4.4 Bras d'Or Class FHE 400

HMCS Bras d'Or Maiden Voyage 1968 (above) and High Speed trials 1969 (below)

Photos courtesy of Bombardier/de Havilland Canada

The FHE-400 Hydrofoil Ship is designed for all weather duty in the North Atlantic and operation in tropical conditions. At hullborne speeds in excess of 12 knots, the endurance is comparable with that of conventional destroyer escorts. Foilborne speeds up to 60 knots and a range of several hundred miles provide a speed advantage in tactical ASW operations. Good hullborne seakeeping is provided by the damping action of the foil system. The ship will operate foilborne in Sea State 5 and has excellent acceleration and manoeuvring characteristics. An important feature of the design is the wide foilborne speed range. Living and operating spaces are air conditioned and heated to the requirements of BRCN/6195. The internal arrangement has been developed from RCN Work Study Projects and is based upon a crew of 20 officers and men. Flexibility has been provided to permit changes in crew structure and number. Seamanship outfit has been prescribed by the RCN to suit ship characteristics. Replenishment techniques have been evolved by the contractor and tested satisfactorily at sea.

The bow foil is used for hullborne and foilborne steering and has both manual and automatic inputs. Bow foil incidence may be manually adjusted to provide optimum pitch response throughout the speed range. The main foil anhedral tips are moveable as "ailerons" to provide roll control at low foilborne speeds and smaller turning diameters at high foilborne speeds. The anhedral tips have both manual and automatic roll control inputs.

Hullborne and foilborne propulsion systems are separate. Low speed endurance is achieved by twin controllable pitch propellers driven by a single 2400 bhp high speed diesel engine. The controllable pitch propellers are used for manoeuvring in harbour and are feathered when the ship is foilborne. High foilborne speed is achieved by twin supercavitating propellers driven by a 25,000 shp gas turbine.

Auxiliary shaft power is provided by the main diesel engine to an auxiliary gearbox when the ship is hullborne. When foilborne operation is initiated, the auxiliary gearbox drive is taken over by a 500 shp gas turbine via an overrunning clutch. The auxiliary gas turbine may be used as a power source when alongside or as an emergency prime mover to drive the hullborne propellers at low speed.

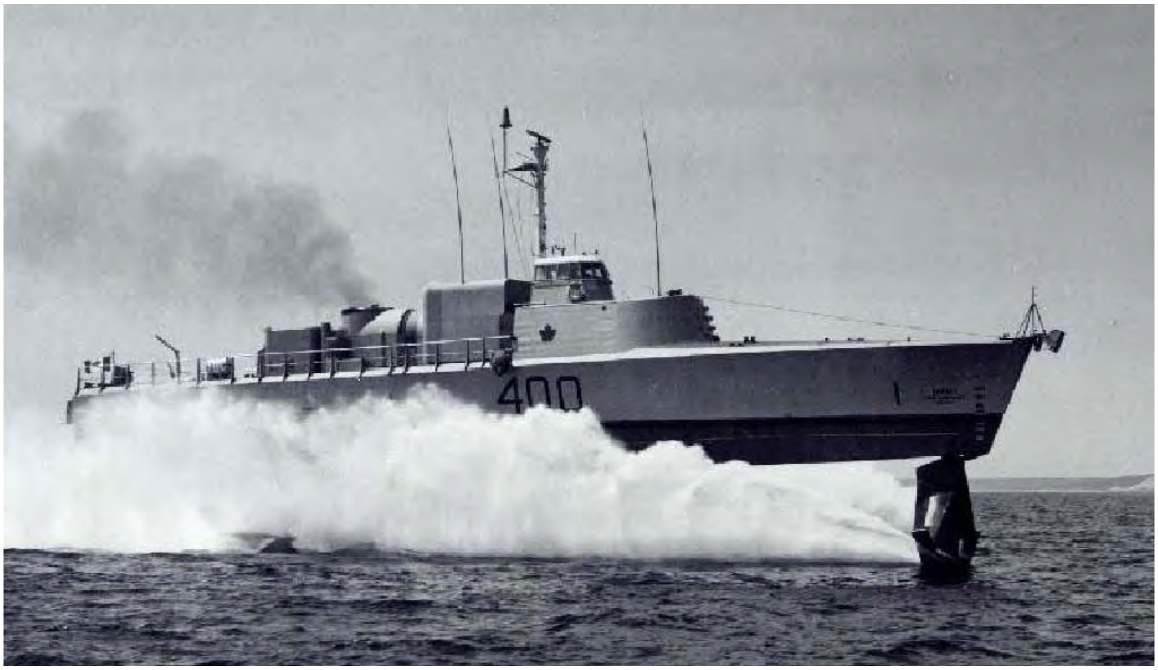
The auxiliary gearbox mounts three 3000 psi hydraulic pumps and three 115 V generators controlled to 400 cps by constant speed drives. The auxiliary gearbox is fitted with a 450 U.S. gpm sea water pump to provide water for fire fighting and machinery cooling. A 190 shp gas turbine is fitted to provide emergency electrical and hydraulic power, and power for the fire protection pump. In addition, the emergency gas turbine provides low pressure air for starting the main gas turbine.

A secondary firefighting capability is available as pressurized sea water from a deck pump. This is a Rover Gas Turbine coupled to a Hayward Tyler Water Pump.

All five engines operate on JP5 or high distillate diesel fuel.

Fighting equipment is not part of the vehicle contract but provisions have been made in conjunction with the RCN and the fighting equipment contractor.

The foregoing description was provided by Dave Monteith of Bombardier/de Havilland Canada, as were the following photos/diagrams **(12).** A multitude of data was provided by Dave Monteith, and the following Paper by John Milman & Cdr Fisher, RCN **(14)** best summarizes the overall technical/design description of the FHE 400 Hydrofoils Ship Project on hand at this time (it is from a 4th or 5th generation copy so the diagrams do not reproduce all that well). A further paper by Cox from "An engineer's outline of the RCN history: Part II" **(1)** provides a succinct account of the overall program.



HMCS BRAS d'OR at 62 knots (1969) - photo by W.R.Carty

The program was essentially a "Design & Prove" contract that required a paper design that would then be built as a prototype and tested against the original design requirement/specification. The end product would be a proven design. The following two documents **(18 & 19)** define both the end design, and the performance of that design by tests of the prototype. de Havilland of Canada was the overall Prime Contractor and produced the design at its facilities at Downsview, Ontario, had the prototype built at the Marine Industries Ltd. shipyard at Sorel, Quebec, and conducted the trials out of Halifax, Nova Scotia.

FHE 400 HYDROFOIL **NONREGISTERED**

CONFIDENTIAL

CANADIAN FORCES (NAVY)

FINAL DESIGN REPORT

FOR

FHE 400 HYDROFOIL SHIP

BRAS D'OR

> This publication contains classified information affecting the national defence of Canada and is to be safeguarded, handled, transported and stowed in accordance with the regulations and orders for the security classification appearing hereon. Release of this publication or information contained herein, to any person not authorized to receive it is prohibited by "The Queen's Regulations and Orders for the Canadian Forces" and "The Official Secrets Act".

THE DE HAVILLAND AIRCRAFT OF CANADA LIMITED
DOWNSVIEW ONTARIO

INTRODUCTION

This document is presented in fulfillment of that part of Contract No. 2BX3-244 which calls for a Phase B report to be written on completion of the detail design, construction, final specification, and shore testing of the Hydrofoil Ship HMCS Bras d'Or.

HMCS Bras d'Or, designated FHE-400 by the Canadian Armed Forces, is a 250-ton hydrofoil ship designed and built by The De Havilland Aircraft of Canada, Limited, to accomplish a specific Naval role under all weather open ocean conditions.

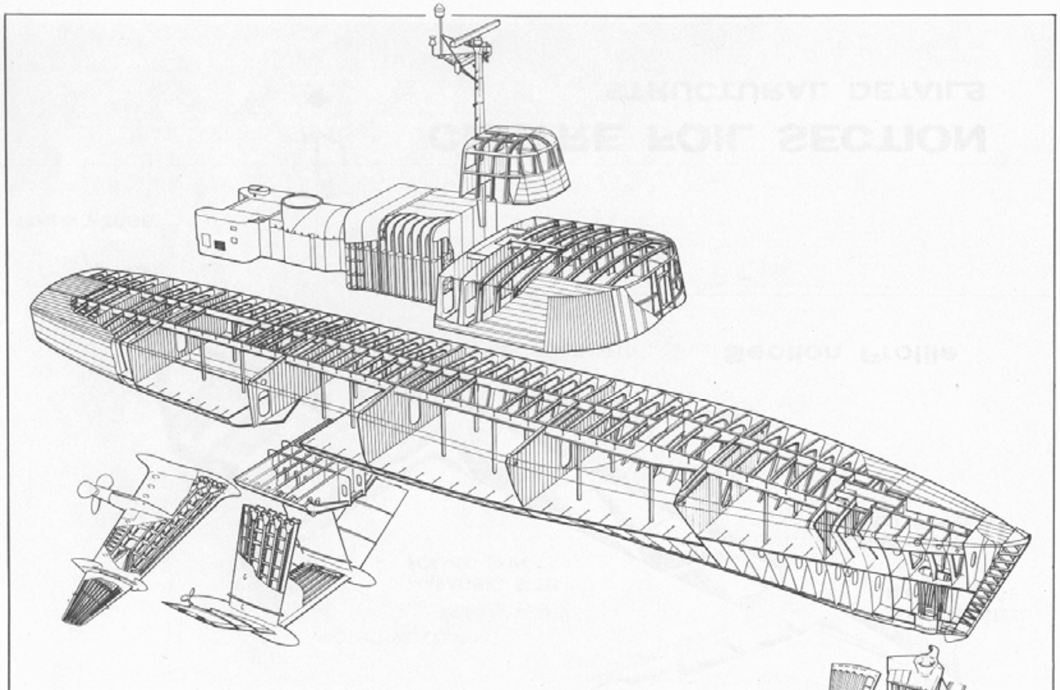
The DDP Statement of Requirements, set out in the following pages, details the technical contractual basis for the design, manufacture and testing of the FHE-400 Anti-submarine Warfare Hydrofoil Ship.

Because of its large size, high speed, and manoeuvrability, with provisions for a modern weapons suit, the FHE-400 has evolved into a complex vehicle. The purpose of this report is to give a clear insight into the technical refinements and sophisticated design and development inherent in the FHE-400 Hydrofoil Ship, including explanations of how major design characteristics were established.

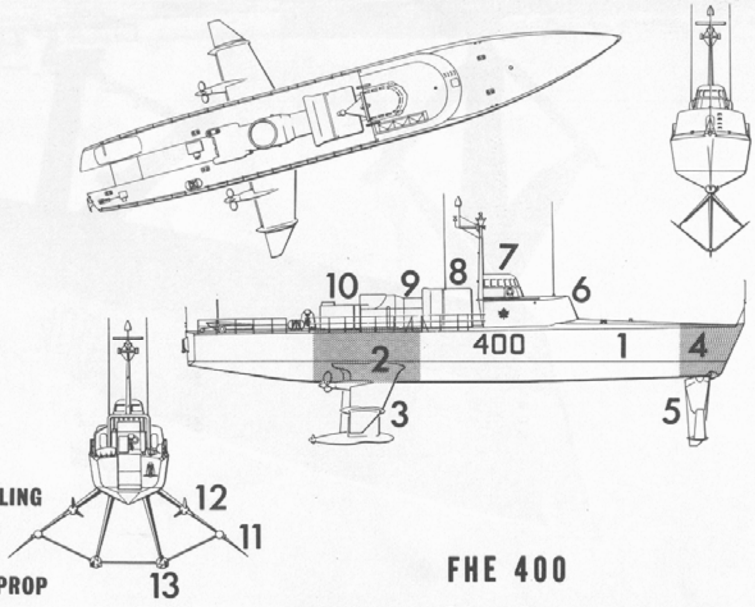
The ship's design details at the start of its long term storage are compiled in the DHC report - "Design Definition of Basic Ship" January, 1972. This introduces the following master references:

HI-1000	Final Assembly - Ship Complete
HI-1001	Descriptive Arrangement
HI-1003	Engineering Breakdown of Components and Systems
FHE-400	Quality Control and Inspection Plan

The embodiment on the ship of modifications to the basic design are authorized by the Engineering Order, EO-X-12801.



STRUCTURAL ARRANGEMENT OF HULL



LEGEND

1 BASIC HULL
2 MAIN FOIL FOUNDATION
3 MAIN FOIL
4 BOW FOIL FOUNDATION
5 BOW FOIL
6 OPERATIONS ROOM
7 BRIDGE
8 FT4A INTAKE
9 FT4A COWLING
10 EXHAUST & G'BOX COWLING
11 MOVABLE TIP
12 CONTROLLABLE PITCH PROP
13 SUPERCAVITATING PROP

FHE 400
PLAN and PROFILE VIEWS

CANADIAN FORCES (NAVY)

SHIP'S HANDBOOK

FOR

FHE 400 HYDROFOIL SHIP

BRAS D'OR

THE DE HAVILLAND AIRCRAFT OF CANADA LIMITED
DOWNSVIEW ONTARIO

INTRODUCTION

This Handbook has been prepared by the de Havilland Aircraft of Canada Limited to assist operators of the FHE-400 Hydrofoil Ship in the operation of the ship and its equipment.

The Handbook is divided into two chapters to cover description and operation. Chapter 1 describes ship structure, controls, engines and transmissions, and systems. Chapter 2 is divided into three parts to cover normal and emergency operating procedures and performance data.

NB - Operational data is contained in the Bridge Handbook.

Each chapter, or part, is divided into sections. A general table of contents listing sections is provided to locate systems, and each chapter is provided with a separate table of contents to locate the various components contained therein.

This Handbook should be used in conjunction with the following documents which detail operation of ship and machinery:

a) FHE-400 Hydrofoil Ship Bridge Handbook
b) 0120 Specific Operating Instructions - Machinery
c) Maintenance Manual for FHE-400 Hydrofoil Ship

This manual does not deal fully with items of proprietary equipment. Full use should be made of literature available from manufacturer. A list of manufacturers' literature is given in Appendix A.

This manual has been written for ship configuration at start of inhibiting procedures in October 1971.

A list of all reference documents is given in Appendix B.

THE CANADIAN HYDROFOIL PROGRAMME

John W. Milman BSc
Commander R. E. Fisher BASc, RCN

SUMMARY

The history of the Canadian Hydrofoil Programme is outlined starting with the work by Alexander Graham Bell and F. W. "Casey" Baldwin in 1911 to 1920 at Baddeck, Nova Scotia, which culminated with the breaking of the then water-speed record using the HD-4. The work during World War II on Smoke Laying Craft for the Canadian Army is mentioned. The concept of Bell and Baldwin was developed after the war by the Defence Research Board at the Naval Research Establishment at Dartmouth, Nova Scotia. Three craft were built, the 8-ton Massawippi, *the 17-ton* Bras D'Or, *and the 3-ton "Rx" research craft. The design and performance of these craft are discussed.*

The Naval Research Establishment, as a result of its programme, developed a concept for a 200-ton open-ocean hydrofoil ship. The concept was investigated by De Havilland Aircraft of Canada Ltd and their design study conclusions and proposals were endorsed by the Royal Canadian Navy. De Havilland was given a contract in April 1963 to design and construct a Development Prototype Hydrofoil Ship. This paper reviews the NRE concept and the current RCN development programme, including salient features of the FHE 400 prototype ship design.

Highlights of some of the theoretical work and research in the development of the ship are outlined. Considerations in the design of the subcavitating and the superventilating foil sections are also reviewed.

I. HISTORICAL REVIEW OF CANADIAN HYDROFOIL RESEARCH

HYDROFOIL research in Canada has its origins in the work of Alexander Graham Bell and F. W. "Casey" Baldwin at Baddeck, Nova Scotia, during the period 1911-20. Mr Philip L. Rhodes, the well-known naval architect of New York, also contributed to this work by his assistance in the closing phase of experiments. Their research was a development of earlier work by Enrico Forlanini of Italy from 1898 to 1905 and was confined to surface-piercing "ladder" type foil systems.

Experiments by Bell and Baldwin culminated in the development of the "HD-4" hydrofoil. In 1919 this remarkable craft achieved a world water-speed record of 61.5 knots. Over thirty years were to elapse before this record was exceeded by another hydrofoil, the American Grumman XCH-4. The HD-4 was 60 ft long by 5 ft 9 in beam of the main hull, with an all-up weight of 11,000 lb and was powered by two 350 hp Liberty aero-engines driving pusher airscrews. The foil sections were developed empirically by Baldwin and Rhodes. It was claimed that these produced a maximum lift/drag ratio of eight at 30 knots. This dropped to four at 60 knots, indicating that severe cavitation was occurring. See Refs (1), (2), (3) and (4).

Regrettably, little work on this novel concept was conducted after 1920 in Canada until, in 1943, the National Research Council undertook the development of expendable smoke-laying hydrofoil craft for the Canadian Army. These were termed the "Comox" boats. Equipped with surface-piercing foils, these craft were 20 ft in length and were capable of operating at speeds up to 35 knots in wave heights of 6 to 9 ft.[5]

In 1947-49, a 45 ft hydrofoil craft powered by a Rolls-Royce "Merlin" aircraft engine of 1,200 hp was designed by Philip Rhodes, based on the HD-4 experimentation, for Cdr D. M. Hodgson, RCNR, of Montreal. The craft was to be used in an attempt to set a new water-speed record. At about this time, the Defence Research Board (DRB) became interested in the potential naval applications of hydrofoils and the craft was built with some design modifications under DRB direction. It was designated R-100 and named *Massawippi* after Lake Massawippi, Quebec, the site of its construction and first tests. The craft was then shipped to Halifax for further trials and in 1951 the responsibility for the project was transferred to the Naval Research Establishment (NRE) of the Defence Research Board.

Early trials were conducted at all-up weights in the 8,000 to 10,000 lb range. Good performance was achieved at speeds up to about 55 knots. However, it was considered that craft weight in relation to size was not representative of the length/weight ratios for operational naval roles then envisaged for hydrofoils. In consequence, *Massawippi* was ballasted for an all-up weight of 12,000 lb and instrumented for further tests. At this weight, the craft exhibited an instability in pitch associated with cavitation on the foils. It is interesting to note that a similar tendency to porpoise was evident in the HD-4 characteristics.

Concurrent with the R-100 trials, a contract was awarded to Saunders-Roe Ltd of Cowes, Isle of Wight, England, for the design study of a 100-ton hydrofoil craft (designated R-102) for naval employment. The British Admiralty supported a series of model tests for this design study and the investigation of R-100 behaviour. The study concluded, however, that a craft of this size was not feasible within the limitations of power plants and structural materials then available.

In consequence, a further design study contract was established with Saunders-Roe to design a craft (known as R-101), based upon existing materials and power plants. The study considered two versions of a craft of about 80 ft in length, each having an all-up weight of 47 tons, but designed for diametrically opposed proportions of hullborne and foilborne time in their respective missions. One version was an "orthodox" craft, analogous to a "boat that flies", and intended for missions where hullborne operation would predominate (about 80% of mission time). The other version was an "unorthodox" craft, likened to "an aircraft that acts like a boat" and intended for missions where foilborne operation would predominate (about 80% of the time).

It was decided in late 1953 to design and build an approximate one-third scale model of the "orthodox" version. This project was undertaken by Saunders-Roe and resulted in the delivery in mid-1957 of the 17½-ton, 59 ft *Bras D'Or* or R-103. It was powered by two 1,500 hp Rolls-Royce "Griffin" aero-engines and designed for a top speed of 55 knots. Extensive trials in 1958 revealed several areas in which further tests and modifications were required.

During the work by Saunders-Roe on the R-101 study and the *Bras D'Or*, NRE designed a new set of foils for the *Massa-*

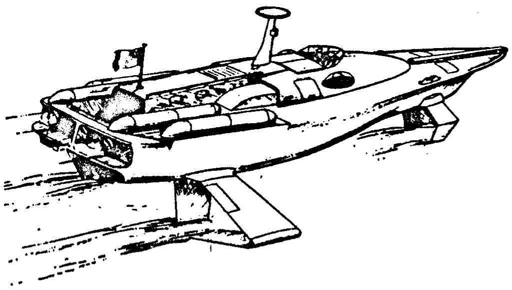


Figure 1. Artist's impression of NRE 200-ton design

wippi. In 1956, *Massawippi* was tested with the new foils at an increased all-up weight of 16,800 lb. The craft performed well in all of these tests, including a single sea trial, without the porpoising associated with the original foils.

Foil systems of the R-101 designs and the *Bras D'Or*, including the set designed by NRE for *Massawippi*, were of the "V" ladder type. This marked a significant departure from the earlier straight dihedral ladder type foils employed on the HD-4, the original foil system of *Massawippi* was in the R-102 design. In the later designs, a cavitation-delaying foil section was adopted. This was originally developed by Walchner during World War II[6] and is known as the "Walchner 'C' section".

In addition to the craft previously described, NRE developed and constructed a small hydrofoil as a basic research vehicle, starting in 1954. Designated "Rx", it has a simple scow-like form, an all-up weight of approximately 6,000 lb and is powered by a Chrysler "Imperial" marine gasoline engine up-rated to 335 hp. The foils are mounted on parallel rails along the gunwale to permit convenient alteration in their longitudinal position when required. Rx is fully instrumented to enable motions in the six degrees of freedom to be measured as well as thrust, torque, rpm and foil unit lift. It is being employed extensively in model tests of the FHE 400 hydrofoil ship design as described in the later sections of this paper.

A central theme of hydrofoil research in Canada, as illustrated by the preceding review, is the concentration upon surface-piercing foil systems and their development by NRE for application in relatively small craft capable of open-sea operations in the 45-60-knot speed range. It is against this background that considerations leading to the RCN programme for an ocean-going hydrofoil ship are traced in the following section.

II. CONCEPT FOR AN OPEN-OCEAN HYDROFOIL SHIP

1. Concept Originated by the Naval Research Establishment

A conclusion of studies in 1953 was that fixed, surface-piercing hydrofoil craft in the 40-60-knot speed range would be limited in size to about 50 tons. However, by 1959 NRE considered that this limitation was no longer applicable. Developments in the intervening years by the aircraft industry now offered the prospect of efficient lightweight, high strength materials and structures and high power, lightweight propulsion units essential to the feasibility of large hydrofoil craft. At about the same time, Grumman Aircraft Engineering Corporation also concluded that larger hydrofoils would be practicable and envisaged commercial craft in the 500-3,000 ton range.[7]

NRE therefore investigated the requirements for the smallest, simplest, and most economical vehicle which could operate in the open ocean with acceptable seakeeping, comfort and reliability and achieve a high degree of effectiveness in anti-submarine or other appropriate naval roles. It concluded that a 200-ton ship with a surface-piercing foil system and 50 to 60-knot speed capabilities would be highly effective in many open-ocean ASW roles. Equally significant was the conclusion that the relatively low cost of the system would make it feasible as a "Small and Many" concept at a cost effectiveness

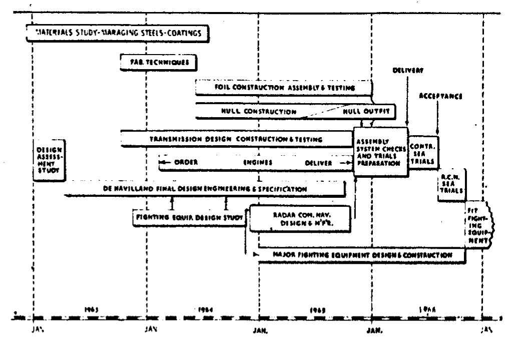


Figure 2. The 400 hydrofoil programme

superior to conventional surface forces.

Consideration of various craft configurations resulted in the form shown in Fig. 1. It will be noted that the foil system combines features of the Grunberg and the Bell-Baldwin systems employing a fixed, surface-piercing hoop main foil generating 90% of the total lift and a "V" ladder bow or pitch stabilising foil unit. The canard configuration of foils inherent in this system offers some decided advantages in craft intended for rough water operation. It avoids a long bow overhang and permits fine lines forward, thus reducing wave impact loads. The canard configuration also promotes good internal and propulsion machinery arrangements, is well suited to towed sonar installations and can achieve good foilborne stability in following seas. Since it was anticipated that, in the roles envisaged, the craft would operate largely in the hullborne mode, displacement seakeeping qualities were considered of paramount importance.

The principal characteristics of the NRE design were:

Length over-all	130 ft (39.6 m)
Beam of hull	28 ft (8.5 m)
Depth of hull	14 ft (4.3 m)
Span of main foils	64 ft (19.5 m)
Foil base length	81 ft (24.7 m)
Draught in displacement mode	23 ft (7.0 m)
Draught in foilborne mode	6 ft (1.8 m)
Foilborne power	16,000 hp
Displacement power	3,000 hp
Maximum foilborne speed in calm water	60 knots
Foilborne speed in SS 5	50 knots
Normal cruise displacement mode	12 knots
Maximum speed displacement mode	18 knots

At a tripartite conference early 1960, a group of specialists from Britain and the United States reviewed the NRE report. The conference concluded that the concept was feasible and warranted further study.

2. Feasibility Study by De Havilland Aircraft Co of Canada Ltd

While concluding that the development of high strength materials, lightweight marine gas turbines, transmissions, and supercavitating propellers placed the concept within the bounds of practical realisation, NRE recognised the need to establish design criteria for ocean-going hydrofoils. It noted that aircraft companies were particularly well equipped for this task by virtue of their experience in lightweight structures, fluid dynamics and in computer systems enabling the simulation of a craft in its environment.

The review of the tripartite conference led in 1960 to the award of a contract to De Havilland by the Department of Defence Production (DDP) for a comprehensive design study of the NRE concept. Objectives of the initial phase were to examine the concept in depth, pursue parametric studies and to ascertain the engineering feasibility of the proposed design. The basic equations of motion were written and a computer simulation of the craft in sinusoidal seas was conducted while a method of representing random seas was being developed.

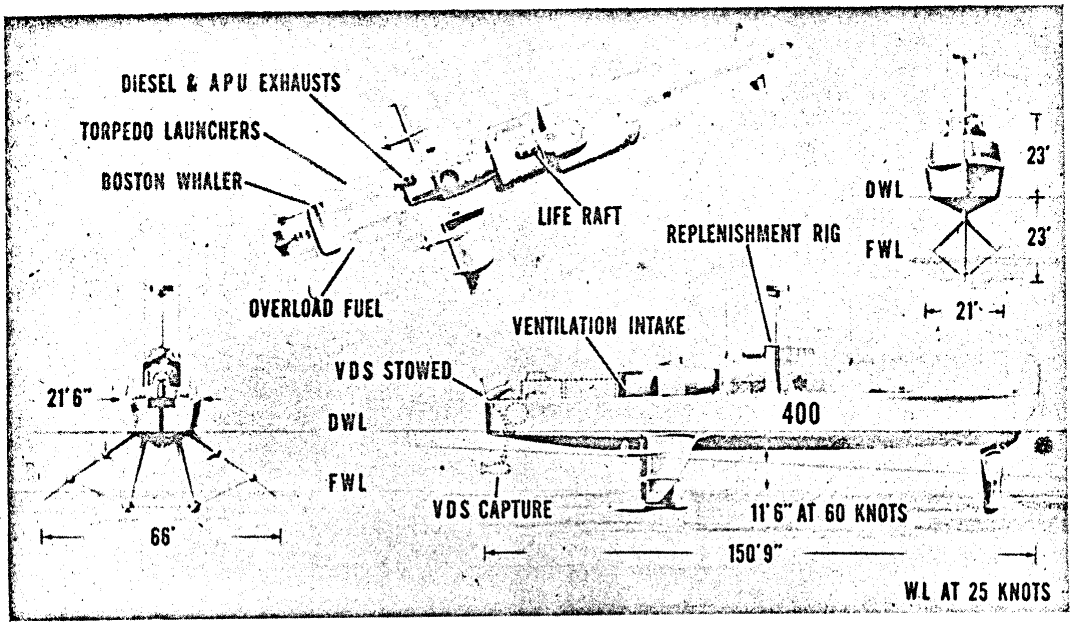


Figure 3. RCN prototype ASW hydrofoil ship. Plan and profile views

Recommendations for a separate foil materials study and proposals for a model test programme in the Phase II study were also formulated.

The report of this first phase rendered in June 1961 concluded that the hydrofoil craft design conceived by NRE and developed by De Havilland was technically feasible. In particular, the study confirmed that a canard configuration and a 150- to 200-ton design weight were optimum for the roles envisaged.

The succeeding Phase II study was aimed at developing a preliminary design for a 200-ton ship for employment primarily in open-ocean ASW roles. An objective was to develop the engineering basis to establish feasibility in detail and produce cost estimates together with proposals for a full-scale prototype ship construction programme. An extensive theoretical and model test programme was carried out. These included:

- **(a)** Resistance measurements on a one-twenty-fifth scale model of the ship at hullborne and take-off speeds and a qualitative assessment of hullborne seakeeping. These were conducted at Stevens Institute of Technology, New Jersey.
- **(b)** Tests of one-eighth scale models of the main and bow foils at the National Physical Laboratory, England, to establish the basic stability derivatives of the units and pressure distributions over critical regions of the main foil.
- **(c)** Tests of a representative one-quarter scale model of the foil system on the Rx research vehicle at NRE. These were primarily intended to check the validity of the analogue computer simulation of the full-scale craft at De Havilland.
- **(d)** A random seaway analogue computer simulation of the full-scale craft and the one-quarter scale Rx vehicle in foilborne operation. The full form and its hydrodynamic effects in take-off and landing were not simulated. The computer was used to simulate the non-linear equations of motion of the foil system in six degrees of freedom in random Sea State 5. It also accounted for orbital velocities in head, beam, and following seas, unsteady flow hydrodynamics, partial ventilation of foil and strut elements, virtual inertia effects in waves, and the onset of local cavitation. A wave pole was developed by NRE to measure wave height and frequency during Rx tests. This enabled comparisons between the Rx craft analogue simulation and its actual behaviour by means of taped records later reduced at the National Research Council spectral analysis centre in Ottawa. A comprehensive description of this work is contained in Ref. (8), including the comparison between analogue simulation and the Rx trials results upon which the reliance on computer predictions for the full-scale craft have been based.

It was recognised in the Phase I study that efficiency, strength, weight, and operational life considerations would impose severe requirements upon the foil system materials. During this period, data on the new "Maraging" Ni-Co-Mo steels were released. Although these steels appeared to offer some considerable promise, little data on characteristics and fabrication were available. Accordingly, a separate materials research programme was sponsored by the RCN and a contract was awarded to De Havilland for the investigation of high-strength steels and protective coatings to determine their relative suitabilities for hydrofoils and other marine applications. Highlights and conclusions of this study are presented in a later section.

The most important conclusion was that the computer studies and model tests had shown that a fixed, surface-piercing foil system can be designed to operate successfully on all headings in sea states up to and including SS 5. This and more recent work has completely discredited widely held views that surface-piercing systems cannot be expected to perform satisfactorily in certain following sea conditions.

Study predictions that only a supercavitating bow foil could provide acceptable response characteristics were vindicated by NRE trials of the one-quarter scale Rx craft. While the supercavitating foil has a lower lift-drag ratio than a sub-cavitating foil, it constitutes a relatively small penalty because the bow foil supports only 10% of the static weight.

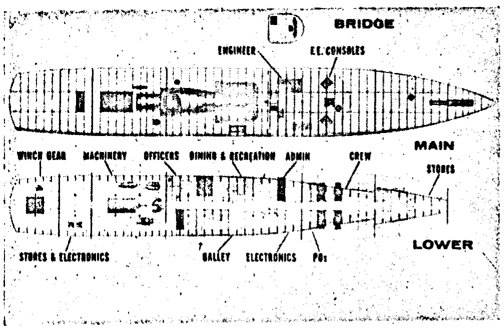


Figure 4. RCN prototype ASW hydrofoil ship. Deck plans

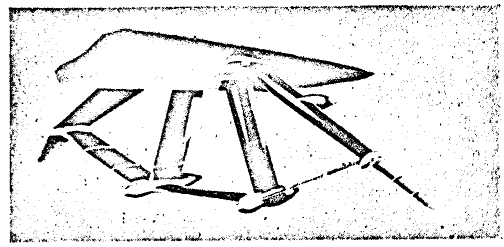


Figure 5. RCN prop RCN prototype ship. Main foil

Based upon the previous expectation that the full-scale ship would spend the majority of its time at sea in the hullborne mode, hull lines were optimised for low displacement resistance and to minimise wave impact loads. The damping provided by the large immersed area of the foil system yields displacement seakeeping comparable with a much larger ship. As demonstrated in the early trials of the one-twenty-fifth scale model, this damping results in a surprisingly low increment of resistance from calm to rough water conditions. Thus, while the non-retractable foils impose a drag penalty in calm water, they confer a decided advantage in rough seas.

In its Phase II design report submitted in late 1962, De Havilland presented a development in detail of the NRE conceptual design, together with a formal proposal to the RCN for the construction of a full-scale prototype ship. A thorough technical assessment of the proposed design was made by the RCN, including consideration of a suitable ASW system outfit. In early 1963 approval was given to a programme for the design and construction of a full-scale development prototype ASW ship. The latter was subsequently assigned designator and hull number FHE 400 by the RCN.

III. RCN DEVELOPMENT PROTOTYPE HYDROFOIL SHIP — FHE 400 PROGRAMME

Based upon the NRE concept and its examination in depth by the 1961-62 De Havilland feasibility studies, a programme for the development and evaluation of a full-scale prototype ship was launched in April 1963. Its fundamental objectives are:

(1) To establish the feasibility of the proposed size and form of ship for open-ocean operations and to test the validity of design predictions.

(2) To develop a Fighting Equipment system attuned to the characteristics of the vehicle design which will permit a thorough assessment of the prototype ship's capabilities in ASW operations.

RCN interest in the hydrofoil is centred on its potential as a practicable and effective element of ocean-going ASW forces. As such, the first objective is a prerequisite to the second and the latter will be fundamental to the consideration of any subsequent warship production programme.

Fig. 2 outlines the major components of the programme and their phasing. Prime contractor for the design and construction of the ship is De Havilland Aircraft Co of Canada Ltd. Design and production of Fighting Equipment which includes the complex of navigation, detection, communication, armament, and tactical data sub-systems is under contract to Canadian Westinghouse. Construction and outfitting of the ship is being undertaken by Marine Industries Ltd, Sorel, PQ, on sub-contract to De Havilland. The ship programme is phased to accommodate the sequence of construction and outfitting at the shipyard for the earliest possible delivery date. Thus, design of some systems and manufacturing of others are proceeding concurrently in many instances. At this stage, the detailed design is well advanced in all areas. Foil system manufacture and hull construction are under way. The latter, as lead item, is due for completion in September 1965. The schedule is a demanding one considering the attendant uncertainties of an extensive development programme and the reliance upon a large number of firms and agencies in the fulfilment of individual tasks. The PERT (Programme Evaluation and Review Technique) method is being employed in the two prime contracts to assist in management of the project which is drawing upon a wide variety of support from research agencies and suppliers in Canada, Sweden, Britain, and the United States.

After launching, instrumented calm water and rough water trials will be conducted prior to the installation of Fighting Equipment in late 1966 for operational evaluation in the anti-submarine role. The base of operations will be RCN facilities at Halifax, Nova Scotia. Plans for shore support include the construction of a docking facility adapted to the special needs of the prototype ship. Preliminary studies have now been completed and design work is progressing on a facility which will embody a marine elevator type dock and meet the needs of other RCN vessels as well. Construction is scheduled for completion in April 1966.

2. FHE 400 — Prototype Ship — Design Basis

The design basis for the prototype ship established by the 1961-62 De Havilland studies of the NRE concept has been closely adhered to. In its design development, apart from the specified aims for high speed and manoeuvrability, emphasis has been placed upon the need for good seakeeping in foilborne and particularly hullborne operation.

An objective which is fundamental to the NRE concept and its realisation in the RCN development programme, is to achieve the minimum size and cost of ship practicable for open-ocean operations in the ASW role. Early parametric studies by De Havilland confirmed that about 200 tons was the optimum size for the requirement. A smaller ship would be deficient in range while a larger one would not yield a significant increase in payload because of the rising proportion of foil system weight with increasing size. On the other hand, seakeeping ability improves with size. These were important considerations in the final decision on form and size of the ship from the standpoint of habitability and operational effectiveness in open-ocean employment, particularly for extended periods in the hullborne mode.

Accordingly, a fundamental aim has been the achievement of the smallest practicable ship with hullborne seakeeping qualities equivalent to conventional warships of over ten times its size. This is made possible by a design of the hull complementary to the non-retractable foil system. The latter is a natural ally which, through its extensive immersed area, exerts a powerful damping action on ship motions, particularly in roll.

A notable feature of the ship is its broad foilborne speed range capabilities compared to contemporaries employing submerged automatically controlled foil systems. This is due in

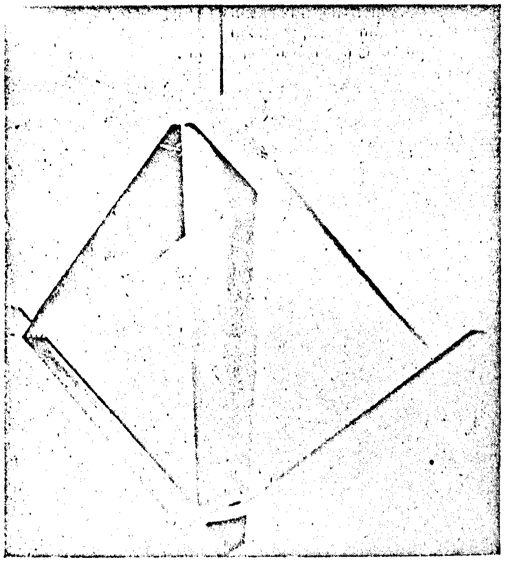


Figure 6. RCN prototype ASW hydrofoil ship. Bow foil

part to the rapid low speed take-off provided by the surface-piercing foils and also because the fundamental design aim was to achieve the maximum speed, particularly in rough water. Detailed consideration of operational requirements have also been a heavy influence in the refinement of the over-all design of the ship and its facilities. However, the generally sensitive interdependencies of speed, payload, range, size, and cost in a ship of this type have been a decisive factor in limiting deviations from the basic design.

The foil system of FHE 400 has no direct precedent. As a key feature upon which the feasibility of the concept hinges, its design has been supported by a comprehensive programme of material research and hydrodynamic development, beyond that of the earlier Phase I and II studies.

A specific aim in the prototype design is to employ proved equipments where suitable and to restrict operational features to those essential to proof of feasibility. The general approach, however, has been to minimise the transitional development which would be necessary for a warship class.

3. Related International Designs

International developments in hydrofoil craft have been prolific and widely reported in recent years. These have marked a growing interest in commercial applications, exemplified by the *Denison* and the Supramar series of hydrofoils. None of these, however, have been designed for long-range open-ocean employment and are generally limited to operation in low sea states.

In the military sphere, the Canadian FHE 400 programme is joined by the United States Navy PC(H) and AG(EH) projects described in a recent paper[9] by Mr Ralph Lacey, Bureau of Ships. Of these three ships, only the AG(EH) and FHE 400 have been specifically designed for ocean operations. The fundamental differences between the latter two, as illustrated by Mr Lacey's paper, lie in size, foil configuration, and end purpose. In contrast to the 320-ton experimental AG(EH) employing a "conventional" configuration of automatically controlled, submerged foils capable of retraction, the 200-ton FHE 400 development prototype is based upon a "canard" disposition of surface-piercing, non-retractable foils with an over-all design and outfit specifically oriented to an ASW application. The pivotal point in the design of either ship is the type and configuration of foil system. While each has its own particular virtues and disadvantages, the choice of foil system for FHE 400 was influenced by the requirement for good seakeeping qualities and a high degree of inherent simplicity, ruggedness, and reliability in the demanding environment of ocean-going naval operations. In many respects the development of hydrofoil craft and equipment are in their infancy. Contributions to the advancement of these developments, especially in the military sphere, are being made by the USN and RCN programmes. A close identity of interests links these two projects and the attendant co-operation has been of great benefit in the progress towards allied goals.

4. FHE 400 Design

Principal Features

The form and external features of the ship are shown in the views of Fig. 3. The general layout of main and lower decks, including bridge and operations room, is illustrated by Fig. 4. These are in the course of mock-up development in a full-scale wooden replica of the hull and superstructure at De Havilland.

Leading particulars are summarised in Table I and do not differ substantially from those of the Phase II design proposal.

Hull and Superstructure

The hull structure design involves some departures from normal practice. It caters for hull bending while foilborne, high bottom impact loads at take-off and foil attachment fittings.

Hull and superstructure will be of all aluminium welded construction, fabricated from ALCAN D54S or equivalent plate and extrusions except for the foil attachments which are 7075(T73) aluminium forgings bolted to the welded structure. Extensive use has been made of large extrusions of combined stringers and plating.

The slender hull, designed for minimum resistance, is highly stressed. In consequence, structural joints must be carefully designed and marry up precisely.

The hull is being constructed in the inverted position on an erection bed. When completed, it will be rotated to an upright position for the erection of superstructure, outfitting of systems and attachment of foils.

TABLE I

PRINCIPAL PARAMETERS AND FEATURES — FHE 400

Dimensions	
Length over-all	151 ft 5 in (46.2 m)
Length of waterline	146 ft 6 in (44.6 m)
Beam of hull	21 ft 6 in (6.6 m)
Foil base	90 ft 0 in (27.5 m)
Bow foil span	22 ft 6 in (6.6 m)
Main foil span	66 ft 0 in (20.1 m)
Hull depth	15 ft 0 in (4.6 m)
Keel clearance at 60 knots ...	11 ft 6 in (3.5 m)
Draughts	
Hullborne draught	23 ft 6 in (7.2 m)
Foilborne (60 knots) draught ...	7 ft 6 in (2.3 m)
Displacement	about 200 tons
Main, Auxiliary, and Emergency Power Plants	
Foilborne gas turbine .. ... (Pratt & Whitney FT4A-2)	22,000 shp cont
Hullborne diesel ... ... (Davy Paxman 16YJCM)	2,000 bhp cont
Auxiliary gas turbine and hull-borne boost ... ... (Canadian Pratt & Whitney ST6A-53)	390 shp cont
Emergency gas turbine ... ... (AiResearch GTCP85-291) (AiResearch GTCP85-291)	200 shp cont
Propellers	
Foilborne — twin supercavitating props (fixed pitch)	3 ft 8 in dia
Hullborne — twin controllable pitch props	7 ft 0 in dia

Foil System

The system consists of two surface-piercing, non-retractable units, the bow foil supporting 10% of the ship's weight with the remaining load on the main foil.

The bow foil (Fig. 6) is a supercavitating design for good response in a seaway and acts as a wave sensor to trim stabilise the ship when foilborne. The centre strut is coupled to a shaft which rotates about its axis for steering control at all but low harbour speeds when the use of the controllable pitch propellers is necessary. The shaft can also be raked fore and aft to adjust the pitch angle of the bow foil for hullborne or foilborne attitudes.

The main foil (Fig. 5) has elements with delayed cavitation sections and is an unusual combination of surface-piercing and submerged foils. The large anhedral foils provide reserve lift at the low take-off speeds. Anhedral tips are rotatable and can be manually or automatically controlled in incidence to ensure adequate roll stability at very low foilborne speeds. These can also be employed at higher foilborne speeds to decrease turning diameters in "co-ordinated" turns. Fences are fitted to the high-speed foils and struts to inhibit ventilation.

The foil system is constructed of welded 250 ksi maraging steel of the 18% nickel variety, to which a protective coating, being developed by De Havilland, will be applied. Foil elements are bolted to each other and to the hull. Leading edges of the foils are replaceable and made of INCO 718 stainless steel.

Although the hull and foil elements are relatively simple structures, an analysis by conventional means would be unreliable because of the multiple load paths. Matrix methods have therefore been adopted in critical areas such as the foil elements and main foil foundation.

Although the ship is relatively small, the foil system acts as a strong damper to hullborne motions. Model tests indicate that hullborne motions will be less severe than those of a destroyer escort.

Foilborne Propulsion System

The roughly ten to one difference in foilborne and hullborne power requirements dictate separate propulsion systems for economical performance.

The foilborne system is powered by the FT4A-2 turbo-shaft engine rated at 22,000 shp continuous duty and mounted in a protective cowling headed by an air intake abaft the operations room on the main deck. This arrangement minimises noise and heat transfer to the living spaces of the ship and avoids large structural cut-outs in the highly stressed hull. Power is transmitted from a dual output gearbox abaft the engine via downshafts in the main foil struts to a pod-mounted gearbox and supercavitating propeller at the foot of each strut.

The propellers are fixed pitch, three bladed and 44 in in diameter. The design is currently under joint development by the National Physical Laboratory, England, and De Havilland, Canada. Overrunning clutches in the pods automatically disengage the propeller during hullborne operations.

Both hullborne and foilborne transmissions are being designed and built by General Electric, Lynn, Massachusetts, under contract with De Havilland. Previous experience with the transmissions designed by GE for HS *Denison* and the AG(EH) will be a significant benefit to the FHE 400 transmission development.

Hullborne Propulsion System

The hullborne system is powered by the 2,000 bhp Paxman 16YJCM diesel centred in the engine room as shown by Fig. 4. Power is transmitted by a dual output gearbox and downshafts to an outboard gearbox and propeller at a pod on each anhedral foil. The propellers are 84 in in diameter, three bladed, controllable in pitch and feathered to minimise wave impact loads during foilborne operations. These are being designed and built by KMW, Sweden.

Auxiliary Machinery and Systems

Engine room. The engine room shown on the lower deck plan of Fig. 4 contains the propulsion diesel and all auxiliary systems, including the 390 shp ST-6A auxiliary gas turbine and 200 shp AiResearch emergency gas turbine driving generators, hydraulic and salt water pumps. The auxiliary system is designed around a dual input auxiliary gearbox driven via clutches from either the diesel while hullborne or the ST-6A while foilborne. The gearbox is also capable of coupling the ST-6A to the displacement transmission for "boost" power with the diesel or by itself for emergency propulsion. The emergency gas turbine pack provides a secondary source of electric and hydraulic power, firefighting services and bleed air for main gas turbine starting. The engine room is unmanned and controlled from the bridge and a machinery console in the operations room.

Sub-Systems

The hydraulic system operates bow foil steering and trim, anhedral tips, VDS and anchor winches and various lubricating pumps.

The pneumatic system provides compressed air for gas turbine and diesel starting, torpedo launching, and other services.

Fresh water is supplied from two distillation units. Diesel-engine jacket water is the heat source for the units.

Electric power is generated at 115/200 v, 400 cycle, three phase.

The ship is heated from an exhaust gas heater exchanger operating from the diesel or ST-6A turbine. Electrically driven air-conditioning units are employed.

Firefighting services include a remote-controlled CO_2 flooding system for the engine room, fire hydrants on upper and lower decks, and a portable gas turbine powered emergency pump.

The fuel system is designed to accommodate any diesel or turbo fuel suitable for the four engines. JP5 will be the standard fuel in FHE 400. Four tanks are incorporated below the lower deck.

The bow foil steering system includes features for manual or automatic control of heading, the latter operating from the ship's gyro compass.

Seamanship Outfit

Outfit plans include anchor and associated facilities on the quarterdeck, with a lightweight winch in the compartment below. Hydraulic-powered bollards and other normal fittings for line handling are being provided. A 13½ ft Boston whaler with an 18 hp outboard motor will be carried as shown in Fig. 3.

Facilities for refuelling and replenishment at sea are being incorporated.

Variable Depth Sonar Winch and Handling Gear

Facilities for the streaming and recovery of a towed VDS body are being developed based upon handling gear designed to recover over-the-stern. These are in the course of design. A representative installation is shown in Fig. 3.

Accommodation

Feasibility of the ship is dependent upon its habitability in open-ocean operations. Environmental considerations have therefore heavily influenced accommodation design. Planning has been based on a crew of four officers and sixteen men with provisions for operations in excess of two weeks at sea. This is subject to possible change when operating and maintenance tasks are more fully explored during the evaluation. Because of the uncertainties, an aim is flexibility of arrangement. The general arrangement which has now been mocked up is shown in Fig. 4.

The galley provides for storage, preparation, and cafeteria style serving of all food. Meals will largely consist of precooked and frozen foods, selected in portions on board according to the menu and served after rapid heating in a micro-wave oven. Conventional foods can be prepared when practicable. This approach has been dictated by weight, space, manpower, and foilborne motion considerations.

Bridge and Operations Room

A general arrangement of bridge and operations room is shown in Fig. 4. The bridge is confined to ship control and navigation functions and provides for two manned positions, a primary and secondary. The operations room is the centre for tactical control of the ship and its weapons system. A representative arrangement of manned consoles is shown. The engineers' console is also fitted in this space. Systems engineering analysis techniques, including work study, have been applied to the design of arrangements and definition of operator duties and qualifications.

5. Problem Areas

Some degree of uncertainty on the full attainment of objectives is inherent in any development programme, however well founded. The FHE 400 prototype will in many respects be the product of recent research and developments. Herein, certain possible difficulties, which may emerge in evaluation, have been acknowledged and highlighted as "key problem areas" in the project. These bear upon questions of operational as well as technical feasibility of the design and include foil materials and coatings, supercavitating propeller design, seakeeping and noise influences on the habitability of the ship.

IV. RESEARCH AND DEVELOPMENT ASPECTS

1. Introduction

The FHE 400 programme constitutes the development of a complete "weapon system" based upon a relatively unprecedented vehicle design which, compared to conventional warships, places stringent limitations on the size and weight of its elements, including systems and payload. This has necessitated some research and a considerable dependence upon development or adaptation of lightweight hardware. The latter is, unfortunately, a costly process, particularly for a single experimental ship. The foil system is, however, the focal point of development effort upon which the success of the entire programme depends. Theoretical studies and research have also played a considerable role in the work to ensure a sound foil system hydrodynamic, material and structural design. These encompass an extensive range of studies and tests over the past four years.

The scope of this paper permits only a brief review of the vehicle considerations. Highlights are grouped and summarised in the following sub-sections.

2. Hydrodynamics

In the process of developing a specific foil system for FHE 400, it is considered that significant contributions have been made to the design of surface-piercing hydrofoil craft. This applies particularly to the dynamic simulation of craft motion in a random seaway and in subcavitating foil design. Other contributions are also being made to the art of superventilating foil sections and supercavitating propeller design. Some considerable effort has also been applied to hydro-elastic studies and tests on divergence and flutter clearance margins of the main and bow foil.

(a) *Craft Motion in a Random Seaway*

A fundamental aim of the NRE concept was an all-weather craft capable of open-ocean performance. A major problem in the feasibility design studies was, however, the estimation of the degree of stability for foilborne operations in a random sea. Up to 1960, little work had been published on this subject. Accordingly, De Havilland, as previously noted, undertook the development of the equations of motion and a method of representing a random seaway for an analogue computer simulation of craft in six degrees of freedom. The initial simulation was in sinusoidal seas and results were correlated with model tests at NPL, London.

Subsequently, random seaway simulation was incorporated during the Phase II studies, and has since been extensively employed in the design development and proving of the foil system. The forthcoming phase of computer simulation studies will be applied to the anhedral tip and bow foil control systems to establish gains and stiffness requirements.

A comprehensive treatment of the theory of craft motion and the correlation of computer predictions with trials results is contained in the paper of Ref. (8) presented by Davis and Oates to the ONR Symposium at Bergen, Norway, in August 1964.

(b) *Subcavitating Foil Design*

The main foil design requirement is for cavitation-free operation at 60 knots in calm water and for a wide angle of attack range at 50 knots in Sea State 5.

Design of a satisfactory non-cavitating foil involves the determination of the shape required to support a given pressure distribution. At infinite depth, this problem is identical to the airfoil, for which methods of computation already exist.

However, the free surface can cause significant effects on the pressure distribution at practical depth/chord ratios and Froude numbers. Thus an extension of airfoil theory is necessary to account for the effect of the free surface.

Such a technique was developed for the FHE 400 design programme using the method of singularities in which the lift is represented directly by vortices, and thickness by doublets. This work is described in Ref. (10).

Using this technique, hydrofoils can be designed to have a minimum cavitation number for a given thickness and lift, by specifying flat-topped types of pressure distributions. However, at off-design angles of incidence, these profiles have poor cavitation characteristics, since the additional lift due to change of incidence causes sharp (negative) pressure peaks near the leading edge. The objective therefore is to design a profile having as wide a cavitation-free range as possible. This can be achieved by designing a profile which will have a positive pressure peak near the leading edge on both upper and lower surfaces at the design angle of attack. The negative pressure peak due to change of incidence will then "fill in" this part of the pressure diagram, leading to a flat-topped pressure distribution on one side at each extreme of the cavitation-free incidence range.

(c) *Fully Ventilated Foil Design*

The environment and stability requirements for the bow foil favour the use of a fully ventilating foil section. However, it is difficult to design such a foil which would have satisfactory characteristics due to the wide range of angle of attack experienced in a seaway and the need for a section with good low speed resistance. In developing the foil section, it is first necessary to define the pressure face for normal supercavitating or fully ventilating operation. A Tulin-Burkart pressure face is used with a design C_L of 0.1 and a nominal operating C_L of 0.2, using the method outlined in Ref. (11).

For minimum resistance in the displacement mode, the foil should have an upper surface shape approaching that of a circular arc, the ordinates of which should have the minimum included angle compatible with structural requirements. In a seaway, however, very small relative angles of attack occur, and under such conditions, the flow will re-attach to the circular arc top surface, with a consequent large lift increment in the fully wetted condition, due to the camber of this type of foil. Since re-attachment leads to violent pitching motions, it is necessary to provide a spoiler on the upper surface, in the form of a "step" to prevent flow re-attachment over the rear portion of the foil during foilborne operations.

3. Materials Investigation

One of the major problems in the development of a surface-piercing hydrofoil craft of the FHE 400 size is the limited selection of structural materials with the high strength/weight ratio and other properties required for an efficient and durable foil system.

As previously mentioned, De Havilland were assigned a contract to conduct a comprehensive investigation to determine the best materials and protective coatings available in the time scale for production of the FHE 400 foil system. The Department of Mines and Technical Surveys was also engaged as a consultant.

A number of materials were investigated for various properties in tension, shear, fatigue, impact, weldability, and for resistance to normal corrosion and stress corrosion.

The results of these studies led to the selection of an 18% nickel maraging steel with a 250,000 psi yield strength. An extensive series of tests were conducted. Fatigue characteristics were determined by random load tests using the load spectrum derived from the analogue simulation of the ship.

The need for coatings to provide adequate protection of foils against corrosion was established. Investigations were conducted on a large variety of types for adhesion, water absorption, resistance to cavitation erosion and other critical properties. These have resulted in a concentration on two of the most promising, both of organic composition. Small-scale tests of these coatings have been run in cavitation loops developed by De Havilland at speeds of 65 knots. Larger-scale tests are in progress at Grumman Aircraft Engineering Corporation facilities. Qualitative trials on large underwater sections of two RCN destroyers are being conducted. Arrangements have also been made for tests of these on the bow foil of the USN Hydrofoil PC(H).

The Department of Mines and Technical Surveys is investigating the properties of the new 12% nickel maraging steels (180 ksi yield) which appear to offer attractive advantages as a replacement for the 18% material in any future foil manufacture. This is subject to determination of suitable fatigue properties and other qualities.

The necessity and feasibility of a cathodic protection system for the ship is also under investigation.

4. Habitability

In the final analysis, the feasibility and operational capabilities of the ship will be dependent upon the habitability of the ship and thus the efficiency of its crew. The nature of FHE 400 and its envisaged operation presents some unusual environmental conditions, particularly while foilborne. Accordingly, considerable attention has been given to habitability aspects in the design of accommodation and operator facilities. Factors which have influenced these are ship motions, noise, and vibration, together with space, weight, manpower, and equipment limitations.

Extensive use has been made of "Method Study" in establishing requirements and the design of arrangements. Its applications by the RCN are described in Ref. (12), including the study from which the FHE 400 galley design was developed. Accommodation, bridge and operations room arrangements and management have also been defined by RCN method studies. These have been of great assistance in charting requirements and designs which have, in most instances, little precedent in conventional warships. In keeping with the concept, every effort has been made to minimise operating and maintenance requirements, thus to achieve the smallest crew for efficient, "round-the-clock" operation at sea. While living accommodation is not cramped by submarine or MTB standards, the limitations of layout and other criteria have required careful design of arrangements and the development or adaptation of lightweight, easily maintainable equipment and furnishings.

Measures to ensure adequate levels of comfort and efficiency while foilborne have received particular attention. Human thresholds of tolerance to ship motion are not well defined. While hullborne motions are predicted to be less severe than a destroyer escort, there is the uncertain effect of the stiff damping action of the foil system. Finally, there is the entirely different nature of foilborne motions and the difficulty of predicting crew reaction to these. While tests in Rx craft indicate that levels of acceleration should be acceptable, it should be noted that a surface-piercing foil craft such as FHE 400 is a semi-contouring or partial response system with less potential for smoothness of ride than an equivalent craft with submerged automatically controlled foils.

In the study of FHE 400 environmental factors by the Canadian Forces Institute of Aviation Medicine, attention has focused upon foilborne motion considerations. Part of the investigative programme includes the study and test of sleeping and operator console arrangements under simulated foilborne motion conditions using "live subjects". A motion simulator platform which can reproduce foilborne motions in roll, heave, and pitch has been constructed for this purpose at the National Research Council laboratories in Ottawa. It is operated from magnetic tapes of the predicted random seaway motions of FHE 400 derived from the De Havilland computer simulation.

Experimental mock-ups of crew bunks and operator control positions will be instrumented and tested to assess comfort and efficiency of arrangements, including modifications to their form or employment to minimise any adverse effects of foilborne motion. Trials are now under way on an experimental version of the bunk design concept developed by IAM.

REFERENCES

(1) Bell, Alexander Graham and Baldwin, F. W.: "Report to Admiral Griffin on the HD-4." *Beinn Breagh Recorder*, Vol 23, 1919.
(2) Nutting, W. W.: "The HD-4, a seventy-miler with remarkable possibilities." Reprinted Smithsonian Report for 1919, Publication 2395, Government Printing Office, Washington, DC, 1921.
(3) Crewe, P. R.: "The hydrofoil boat: its history and future prospects." *Trans. INA*, Vol 100, 1958.
(4) Eames, M. C.: "The influence of cavitation on hydrofoil craft design." *Canadian Aeronautical J*, Vol 6, 1960.
(5) Kuhring, M. S.: "The Comox torpedo — a Canadian contribution towards hydrofoil development." National Research Council, Canada, Report No ME210, June 1958.
(6) Walchner, O.: "Contribution to the design of ship propellers without cavitation." Translation by Saunders-Roe Ltd, Isle of Wight, of an AVA Monograph, *c* 1945.
(7) *A Study of Hydrofoil Seacraft.* Grumman Aircraft Engineering Corporation, Long Island, NY, for US Department of Commerce, Maritime Administration, Oct 1958.
(8) Davis, B. V. and Oates, G. L.: *Hydrofoil Motions in a Random Seaway.* De Havilland Aircraft of Canada Ltd, Aug 1964.
(9) Lacey, E. Ralph: "A progress report on hydrofoil ships." *Trans. RINA*, Vol 106, 1964.
(10) Richardson, J. R.: "Theoretical pressure distribution for two-dimensional, sub-cavitating hydrofoils near a free surface." Engineering Research Association, Toronto, Canada, June 1961.
(11) Johnson, V. E.: "Theoretical and experimental investigation of supercavitating hydrofoils operating near the free water surface." NASA TR-R93, 1961.
(12) Farrell, Capt K. P., RCN, Judge, R. and Engh, Lt I. B., RCN: "The RCN's application of method study to ship design." Eastern Canadian Section, The Society of Naval Architects and Marine Engineers, Jan 1965.

This paper was presented to the meeting of The Royal Institution of Naval Architects in the Weir Lecture Hall, 10 Upper Belgrave Street, London SW1, on March 24th, 1965.

An extract from the paper by J.H.W.Cox published in the book "The RCN In Retrospect 1910-1968" as "An engineer's outline the RCN history: Part II"(1), follows:

Canadian naval interest in hydrofoils had its beginnings in 1945 when General George Pearkes, then general officer commanding Pacific, stated a requirement for a high speed smoke maker to be used in amphibious operations. A hydrofoil seemed the only practical solution, and by the end of the war four prototype vehicles had been delivered. The NRE, aware of the attractions of high speed vessels and of the potential offered by hydrofoils, pursued the subject over more than a decade and through a succession of test craft all of which used the "surface piercing" form of foil. In 1959, the NRE tabled a report proposing a 200-ton all-weather hydrofoil for ASW applications. This proposal was discussed the following January at a meeting of American, British and Canadian scientists. It was agreed that each nation would concentrate its high speed research: the British on hovercraft, the Americans on submerged-foil hydrofoils and the Canadians on surface-piercing foils. The conference recommended an extension of NRE hydrofoil work to a prototype craft. De Havilland Aircraft of Canada (DHC) was given a feasibility study in 1961, and by the end of the following year sufficient work had been done that the Naval Board was able to authorize production of a prototype ASW hydrofoil ship for which DHC was the prime contractor. The name **Bras d'Or**, *and the designation* "**FHE 400**", *were adopted later. Parallel studies examined questions of materials, fighting equipment, and foilborne stability. Canadian Westinghouse was awarded a contract to design and develop the fighting equipment suite. Tests and trial of structural members and foils, protective coatings, super cavitating propeller models, hydraulic steering and stabilizer actuator, the action information system, and the full- scale foil-borne propulsion system were progressively completed permitting identification and correction of problems as they arose. Assembly of the ship took place at the Sorel Shipyard of Marine Industries. On 5 November 1966, ironically "Guy Fawkes Day", a disastrous fire occurred in the nearly completed ship. In April of the following year, after the programme had been reappraised, it was decided to repair the fire damage, make a number of modifications to the design, complete the ship, and take delivery of the fighting equipment but to defer the fitting until completion of the initial foilborne sea trials.*

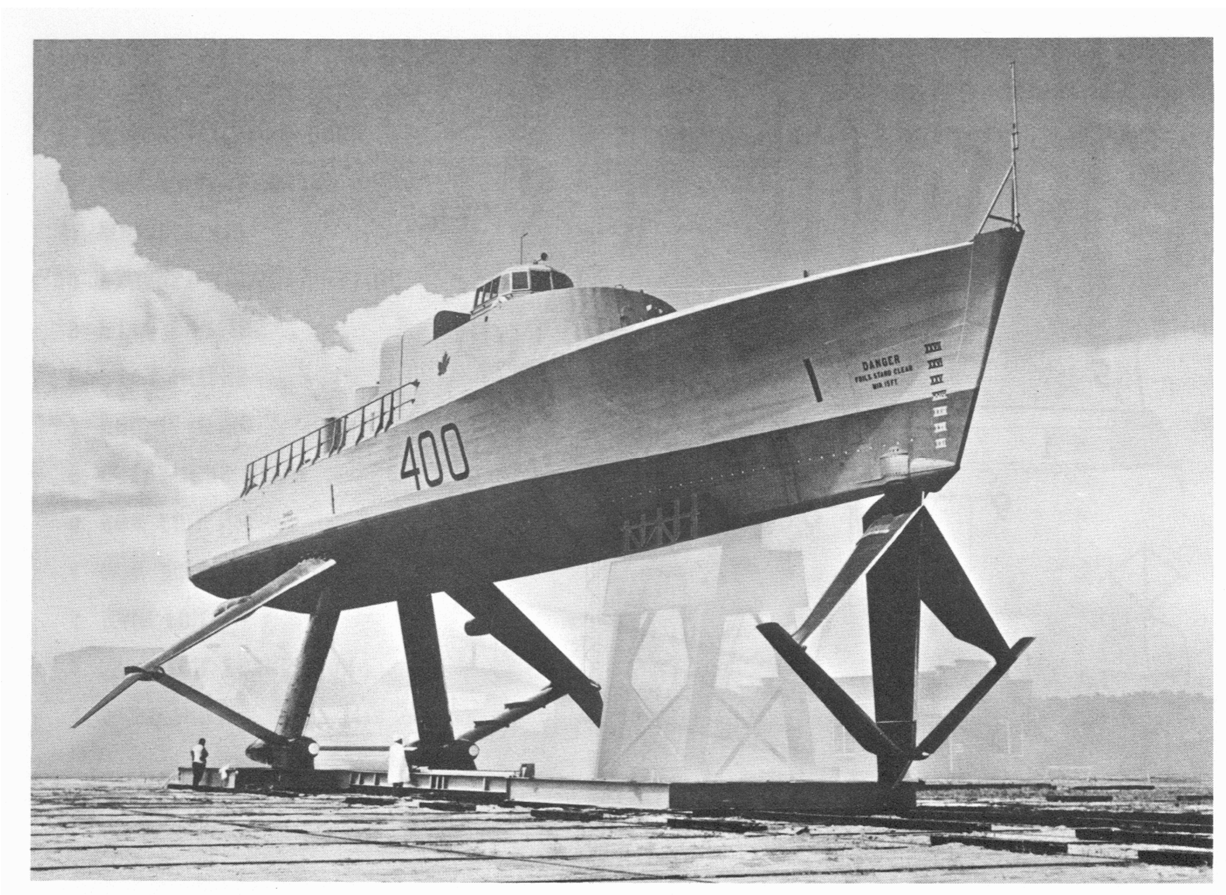
In September 1968 the ship, having been delivered to Halifax from Sorel on its specially constructed "slave dock", commenced hullborne sea trial without the foilborne transmission system. On 9 April 1969, with the foilborne transmission satisfactorily through its shore trials and now installed in the ship, Bras d'Or became foilborne for the first time. That summer a foilborne speed of sixty-three knots was recorded in the full-load condition in three- to four-foot waves. Foilborne trials were interrupted for a year when the main foil centre span was found to have developed cracks from a water leak. This required the span to be replaced. When a full trials programme including rough water trials was resumed, it included operation hullborne in seas up to state six (twelve foot waves). The feasibility of a 200-ton all-weather open-ocean hydrofoil had certainly been established. Unfortunately, the costs of a refit, including further foil repairs, fitting the fighting equipment, and carrying out trials of the ship as an ASW vehicle, were felt to be unwarranted. Even if the trials were successful, the RCN was not certain that the construction of a squadron of such ships, at the expense of a similar investment in conventional vessels, would be justified. In 1971 the Bras d'Or was laid up in a state of preservation pending a final decision on its disposal.

So ended a warship design program that uniquely involved the building and testing of a prototype to prove the design (as happens in a new aircraft program). Production of the ship was not entered into. Consequently, all of the design, build and test elements of the program are considered part of the Design House contribution by Industry to the Navy.

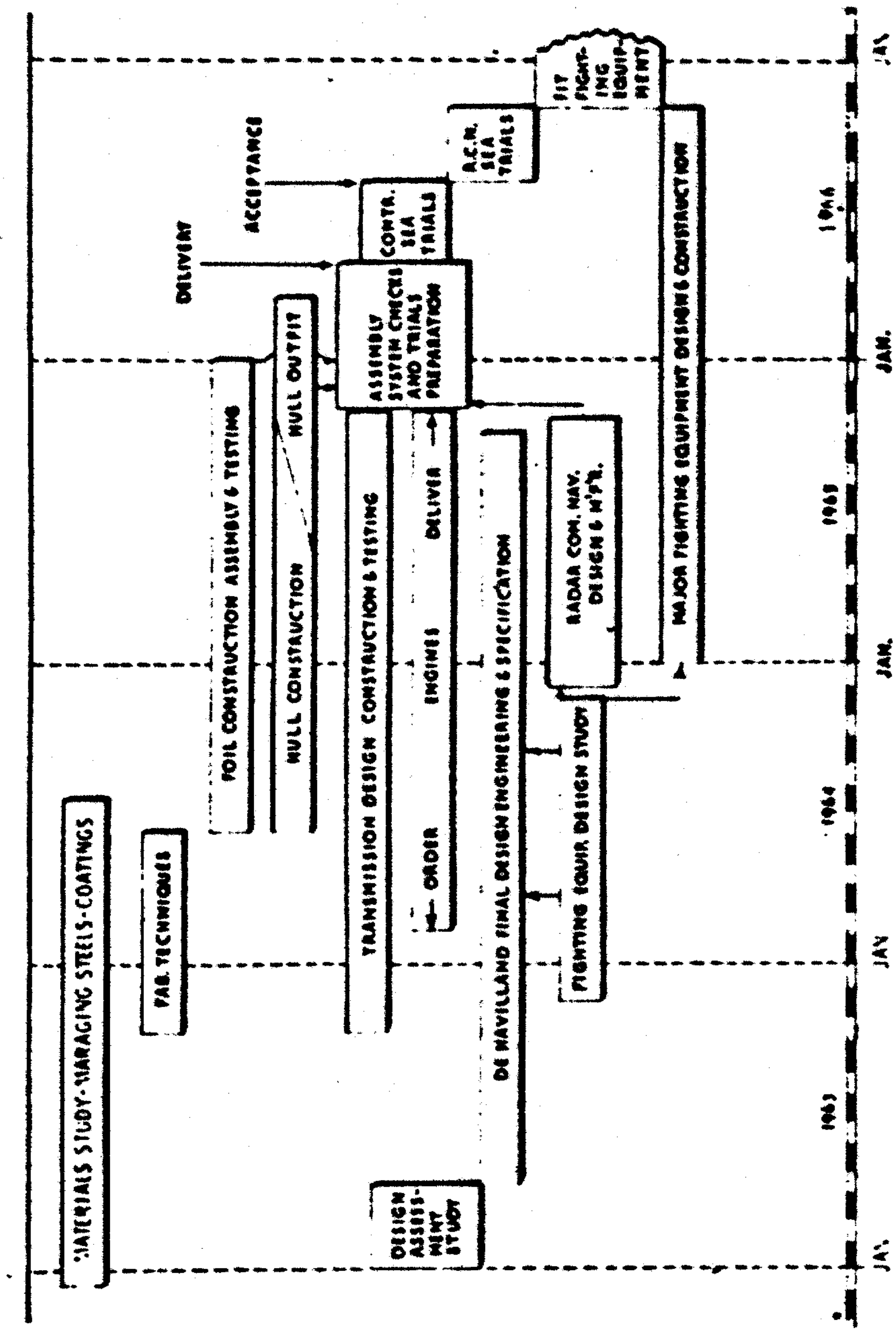
More detailed technical papers, one dealing with the Program aspect and the other dealing with the Technical Development aspect, are recommended reading, viz:

1. ***Development of the Canadian Antisubmarine Hydrofoil Ship***
   By Capt. R.G.Monteith, RCN & R.W.Becker – presented to the Canadian Congress of Engineers in Montreal, 2 June 1967 **(15).**

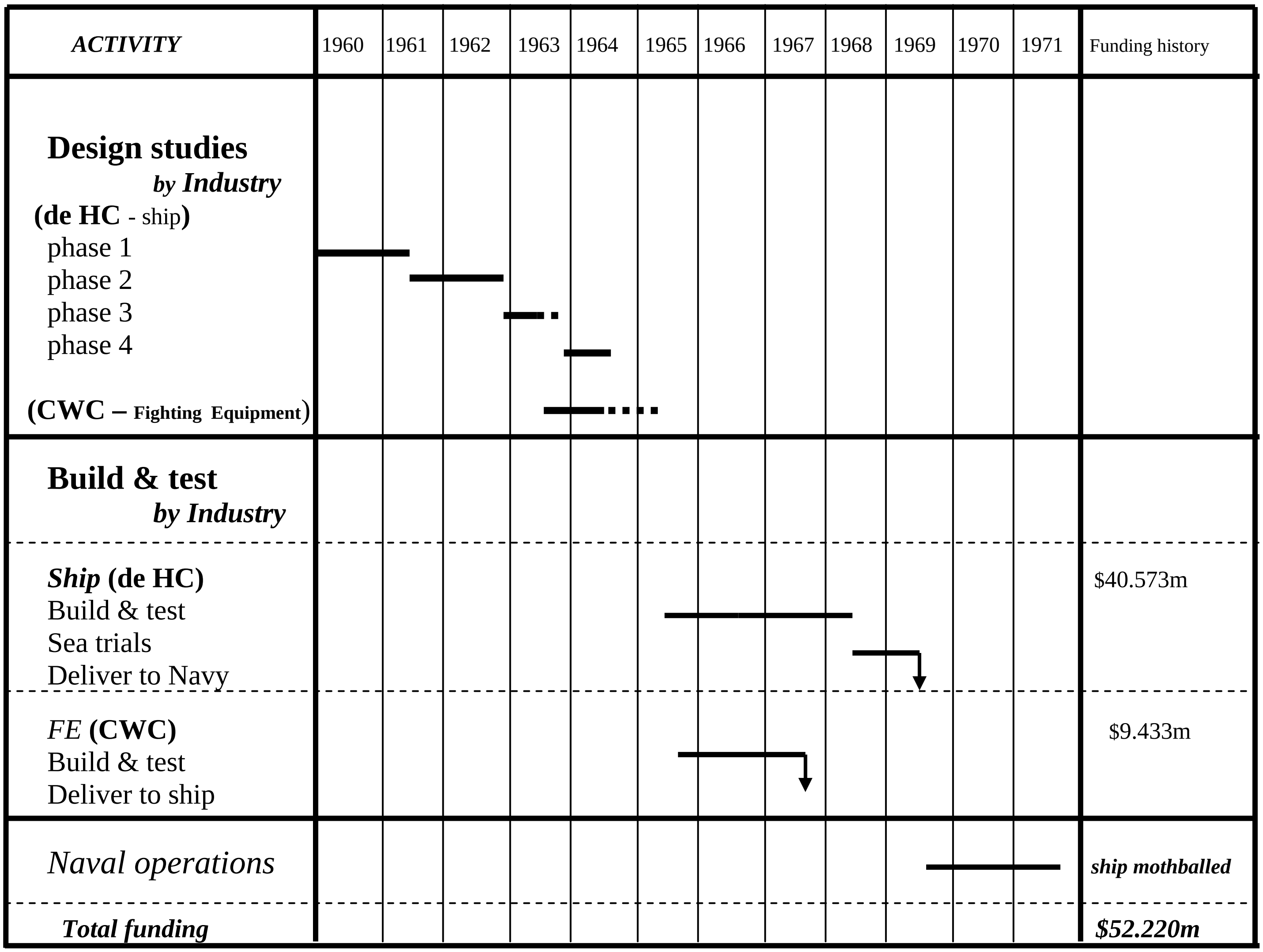
2. ***Structural Design & Development of the FHE 400 Hydrofoil Vessel***
   By S. Morita, de Havilland Aircraft of Canada Ltd – presented to the 1967 SESA Spring Meeting **(16).**



FHE 400 HMCS Bras d'Or Hydrofoil Ship



Program Plan for Design, Build & Outfit of Bras d'Or Hydrofoil Ship



Synopsis of FHE 400 “Study, Design, Build & Test Program

(devised from various source documents)

4.5 TRUMP Modernization of Iroquois Class DDH 280's

The update and modernization of the four DDH 280 "Iroquois" Class destroyers, sometimes referred to as the TRIBAL class since each ship carried the name of a Canadian aboriginal Indian tribe and hence the acronym **T**ribal **R**efit **U**pdate and **M**odernization **P**rogram – **TRUMP**, was the most ambitious and complete redesign of a Canadian warship incorporated into the original ship's hull that had ever been undertaken.

The requirement was for the ships to be capable of extending their capabilities to include the roles of Task Group Command and Supportive Air Defence. The result of the program was a great success and the ships often have subsequently provided Task Group Command of the NATO North Atlantic Fleet.

The decision to proceed with the TRUMP program was based on the economic benefit of upgrading a ship's hull which had proven successful in the ship's initial role and which had at least a further 15 years life. The need to implement the upgrading of the ship's overall capability was based on the changing threat scenario to blue water ships that had arisen since the DDH 280's were first conceived and subsequently built.

The contracting was somewhat unique in that the overall ship program was awarded to a non-ship design or ship-building Canadian company, viz; Litton Canada, based on the fact that the parent company in the USA did have these skills and the Canadian company would deliver and commission the major new weapon system, the Vertical Launch System.

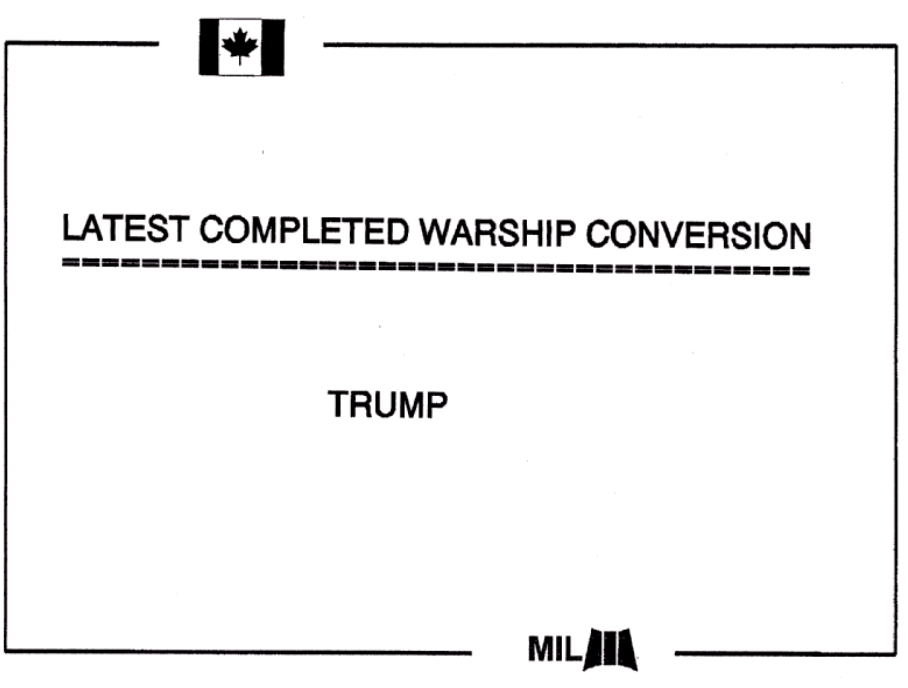
Technically this required a major reallocation of existing equipment from three decks in the bow to other areas of the ship in order to integrate a 120 tonnes VLS and its supporting structure which would not adversely affect the ship structure under the shock load of a missile launch, and to provide adequate space for maintenance considerations of the VLS system. The following are some of the slide presentations used in the Washington briefing in February 1994 to personnel of the US Navy and the Naval Attaches of foreign navies posted to Washington, DC. (see Chapter 5 of this publication for more details) wherein VAdm (ret) Allan presented an in depth history of the Canadian Navy's experience with the modernization of its warship fleet based on both the changing roles of its ships over time and the economics of upgrading those ships versus the build of new ships for the new threat scenario and taskings envisaged **(7).** Canadian Industry has played a major role in the implementation of those upgrades, both at the engineering design level **(8)** and the shipyard implementation level, as well as in the supply of sophisticated, modern equipment of high quality to current international quality standards..

A very important element of a ship design and build program is the interface between the designers and the shipbuilders, and the former needs to understand the capabilities of the latter if maximum efficiency is to be achieved, or to put in the opposite way, to avoid implementation mistakes which are both costly and time consuming to correct. The necessary interface is known as Production Engineering, which is intended to ensure that the design presented can be made with the tools and other constraints of the shipyard. Ideally, this physical interface has been to have both design and build in the same physical facility.

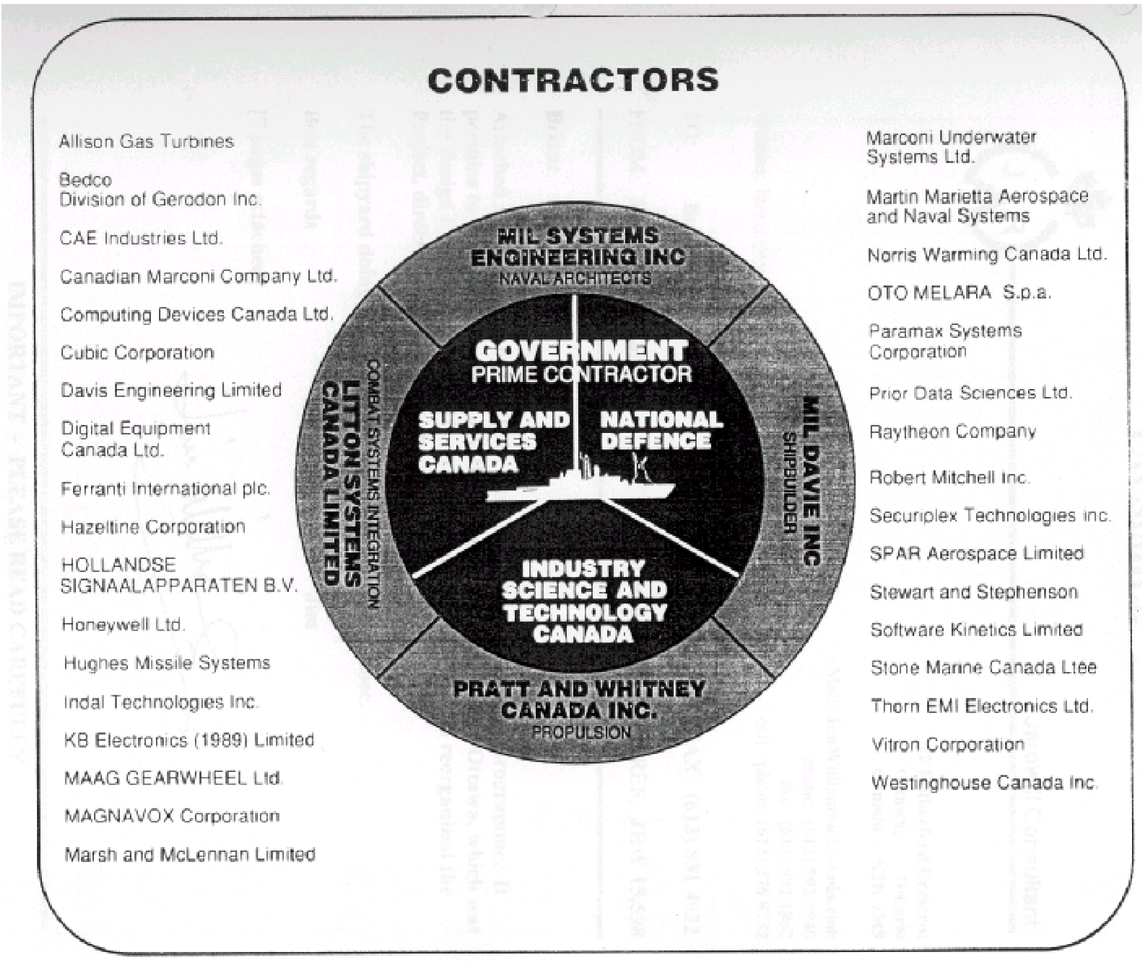
On the other hand, in a quite small Navy such as Canada's subsequent to World War II and the Navy's need to maintain its ships where possible with minor changes promulgated by SHIPALTS which were required in their hundreds from a central design/drawing office under the NCDO contracting formula, it was increasingly necessary for the design/draughting office to be close to Naval Engineering Headquarters located in Ottawa. The Production Engineering interface required by the SHIPALT system was minor with most of the resulting work being done in the two Naval Dockyards located at Halifax on the east coast and Esquimalt on the west coast.

The Production Engineering solution in the case of a major program such as TRUMP could be satisfied by posting shipyard Production Engineering personnel in the Design Office, and this proved a workable system (although there were some hiccups, as one might expect). During the actual ship modification phase, the Design Office personnel were in turn posted to the shipyard, and this allowed any incompatibilities which did get through the design phase to be quickly corrected during the build phase.

In more modern times, much of this Production Engineering interface can be accomplished through the utilization of integrated computer design between the Design Office and the shipyard Production Engineering office.

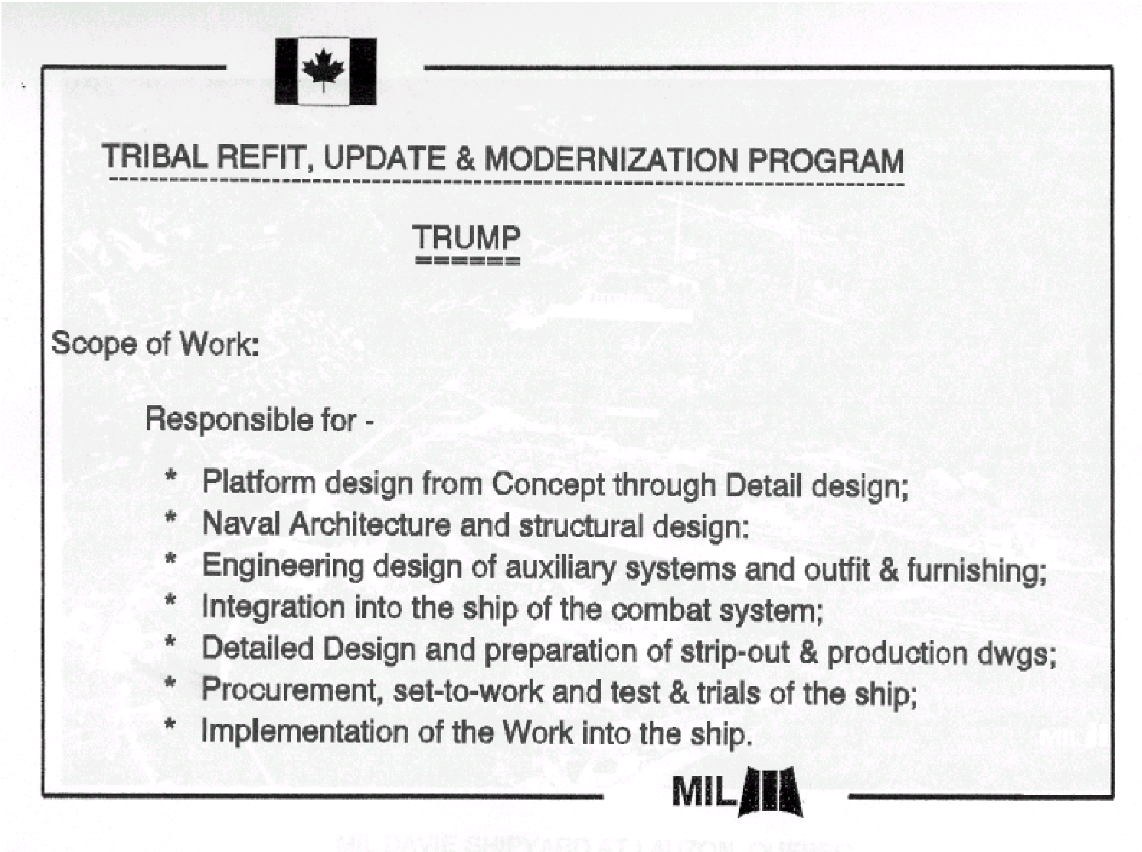


DDH 280 pre-TRUMP



The preceding chart shows the contracting structure between the Crown (the Navy via its Departmental and Procurement Departments) and four first tier contractors, viz; Litton Systems Canada Limited – the Program Manager & Supplier of the VLS, MIL Systems Engineering Inc.– the ship designer and systems integrator, MIL Davie Inc.– the shipbuilder, and Pratt & Whitney Canada Inc. – the supplier of the new propulsion units.

The outer ring of the chart shows most of the second tier suppliers of other required goods and services. About half way through the build phase of the program the Crown claimed the role of Program Manager from Litton.



This chart shows the responsibilities of the Designer. An important phase was the identification of that equipment that was to be removed from the ship, some of which was to be discarded and some of which was to be refitted in a new location on the TRUMPed ship.

NAVAL ARCHITECTURAL CHALLENGES

* Trim & Stability
* Hull Girder Strength
* New VLS system
* New IR suppression
* New cruise engine
* New machinery control system
* New WDFS system
* Modified gear box
* New fire detection system
* New smoke evacuation system
* New CIWS
* New main gun
* New 1000kW electrical power generator

MIL

TRUMP ENGINEERING DELIVERABLES

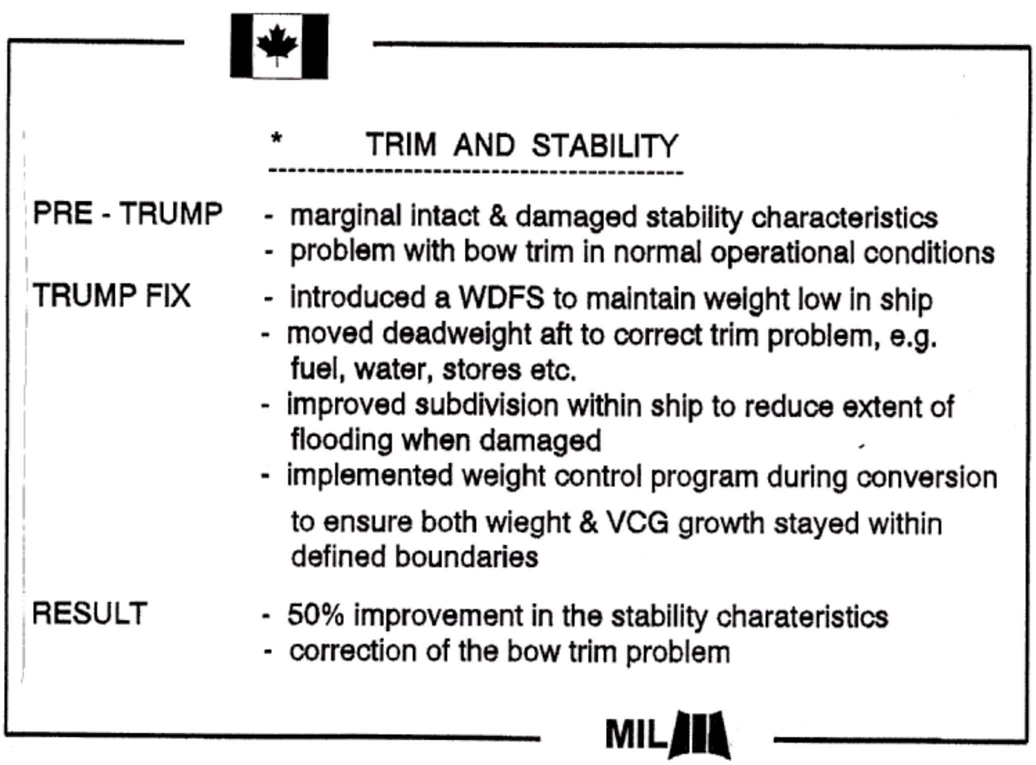
* 14,075 new and revised drawings
* 2,275 SDRL Reports
* 251 Equipment / Subsystems
* 668 Line Item Spares
* more than 1,225,000 man-hours of engineering

MIL

The first of the two previous charts succinctly lists the major design challenges. Infra Red suppression of the engine flumes was a passive element in the stealth signature of the upgraded ships whereas the Close In Weapon System (the radar directed Gatlin gun) was an aggressive active element. The Water Displacement Fuel System very effectively stabilized the ship during manoeuvres, especially during a Vertical Launch System launch.

Those requirements developed into the multitude of drawings, reports and equipment activities that consumed almost a million and a quarter man-hours of direct design and draughting personnel, as shown in the second chart. When the administrative indirect mark-ups for management and support staff activities were added the program consumed considerably more than a million and a half man-hours. The paperwork produced was mountainous but necessary in order to retain configuration of the ships in their extended lives.

There follows some data on particular ship systems affected by the TRUMP program, which are self explanatory.



* LONGITUDINAL STRENGTH

PRE - TRUMP - low factors of safety in the hull girder to resist wave-induced shear forces and bending moments

TRUMP FIX - redistribution of load items to reduce load variation along the length of the ship
- addition of longitudinal girders on 1 deck and along the bottom plating
- replacement of side shell plating aft in way of the flight deck

RESULT - 20% increase in structural factors of safety

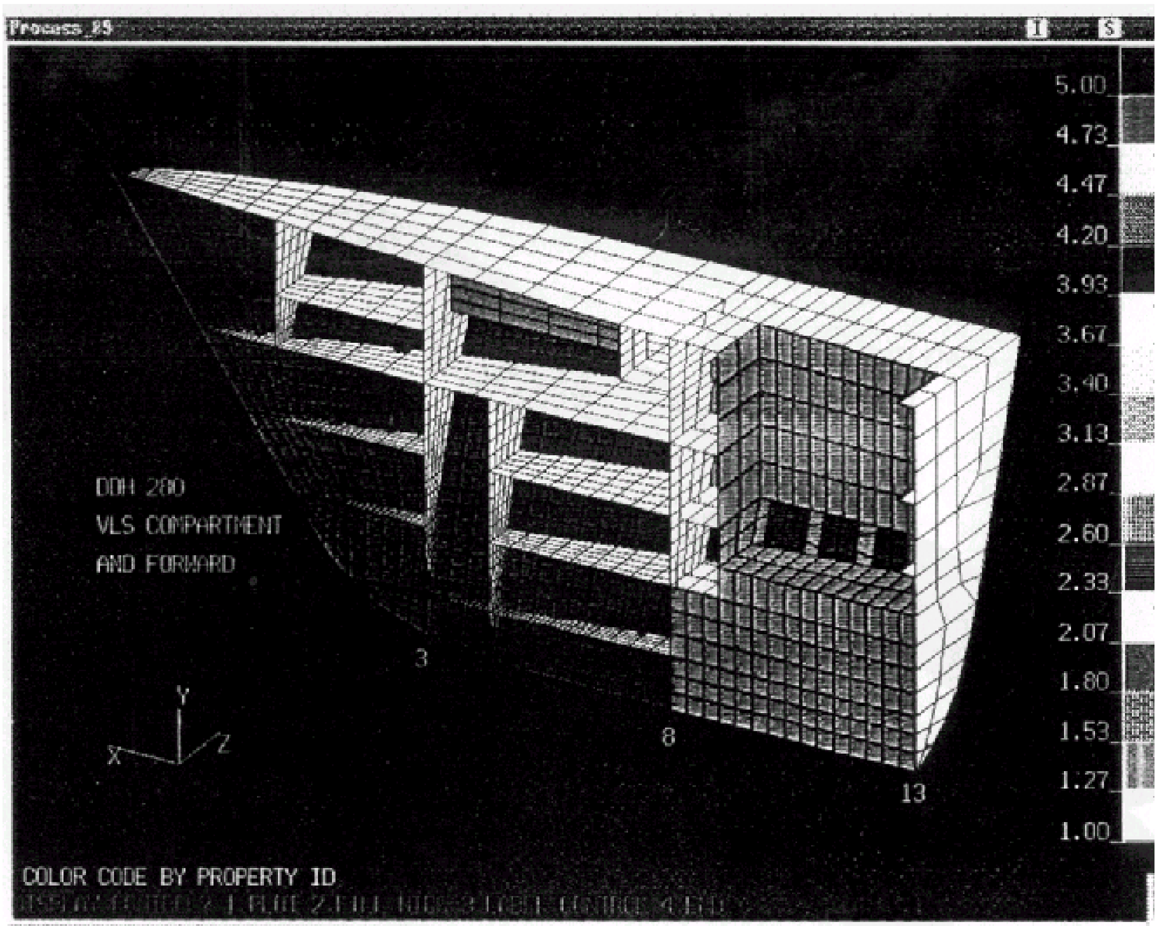
MIL

* VLS INTEGRATION

The DDH 280 is the smallest warship in the world to be fitted with this Vertical Launch System

PROBLEMS - freeing up enough space on three deck levels to fit it physically
- supporting the 120 tonnes weight of the system
- ensuring that the foundation and support structure would deflect uniformly under the shock load
- providing adequate space around and under the module for repair and maintenance

MIL

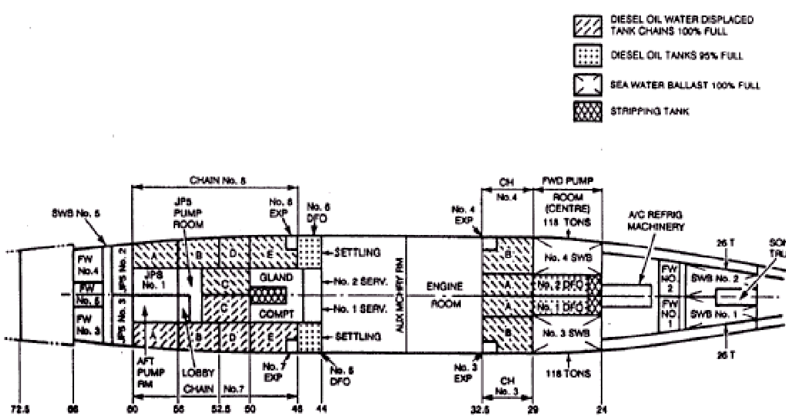


FINITE ELEMENT ANALYSIS for VLS INSTALLATION

* CHARACTERISTICS OF WDFS

- 78% of ship's 650 tonnes of fuel were converted to water displaced configuration
- tank boundaries of these fuel chains were heavily reinforced to withstand higher operating pressures
- internal structure was modified to ensure optimal flow of both fuel and water throughout the tanks
- extensive stripping system was installed to prevent:
  a) water damaging the ship's machinery
  b) fuel polluting the water surrounding the ship

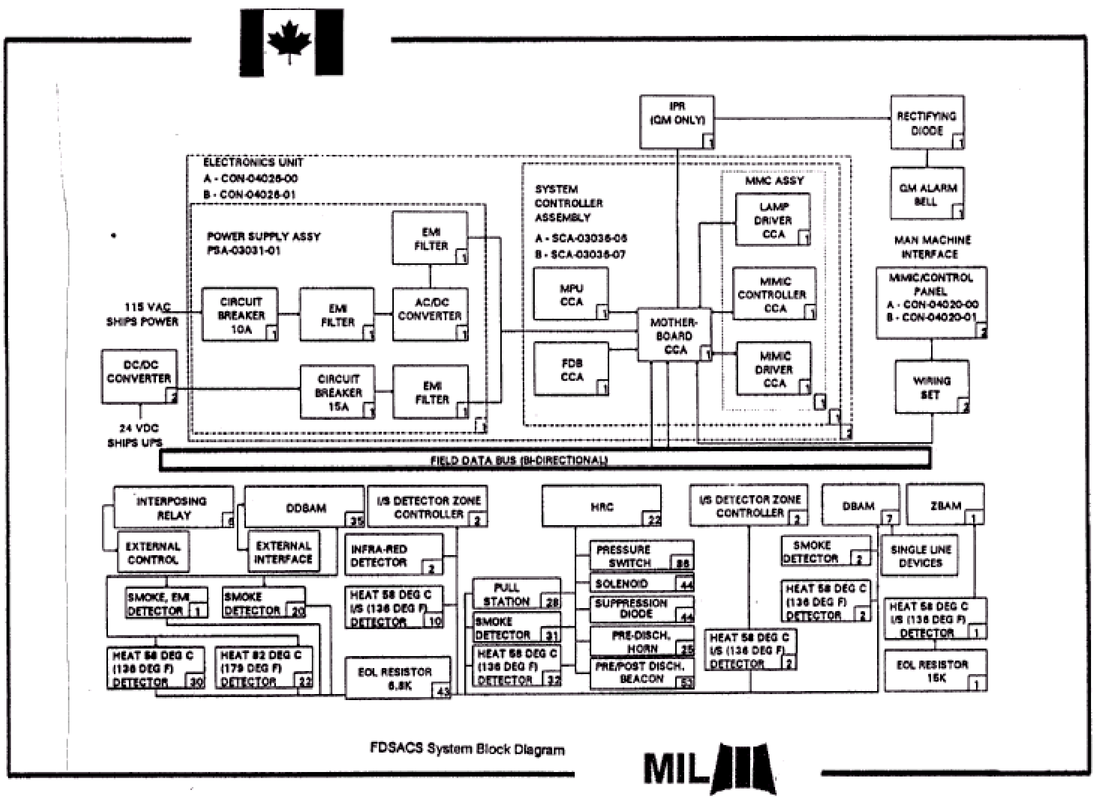
MIL



DDH 280 TRUMP TANK CONFIGURATION

MIL

NEW WATER DISPLACED FUEL SYSTEM

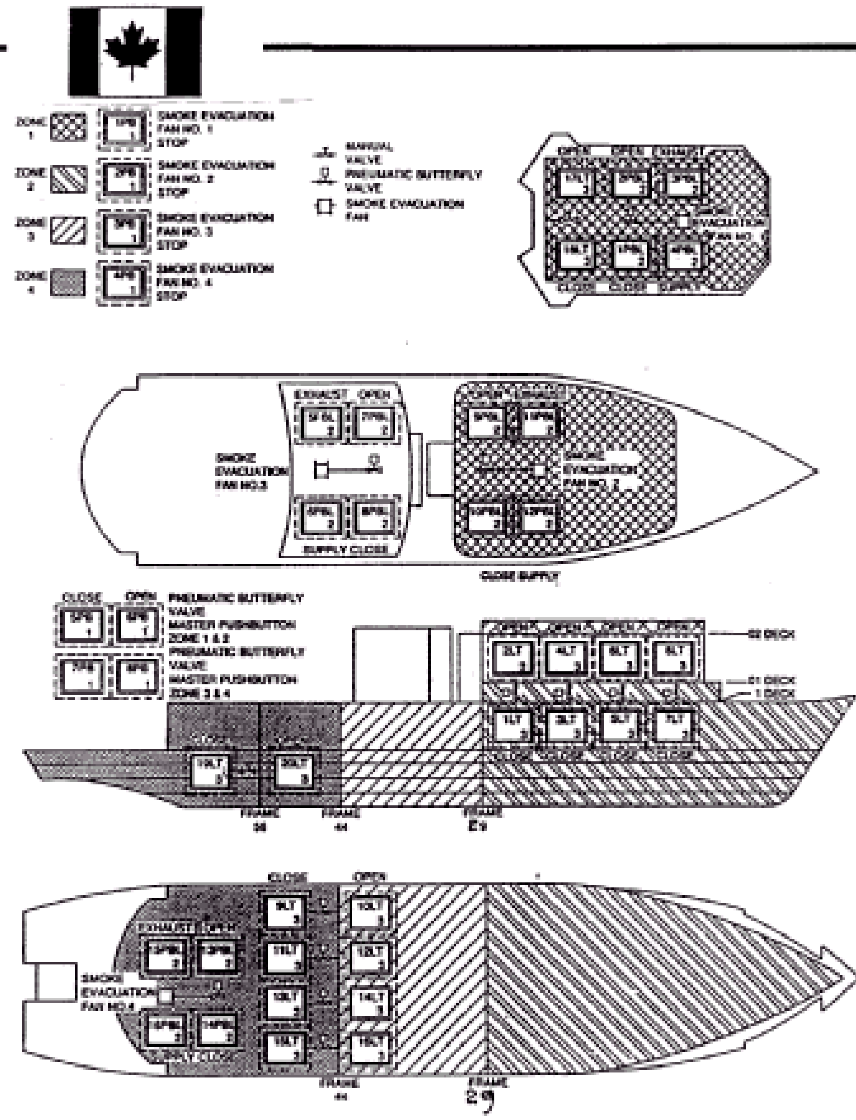


FDSACS System Block Diagram

These latter charts show some schematic details of the new :

- **The Water Displaced Fuel System**
- **The Fire Detection and Suppression System**
- **The Smoke Detection and Evacuation System**

………three very pervasive systems throughout the ship.



Smoke Evacuation System Control Panel and Zone Configuration

DDH 280 post-TRUMP

CHANGES TO THE TRUMP PROGRAM

As you know Litton filed suit in the Federal Court against the Crown, MIL Group, Davie, MSEI and Pratt & Whitney for $750 million. The consequence has been that the Crown and Litton have come to an agreement whereby the Crown becomes Prime Contractor, and Litton, MSEI, Davie and Pratt & Whitney become subcontractors to the Crown. The process is underway to make this transition, and will require some extraordinary efforts by all parties to complete the process by 27 August, the date set by the Crown.

Insofar as MSEI is concerned the change will be beneficial. The Crown has immediately scheduled the third ship, HMCS Athabaskan, into the TRUMP activity. The lift-off, taking into account the modifications incorporated for the Gulf war plus the ShipAlts incorporated since we last lifted-off the ship, will start 15 July at Halifax. The Crown has scheduled the ship into Davie's yard at Lauzon for the 18th of September for a 30 month refit and modernization program, and HMCS Huron will follow in April 1992; she will also need "de-Gulfing and ShipAlt identification" in a second lift-off.

The process will include an assignment of Litton's sub-contract with MSEI to the Crown, which means we must identify and settle all outstanding claims and technical problems, and negotiate revised Statement Of Work and Terms & Conditions, as appropriate, with the Crown prior to August 27. We will all need to work aggressively to meet the change-over schedule. It is to MSEI's advantage to do this effectively. The Action Task Force has been set up and Action Item Managers appointed. They include Bill Craig (Lift-off), David Craig (Schedules & Claims), Clark Gudgeon (SOW), myself (Terms & Conditions) and John Keast (New work opportunities). Andy Davidson, Ron Bosquet and Bob Bain all have strong supporting roles across these action items. Priority for resources will be applied in the order notated above.

MSEI needs a smooth transition. The change gives us much needed work loading now, and could lead to additional work if we show the Crown that we are a solid professional organization. Your whole-hearted support both in house and in the field will provide that professional image.

Thank you

Jim Williams

2/07/91

The author, Jim Williams (on left, at the time President of MIL Systems Engineering Inc.) and his Vice President Marketing, Paul Gulyas, with the company's 1/80th scale model of the TRUMPed DDH 280 class.

Photo' courtesy of Bruno Schlumberger, Ottawa Citizen, 8 March 1990


MIL Systems
MIL Systems
MIL Systems
MIL
MIL Davie
MIL Davie

4.6 Kingston Class MCDV 700

A Foreword, extract by Cdr. McKee from
"The Ships of Canada's Naval Forces 1910-2002" **(21)**

Maritime Coastal Defence Vessels

The MCDVs came about as a result of four influences within the Navy: by the late 1970s the Navy had almost no mine warfare capability, the Bay Class minesweepers having been relegated to training purposes with their minesweeping gear removed; the ships being used by the Naval Reserves were becoming very old (the early 1950s "Porte" Class gate vessels and the small, single-purpose ex-RCMP motor launches) for which the new MCMV (Mine Countermeasures Vessels) would make excellent replacements; the City Class frigate construction program was well underway, with no further such expensive ships likely in the foreseeable future, and yet the Naval staff wished to encourage a continuing naval draw on whatever capital construction dollars might be made available from a reluctant treasury; and there was a perceived national requirement for new inshore, restricted waters operational naval ships which the City Class could not easily meet.

There were at least five main criteria for these new ships: they must be built in Canada, shipbuilding being labour-intensive; they must be as inexpensive to build as practicable, with maximum use of commercial, rather than naval, components and building facilities; they must be operable by Naval Reserves with less technical background training than the Regular Force; they must be inexpensive to build and operate; and their design must be flexible to meet demands for several roles, especially in addition to that of traditional mine warfare using bottom searching and sweeping.

A visit by a squadron of the Royal Navy's Reserve-manned, very similar River Class minesweepers at our 75th Anniversary observations in Halifax in the summer of 1985 was of much interest, and at least showed a proven example of how these criteria could be met. In fact, the Canadian ships of two years later are very similar, with largely commercial construction and engines, a large, open space aft to allow for multiple uses, including lift-aboard containers that could house various options for mine-hunting, sweeping, extra accommodation, supplies, or whatever else occasion might require.

In each ship there are usually two Regular Force technical petty officers for the electronics fit and the engine room. Apart from that, the Reserves man all of them, divided evenly between the East and West coasts, with summer training and familiarization visits by some East coast units to the Great Lakes.

Special or unique equipment is found in these ships: two separated, square rather than round funnels, being less expensive to manufacture, and leaving space between them for the minesweeping control position looking aft above the open quarterdeck; their propellers are shrouded in a circular "hood" and on what is referred to as a "Z" drive, mounted on a rotatable vertical shsft similar to that of an outboard motor. They have no rudders as such, their steering being managed similarly as with an outboard, by rotating the vertical unit. The ships can turn in less than their own length and can be stopped in a matter of a few feet, a valuable asset when mine-hunting in restricted waters. They are fitted with the latest in minor war vessels' navigation and communications equipment, and are reportedly comfortable to live in.

—CDR F.W. McKee

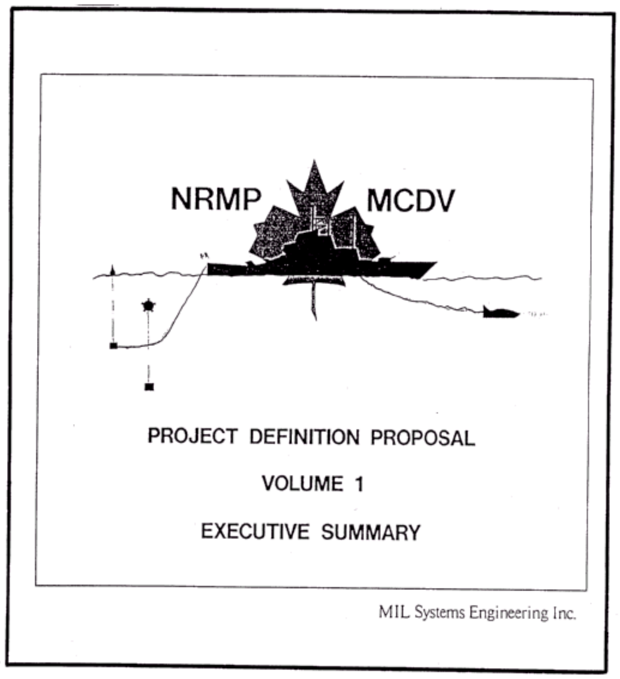
PARTICULARS OF CLASS

Displacement:	970 tonnes
Dimensions:	55.3m x 11.3m x 3.4m
Speed:	15 kts
Crew:	37
Armament :	1 40mm gun 2 sites for machine guns

All vessels were built by Halifax Shipyards Limited, Halifax, NS

A contract for $650 million was let to Halifax Shipyards Ltd in May 1992 to build twelve of these ships. They were designed to commercial standards and intended to conduct coastal patrols, minesweeping, law enforcement, pollution surveillance/response and search and rescue duties. The ships are fitted with modular payloads to carry out the assigned duties. The navy has seven modules available: four route survey modules; two mechanical minesweeping and one bottom inspection module. Steel cutting started in December 1993 and by July 1999 all were in commission.

MCDV Concept (by Jim Williams)



As has been recorded in Chapter 3.2, in 1987 MIL Systems Engineering submitted to the Navy a self-funded Project Definition Proposal that included a concept Design for an MCDV. This was followed up in 1989 with a Discussion Paper for an updated version of the original Design. In 1991 DND, via its Contracting arm DSS (later named PWGSC), requested Bid Submissions from Industry, and let it be known that there was $10 million in the budget for this phase of the eventual complete project, of which $1 million was reserved for in-DND costs; the remaining $9 million was to be shared between two successful bidders from Industry. MIL Systems Engineering submitted two Bids, one fully compliant and one with a modified data package requirement, in order to get a costed Bid as close as possible to the need of the Navy's budget. In the event, that latter Bid of $6.5 million was rejected, notwithstanding that MIL Systems Engineering had previously invested more than $0.5 million in its pre Bid Request period of 1987 to 1989. DSS awarded two Industry Bidders $4.5 million each; it is well known that eventually both Bidders spent close to $10 million each. This required that the winner of the production contract would have to dilute any profit earned in that contract by $5 million or so before it could honestly claim to have earned a profit. As stated below, the construction contract was fixed price at $62.5 million so that a minimum profit of 8% was required to break even. This method of imposing contracting competition by the Government on Industry left a lot to be desired since the subsequent contract auditing was usually very thorough by DSS's Audit Service Bureau.

MCDV Project (by Tony Thatcher)

The Maritime Coastal Defence Vessel (MCDV) program was awarded to SNC-Lavalin as Prime Contractor, for the construction of 12 ships, in May 1992.

As the Prime Contractor and Project Manager, SNC-Lavalin accepted total systems responsibility for the design, construction and delivery of 12 maritime coastal defence vessels, 2 mechanical minesweeping payloads, 4 route service payloads, 1 bottom object inspection payload, 2 differential global positioning systems and 2 route survey data analysis facilities.

The Government of Canada, who awarded this contract to a company with no vested interests in the shipbuilding industry, regards the success of the project as a major accomplishment. The seven-year fixed price contract, valued at $62.5 million, was successfully completed on schedule, did not incur any cost overruns and achieved a total direct Canadian content of 85 %. SNC-Lavalin provided all Project Management services for this turnkey project.

The KINGSTON Class maritime coastal defence vessels will be used primarily by the Naval Reserve to conduct coastal patrol and surveillance as well as mine countermeasure missions. Each vessel, built in accordance with Lloyd's commercial construction regulations, displaces less than 1,000 tons, is 55 meters in length, 11.3 meters in width and has 3.4 meters draft. Each vessel can accommodate up to 37 personnel.