer one gets to the ship's bottom. But from a hydrodynamic viewpoint it is better to round the vessel's sides in towards the keel, which tends to have just the opposite effect. A compromise is to make the vessel's cross-section comparatively square (Fig. 2). While this increases ship resistance, it still allows machinery to be located low in the ship and provides room for the necessary side protection.

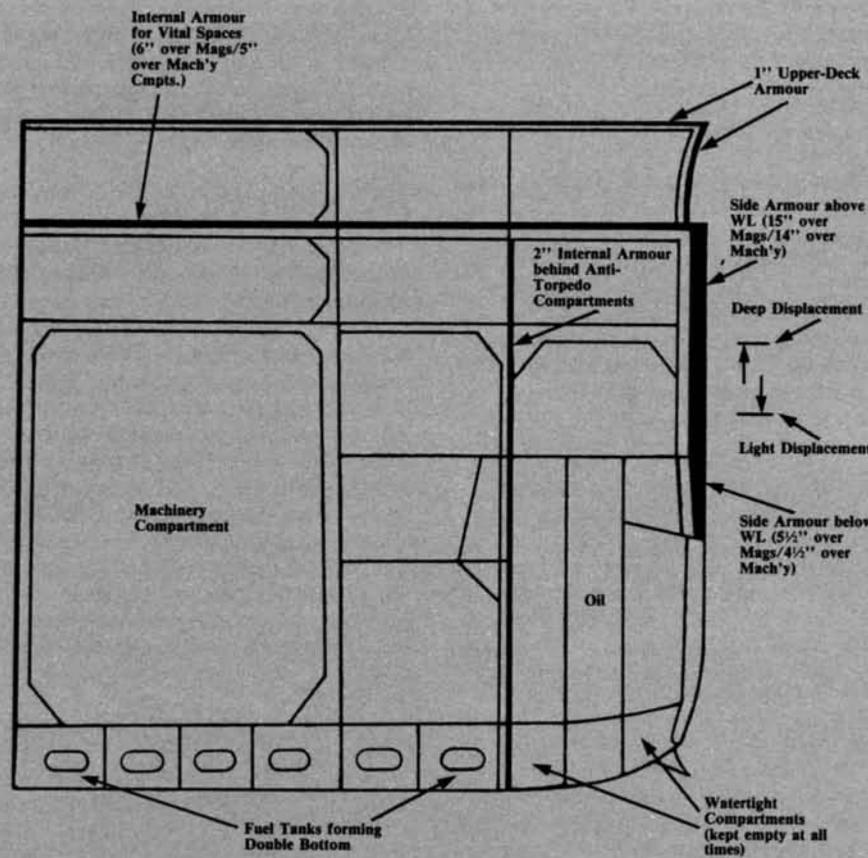


Figure 2. Cross-Sectional View of the Defensive Features of a *King George V* Battleship

Although such protection systems do work they are very expensive in terms of ship internal volume. A present, only aircraft carriers (and large ones at that) can afford the luxury of such arrangements. Cruisers and smaller warships must continue to rely on features such as extensive subdivision and inherent stability to keep afloat and remain operational.

Most warships today are designed to withstand the flooding of three compartments (or the equivalent of 15% of the vessel's length) before sinking. Owing to the relatively low transverse waterplane area in many smaller warships, asymmetric flooding can easily result in the vessel capsizing. To prevent this, any features likely to cause such an occurrence, particularly centreline longitudinal watertight bulkheads, are kept to a minimum. Where they are necessary, such as in the case of fuel and ballast tanks, the fitted cross-connects can be used to ensure that the tanks flood coincidentally.

To this point we have focused on the immediate flooding danger, however there are other dangers such as the loss of essential systems and hull strength. To prevent loss of essential systems involves locating them away from the impact zone, and in larger ships this is achieved by placing athwartships distance between the danger and the ship's vitals. But in smaller vessels where the athwartships distance is inadequate to absorb the damage, one must make use of longitudinal distance to move vital equipment away from the vulnerable midships area. Thus, emergency generators and diesel fire-pumps could be located at the vessel extremities away from the machinery spaces amidships. (Due to the large radius of damage from underwater weapons, there is little to be gained by using vertical distance for protection except in the largest ships.)

Another aspect of protecting against the effects of underwater attack is that the loss of hull cross-sectional area resulting from an explosion can be devastating. Should sudden flooding not sink the ship, catastrophic failure of the hull-girder surely would. Strengthening the hull-girder and incorporating extra-thick plating or over-strength longitudinals at the upper hull-flange can provide some protection against this danger.

Non-Contact Explosions

Non-contact explosions encompass a wide variety of threats including those from abovewater near misses, own weapon's detonation and specially designed weapons employing non-contact fuse systems. Many of the design features which defend against contact weapons are useful against these threats, but there are particular aspects of these devices which require further defensive measures to be built into the ship.

An underwater explosion produces a rising, oscillating gas bubble that can exert a tremendous force against anything with which it comes in contact. The effect of this can be even more catastrophic than if a warhead exploded directly against the ship's side. The employment of this as a method of attack was first used by the Germans during World War II at great cost to the Allies. The ideal situations was to explode a warhead directly below a ship's keel where the resulting oscillating gas bubble would be trapped by the hull above it. As the bubble expanded and contracted it would alternately lift and drop the ship, eventually overstressing the hull-girder through whipping until the ship broke in two.

One possible countermeasure to this is to absorb the gas bubble during its first pulse by using a double bottom with an outer skin thin enough to absorb the energy of the pulse by buckling, yet thick enough to withstand the normal pressures of the sea. Unfortunately a double bottom requires extra internal volume low down in the ship, typically in the machinery compartments which in smaller ships are often so densely packed that they are short of space to begin with. And since the effectiveness of the measure increases with the separation of the inner and outer plating, usually only relatively large vessels can afford the volume for an effective system. Again, apart from using a double bottom there is little else one can do except to build sufficient flexibility and strength into the upper-deck plating or longitudinal framing.

Even if an explosion does not occur close to the hull, the ship might still be subjected to an intense shock-wave. The effects of a shock-wave against the ship's bottom can deform or rupture bottom-plating and framing, or be transmitted through the vessel's structure to cause damage to fitted systems and equipment. To defend against this, the bottom structure must be made to absorb a specified amount of punishment prior to giving way, and the ship's internal structure must be both strong and resilient with the emphasis being on maintaining a uniformity of strength throughout the design. This requires careful attention to detail particularly with regard to such things as reinforcements and structural connections. If they are too weak they will break under shock, but if they are too strong they might act as hardspots that will not flex with the rest of the structure and will crack.

To guard against the effects of shock on the ship's internals, one must provide protection in the form of mounting methods and individual design features for all of the ship's important systems, machinery and equipment. This means not only providing shock mounts for equipment and resilient hangers for, say, piping or lighting systems, but also providing adequate space for movement of the equipment under shock load. Moreover, equipment must be made sufficiently rugged to withstand the accelerations and decelerations that can be experienced on resilient mounts. It is for this reason that brittle materials (such as cast iron) cannot be used in vital equipment.

Abovewater Threats

Abovewater weapons pose a more varied threat than underwater weapons due to the greater number of weapon characteristics and modes of delivery. In addition many abovewater threats can easily turn into underwater problems in the event of a near miss. Furthermore, not only must a ship resist conventional abovewater threats, but it must also be able to defeat the particular attributes of chemical, bacteriological and nuclear weapons.

Conventional Threats

To be protected against the effects of conventional abovewater weapons, a ship's systems must resist the effects of explosion, fragment damage, fire and blast. At one time initial protection was provided by increasing the thickness of the ship's side-plating, but even in battleships there was not always sufficient buoyancy to protect all the spaces against the possible threats. As a result, armour or protective plating came to be apportioned where it was needed most, typically over the magazines, engineering spaces and control positions — the thickness of the armour being dependent upon the compartment's importance. Later, with the advent of timed fuses and armour-piercing bombs and shells, a topside or bursting plate was positioned on the vessel's shell. The plate would cause these projectiles to explode and expend their energy in a less important space before contacting the armour about the vitals.

In the USN's *Iowa*-class battleships portions of the hull are protected by up to 307mm of armour plating, with even greater thicknesses protecting vital equipment such as the gun turrets and barbettes. But such weights of armour require a large (over 56,000 tonnes) ship to carry them, and as one descends the tonnage scale to ships that we are more familiar with (say, 5,000 tonnes), the ability of the vessel to carry substantial armour decreases.

In the past, however, even small combatants had some type of protection for vital equipment even if it were only some form of splinter-plating. U.S. destroyers of the same vintage as the *Iowa* class, for example, employed up to 19mm of special tempered steel over their machinery spaces, bridges and gun-directors, and splinter mats or "plastic armour" panels were often fitted around exposed positions on the upper deck. The "plastic" armour was actually a composite of stone chippings embedded in bituminous cement with a thin steel backing for rigidity and support. Even the lowly corvette had some such protection as well as a certain amount of splinter-plating.

The advent of the electronic age has made the provision of such protection more difficult, partially due to the vast increase in the volume of spaces needing protection. In the pre-electronic age a large portion of a vessel's vital compartments consisted of her machinery spaces or other spaces within the hull such as the magazines. The majority of the armour protection was thus relatively low down where it did not have an extreme effect on the ship's natural centre of gravity.

The requirement that most sensors, communication gear and weapons must have their associated data-processing equipment close by has led to ship designs where the majority of such equipment is located high up within the hull and superstructure. The designs of the DDH-280 and USN CG-47 are good examples of this. But to enable these ships to operate with adequate stability, countermeasures such as permanent ballast, water-displaced fuel systems and aluminum superstructures often have to be provided. Fitting even moderate amounts of steel protection is clearly impractical because of the dangerous increase to top-weight.

However, in view of the threat posed to such vessels by the "cheap kill" phenomenon, several navies are now recognizing the value of new, light-weight armouring materials such as KEVLAR, aluminum composites or NAVTRUSS (a corrugated core, all-welded sandwich panel material) which can provide the equivalent protection of steel plate for much less weight. Some types of KEVLAR are claimed to offer the same amount of protection as twice their weight in steel. Many U.S. ships are now being retrofitted with light-weight armour, and in the FFG-7 class it is rumoured that up to ¾ of an inch of aluminum armour has been fitted around the magazines with ¾ of an inch of KEVLAR protecting all vital electronics and command spaces.[1] The light weight of these composite materials means that they can also be used to protect the extremely vulnerable antenna motors, waveguides and cable runs which are situated in exposed upper-deck and mast locations.

Although compartment armour does offer some protection, every millimetre of armour is costly in terms of weight and money. A better solution is to situate vital compartments where they have the least chance of being hit by placing the maximum distance, athwartships and vertically, between the compartment and the most likely point of weapon impact on the vessel's shell. Thus for abovewater threats, as a general rule, compartments should be sited low on the centre-line, and away from the midships area where RCS and IR signatures are usually high.

In addition to the danger of a direct hit on a compartment's exterior bulkheads, there is the danger that the effects of an internal explosion will be transmitted through the ship to remote vital spaces. One can either build armoured boxes around each of the vital compartments (which is very expensive in terms of weight) or, more practically, design the ship's bulkheads to withstand the overpressure generated by such an explosion. In missile magazines where even in peacetime there is danger of sudden internal overpressures (e.g. accidental firing of a rocket motor), an alternative protection system of blow-off ports or gas vents can be employed. When such compartments are located below the weatherdeck, however, the vent trunking to the upper deck will use some of the ship's valuable internal volume.

NBC Defence

The dangers posed by *unconventional* threats can be countered by many of the measures discussed so far, but some particular aspects of nuclear, biological and chemical weapons require that additional defence features be built into a vessel.

Nuclear

With regards to a nuclear explosion, a ship must be able to withstand the actual detonation which, in itself, is a conventional (albeit high-risk) threat. As a defence against *blast*, all of a vessel's abovewater structures, vital fittings and equipment are usually built to withstand a specified overpressure of (typically) 3 to 7 psi above atmospheric.[2] But in addition to this, the ship's configuration must be designed to avoid "blast traps" (i.e. such things as acute interior structural intersections, overhangs and any other features which may focus and increase the pressure from a blast). If blast traps can't be avoided, then they should be suitably reinforced.

Thermal Effects

Damage from the thermal effects of an explosion can be caused by conventional or nuclear weapons. To protect against this danger involves taking care in the choice of materials for structural and important fittings. Metals, alloys or composites which lose or change important characteristics such as ductility or tensile strength at elevated temperatures must not be used for "important" exterior applications. This can prove particularly significant for such features as masts and antennas which are often made of high-strength materials or composites which possess just these failings.

Electromagnetic Pulse

The explosion of a nuclear device produces an instantaneous flash of electromagnetic energy which can destroy or at least seriously affect the solid-state electronic components found in most modern ships' systems. To defend against these effects requires not only attention to the details of circuit and individual equipment design, which are the perview of the equipment designer, but additional care in the design of ship structure and layout.

In particular the ship designer must attempt to prevent the field energy created by the burst from reaching and affecting the ship's internal components. This requires attention to three particular design areas. Firstly, vital electronic equipment must be kept away from the ship's exterior since the field energy can diffuse through the ship's structure. Secondly, the structure and fittings must be checked to ensure that they don't act as antennas and transmit the effects of the pulse into the ship's interior. Features which are likely to cause these problems include exterior cables and waveguides. Thirdly, the direct entry of the pulse into the ship through openings in the ship's structure must be prevented. Thus particular care must be taken in the design of doors, hatches, intakes, exhausts and similar means of access and egress.

From an overall design viewpoint, these features all lead to an interior, low-down position being the best location for components sensitive to EMP effects.

Radiation, Chemical and Bacteriological Agents

To defend against the effects of these weapons, a ship's first line of defence includes the familiar pre-wet and citadel facilities such as are found in Canadian warships. But to ensure that these systems work properly involves paying attention to the details of a ship's upper-deck and superstructure design. The fitted sprays must adequately cover all areas of the superstructure, and any features which affect the spray pattern or inhibit the flow of water overboard should be avoided. The use of deck camber, the avoidance of pockets and the provision of adequate drainage all contribute to ensuring the proper operation of the system.

Although the pre-wet system can help to prevent radioactive particles and chemical and bacteriological agents from adhering to the ship's skin, preventing the ingress of such material to the ship's interior through the air supply involves providing a gas-tight citadel with a positive internal air pressure. In order to maintain this pressure some "make-up" air has to be drawn into the ship through filter units to replace any leakage. Thus to minimize the amount of make-up air required, care must be taken during design, construction and maintenance to ensure that there are no unintentional air leaks from poor structural joints, worn glands or poor bulkhead penetrations.

Since the aim of the citadel system is to prevent the exposure of personnel to the various contaminants, the ship must be designed to keep the crew off the upper deck or, in the case of radiation, away from the ship's side. Such modern features as enclosed bridges and unmanned upper-deck weapons have done much to contribute to the integrity of the citadel. Airlocks and cleansing stations must be provided where access is required to and from the upper deck and the various non- or sub-citadel spaces such as the machinery rooms. These constitute yet another consumer of ship's interior volume.

In order to keep personnel away from the probing effects of radiation, it is best to locate manned spaces in positions where structure, the sea and distance can be used to shield the compartment. The possibility of such protection gives added incentive to placing vital manned compartments, such as the operations room, deep in the ship. The thicker ship's structure and the sea can provide shielding from the sides, while the intervening structure and distance to the upper deck can provide overhead protection.

MAINTAINING CAPABILITY

Should a vessel's own weapons and countermeasures (including the use of structure and location) fail to prevent damage to the ship's vitals, then other design features must be availble to reduce or negate the effects of the damage on the ship's capabilities. The designer must therefore incorporate the concepts of *back-up, separation, duplication* and *avoidance of single points of failure* in the overall passive protection scheme of the ship.

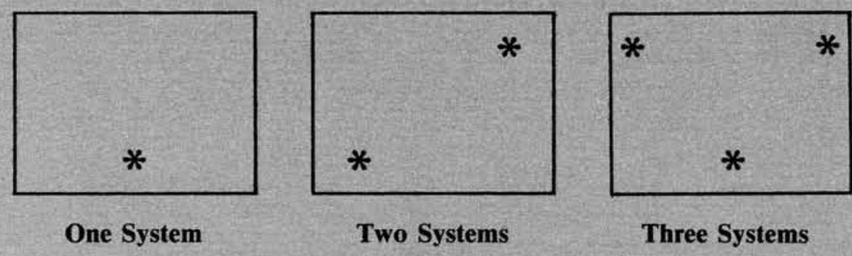


Figure 3. System Separation Configurations

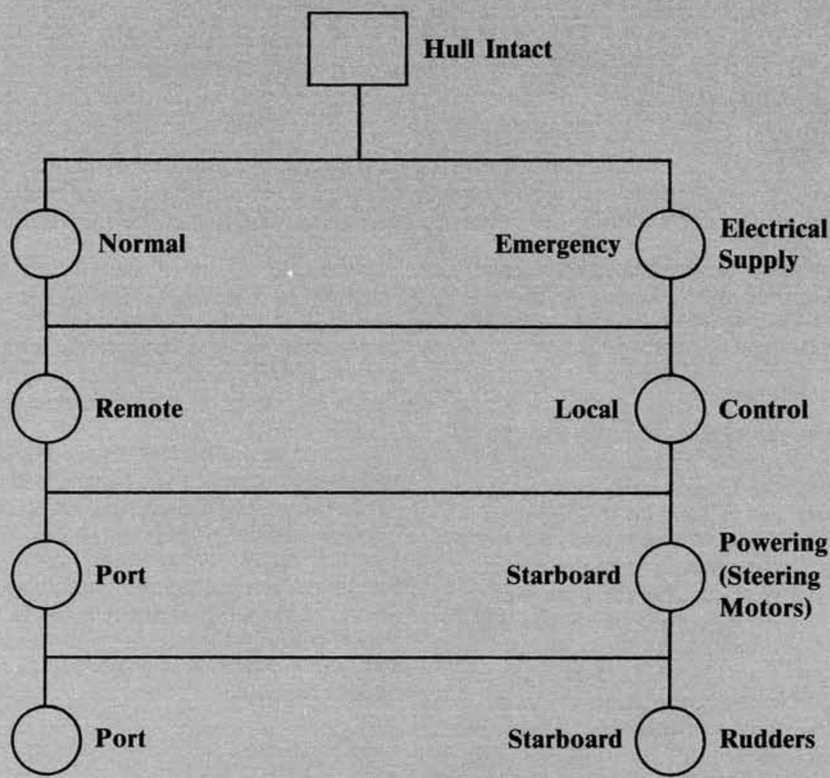


Figure 4. Simple Fault-Tree Diagram
(Items needed to allow use of rudders)

Back-up

This refers to the provision of alternative, less sophisticated equipment or systems which, while not as capable as the originals, still allow the maintenance of a certain, albeit lower, level of performance. For example a fire-control radar may be backed up by an electro-optical device, which in turn can be backed up by a manual designator. A back-up does not necessarily have to be a physically distinct system. It can be a secondary mode of a system in which certain otherwise necessary components are bypassed.

Separation

This concept refers to the idea of physically separating the main and alternate or duplicate systems from one another to prevent total loss of capability from a single hit.

The distance required for separation is usually based upon the defined damage radius of a weapon. For example, in practical terms, underwater damage (in the longitudinal sense) may be equated to flooding three adjacent watertight compartments or 15% of the ship's length. Thus by ensuring that back-up equipment is always available outside of these limits one ensures some survival of capability. In the transverse and vertical directions, back-up equipment and systems must usually be situated on different decks and on opposite sides of the vessel. When combined with the earlier requirements for a protected location, these requirements can lead to configurations similar to those shown in Figure 3.

Duplication

Whereas *back-up* encompasses the provision of less capable equipment or systems, *duplication* involves providing multiples of the same type. There is usually greater duplication in the more important systems, but not always for reasons of survivability. In some cases the duplication of equipment is necessary to provide the full capability of a particular system (e.g. the main engines). In other cases duplication provides much more capability than is operationally necessary, but is justified by the need for overhaul and maintenance as well as survivability — a good example being the ship's fire-pumps where the loss of one or two can usually be accepted without a great decrease in normal useful capability.

Single Points of Failure

Back-up, physical separation and duplication — the latter two in particular — imply independence of operation. A failure in one system must not affect the second. This can only be accomplished through a ship-level rigorous elimination of *single points of failure*. This can be any single component which, through its loss, will cause total loss of a specific capability. Often thought of as a piece of equipment, it could equally be a connection box, a pipe or a wiring run. Using the example of the fire-control radar, the utility of the electro-optical back-up is compromised if both it and the fire-control radar receive their electrical supply from the same power panel.

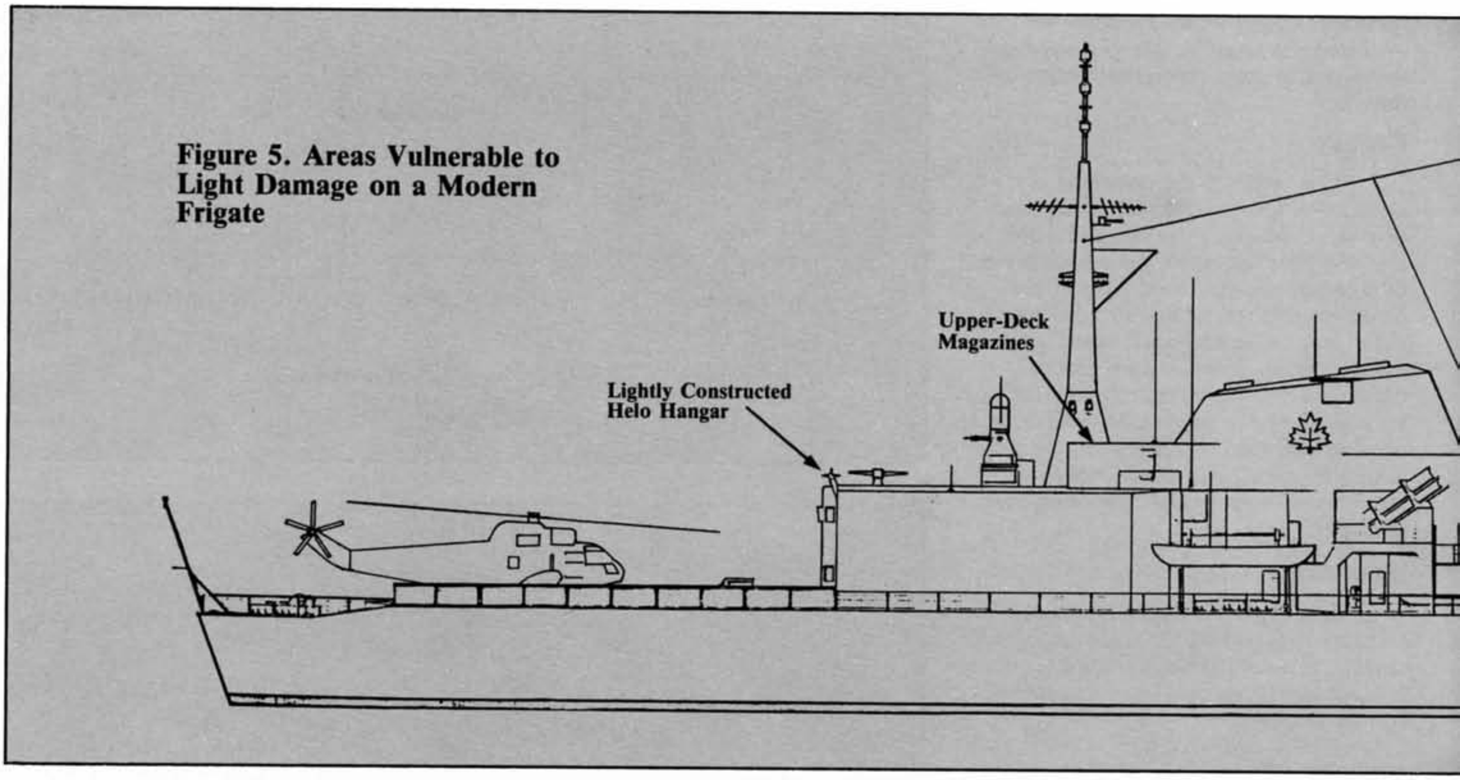
Fault-Tree Diagrams

In order to integrate the three concepts of *back-up, separation* and *duplication* into a survivable system, a fault-tree diagram (Fig. 4) is usually constructed. By using it to identify single points of failure or, say, back-up duplicated systems which are not sufficiently separated, the designer can work towards increasing overall survivability.

APPLICATIONS

To appreciate how these concepts are closely interrelated, it is necessary to

Figure 5. Areas Vulnerable to Light Damage on a Modern Frigate



examine some of the ship-level measures which are incorporated into the hull, marine and combat systems to assist the ship's survivability.

Hull Systems

By the nature of modern structural design, a conventional warship hull is fairly robust. Longitudinal framing systems, the use of welding and the incorporation of high-strength steels all give a degree of resistance to the immediate effects of weapons. Larger ships are sometimes fitted with extra, major bottom longitudinals in addition to the main keel, but in smaller ships there is usually not sufficient space to allow the incorporation of such structural redundancy. However, extra-thick shear strakes and deck-plating have been used to provide a measure of extra hull-strength in some post-World War II U.S. destroyers.

Should a vessel not be immediately destroyed through initial damage there still remains the possibility of it eventually sinking through a loss of stability and/or buoyancy. To prevent this, the designer must arrange the overall weight and bulkhead distribution of the ship such that it can survive flooding over a significant area. In addition he must incorporate features which reduce the risk of gradual or progressive flooding reaching compartments not affected by the initial attack. Careful attention must therefore be paid to the design and positioning of doors, hatches, ventilation and machinery ducting, and piping and cabling runs. Wherever such items penetrate watertight bulkheads or decks, suitable gland arrangements or other means of maintaining watertight integrity must be provided. And, of course, the number of penetrations must be kept to an acceptable minimum, and should be located above the waterline whenever possible.

The choice of abovewater hull-form can also contribute to enhancing a damaged ship's stability and survivability. The use of flare throughout the hull's length provides greater waterplane area for greater immersion, and this slows down the rate of loss of metacentric height compared to the normal wall-sided ship and provides greater protection against capsizing.

Ship Systems

A ship's systems are usually preserved from damage and kept functioning by siting them in well protected areas, and by providing redundant systems as back-ups. It is not the purpose of this article to examine particular equipment or system details, but rather to discuss the overall philosophy behind designing passive protection features for these systems. In some places, though, specific examples will be cited.

Marine Systems

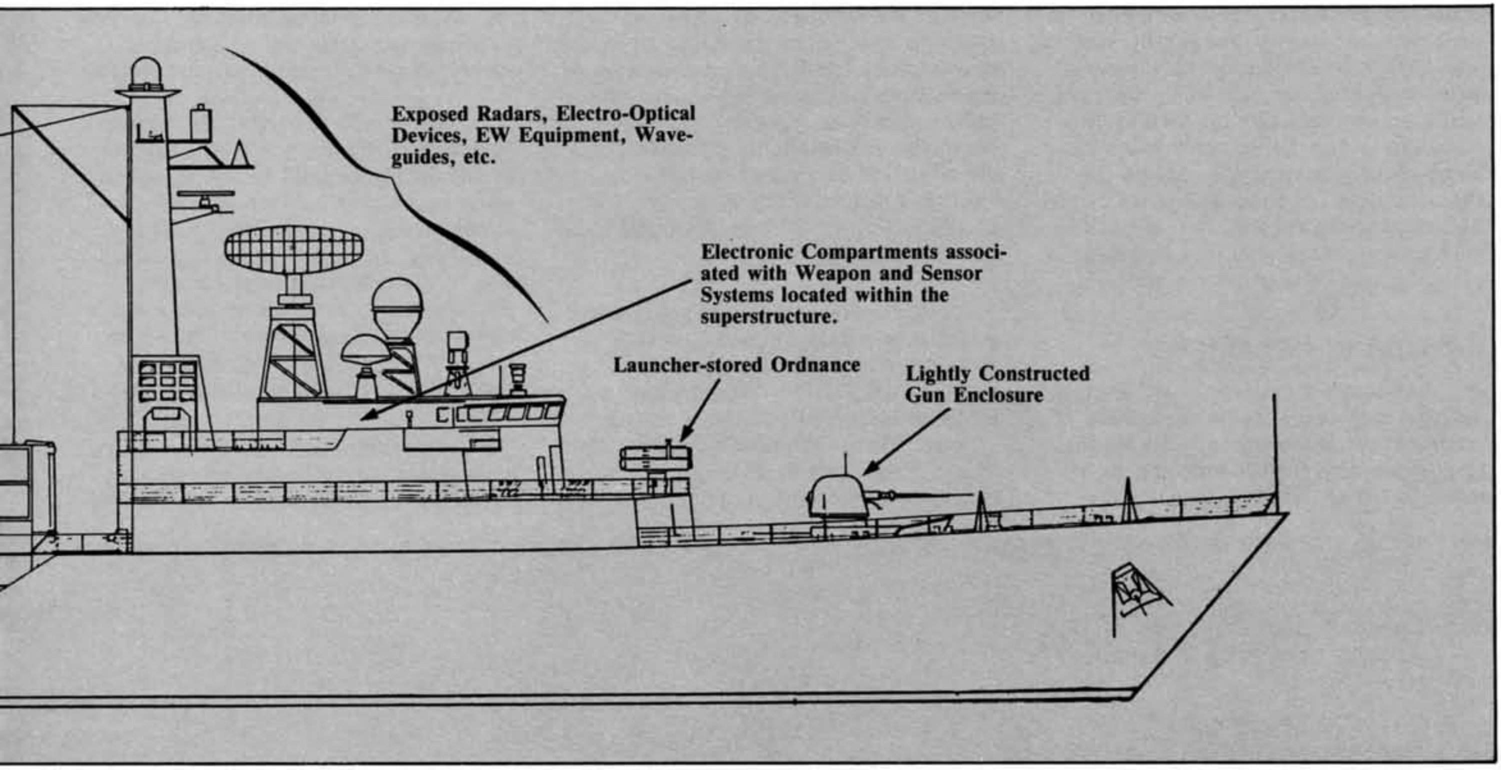
The protection of main-propulsion and auxiliary machinery is mostly concerned with the dangers from underwater threats because such machinery is usually located deep in the ship's hull. And considering the large damage radii of the principal underwater weapons (the mine and the torpedo), the best method of protection is to provide separated, multiple independent machinery units.

Larger vessels such as carriers or battleships may, for example, have up to four shafts, each driven by autonomous propulsion plants separated both transversely and longitudinally. Additionally, the propellers are arranged to ensure the survival of at least a portion of their number given a hit anywhere in the stern area. In these large ships multiple rudders are often fitted and arranged for the same reason. Together, the various combinations of multiple propulsion units and control surfaces provide redundancy in power and manoeuvrability.

The use of longitudinally separated independent machinery plants for each of a vessel's shafts is practicable in vessels of destroyer and frigate size (e.g. the Danish *Peder Suram*). But for frigates and smaller escort vessels it is sometimes felt that the power of modern explosives and the smallness of the hulls makes the value of fitting separate main-propulsion or shafting plants questionable. Instead, one suggested solution involves fitting the vessel's main machinery aft, away from the usually targeted midships area, and fitting an auxiliary or emergency propulsion unit close to the bow. The FFG-7 is an example of this type of design.

Auxiliary Systems

Ships' auxiliary systems are often overlooked when survivability measures are being designed into a warship, yet without them a vessel cannot operate. They provide the hotel services for the



crew, the power and ancillary services for the propulsion, weapon and sensor systems, plus they form the basis of many of the vessel's damage-control features.

The provision of adequate redundancy for such systems usually involves the provision of at least two sources of power, optimally situated in widely separated compartments. (The arrangement of emergency diesels in our own DDEs and DDHs is a good example of this.) An important aspect of building redundancy into auxiliary systems is the provision of *different* types of power sources for essential equipment. For example a ship might have multiple, main generators run by steam or gas turbines which will be backed up by independent diesel generators. Or, for a system such as the firemain, in addition to the alternate electrical supplies for the motor-driven pumps, there will also be pumps driven by steam or independent diesels. Thus, even a complete loss of electrical power will leave some capability in the system.

The importance attached to the new capabilities provided by the growth in electronics has particularly affected the design of auxiliary systems since many previously overlooked and less important systems now require improved levels of survivability. In addition to the requirements for adequate redundant electrical power supplies, back-up sources of cooling air, chilled water and dry air must also be provided.

Combat Systems

Maintaining combat capability follows very much the same methodology as that for maintaining capability in a ship's marine systems, however the inherent vulnerability of most combat equipment makes the task much more difficult. Survival of capability usually depends on a scheme of separated, back-up or duplicate systems, but given the power of modern airburst weapons the separation necessary to ensure survival is quite large. In a small warship the provision of a back-up or duplicate sensor or weapon system is best accompanied by significant longitudinal separation.

The current practice of placing all of a ship's control equipment in centralized operations rooms and MCRs automatically creates single points of failure for much of the ship's combat capability. Fortunately, a possible solution to this problem is now on the horizon. Within a few years it should be possible to do away with systems based upon large centralized computers and replace them with a network of smaller, distributed processors. The much-heralded SHINPADS, with its built-in system redundancy, would greatly increase the chances of a ship maintaining its combat capability. In any event, the concept of a centralized operations room, MCR and damage-control HQ will probably continue for organizational and operational reasons related to decision-making.

With today's greatly increased data-processing ability and use of distributed networks such as SHINPADS, the staffs of these centralized control areas could be restricted to a few, key decision-makers, and the remainder of the system operators could be dispersed to work stations throughout the ship. Should the required facility become sufficiently small, alternate locations and teams may then become affordable within a destroyer or frigate-sized hull.

Personnel

The various structural features for protecting vital manned compartments have already been mentioned, but other protective measures could include the decentralization of accommodation and personal stores, along with the provision of alternate victualling and medical facilities. The design should be such that an entire facility cannot be destroyed by a single hit. Unfortunately, though, these arguments often fall foul of such considerations as ease of storing or the desire to group trades by mess.

Zoning

One of the biggest problems with ships today is that the various components of systems are scattered throughout the ship. A hit in any one area of the ship can easily affect the remote equipment. Therefore, to prevent this, ship designers have begun to "zone" interdependent systems within the same area of the ship between a set of watertight bulkheads. The idea is that each zone can continue to operate independently of other parts of the ship which might be damaged.

To carry out the process properly, all the components necessary to a desired capability must be identified and placed within the same area. Should combat capability be involved, the sensor, control and applicable weapon delivery systems must be located coincidentally, while the necessary auxiliary services such as electrical power and chilled water must also be provided. Carrying the concept further, the zone can form a separate citadel and damage-control zone within the ship with its own installed air-conditioning, pumping and fire-suppression services.

RESTORING CAPABILITY

Although a vessel's second-level defences may minimize the immediate consequences of a weapon effect on the ship, preventing further problems as a result of fire or flood requires the services of the Damage-Control Organization. Since this is such a broad topic, this paper will be restricted to a discussion of the features of general ship-design philosophy rather than specific system and organizational details. In particular, attention will be focused on those ship features which ease the work of the DC parties and which will get the vessel back into operation quickly.

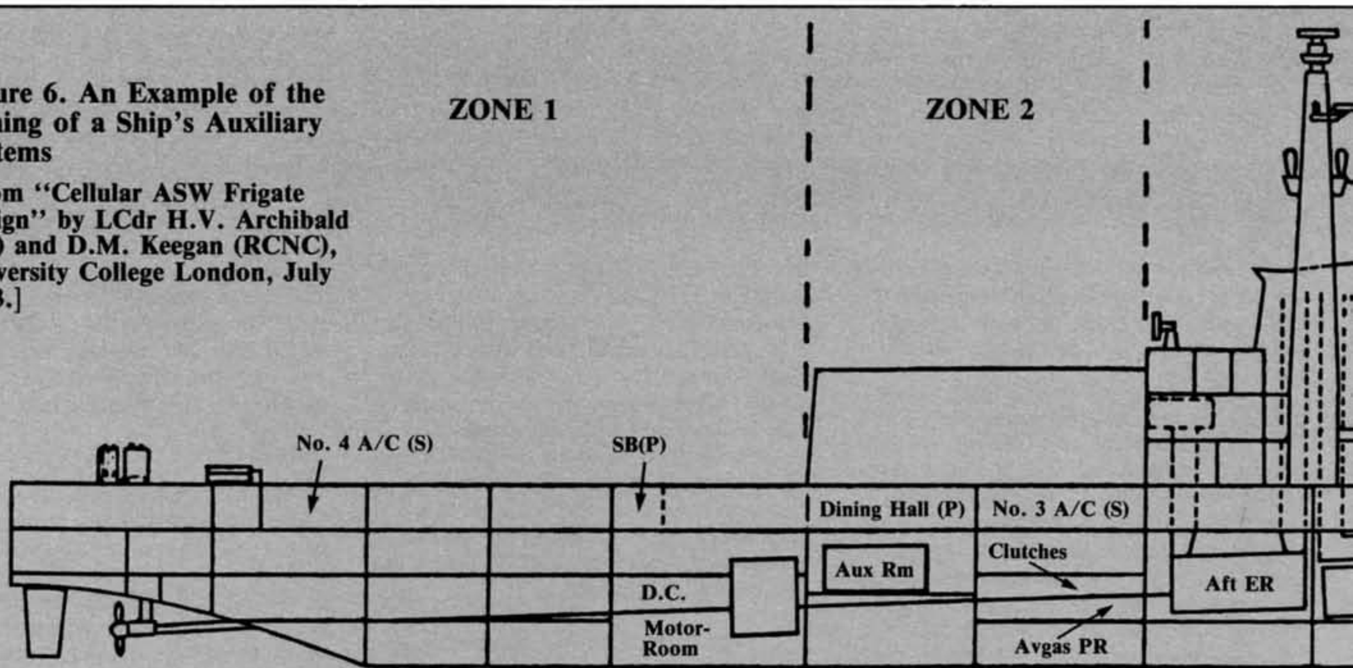
Redundancy and duplication are essential to a damage-control system, so when providing alternate power and pumping supplies the designer must not forget to incorporate back-up control systems. These can include built-in redundancy in the form of alternate, automatic systems and control positions, and a final manual back-up in the form of a lazyrod to permit remote operation should a space become inaccessible or uninhabitable.

Along with providing the necessary equipment to fight the effects of fire or flood, the ship should be configured to allow easy access between various parts of the vessels — particularly those spaces containing equipment vital for continuation of the damage-control function. Therefore, the provision of adequate escape scuttles is particularly important, not only for evacuation purposes, but also for access to damaged compartments.

A continuous, straight, fore-and-aft passageway should be provided to ease movement of personnel in a smoke-filled

Figure 6. An Example of the Zoning of a Ship's Auxiliary Systems

[From "Cellular ASW Frigate Design" by LCdr H.V. Archibald (CF) and D.M. Keegan (RCNC), University College London, July 1983.]

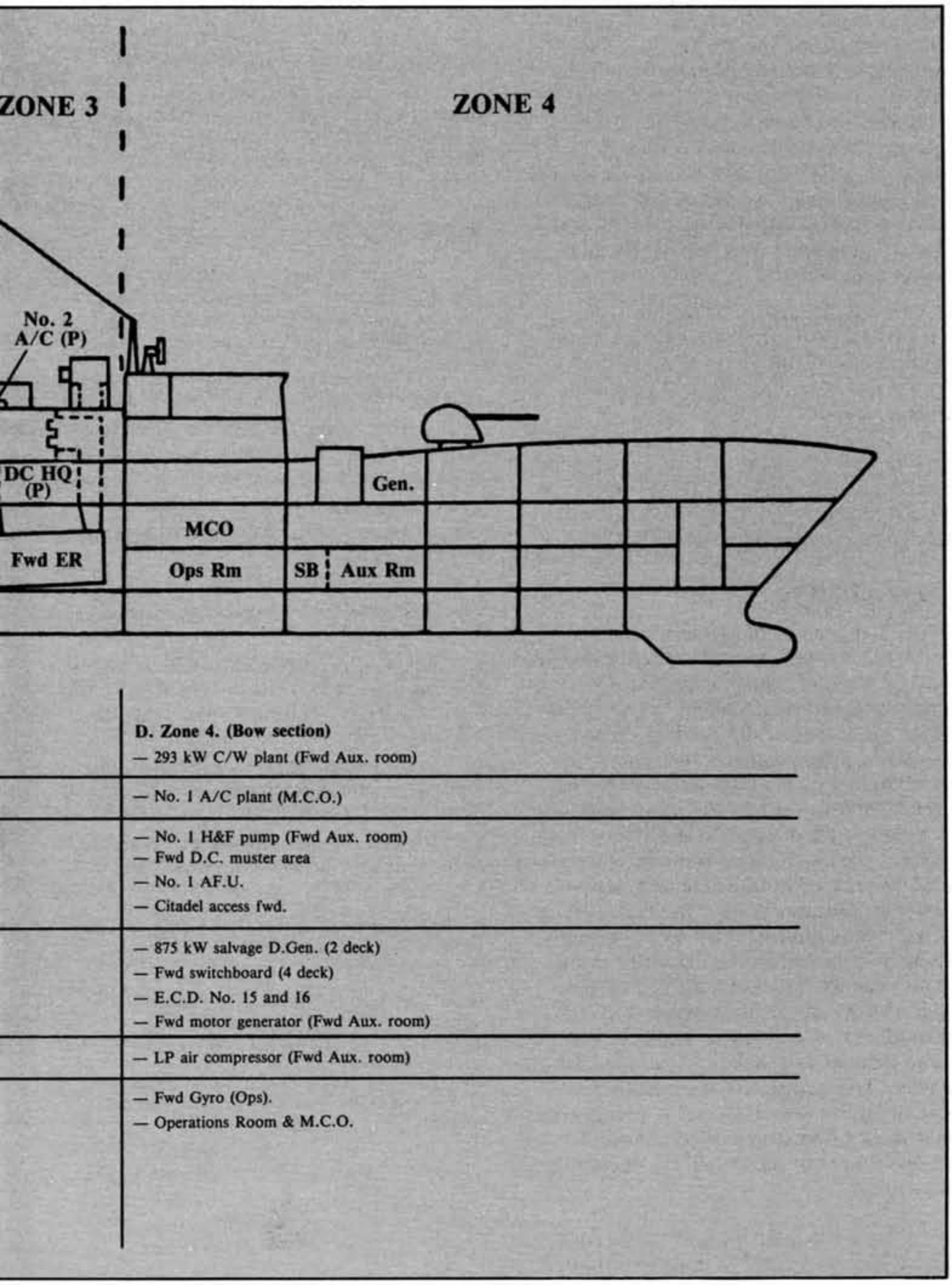


	A. Zone 1. (Stern section)	B. Zone 2. (Aft midships)	C. Zone 3. (Fwd midshi
1. Chilled Water	— 293 kW C/W plant (DC motor-room)	— 293 kW C/W plant (aft Aux. room)	— 293 kW C/W plant (F.E
2. Ventilation	— No. 4 A/C plant	— No. 3 A/C plant	— No. 2 A/C plant (2 dec
3. NBCD & DC	— No. 4 H&F pump (DC motor-room) — Aft citadel entrance — Aft DC muster area — No. 4 A.F.U.	— No. 3 H&F pump (Aft. Aux. room) — Aft DC HQ (Dining Hall) — No. 3 A.F.U.	— No. 2 H&F pump (F.E. — NBCD/DC HQ — No. 2 A.F.U.
4. Electrical	— Aft switchboard room (SB) — No. 2 motor generator (DC motor-room) — E.D.C. No. 1.	— 3 1275 kW D.Gens. — EDC No. 2	— Tyne and 4 MW gen. (01 deck) — EDC No. 3 and No. 4
5. LP Air	— LP air compressor (DC motor-room)	— LP air compressor (Aft Aux. room)	— LP air compressor (A.E
6. Additional	— Aft sewage plants — No. 3 & 4 F/W tanks — 2 2MW DC motors (main propulsion) — Aft Gyro (Ops.)	— Avgas pump-room — Clutches (Main propulsion)	— S.C.C. (2 deck) — A.E.R. and F.E.R.

atmosphere and ease access to compartments. With respect to vital equipment which is usually located in machinery spaces, the provision of direct, trunked access to the upper deck provides a means of bypassing smoke and flames when manually operating equipment in the event of loss of remote functions. Furthermore, when designing passageways, the designer should ensure that they are wide enough to take a standard, two-man-front fire-team, yet not so wide that the fire-fighters would be thrown violently against the bulkheads if the ship were rolling in a seaway. Finally, since access routes must remain viable for as long as possible, items such as ladders and deck-gratings of aluminum construction should be avoided in a ship's design.

To protect against the spread of fire and smoke, attention must be paid to the selection of shipboard furnishings and structural materials, and to the details of the HVAC and any other systems which pass through ship's bulkheads. Not only should PVC cabling and foam-padded furniture not be used, but the use of wood, synthetic carpets, oil-based interior paints and other inflammable materials must be avoided or at least kept to a minimum. Ideally, inflammable liquids should be stored below the waterline.

But even if all these precautions have been taken, a shipboard fire can still produce vast quantities of smoke which will drastically affect the ship's fire-fighting ability. Therefore, systems are now being investigated to increase the speed with which smoke can be removed from the ship's interior. Typically these can take the form of modifications to main-machinery spaces or HVAC exhaust fans.



One necessarily relies on a vessel's main watertight bulkheads to contain the effects of fire and flood, yet the integrity of these bulkheads is dependent upon the detailed design of the many systems which pass through them. Isolation valves must be fitted on both sides of the bulkhead for liquid and air systems, and watertight collars around cable runs must be fitted and properly maintained. Decreasing the number of bulkhead penetrations and improving overall survivability can be achieved by zoning auxiliary (particularly HVAC) systems between bulkheads, within the vital compartments they serve.

Finally, once any fires and floods have been brought under control, the ship's personnel must correct the damage. The ease of carrying out repairs involves consideration by the designer for such features as the type of steel used in construction, access to equipment and the availability of shipboard maintenance facilities. In the initial design the choice of steel must be made on the basis of strength and the ease with which it can be welded under battle conditions. Similarly, for such items as piping runs, electrical cables and the new fibre-optic systems, the configuration of the system and the material selection should be made with consideration for ease of repair.

CONSIDERATIONS

Up to this point, the paper has focused on individual passive-defence features which can aid a vessel in surviving the missions assigned to her. However, little has been said about the rationale of why such features should be incorporated into the ship, or to what level. Although both answers may appear obvious, it must be remembered that, given the complexity of a warship, there are many items competing for limited resources and each one must be fully justified. This is particularly true when determining the balance between active and passive defence features where one must consider that:

a. using passive features alone or in combination with active features to escape detection can be more effective and possibly cheaper than achieving the same performance solely with active measures;

b. passive features cannot usually be changed during a vessel's lifetime unless at great expense;

c. in a warship, defences should be

incorporated against both the high and low ends of the threat spectrum;

d. passive features are often "invisible" and, unfortunately, do not contribute to alleviating the "weaponless" look of many modern warships — thus they may be harder to "sell" to the customer; and

e. passive features often make life more inconvenient or spartan for the crew, or increase the cost of providing other ship-features such as piping and wiring runs.

In the end, the amount of defensive measures incorporated in a vessel is a reflection of its "value" to the Maritime Commander. Unfortunately this is very difficult to quantify. A simplistic view is to equate the value of the ship directly to her replacement or repair cost, but such direct accounting neglects the effect of such a loss on a navy's other resources. Not only does a loss, even temporarily, place extra demands on the remaining assets, but it reduces overall operational capability. In small navies such a loss in availability may have a particularly disproportionate effect on capability.

Other items such as the role the ship is expected to play and the situations it is expected to encounter must be considered in this estimation of "value". From this one must then determine which passive-defence features to implement given a usually tight budget. A suggested method of doing this is to divide a ship's passive-defence needs into those necessary for *peacetime, minor conflict* and *conventional war*, with a possible subcategory of NBC threat for the latter.[3]

It is the author's view that this method would lead to the following considerations and passive-defence measures:

a. **Peacetime**. Even without the threat of an enemy, a ship is still subject to all the hazards of the sea, the additional dangers of exercising in close company and the danger of carrying volatile stores. Due consideration must therefore be given to the economic and political reality that money to repair or, worse, replace a warship in peacetime is very difficult to procure. Understanding this, a basic degree of watertight subdivision (providing a minimum of two, but preferably three compartments) plus the necessary damage-control measures already discussed should be adopted to reduce the dangers of fire, collision or grounding.

b. **Minor Conflict**. In terms of particular hazards, minor conflicts are often characterized by the employment of low to moderate levels of conventional weaponry by the enemy, usually with little or no warning. Added to this is the problem that a ship may not be allowed to use her weapons or may be greatly constrained in their use, so the ship designer must be prepared to defend the ship almost entirely through the use of passive features. The problem is to determine which ones to use.

Usually in these situations there is considerable value attached to the "presence" of a ship, the loss of which can mean considerable political and propaganda value for the "enemy". Therefore, emphasis should be placed upon measures to maintain this "presence" rather than a full combat capability. At a minimum this would require maintaining the ability to stay afloat and move, plus a minimum level of defensive combat and communications capability. So along with protection against fire and flood, there should be means of protecting propulsion machinery, some defensive weapons and the necessary communications equipment. Ideally, this should include locating essential equipment away from the ship's side, and providing at least a minimum of dual redundancy for the vital systems. Repair equipment adequate to fix light damage should also be included.

c. **Conventional War**. When working with passive defences required for a conventional war, the designer is presented with a much greater array of possible enemy weapons and operational scenarios. A ship's weapons and sensors can now be fully brought to bear in defeating the threat. Similarly, the full array of the passive defensive features discussed in this paper become applicable.

CONCLUSION

The process of warship design involves synthesizing many interdependent factors, each of which competes for space, weight and a slice of the total purchase price. Yet in the final analysis a warship's effectiveness is dependent on its ability to inflict fatal damage on the enemy, and to possess sufficient resources to escape such damage to itself. To achieve the latter, there must be a considered balance of both active and passive defensive features to give the best chances of survival commensurate with the ship's value and the anticipated threat. Survivability cannot be a compartmented section of the ship-design process, but instead should be viewed in much the same manner as reliability and maintainability. This article has focused on passive defensive features since it is this area that most often seems to be overlooked or discounted in its impact on operational capability.

Unfortunately, in any article such as this it is inevitable that some areas will have been missed, or that others will have had to be given less than their due for the sake of brevity or security. In conclusion, though, it is hoped that this article will have demonstrated the extent of the considerations for passive protection in ship design, and how they form a vital part of the fabric which makes a warship.

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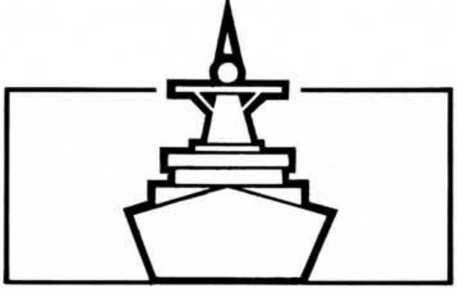

Shipborne Desalination Plants

Operational Factors, Requirements and Considerations

by Lt(N) S. Garon

Introduction

When steam engines and boilers began to be used at sea, large quantities of fresh water became necessary. This situation led to the design, construction and use of a variety of desalination plants, amongst which the following types are presently in use in the sea element of the Canadian Forces:

a. internal heat-addition evaporators (conventional evaporators);

b. external heat-addition evaporators (flash-type evaporators);

c. reverse-osmosis desalinators (ROD units); and

d. vapour-compression evaporators:

Regardless of type, however, there are certain operational factors, requirements and considerations that pertain to all shipborne desalination plants. For example, all desalinators must use a seawater feed, and from this they must produce distillate of a specific quality that depends on whether it is intended for machinery or domestic consumption. Furthermore, they must be able to produce specific *quantities* of distillate, depending on the type of ship, under some extreme environmental conditions.

But what *is* sea water, and to what degree must it be purified? How much distillate must be produced every hour for a steamship or a gas-turbine ship? Under what environmental conditions must the desalinators be able to operate? The answers to these questions represent the factors, requirements and considerations which can be deemed fundamental to any discussion or assessment of shipborne desalinators for the Canadian navy. It is the purpose of this article to provide the answers in a condensed and simple format.

Seawater Quality

Normal sea water is defined[1] as containing an average of 32,000 to 35,000 ppm solids in solution (by weight). These solids (in solution as ions) are usually distributed as follows:

a. calcium bicarbonate $Ca(HCO_3)_2$: 180 ppm;

b. calcium sulfate $CaSO_4$: 1,200 ppm.

c. magnesium sulphate $MgSO_4$: 1,960 ppm;

d. magnesium chloride $MgCl_2$: 3,300 ppm;

e. sodium chloride NaCl : 25,620 ppm;

f. the rest is made up of potassium (380 ppm K) and traces of other chemicals.

The pH of average sea water is from 7 to 8, and is difficult to change because of the presence of HCO_3 and other related chemicals (which are strong buffers). This is an important consideration, particularly in regards to reverse osmosis, because the life expectancy of the membranes (presently around 2,000 hours) could be increased by up to a factor of 3 if the pH of the feed (sea water) were maintained at 5.

As far as harmful micro-organisms are concerned, normal sea water is considered[2] free of them at a minimum distance of 10 miles from shore. However, this minimum distance can be increased, for example, near the estuary of a contaminated river.

Finally, the specific gravity of the average sea water is approximately 1.025, which is roughly equivalent to a density of 10°A on the Admiralty Hydrometer.[3]

Notes:

a. The density scale on the Admiralty Distilling Plant Hydrometer is defined as:

$$(°A) = \frac{(\text{specific gravity} - 1.000)}{0.0025}$$

Therefore, the average sea water has a density of 10°A.

b. As a rough estimate, within the range of salinity that is applicable to our plants, it can be said that °A varies in proportion with the concentration of salt.

c. Density varies with temperature (although for a liquid this variation is slow); therefore, admiralty hydrometers have been graduated to suit a uniform temperature of 200°F.

Distillate Quality

Specifications require that the total ion content or TDS (total dissolved solids) of the sea water be reduced to acceptable levels as follows:

a. *For Machinery Use*: The maximum limit is, as it is specified in NEM, less than 0.065 equivalent per million of chloride (Cl). This is also proportionately equivalent to 2.3 ppm chloride or to about 4.3 ppm TDS.

b. *For Domestic Purposes*: Purities of less than 500 ppm (by weight) or less than 0.05% of salt (by weight) TDS are acceptable, of which 350 ppm[1] may be chlorides.

Note: The authorities for the acceptable TDS in domestic water are the Canadian Health Regulations, the agreement of NATO STANAG 2136, and the World Health Organization.

Live bacteria, for their part, must not be found in the distillate, and a boiling temperature of 165°F (under vacuum) is considered sufficient to treat clean offshore sea water using an evaporator. This temperature, however, might not be sufficient to kill all noxious bacteria which could enter with the "feed" if the ship is operating in heavily contaminated waters. This consideration is particularly important in the case of evaporators because their heavy boiling rates usually cause water droplets to become entrained with the vapours. And, of course, if the ship is operating in bacteriologically con-

Gas - turbine ships must produce two tons of fresh water each hour to meet machinery and domestic requirements.(HMCS Iroquois)

taminated waters, the droplets could contain live bacteria. In this latter case, chlorination would be imposed according to the instructions of CFMO (Canadian Forces Medical Order) 36-02 and NEM.

The situation could be considered different in the case of ROD plants because bacteria cannot (in theory) pass through the membranes.[4] This has not been definitely proven, but it is indeed possible that when a ROD plant runs continuously it effectively prevents the passage of bacteria. There are also some indications[5], however, that if the plant is shut down after having been operated in a contaminated area, the bacteria left on the surface will colonize, damage the membrane, and eventually pass through it. This problem could be avoided if sterilization were performed after shut-down (flooding the unit with a 1% formaldehyde solution, for instance), or if an in-line feed sterilizer were constantly in use during operation of the ROD plant.

Desalination Plant Capacity

Steamships

As a reference figure, a total distillation capacity of one ton/hour/ 20,000 SHP[6] is recommended. This figure includes a typical boiler feedwater loss of 0.5 ton/hour on a steaming ship using two Y-100 boilers, but does not include freshwater needs (for example, the allowance of 30 gal/day per man, etc.). It can be said that on HMC Ships (steamers), a nominal capacity of 3 tons/hour is required. (Note: In this article *tons* refers to long tons — i.e. 2,240 pounds.)

Gas-Turbine Ships

In HMC Ships (gas turbines), the required nominal capacity for freshwater production is approximately 2 tons/hour[6], which includes the requirements for domestic water, the requirements for turbine washing, and 6% of the total evaporation capacity of the auxiliary boilers (to make up for the losses usually associated with them).

Plant Performance

Extreme Conditions

Desalination plants must be capable of continuous operation in arctic and extreme tropical conditions. In the case of ROD plants, arctic operation means that feed preheating might have to be considered to avoid freezing of the per-

meate in and after the membrane (especially if the salt water entering the plant is at a temperature below 32°F). It must also be remembered that the temperature of the sea water has an effect on the output. For instance, all other parameters remaining the same, in colder waters conventional and flash-type evaporators will have an *increased* output, whereas vapour-compression plants and ROD units will have a *reduced* output.

When operating in normal sea water, a desalination plant should be capable of operating for a period of at least 90 days at rated capacity without shut-down for chemical cleaning. Desalination plants must also be capable of being mounted athwartships or longitudinally and still maintain the rated fresh-water output and purity when the ship is under the following conditions of inclination:

a. rolling up to 40° from the vertical to either side, or pitching 10° from the normal horizontal plane;

b. ±5° from the normal horizontal position in the fore-and-aft plane (permanent trim); and

c. ±20° list to either side (permanent list).

Scaling

For economical reasons, there is a growing requirement for a decreased maintenance load, including easier chemical cleaning procedures when applicable. One way to reduce the maintenance load is to control the formation of scale.

The scaling compounds are usually calcium sulphate, magnesium hydroxide and calcium carbonate. Scale formation can be minimized by ensuring that the temperatures of the brine and of the sea water within the plant do not exceed 175°F. Chemical treatment of the feed-water (ameroyal injection, for instance) can also be used for anti-scaling purposes, but the tendency in the case of new designs is to avoid the need for this sort of treatment. A possible method for avoiding rapid reduction of heat-transfer efficiency due to scaling is to locate the heat-transfer components away from the actual evaporation areas. It should be

The requirement for steamships to produce three tons of fresh water each hour allows for typical boiler feedwater losses of 1/2 ton/hour. (HMCS Fraser)

noted that ROD plants can suffer from scaling of the membranes especially if the water recovery is about 25% and if the flow outside the membranes is relatively small.

Performance Ratio

The performance ratio (PR) of a desalination plant is normally defined as the ratio of distillate flow to heating-steam flow (by weight):

$$PR = \frac{\text{lbs/hour of distillate}}{\text{lbs/hour of heating steam}}$$

This definition does not take into account the electrical power required for the various pumps in a given plant, however in most steam-heated plants the electrical power needs are negligible in relation to the input of heating steam. There will be times, though, when a more general definition of the PR will be needed, such as:

$$PR = \frac{\text{lbs/hour of distillate}}{\text{(total BTUs/hour input)/1,000}}$$

Typically, PRs are from 1 to 1.5 for conventional and flash-type evaporators, 10 or more for vapour-compression plants, and from 60 to 100 for ROD units. In any case, the performance ratio of a plant should be at least 1.5.

Plant power requirements (whether steam or electrical) must be kept as low as possible, and every effort should be made to use sources of energy which are already available onboard. If at all possible, energy recovery methods should be used. (In fact an energy recovery pump for possible use with ROD plants has been under study for some time.)

Water Recovery

The water-recovery rates (gallons of distillate produced for the gallons of feedwater processed) should be as high as possible to reduce the need for large pipes and large-capacity pumps. (On the other hand, one must keep in mind that high recovery rates usually mean high scaling rates.) Typical water-recovery rates for conventional and flash-type evaporators are around 5% to 7%, about 25% for ROD units, and as high as 50% or more for vapour-compression plants.

In considering this, it is worth noting that the piping used in any desalination plant should be of good quality and free of rust. This is especially important in the case of ROD units where iron ions from rusted pipes or other sources could very quickly destroy the membranes.

Other Requirements

There are a few other points which are important to mention. For example, the fitted safety devices should be adequate, the operation of the plant should be self-regulating after manual start-up, the capacity of the plant in relation to its size and weight should be high, the design of the plant should be such that foaming is minimal, and, finally, spare parts should be available.

Conclusion

The information provided in this article is not all-inclusive. It is hoped, though, that it will be useful for those who need a simple reference in regards to the operational factors, requirements and considerations which pertain to shipborne desalination plants.

Lieutenant(N) Garon graduated from Laval University in 1978 with a degree in Chemical Engineering. Four years later he received his Certificate of Competency Part II (Marine Systems), earning him a "T.M. Pallas" award from the Canadian Institute of Marine Engineers. Since completing his training he has been working at Venture (NOTC) as the Course Training Officer in Marine Systems Engineering, and has done extensive research for new course material. Lt(N) Garon is a member of the Canadian Institute of Marine Engineers, and is an associate member of IMare.

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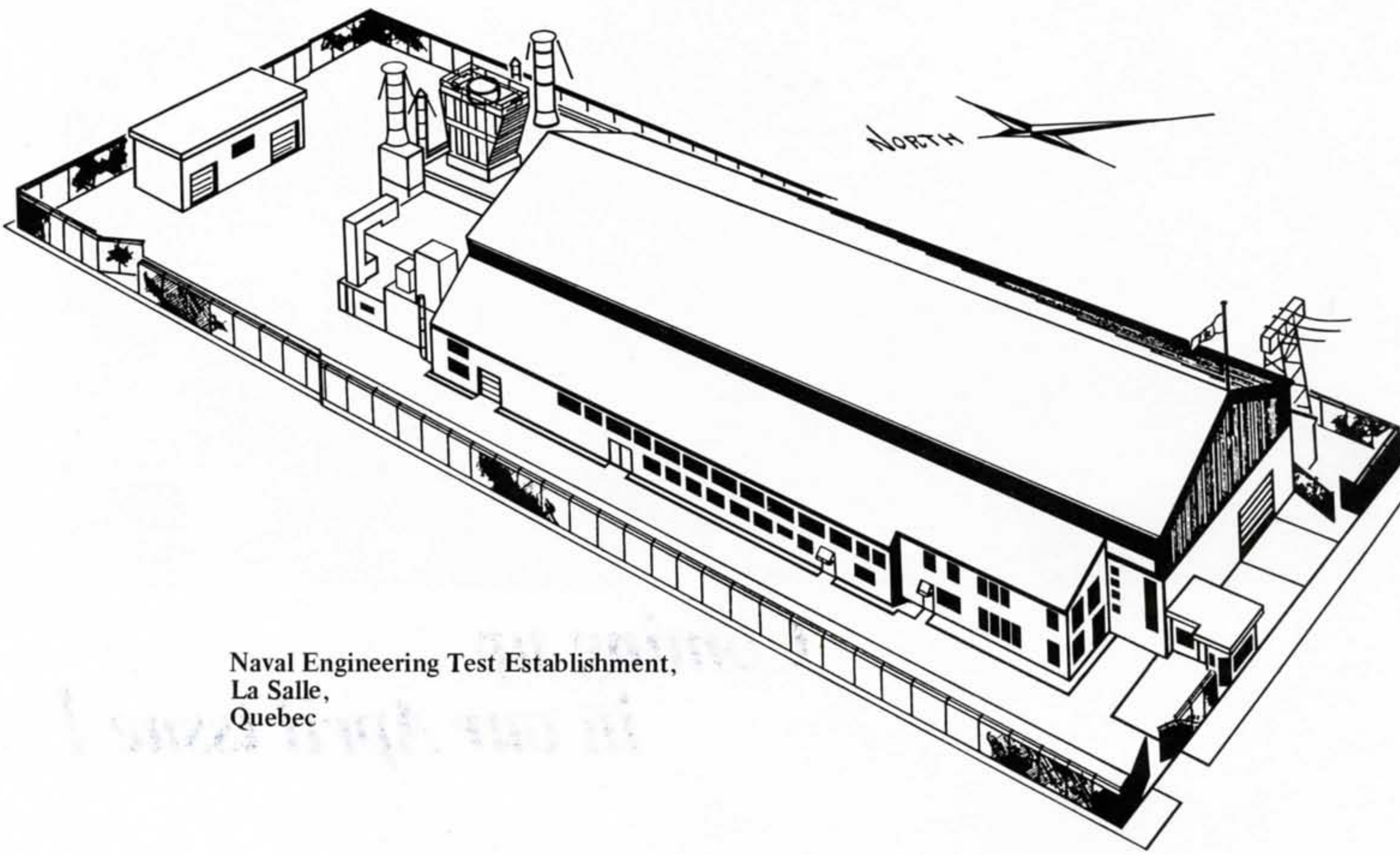

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