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Development and Trialing of HMCS BRAS D'OR—An Open Ocean Hydrofoil

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The hydrofoil, a ship that overcomes hull resistance by operating with the hull above the water surface, is one type of vessel that is able to cruise at speeds of up to 50 knots in significant sea states. This paper presents a review of the Canadian program directly related to the constructing and trialing of HMCS BRAS D'OR, an open ocean hydrofoil. It summarizes the history of the designing, constructing, and trialing of the vessel. The hull layout, foil configuration, and machinery arrangement are discussed in some detail. Practical operating experience and some results obtained during the trials conducted throughout the program are also described.

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K. E. FISCHER M. J. CALLOW

INTRODUCTION

HMCS BRAS D'OR is an open-ocean hydrofoil constructed as a developmental prototype for the Canadian Armed Forces. The hull was built by Marine Industries Limited of Sorel, Quebec under the supervision of the DeHavilland Aircraft of Canada Limited, the design agent and prime contractor, who installed the machinery and associated systems. The ship was designed as an anti-submarine vessel capable of hullborne speeds in excess of 12 knots and foilborne speeds of up to 60 knots. Basic ship trials were conducted in the area near Halifax Nova Scotia, Canada by a joint team comprising The DeHavilland Aircraft of Canada Limited, Defence Research Establishment Atlantic and Canadian Armed Forces personnel.

In June 1971, the ship was dock to undergo a refit and a proposed conversion. Final approval to proceed with this program has not yet been obtained.

HISTORY

The HMCS BRAS D'OR Hydrofoil program was originally conceived by the Defence Research Establishment Atlantic (DREA). The main objective was to develop a small fast economical, and highly effective anti-submarine warship to be the forerunner of a hydrofoil fleet that would employ the small and many conept to anti-submarine warfare. DREA submitted a report in late 1959 proposing a 200-ton, 60-knot, open-ocean hydrofoil. This report indicated that due to technical advances and with the use of lightweight, high-strength materials and light gas turbines, such a vessel could be used to great advantage as an anti-submarine warship. The report was studied in great detail by the sea element of the Canadian Armed Forces. It was generally concurred that such a vehicle had great potential as a warship, and because of the escalating cost of constructing and operating conventional warships, the project appeared most attractive indeed.

In 1960, a feasibility study contract was awarded to The DeHavilland Aircraft of Canada Limited (DHC) to study the DREA concept and assess the engineering feasibility of the proposal. A report was issued in June 1961 which indicated that the concept was feasible.

A preliminary design study contract was then awarded to DHC which included model tests, computer simulations, cost estimates, and a comprehensive study of the technical problems that could be envisaged during the construction and trialing of a full-scale prototype model. The subsequent report was tabled in late 1962 and favorably received by the Canadian Armed Forces. Following a comprehensive study of this report, a further contract was awarded in 1963 to DHC to design, construct, and trial a full-scale developmental prototype hydrofoil complete with fighting equipment. Construction began in 1964.

HMCS BRAS D'OR was scheduled for completion in 1966, and the fighting equipment suit was to be fitted in 1967; however, several major problems intervened which resulted in the program being delayed. Major delays were caused by the addition late in the design stage of control surfaces in the form of movable anhedral tips, a serious fire in the ship during construction in November 1966, and a foilborne transmission failure during a test run at the manufacturers in June 1967.

In late 1967, due to cost escalation and a limited funding ceiling, the installation of the towed sonar and operational fighting equipment was deferred, and it was decided to finish construction of the basic ship, conduct basic ship trials, then fit and trial the towed sonar and operational fighting equipment. At this point in time, HMCS BRAS D'OR was regarded as a developmental model, rather than a prototype.

Ship construction was completed in mid 1968, but as the foilborne transmission was not yet repaired, it was decided to launch the ship without it and conduct hullborne trials. In September 1968 when the transmission was repaired, the ship was docked and the transmission installed. Trials recommenced in March 1969. The first foilborne run took place in April 1969, and

Length overall	150 ft-9 in.
Hull molded breadth	21 ft-6 in.
Hull Depth	15 ft-7 in.
Overall main foil span	66 ft.
Bow foil span	21 ft.
Foilbase (between bow and main $\frac{1}{4}$ chords)	90 ft.
Hullborne draft (450,000 lb)	23 ft-4 in.
Foilborne draft at 60 knots	7 ft.-4 in.
Static freeboard	8 ft aft 11 ft fwd.
Keel clearance at 60 knots	10 ft-6 in.
Overall height (supercavitating prop tip to bridge roof)	47 ft-0 in.
Hullborne bridge eye height above sea level	21 ft
Foilborne bridge eye height above sea level	37 ft
Normal foilborne weight	475,000 lb

Normal Compliment ------------------------------------ 20 officers and men

Engines		Continuous Rating	Maximum Rating
Foilborne:	Pratt & Whitney FT4A-2 Gas Turbine	22,000 shp	30,000 shp
Hullborne:	Paxman 16YJCM High-Speed Diesel	2,000 bhp	2,400 bhp
Auxiliary:	United Aircraft ST6A-53 Gas Turbine	390 shp	500 shp
Emergency:	AiResearch GTCP-85-291 Gas Turbine	190 shp	
Fire Pump:	Rover IS-60 Gas Turbine	60 shp	

Propellers

Foilborne:	Two fixed pitch, handed, supercavitating, rotation outboard.	Dia., 44 in. Max. rpm, 2000
Hullborne:	Two KMW feathering, reversing and controllable pitch, handed, rotation inboard	Dia., 84 in.

Speed

Maximum foilborne speed --------------------- 60 knots
Design hullborne speed ---------------------- 12 knots

trials continued until mid-summer of that year.

During a routine docking in July 1969, major cracking gas discovered in the main foil center element to the extent that a replacement foil was required. While awaiting the manufacture of this replacement foil, a temporary hullborne replacement foil sufficient to support the foil system during hullborne operation was manufactured, and the ship proceeded with hullborne trials. In May 1970, the ship was docked and the completed foilborne replacement foil was installed. Basic ship trials recommenced in October 1970 and progressed satisfactorily through June 1971 at which time the ship was docked to undergo a refit and the proposed conversion program to fit the towed sonar and operational fighting equipment systems.

DESCRIPTION

General

HMCS BRAS D'OR shown in Fig. 1, was constructed as an all-weather, open-ocean, 230-ton

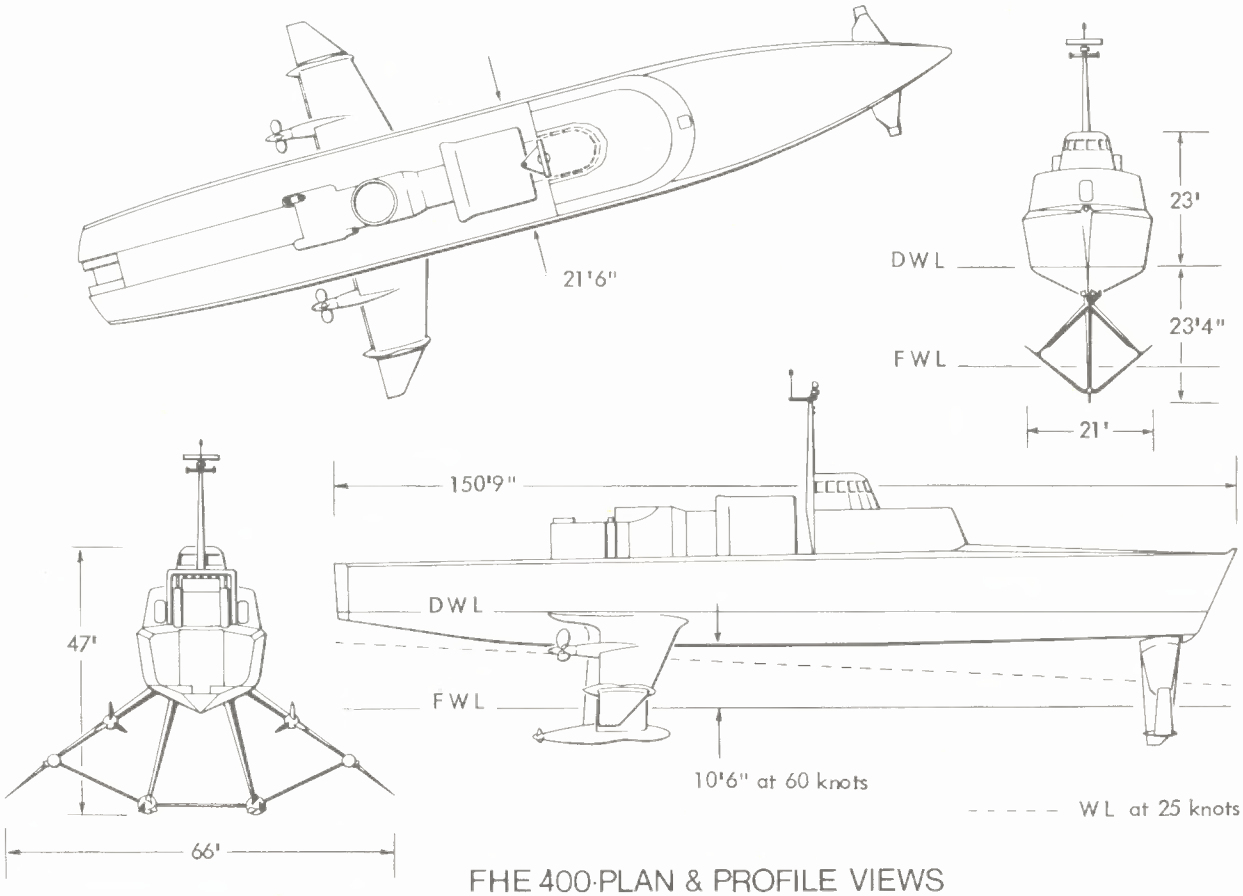

Fig. 1 General arrangement

hydrofoil to operate foilborne in sea state 5 at 50 knots and hullborne in any sea state. She has a sharp bow and low fine lines, with a length width ratio of approximately 7:1. Total displacement for normal operation is 475,000 lb. The large difference in foilborne and hullborne power requirements dictated, providing independent propulsion systems for the two modes of operation. Foilborne propulsion power, where high power is a requirement, is provided by a 22,000-shp Pratt & Whitney FT4 A-2 marinized gas turbine driving two fixed pitch supercavitating propellers through a Z-drive transmission. Hullborne propulsion, where long range is a requirement, is provided by 2000-bhp Paxman 16YJCM Diesel driving two controllable pitch propellers through its own Z-drive transmission. BRAS D'OR is capable of sustaining a complement of 20 at sea for a period of 14 days with a hullborne range and seakeeping capability not much different from that of a conventional destroyer. Principal ship data is listed in Table 1.

Hull

The hull, as shown in Fig. 2, is constructed of all aluminum welded alloy. The outer skin is formed by butt welding extruded aluminum plating over longitudinal stringers supported by transverse frames and bulkheads. Conventional shipbuilding design practices were used to determine the hullborne requirements; however, a different approach was required to meet foilborne requirements. Strengthened longitudianl stringers and re-inforced bow and main foil foundations had to be incorporated to accommodate hull bending during foilborne operation. 5083 (D54S) aluminum plating was used in areas subjected to seawater immersion, 6061 (65S) aluminum was used for internal areas not immersed in seawater, and hard anodized 7075 (T73) aluminum was used for the foil attachment forgings.

Foils

The foil system is of the surface piercing type, meaning that the lifting surface of the foils pierce the air water interface. They are

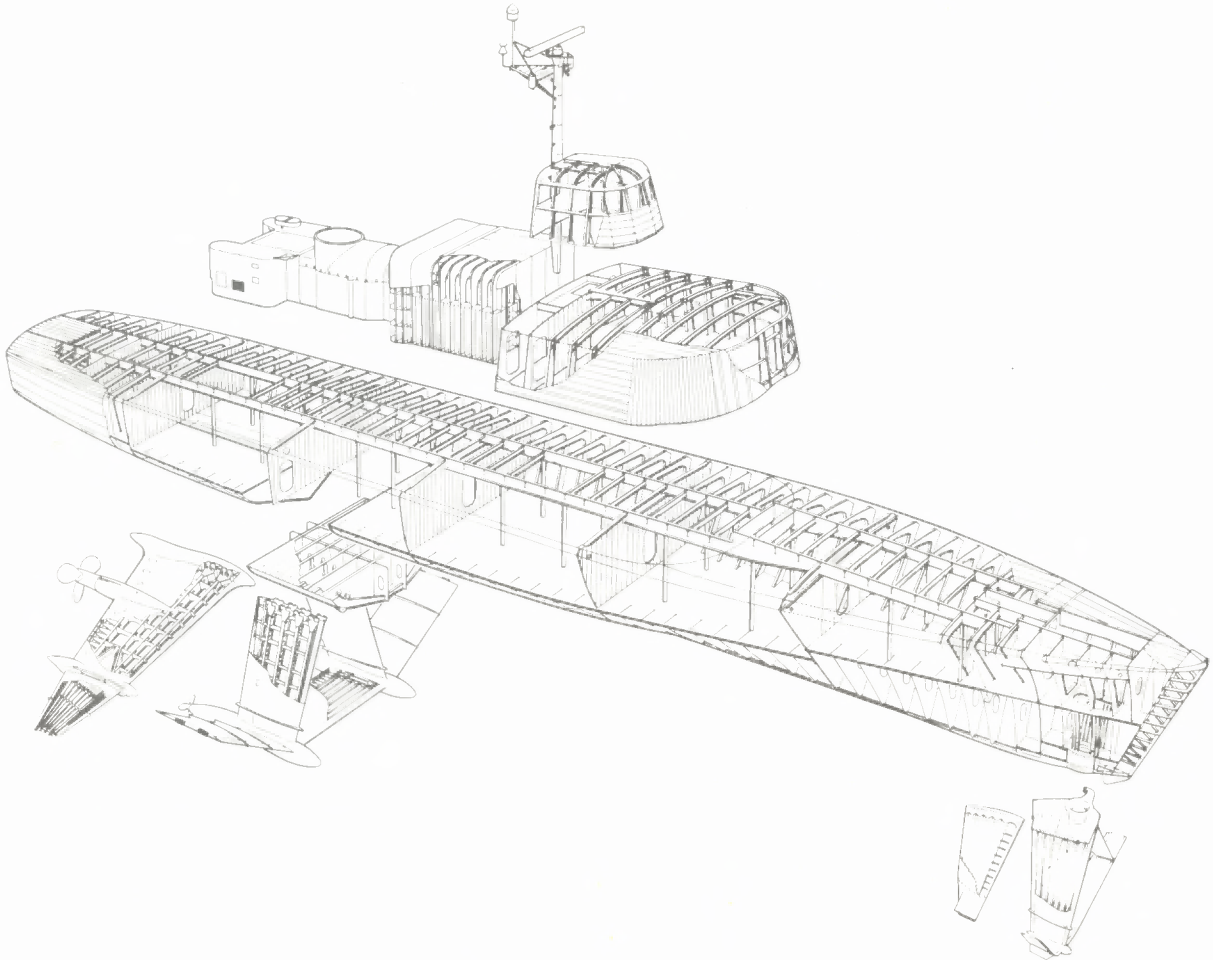

Fig. 2 Hull structural arrangement

non-retractable and of the canard configuration, with 90 percent of the ships weight on the after foil and 10 percent on the forward. Because of the high stresses during foilborne operation, partially due to the large foilborne hull clearance of 10 ft - 8 in., a high-strength steel 18 percent Ni maraging steel was selected for foil material, 250 grade for the sheets and plates, and 200 grade for the end forgings. Since maraging steel is highly susceptible to stress-corrosion cracking when in a seawater environment, protection is provided by a 0.020 coating of neoprene on the outer surface of all foils and struts, except the anhedral tips which are coated with polyurethane. All foil elements, except the main foil anhedrals, are fitted with a replaceable leading edge piece composed of Inconel 718 stainless steel.

The bow foil, shown in Fig. 3, is a diamond-shaped superventilating foil bisected by a vertical strut with a short horizontal section forming the bottom. Three spoilers are bulit into the upper surface of each anhedral and dihedral foil to encourage ventilation down to the lower horizontal section at most foilborne speeds and at most bowfoil incidence angles.

The bowfoil shaft is supported by a shperical bearing to allow movement in the vertical and horizontal planes — the former to vary the foil incidence angle, and the latter to steer the ship. The foil can be moved through + 5 deg to - 15 deg in the vertical plane and is steerable through ± 15 deg in the horizontal plane. It is controlled in steering either manually or by the ships auto pilot system. The fore and aft movement is by manual control only. The bowfoil strut and anhedrals are fabricated structures with the dihedrals being solid. The dihedrals are pin-connected to the lower end of the anhedrals and to the ends of the lower horizontal centerpiece. The strut and anhedrals converge at the top where they are welded to form an apex. The lower end of the strut is also welded to the horizontal centerpiece at the bottom of the foil.

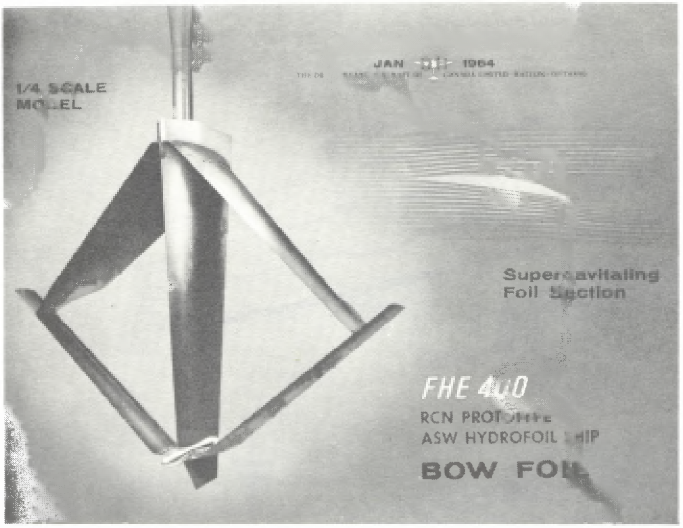

Fig. 3

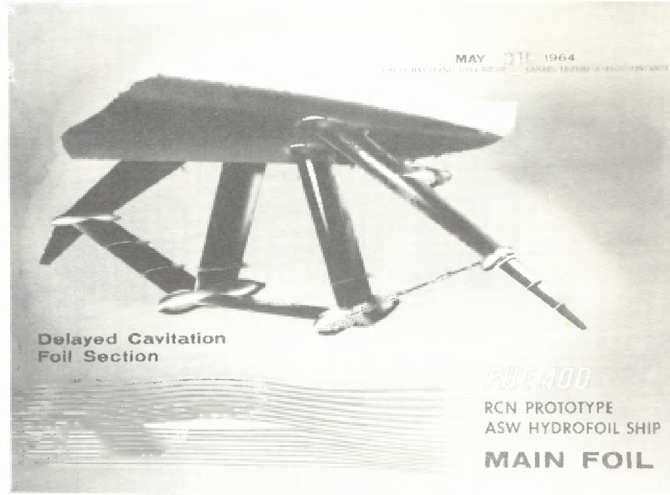

Fig. 4

The main foil, shown in Fig. 4, is composed of two surface piercing anhedrals and dihedrals, two near vertical struts and a fully submerged horizontal centerpiece. The two anhedrals and struts are bolted at the top to the foil foundation in the hull to form the hull attachment. The struts dihedrals and each end of the horizontal centerfoil meet at streamlined pods which accommodate the outer foilborne gearboxes and propeller machinery. The centerfoil and dihedrals are pin-connected at each end. The anhedrals, which support the pods used to accommodate the hullborne outer gearboxes and propeller machinery, are extended beyond the anhedral dihedral pin-connection to form the anhedral tips, the only movable surfaces of the foil system. They were added to the main foil system to ensure stability during high-speed foilborne turning maneuvers and low-speed foilborne operation. The incidence angle of these tips can be controlled either manually to enable coordinated turning, or by the auto-pilot gyros to improve ship stability and motion characteristics. All main foil contours are designed to produce delayed cavitation. Ventilation down the foil system is inhibited by the installation of fences on all foil members.

Generally, the foil design has proved to be successful in that the trial results show that foil parameters are very close to design predictions. The takeoff speed, foilborne turning rates, and ship stability at all foilborne speeds are very satisfactory. The geometric configurations selected for the main and bow foils have proved as a wise choice for a surface piercing foil system.

During the trials program, some foil problems have become evident. Maraging steel is highly susceptible to stress corrosion when in a seawater environment; as a result, some cracking has occurred. Due to the cost and delay involved in designing and manufacturing a new foil system of different material, it was decided to employ non-destructive test techniques at frequent intervals to detect the cracks and repair by welding. To date, this procedure has been employed successfully, and cracks have been detected and weld-repaired before developing to hazardous proportions.

A lateral stiff jerky motion which occurs at 40 to 45 knots produces considerable crew discomfort and fatigue when endured over extended periods. Anhedral tip control modifications to the roll control system in the form of installing motion sensors in each anhedral tip pod to control its own tip in lieu of a single sensor at the ships center of gravity controlling both tips have been proposed to overcome this problem.

Internal Arrangement

Internally HMCS BRAS D'OR is designed to accommodate the machinery, fighting equipment, and a crew of 20, along with the provisions required for periods of independent operation up to 14 days. As shown in Fig. 5, the ship contains two continuous full-length decks and two superstructure decks.

The space beneath the lower continuous deck is occupied by fuel tanks, void spaces, a vent

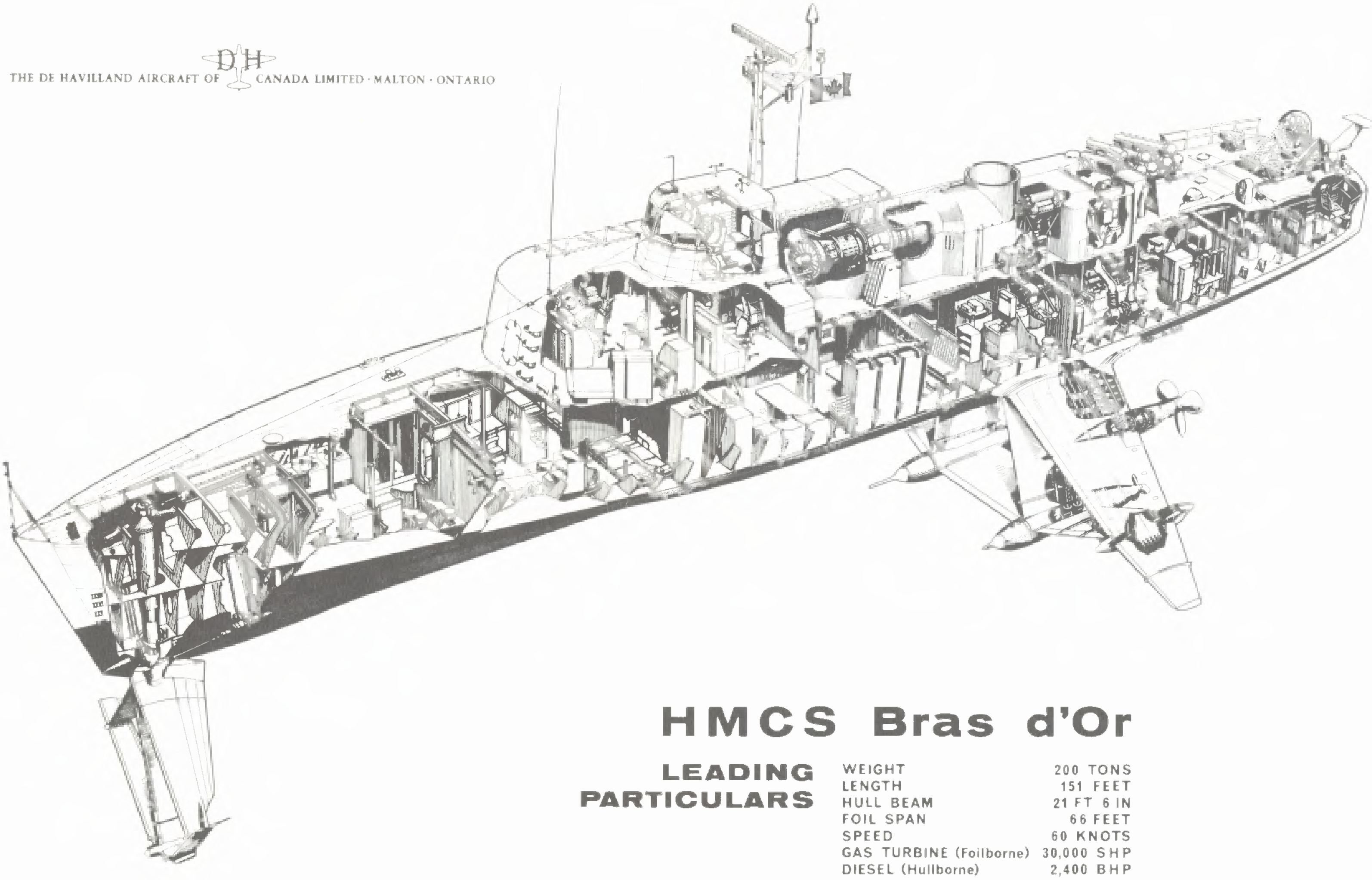

Fig. 5 Isometric cutaway

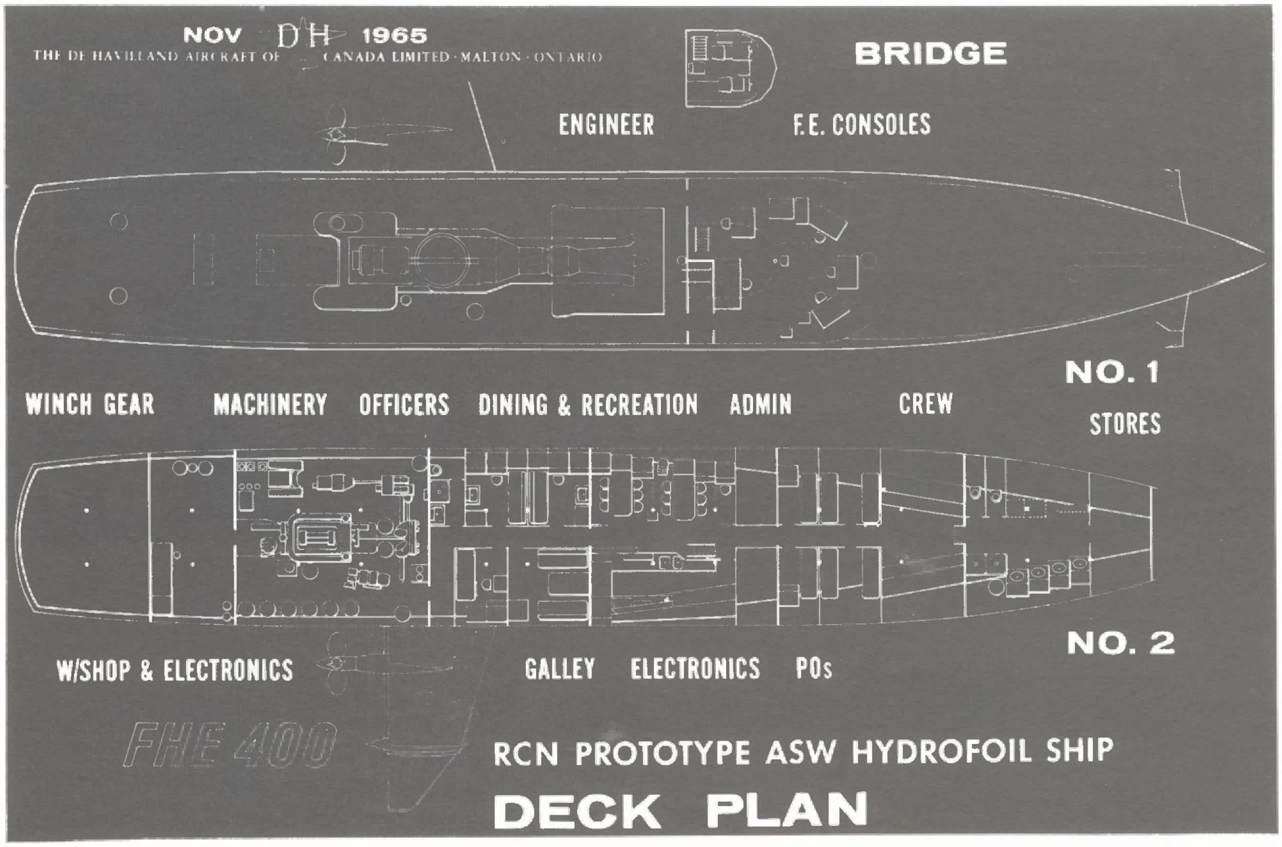

Fig. 6 Deck plan

tank, and the bowfoil steering actuator in the bow.

The main ship components and living quarters, as shown in Fig. 6, are located above the lower deck. The aftermost space houses the towed sonar and associated handling gear. This is separated from the engine room by a combined workship and sonar electronics space. The officers' quarters are located directly forward of the engine room and lead into the ship's cafeteria and galley. An electronics bay separates this eating area from the crew's sleeping and washing areas. The forward most compartment in the ship houses the bowfoil trim actuator.

The upper deck, also shown in Fig. 6, provides the foundation for the foilborne propulsion gas turbine and inboard transmission gearbox, as well as the torpedo launcher and a firefighting gas turbine/pump assembly.

The lower superstructure deck accommodates the ship's combat information system and the machinery operators control panel. The radar and sonar displays, along with the communications equipment and a plotting table, are located in this space.

The upper super structure deck, known as the bridge, provides space, instruments, and controls for conning and navigating the ship. This space, shown in Fig. 7, resembles an aircraft cockpit and is equipped with dual controls. A seat, chart table, decca receiver, loran receiver, and aircraft type azimuth circle are provided to enable the ship's navigator to effectively carry out his functions.

Trials Instrumentation

The instrumentation installed in HMCS BRAS D'OR enables recording of approximately 400 different paramenters. Basically, the equipment is composed of the transducers, signal conditioning equipment, recorders, and a remote pushbutton control panel. The signal conditioning equipment contains a patch panel facility which enables parameters to be recorded on the tape or oscillograph recorders, or on both.

The recording equipment consists of two light beam oscillographs, two 7-channel magnetic tape recorders, three 35-MM cameras, two 16-MM movie cameras, and a closed-circuit television video recorder. One oscillograph is a 50-channel closed magazine type with the other being a 52-channel direct writing type for instantaneous

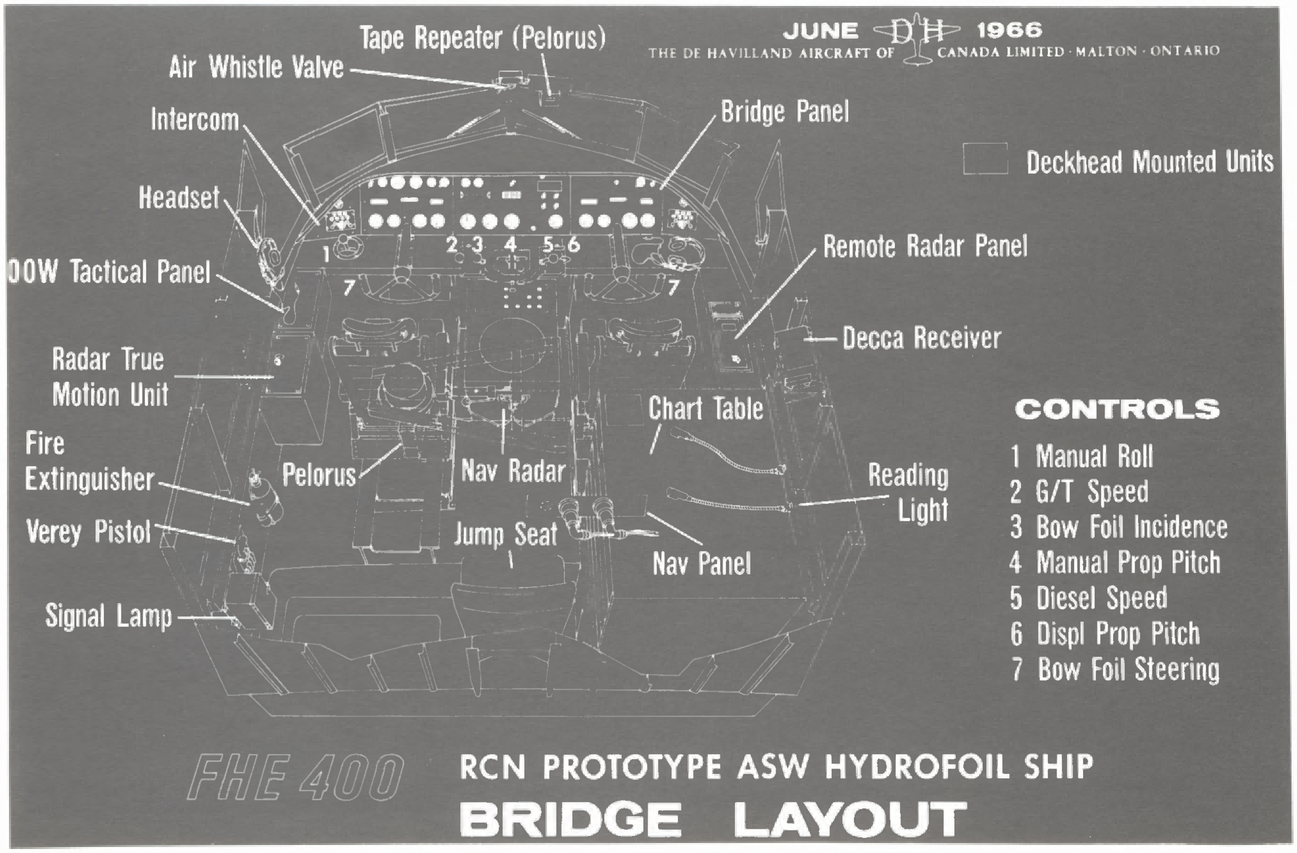

Fig. 7 Bridge layout

viewing. The tape recording capacity is increased by employing frequency multiplexing on one of the tape recorders. The 35-MM cameras are located to photograph the machinery operators control panel and a trials photo panel. The 16-MM cameras record the water flow over the main and bowfoils.

The closed-circuit television system comprises four cameras, four monitors, and a video recorder. Two cameras view the water flow over the two foils, the third views the sea forward of the ship, and the fourth is portable for use as desired. Any one of the four views can be video recorded for later viewing by switch selection.

Machinery Arrangement

The requirement to provide long-range, economical, low-speed cruise performance in the hullborne mode, and high-speed dash capability in the foilborne mode virtually dictated the need for separate propulsion systems for the two modes. Only a brief study was required to establish the superiority where the inherently high power-to-weight ratio was essential. On the other hand, a study to optimize the hullborne propulsion machinery left no doubt that the superior fuel economy of the modern high-speed diesel far outweighed the adverse power-to-weight ratio of the type. The preliminary propulsion studies also considered the virtue of propeller versus reaction propulsion. The latter was confined to gas reaction, because waterjets were not considered to have reached an adequate state of the art for the power envisaged. Jet propulsion was found to be inefficient because of the vast disparity in the ship and efflux velocities; thus further design effort was confined to propeller propulsion.

The nominal engine sizes for the two modes were easily determined once the size, performance, and operational parameters for the ship were defined. A fairly large selection of engines was found which could be employed in either single-or multi-engine configurations. A weeding-out process, using the total installed weight including subsystems, plus the weight of consumables for a specific duty cycle, was employed to reject machinery which was either too heavy or to thirsty, or both.

The Pratt & Whitney FT4A-2 Free Turbine Gas Turbine Engine was finally chosen as the foil-

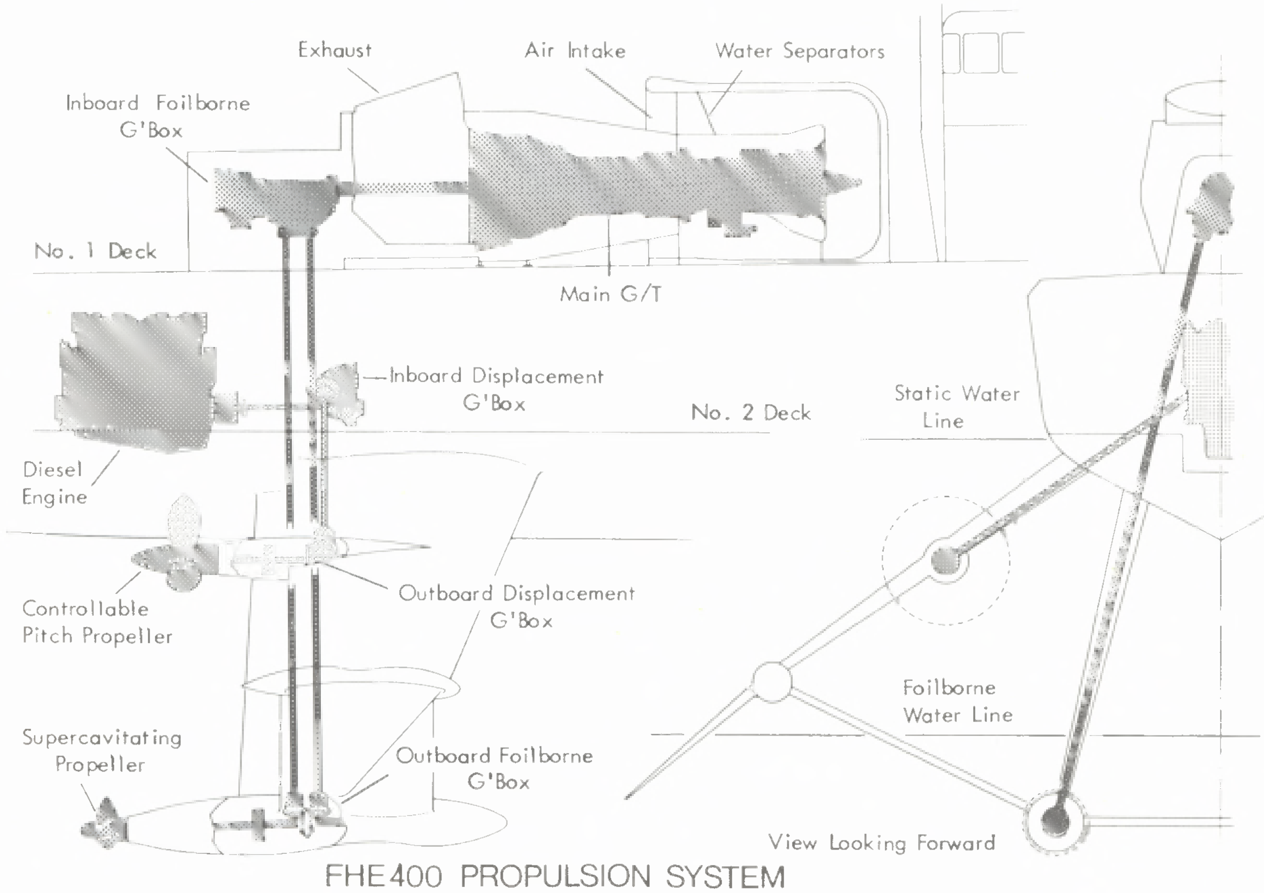

Fig. 8 Propulsion system

borne power plant, because considerable effort was being put into the marinizing program for the engine and the HMCS BRAS D'OR installation afforded the engine minimum protection.

Fig. 8 shows the above deck location of the engine encased in an aircraft-style cowl of stainless-steel-lined aluminum. The cowl is fan cooled with separate fans forward and aft of the fire wall which separates the engine hot and cold sections.

The engine carries a P&W electrically heated bellmouth, but no intake screen which was omitted because of a suspected icing hazard. Screening of large objects is achieved by the 1.0-in. section, 2-in. pitch, water separation splitters mounted at the mouth of the intake. The intake configuration was tested in a wind tunnel to confirm pressure losses and flow distortion arising from cross winds and was found to keep intake distortion to below 3 percent and pressure loss to less than 3.0-in. water for a mass flow of approximately 250 lb/sec. The engine drive shaft couples directly to a dental coupling on the inboard foilborne gearbox which splits the drive into port and starboard and transmits it via twin 7200-rpm shafts per side to outboard gearboxes, where 4:1 reduction star gearing takes the drive to SSS overrunning clutches and the 4.0-ft-dia supercavitating propellers. The propellers are forged from Inconel 718 with bolted-on blades. The propeller design was joint effort between The DeHavilland Aircraft of Canada Limited and National Physical Laboratory, London and employed stressing techniques derived from gas turbine engine practice.

The hullborne propulsion system consists of a 2000-hp, Davey-Paxman, high-speed, turbocharged marine diesel chosen for its simple, rugged, lightweight design and good economy. It is coupled to 7.0-ft-dia fully feathering, controllable-pitch propellers via a transmission which is very similar in concept to the foilborne transmission, except that single shafts are used on each side and pneumatic bag isolation clutches are used inboard.

Fig. 9 shows the machinery compartment layout. A "total weight" study of auxiliary machinery configurations clearly showed the advantage of

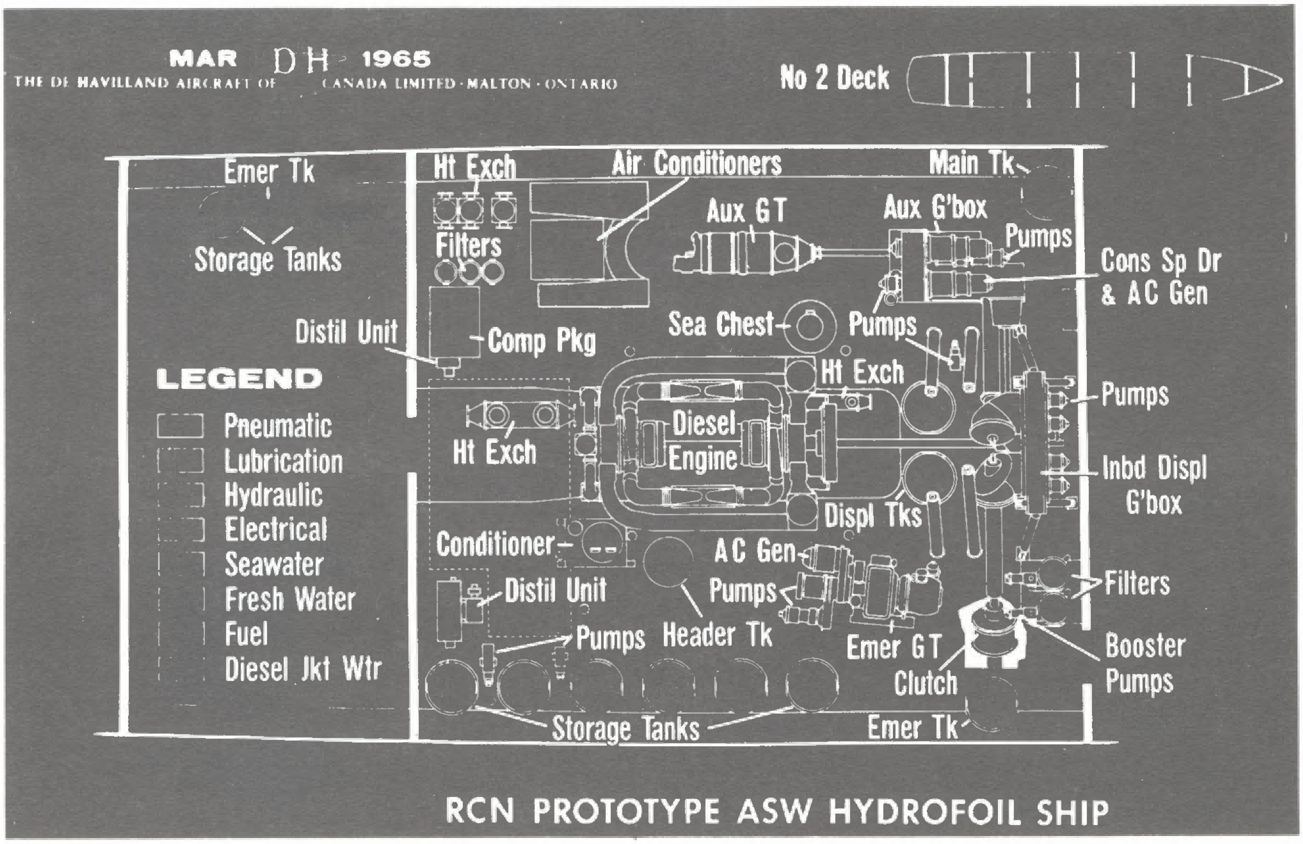

Fig. 9 Engine room layout

taking power from the main diesel for the auxiliaries when operating in the hullborne mode, with a small gas turbine (390-hp United Aircraft of Canada Limited ST-6) for foilborne/emergency use. Further economies were to be realized by using exhaust gas waste heat for ship's heating using a special lightweight exhaust gas-to-air heat exchanger.

The auxiliary gearbox provides pads for hydraulic pumps, constant speed drives and 400-Hz generators, and a sea water pump for machinery cooling. The auxiliary gearbox is a unique design and incorporates dual inputs via SSS clutches with input gear ratios arranged so that the ST-6 always assumes the load when it is running and automatically drops the load back onto the diesel when shut down. The clutch between the diesel and the auxiliary gearbox has a lock which permits the ST-6 to put power into the displacement propulsion system for boost or emergency propulsion; the diesel can be manually disconnected from the transmission.

The ST-6 is coupled to the auxiliary gearbox input clutch via a simple carden shaft. The engine and gearbox are both on flexible mounts to minimize noise transmission and shock damage.

The three aircraft-type, 400-Hz generators are driven via Sundstrand constant speed drives which achieve better than 2-Hz regulation over a speed range of approximately 60 to 105 percent of rated speed. System rated capacity is 180 kva, 115/208 v, three-phase. A 28-v dc system is employed for emergency systems, some controls, small motors, etc., and comprises approximately 100 amp-hr battery pack charged from a pair of 100-amp transformer-rectifier units.

Hydraulic power is obtained from three groups of aircraft-type, axial piston, pressure compensated pumps. Two of the groups comprise tandem-mounted pumps driven continuously by the gearbox at speeds up to 3600 rpm. The third group of three tandem pumps is driven at a maximum speed of 6000 rpm via an electromagnetic clutch. The hydraulic system is of the ring main variety and is pressure compensated at 3000 psi. The major demands on the system come from the ship's steering and stability augmentation systems. Fig. 10 shows the steering arrangement and the three-stage servo-actuator. The actuator has a stroke of 12.0 in. and a piston area of 46.0 sq in. The system is capable of 130,000-lb load and can rotate the bow foil at rates up to 24.0 deg/sec. The main foil anhedral tips are driven by actuators which are similar to the steering unit, but somewhat smaller. The hydraulic system also provides approximately 45 gpm. for driving the lubrication pumps for the transmission system. Total hydraulic capacity is approximately 190 gpm.

Fig. 11 shows the control arrangment for the ship. Direct mechanical controls are employed for ship's steering and main gas turbine control to ensure a high degree of reliability. The use of cable and pulley arrangements permitted duplication of steering controls on the bridge and of the engine controls on the bridge and Engineer's console. The steering actuator also accepts electrical inputs from the auto-pilot for heading hold and yaw damping. The auto-pilot signals to the steering and anhedral tip actuators can be isolated electrically and hydraulically.

Diesel engine and controllable pitch propeller control is via a combination of cable and pulley and electro-pneumatic controls. The diesel is provided with manual over-ride control at the engine governor and manually operated valves are provided for emergency control of the propellers.

In addition to the two gas turbines already mentioned, a Garret GTCP-85 Combined Bleed and Shaft-Power Engine provides emergency hydraulic and electric power, and seawater; the compressor bleed is used for air-starting the FT-4.

A Rover IS-60 gas turbine/fire pump unit is built into a deck-mounted enclosure and is connected to the ship's fire main.

Although reciporcating engines have performed well in the smaller and slower hydrofoils, the larger, faster vessels cannot tolerate the weight disadvantage they would incur with a multi-engine installation. This is particularly true where a relatively short range, say 500 to 1000 miles, is required and the fuel consumption advantages of, for example, the diesel over conventional gas turbines is nullified by their installed weight.

The new advanced technology engines are an even better proposition for hydrofoils with their advantageous power-to-weight ratios and excellent fuel economy over a wide range of operating speeds. There is, however, little choice of engines if one wants to design a hydrofoil ship which requires 20,000 to 40,000 hp and even less choice if one only requires 5000 to 10,000 hp and does not want to run a 20,000-hp advanced technology engine at half power.

The smaller engines have not, as yet, achieved the same level of economy as the bigger ones.

Regenerative engines will possibly be unsuitable, as fouling of the heat exchangers would prove to be a serious problem. Also, when the

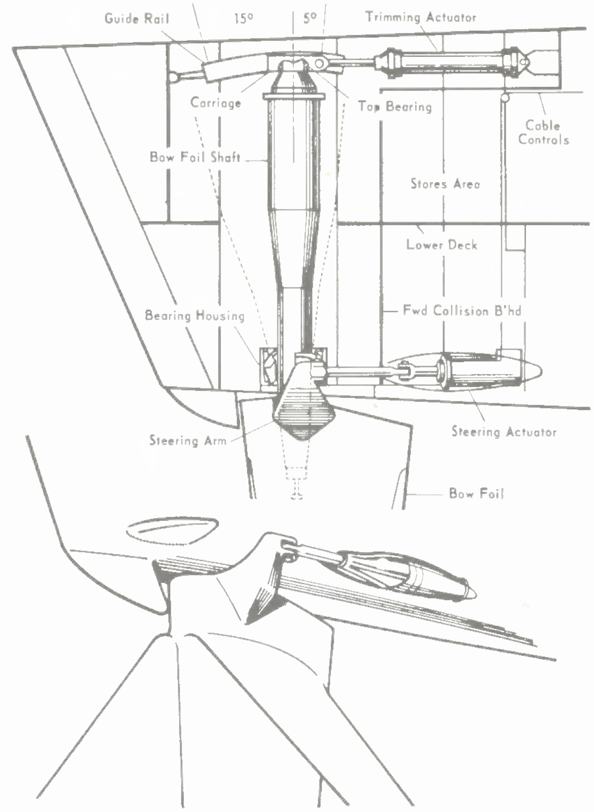

Fig. 10 Bow foil control arrangement

5000 to 10,000-hp regenerative engines become available, their power-to-weight ratios will be of about the same order as that for equivalent diesel installations and will cease to have an advantage over the reciprocating engine from the point of view of weight, space, and fuel economy. The other important aspect — reliability — will have to be judged when the new machines have shown their colors.

TRIALS

General

The trials program planned for HMCS BRAS D'OR is divided into four different groups — basic ship calm water, basic ship rough water, sonar body towing, and operational fighting equipment trials. The latter two are not yet possible, as the towed sonar and operational fighting equipment have not yet been installed.

The main purpose of the calm water trials was to verify the design predictions under controlled conditions, establish a base for conducting rough water trials, and optimize ships' systems and machinery performance. These included fuel consumption, turning performance, and ship

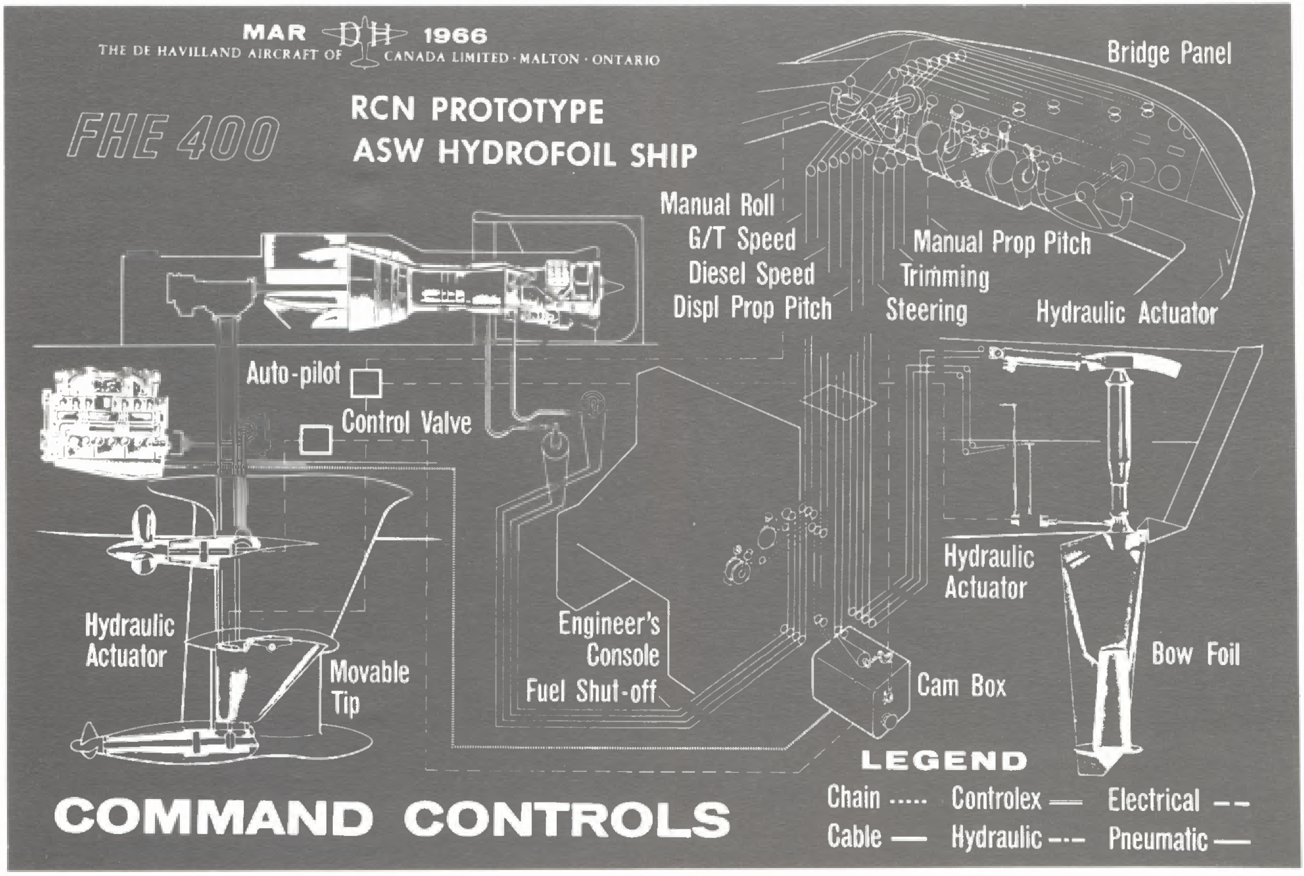

Fig. 11 Command controls

maneuvering trials carried out at different speeds and different ship weights. Figs. 12 and 13, respectively, show hullborne and foilborne operation during calm water trials.

The rough water trials objective was to prove that the ship is a sea-going vehicle capable of independent open-ocean operation for periods of up to 14 days. This program is patterned after the calm water trials program, and a large portion of the calm water trials were repeated in different sea states, including foilborne trials in sea state 5 and hullborne trials in sea state 7.

Most of the calm water and approximately 50 percent of the rough water trials have been completed. As of October 1971, the ship has spent 646 hr at sea, 95 of them in the foilborne mode. Maximum speeds of 63-knots foilborne and 13-knots hullborne have been achieved.

Data obtained from trials conducted to date indicate that ship performance in every respect equals or exceeds design predictions. Ship stability is very good, and response to the ships controls is excellent. The transition from hullborne to foilborne operation and vice versa is almost imperceptable. Operation has been successfully conducted in all sea states, including sea state 5 in the foilborne mode and sea state 7 in the hullborne mode. Neither mode of operation has presented any major problems. Foilborne motion data recorded indicates that up to and including sea state 5, the ship provides a stable weapons launching platform, and due to the damping resulting from the massive foil structure, the ships motion characteristics while hullborne are comparable to that of a ship with a displacement 10 times larger. The calm water data has provided a firm base for conducting rough water trials, and ship reliability has improved to the extent that very few trials are now aborted due to machinery or system malfunctions. Recent trials have progressed very satisfactorily and have included several independent deployment trials, one of which included a 14-day trial commencing at Halifax and visiting Bermuda and Norfolk en route.

Machinery and Systems

The Trials Program to date has concentrated on the hydrodynamic behavior and structural integrity aspects of the ship's design. These indeed are the areas where the state of the art is

Fig. 12 Under hullborne operation

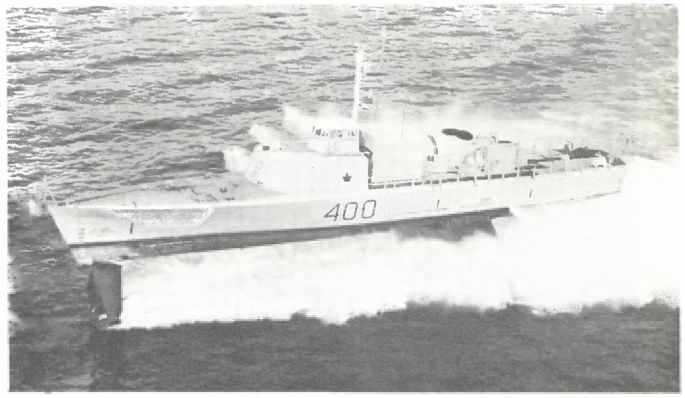

Fig. 13 Under foilborne operation

being pushed ahead. One exception to this is the Foilborne Transmission System where the high-speed/high-torque transmission requirements put unusual demands on the machinery. The Trials Program has, in fact, been a development period for ship's propulsion and systems machinery. The transmission system was developed on the test bed at GE-LYNN before installation in the ship, but ran into lubrication problems almost immediately when we found that the heat loss in the outboard gearboxes resulted in overcooling of the oil and made it almost impossible to start from cold because the hydraulically driven lube pumps were overloaded. Shore steam heat applied prior to leaving harbor solved that problem. The transmission machinery itself has been very reliable with only one persistent problem still to be resolved, i.e., fretting wear on the downshaft dental couplings at the inboard foilborne gearbox. The problem is aggravated by axial motion on the gear teeth coupled with lube starvation due to the fluid centrifuging out without passing through the mesh. Fig. 14 shows fretting damage after approximately 50 hr of operation. Lubrication system problems also included the perennial ones of foaming and venting difficulties. Relatively small cylindrical tanks are used with a maximum dwell time of 2 min. which has proved to be marginal.

The hydraulic system has, until quite recently, been a serious problem area. Numerous pump failures have incurred, all of a random nature, without a pattern being established. This led to the tedious task of re-designing case drain and seal drain systems. Provision of extensive temperature and pressure instrumentation did not improve the reliability or produce any clues as to the cause of the problem. It was generally conceded that the hardware was unsuited to the task. The pumps were at an early stage of their development when ordered. Fig. 15 shows one of the pump barrel failures. In this instance, it was possible to stop the machinery before the pump mangled itself into an unrecognizable mess. New and improved versions of the pumps were recently installed and appear to be performing in a more reliable manner. Running hours previously attained have already been exceeded with two examples of the new pump.

Other hydraulic system problems have been evident in cracked return pipes and, surprisingly, the sheared head caps on flow controllers. It is suspected that the latter problem results from pressure spiking in the system. The problem is presently being explored.

The gas turbines have been remarkably troublefree; their biggest problem being salt ingestion. Washing techniques have not yet been developed which will do the job of removing salt from four different engines and not incur a weight penalty. Fresh water by itself does not appear adequate and has the additional disadvantage of freezing. It is expected that a water/alcohol mix will have to be used to achieve cold weather washing capability and, perhaps, better washing.

The FT4 has not shown any deterioration in performance as a result of salt accretion, but then it seldom is required to run at anything over 75 percent power. The ST-6 and GT-85, on the other hand, show signs of power loss and overtemping in warmer ambients (70 to 90 F) when salt accretion is beginning to foul the gas path. Another problem with the salt atmosphere is that engine control sense lines will clog after a shutdown and make restarting difficult or impossible. Development work is progressing on filters for the sense lines, but, to date, the typical 10-micron

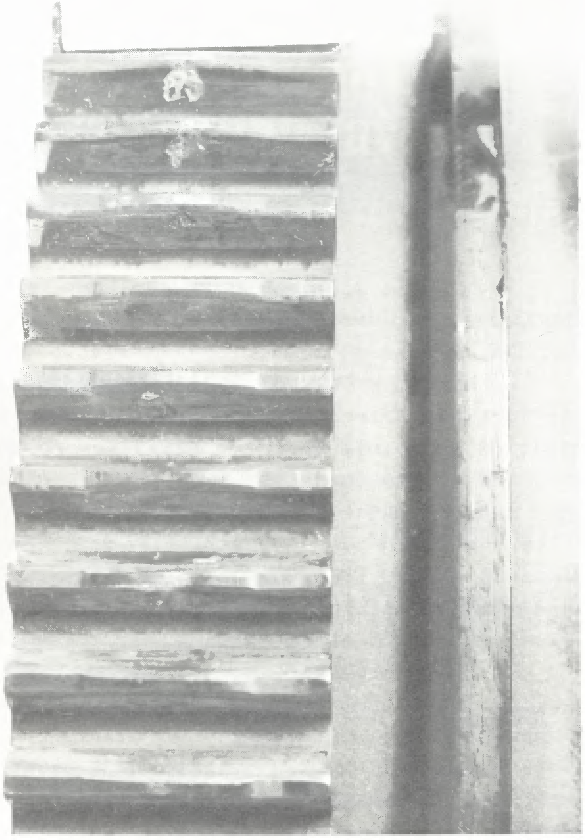

Fig. 14 Foilborne transmission coupling wear

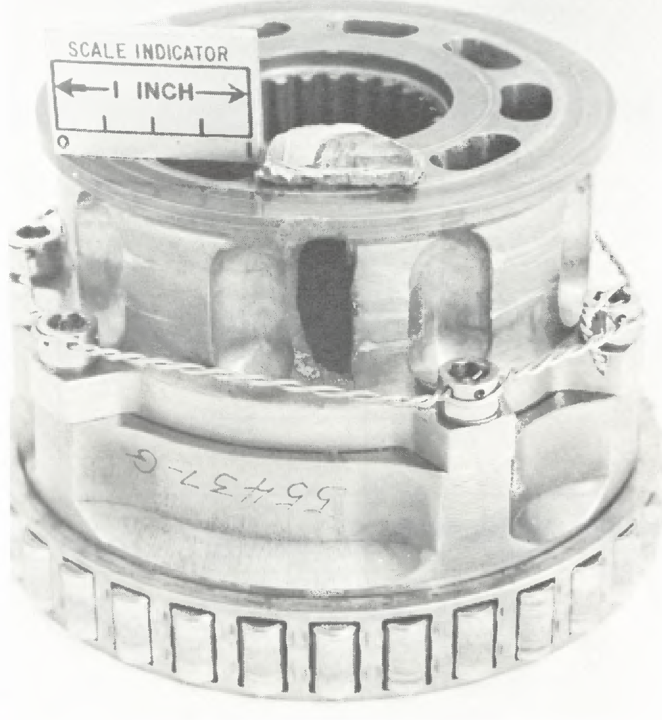

Fig. 15 Hydraulic pump barrel failure

filter has proved to be inadequate. It is suspected that a 1.0-micron absolute filtration is required to keep the salt out.

Experience showed that a free turbine engine, such as the ST-6, has difficulty in maintaining a steady speed when it is coupled to a low-inertia load which fluctuates over a wide range. Fig. 16 shows a typical time history for ST-6 rpm when subjected to the hydraulic loads demanded by cyclic actuation of the steering gear. No turbine temperatures have been recorded for this condition as yet, but the long-term effects of the thermal cycling are of some concern.

On the other hand, the FT4, also coupled to a low-inertia load, runs remarkably steadily regardless of the seaway into which the ship is headed. There was some concern at first that running in rough water might result in speed fluctuation, but this problem did not materialize.

FUTURE ACTIVITIES

HMCS BRAS D'OR has completed more than half of the basic ship trials. For most practical purposes, it has proved to be a seaworthy open-ocean vessel and is worthy of operational evaluation as a warship. It is proposed to install and trial a towed body sonar system and an operational fighting equipment suit commencing in late 1971. This phase of the program is expected to take approximately $2\frac{1}{2}$ years. Following the technical evaluation of the towed sonar and operational fighting equipment, the ship will be turned over to operational personnel to evaluate as an operational warship. At this point in the program with the ship and operational evaluation complete, the ship might be used as a full-scale test model for foil, hull, propeller, and other modifications that will be required prior to commencement of a production program.

CONCLUSIONS

The overall program to date has been very successful from a technical point of view in that a hydrofoil has been constructed, partially trialed, and proven as an open-ocean vehicle to be capable of carrying out sustained independent operation in any sea state. The motion data recorded indicates that a hydrofoil, although relatively small compared to conventional warships, provides attributes that make it highly effective

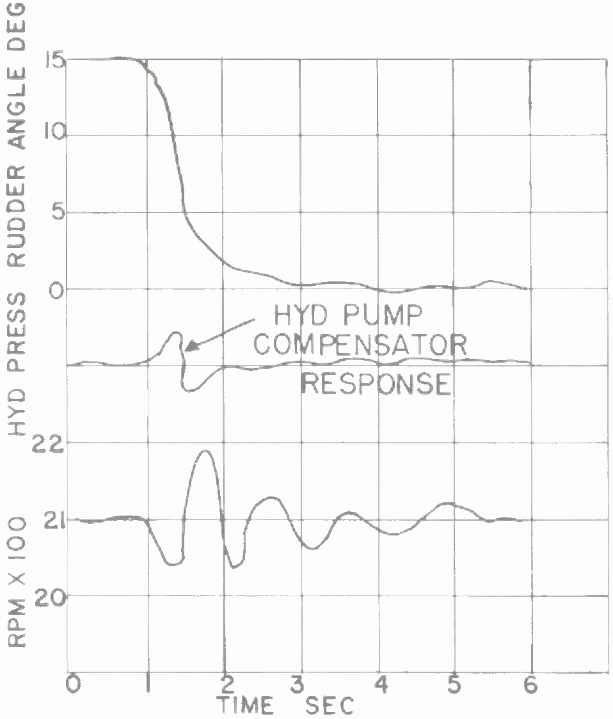

Fig. 16 ST-6 output shaft oscillation with load

for military tactical employment. Although HMCS BRAS D'OR was designed primarily as an anti-submarine vessel, it could very easily be converted to function as a high-speed gun-boat or missile carrier.

The chief objective of the hydrofoil program was to construct and evaluate a fast economical and highly effective open-ocean, anti-submarine vessel. Although the towed sonar and operational fighting equipment have not yet been installed and trialed, the data evaluated to date indicates that the hydrofoil is such a vehicle.

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