# JETFOIL AS AN OFFSHORE PATROL VESSEL (OPV)

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## Abstract

Today's offshore patrol missions present a variety of requirements on the vessels assigned to accomplish this role. Data indicates that the vessels in service cannot adequately perform these missions. This paper presents a potential solution. This solution is based on the fact the hydrofoils have developed to the point where production vessels are available to perform the offshore missions. The Royal Navy of the United Kingdom have ordered a version of the Boeing JETFOIL* in order to evaluate this potential solution. This vessel christened HMS SPEEDY is presently undergoing production trials and will be delivered to the Royal Navy in April of 1980. This paper provides brief descriptions of offshore missions and a description of HMS SPEEDY. The performance of this variant of the JETFOIL is also summarized.

## Introduction

### Offshore Patrol Missions

Offshore patrol missions are varied and change with time. There are military, law enforcement and commercial applications and these applications are different from country to country. Peacetime maritime patrol functions include prevention of terrorist activities. In wartime coastal defense, inshore undersea warfare, and other tasks may be assigned. Each separate task has its own unique requirements. A few of these missions are briefly described in the following paragraphs.

Law Enforcement. Prevention of smuggling is a historic task assigned to the maritime force. In order to successfully accomplish this task the vessel employed must have the capability to surprise, overtake and apprehend suspects. Fast response to inspect a limited area and barrier establishment is also a requirement.

Search and Rescue. This assignment requires rapid response. Extended periods of search are necessary. Rescue equipment such as rafts, pumps, and fire fighting equipment are required on-site. Capability to operate in severe weather is essential.

*Boeing Trademark

Oil and Gas Rig Defense. Terrorist activities in peacetime and military threats in wartime present a difficult patrol mission. Random inspection of vessels near key facilities provide some protection. Aircraft and helicopters alone are not adequate because of the inability to board and inspect.

Fisheries Patrol. Recently many countries extended their jurisdiction over marine fisheries from twelve (12) nautical miles to two hundred (200) nautical miles off its coast. This created thousands of square miles of ocean that requires patrol, inspection and law enforcement.

Conclusions. The missions briefly described above, as well as many others, illustrate that existing methods and crafts are not adequate. Coincident with this need, hydrofoil technology has progressed to the point where production vessels can be made available to perform these missions. This paper will describe a hydrofoil which is being delivered to demonstrate capability for offshore missions.

### Boeing Hydrofoils

The Boeing Company has been developing hydrofoils for twenty (20) years. In 1962, Boeing built "Little Squirt" as a Company sponsored research craft. It was used in the development of a number of systems, including an automatic control systsm. It was also the first craft to demonstrate application of the waterjet propulsion system to hydrofoils. "Little Squirt" is pictured in Figure 1.

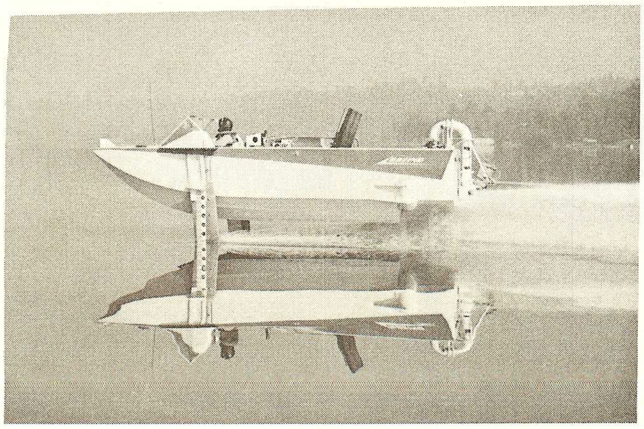

Fig. 1 "Little Squirt"

"Fresh I" shown in Figure 2 was completed in 1963 and recorded a record foilborne speed of 84 knots. Its greatest contribution was in the field of stability and control, where it demonstrated the importance of directional and roll stability.

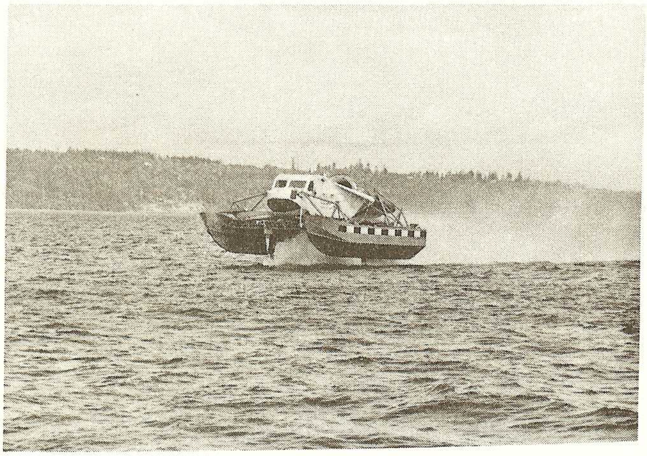

Fig. 2 "Fresh I"

The patrol craft PCH-1 "High Point" shown in Figure 3 was the first military hydrofoil to be developed for the United States Navy. It was designed by the U. S. Navy Bureau of Ships and built by Boeing. The ship was delivered to the Navy in 1963. "High Point" exposed the critical problems associated with high-speed underwater transmissions and propeller systems. It was also used to conduct research and development on hydrofoil technology and candidate weapon systems.

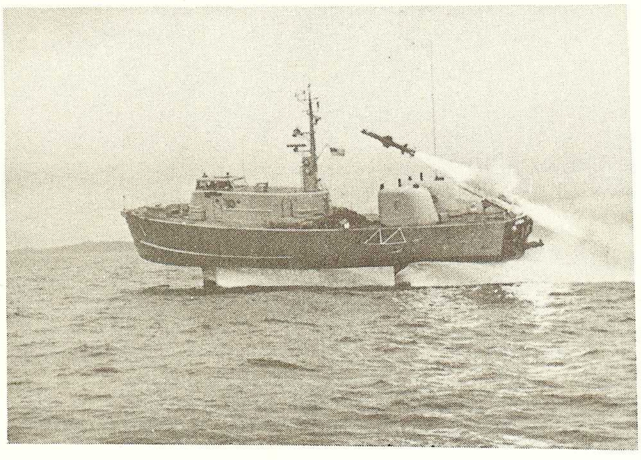

Fig. 3 "High Point"

The PGH program to develop a hydrofoil was initiated in late 1965.

Grumman was awarded a contract for PGH-1 and Boeing for PGH-2. The resulting designs were significantly different. PGH-2, "Tucumcari" is shown in Figure 4 and is best recognized for its waterjet propulsion system. "Tucumcari" incorporated a unique foil system with aft foils canted downward from center to tip as well as the Boeing automatic control system and acoustic height sensor.

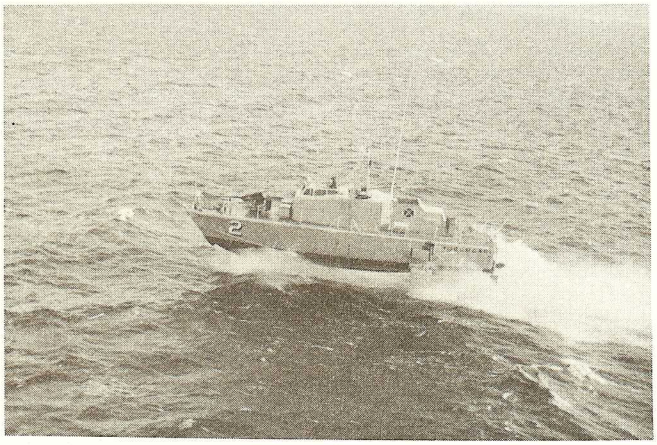

Fig. 4 "Tucumcari"

The PHM is a new type of missile-carrying hydrofoil patrol boat. PEGASUS (PHM-1) was delivered to the United States Navy in July 1977. It carries a 76-mm Oto Melara cannon and is equipped with Harpoon missiles. PEGASUS operated with the Pacific fleet until mid-1979 when it was assigned to the Atlantic fleet. Five additional PHM's have been ordered by the U. S. Navy and are presently being constructed by Boeing. PHM-1 is shown in Figure 5.

Fig. 5 "PHM-1"

The other hydrofoil presently in production by Boeing is the "JETFOIL." The JETFOIL is a submerged foil, automatically controlled, water-jet propelled hydrofoil. At the present there are ten (10) in commercial service and two (2) more will go into service early next year. These vessels are in operation in Hong Kong, Japan, Venezuela and Northern Europe. A picture of a commercial "JETFOIL" is provided by Figure 6.

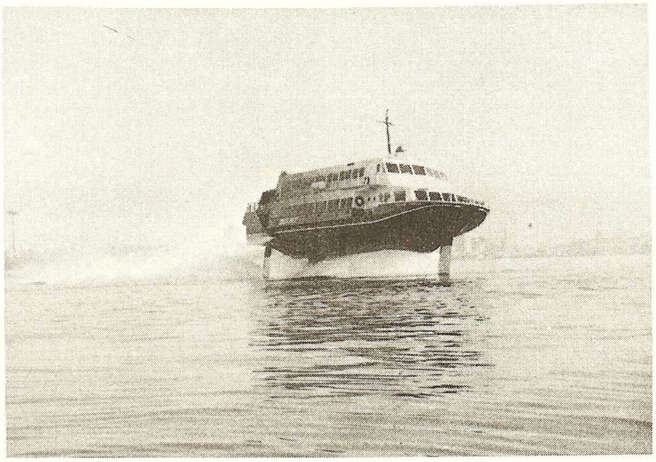

Fig. 6 "JETFOIL"

HMS SPEEDY

The role of fisheries protection in the United Kingdom (UK) has changed significantly since 1976 when the jurisdiction changed from 12 nautical miles off its coast to 200 miles. Since the fisheries are a resource of great value to the UK, an adequate management and enforcement capability over activity in the extended zone is essential. Previously, the mission was to prevent unauthorized foreign fishing vessels from fishing within the 12-mile line and ensure that closed season regulations were not violated. The primary task was patrol of the 12-mile line.

The Fisheries Protection Mission now has two principal objectives. The first objective is to enforce the laws and regulations promulgated to ensure conservation of fisheries resources; the second, to prevent potential conflict among fishing ships, particularly in areas where large numbers of ships are concentrated.

The first of these objectives entails a significant level of boarding and visual inspection. On-board inspection provides catch rate information by which marine biologists estimate any changes in fish population. Fishing gear and the mesh size of fishing nets are inspected to ensure compliance with the fishing regulations and to prevent any significant quantities of immature or non-target fish from being caught. The second objective, that of deterring violations of the law and preservation of order on the fishing grounds is dependent on maintaining a visible presence.

Even under the 12-mile limit situation, it was obviously impossible to maintain surveillance over the entire included area. Patrol vessels and aircraft could be present only in a few places at any given time. This is now compounded with multiplication of the patrol areas, so that maintaining a presence in one particular area can be accomplished only at the cost of a deficiency elsewhere. As a result the two objectives are counteractive, in that a large number of visual inspections and boardings in widely dispersed areas are required to realize the first objective, and a continued localized presence is desirable to achieve the second.

In the Spring of 1977 a Boeing commercial JETFOIL (FLYING PRINCESS) made a three-month demonstration tour to Northern European countries including a period of technical trials for the UK. Based on observations during these trials Boeing was commissioned by the Royal Navy to investigate the suitability of a variant of the JETFOIL for performing the fisheries protection mission.

The results of the demonstration by the FLYING PRINCESS and the study conducted revealed that a solution to the fisheries protection role might be found by the addition of hydrofoil ships to the current fleet of conventional Fisheries Protection Vessels (FPV) utilizing the best advantage of the high performance of the hydrofoil and the endurance of the conventional ship. The Royal Navy ordered a variant to the JETFOIL in June of 1978. Christened the HMS SPEEDY on 9 July 1979, this ship is now in production trials at Seattle, Washington. Following trials HMS SPEEDY will be shipped to the UK where fitting out will be accomplished prior to final delivery in April 1980. The Royal Navy then will evaluate it in the fisheries protection role as well as for other offshore missions.

HMS SPEEDY is a variant of the operational Boeing Model 929-115 commercial JETFOIL. Figure 7 shows HMS SPEEDY in test in Puget Sound.

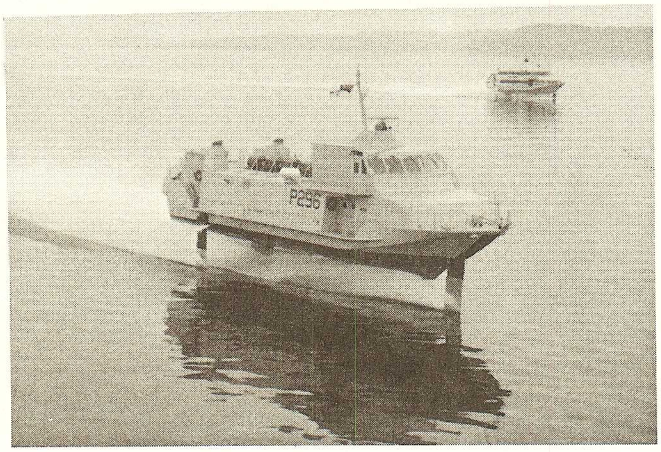


Fig. 7 "HMS SPEEDY"

The basic hull structure, foil system, foilborne propulsion system, hydraulic system, control systems and certain auxiliary systems are common to the commercial JETFOIL. The basic characteristics of HMS SPEEDY are listed in Table 1.

Table 1 HMS SPEEDY Characteristics

| | |
|---|---|
| Displacement: | 115 Long Tons |
| Overall Length: | 90 Feet |
| Maximum Beam: | 31 Feet |
| Draft: | |
| Foils Down | 17 Feet |
| Foils Up | 5.5 Feet |
| Available Fuel: | 24.7 Tons |
| 10% Reserve | 2.47 Tons |
| Useable | 22.23 Tons |
| Foilborne Performance: | |
| Design Cruise Speed | 43 Knots |
| 40-Knot Cruise Range Factor* | 24.3 NM/Tons |
| Fuel Rate | 1.59 Tons/Hour |
| Maximum Range | 560 NM |
| Hullborne Performance: | |
| Design Speed | 6 Knots |
| Range Factor* | 152.4 NM/Ton |
| Range | 3,515 NM |
| Endurance | 586 Hours |
| Fuel Rate | .038 Tons/Hour |
| Foilborne Propulsion: | |
| (2) Allison 501-K20A Gas Turbines Continuous Rated Power 3,780 hp (each) | |
| (2) Rocketdyne R-20 Waterjet Pumps, 24,000 Gallons/min. (each) | |
| Hullborne Propulsion: | |
| (2) Allison 8V-92TI Diesel Engines Continuous Rated Power 550 hp (each) | |
| Crew: 4 Officers, 4 Senior Ratings, 9 Junior Ratings | |
| Maximum Accommodation: 6 Officers, 6 Senior Ratings, 12 Junior Ratings | |

*The range factors shown are for average operating conditions of bow seas in 1.5 metre significant height waves and 20-knot winds.

The most significant configuration changes are discussed in the following paragraphs.

Propulsion. Since high speed as well as loitering is required in the Fisheries Protection Mission it was decided to incorporate a diesel propulsion system for low speed or hullborne operation. This has been accomplished by the addition of two Detroit Diesel Allison Model 8V-92TI engines. One to drive each of the waterjet pumps. Figure 8 provides shaft horsepower and fuel consumption vs engine speed of the diesel. Since weight and space are critical items the standard JETFOIL gearbox was modified to operate as a Combined Operation Diesel or Gas Turbine (CODOG) gearbox. This was accomplished by incorporating an over-running clutch on the input from the turbine and adding a hullborne diesel input shaft with an over-running clutch. The incorporation of the over-running clutches on both input shafts allows operation from the turbines with the diesels running or shut down; or operation from the diesels whenever their RPM exceeds the RPM of the turbines. The basic configuration of the propulsion system is illustrated by Figure 9.

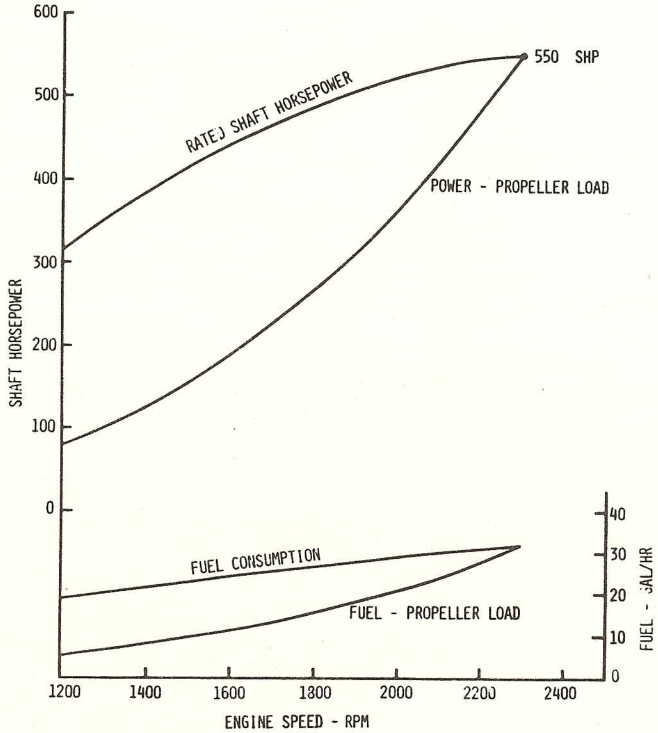


Fig. 8 "Allison Model 8V-92TI Horsepower vs Engine Speed"

Although limited testing has been accomplished the concept has been verified. A single throttle control is being utilized and all critical parameters are monitored on the bridge.

Fuel Capacity. Extended missions and multiday patrols are essential to an offshore mission. The hullborne diesels went part way in satisfying this need, however additional fuel capacity was considered necessary. The amount of fuel carried by HMS SPEEDY is approximately 25 long tons which is approximately twice the standard JETFOIL. This was accomplished by adding two tanks outboard of the main fuel tank. Fuel may be utilized from any of the three tanks and the stability of the JETFOIL is such that any of the three tanks may be drained with no detrimental effects. A fuel transfer system is incorporated which also transfers fuel between tanks.

Inspection Capability. Fisheries protection requires the capability to board and inspect fishing vessels. To provide for this requirement the aft upper deck was removed to provide a working area for launch and recovery of small boats for boarding parties. Two Avon Sea-Riders will be stowed in this area. Davits for launch and recovery are provided. They will be operated from the ship's hydraulic system. Figures 10 and 11 show the plan and elevation of HMS SPEEDY.

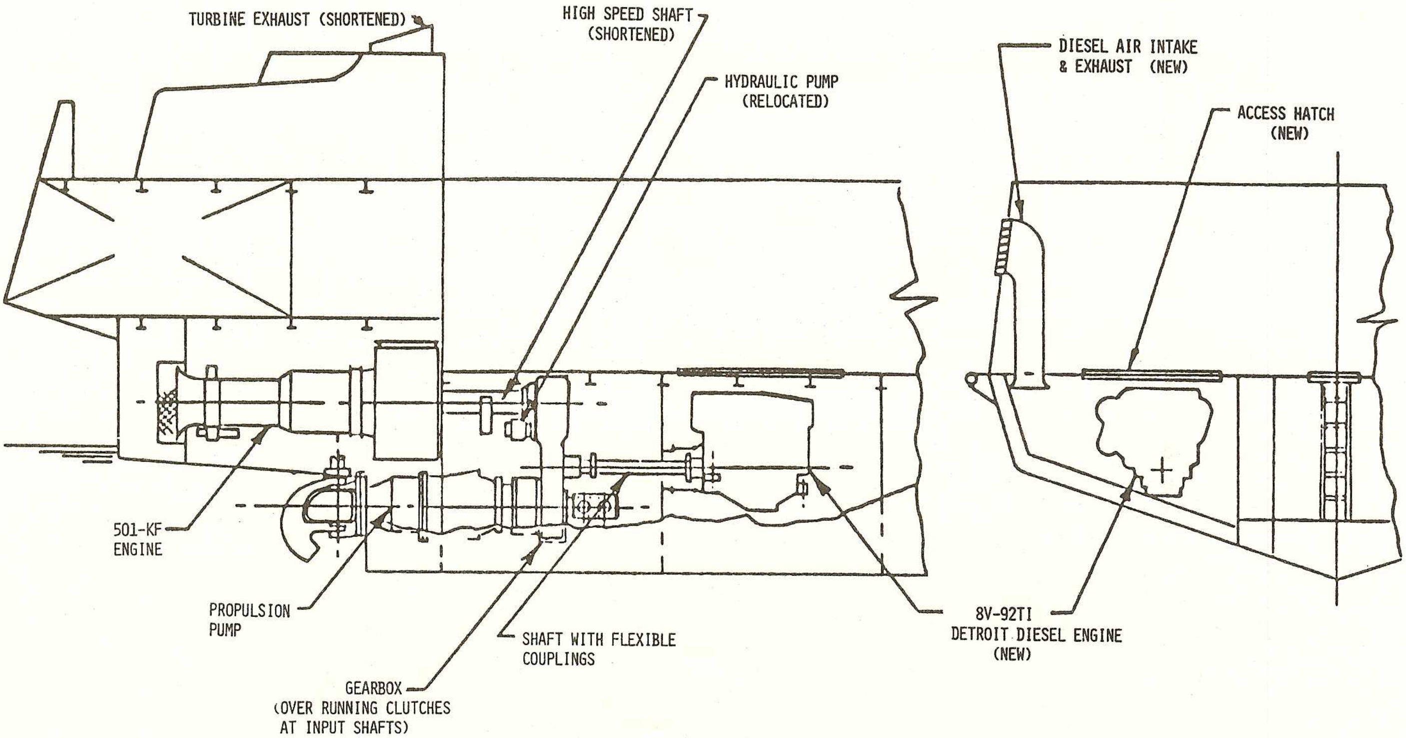


Fig. 9 "Hullborne Propulsion Configuration"

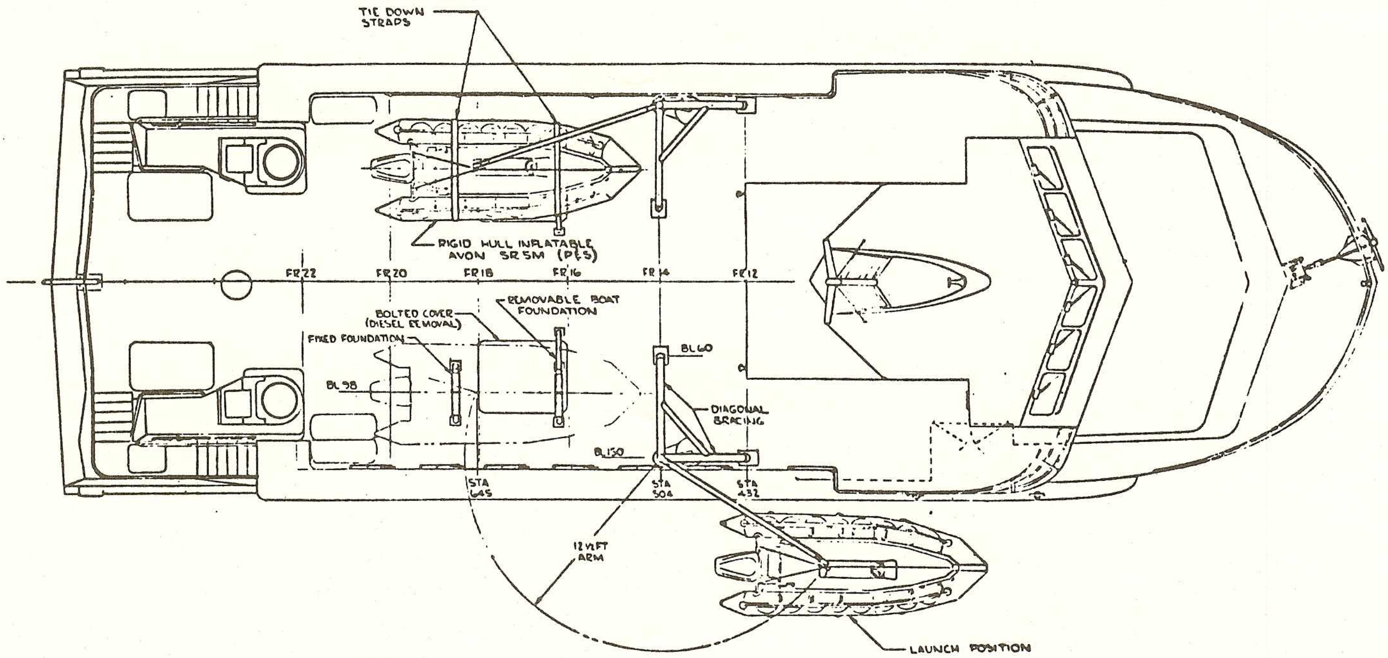


Fig. 10 "HMS SPEEDY Plan View"

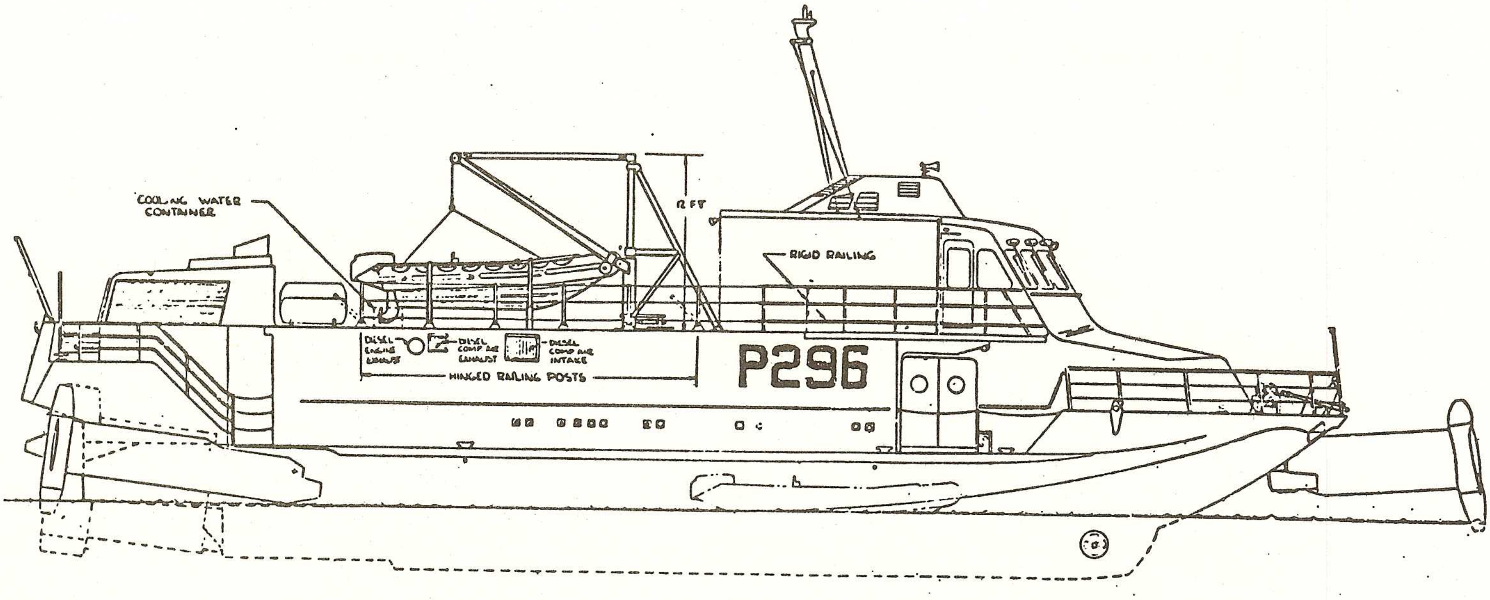


Fig. 11 "HMS SPEEDY Elevation View"

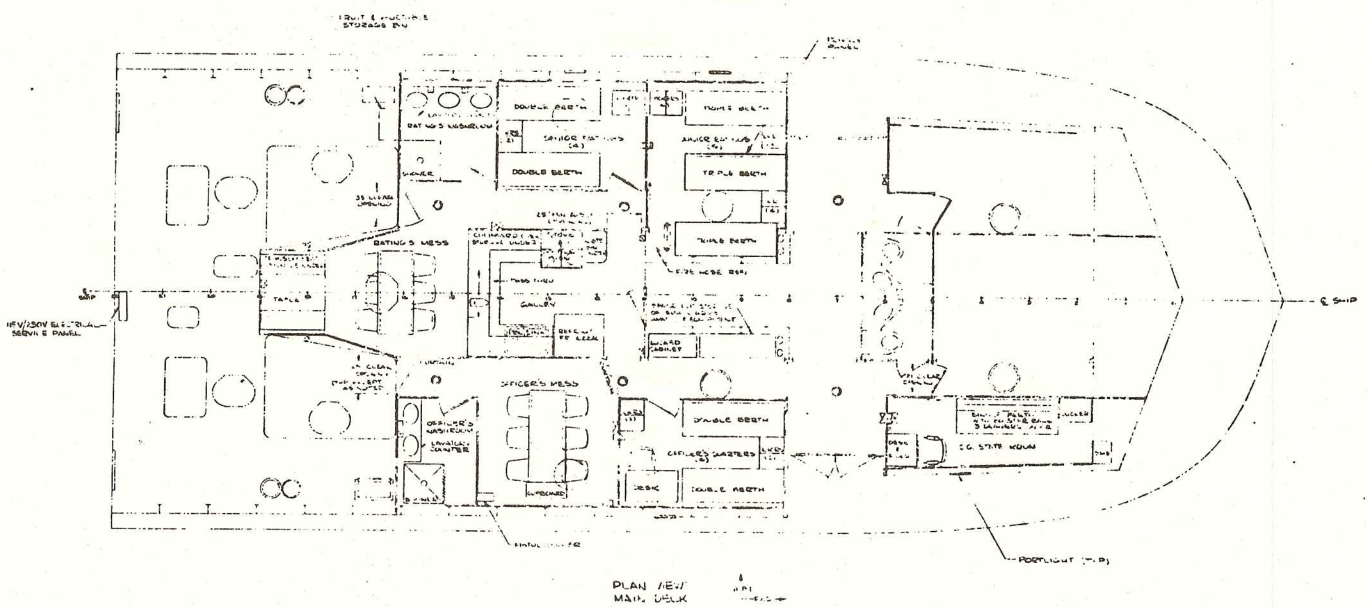


Fig. 12 "HMS SPEEDY Crew Accommodations"

**Communication/Navigation.** A considerable amount of communication and navigation is required for offshore missions. If during inspection of a fishing vessel a violation is discovered, logging of exact time and location is necessary. Communication with Governmental agencies is required to establish action to be taken when a violation is established. Communications with aircraft is essential to define areas to be patrolled. The equipment required to accomplish the communication and navigation will be installed in the lower forward deck of HMS SPEEDY. This equipment will be installed in the UK by Vosper Thornycroft Limited, under a sub-contract to Boeing. The majority of the equipment will be provided by the Royal Navy.

**Crew accommodations.** HMS SPEEDY will be manned by a crew of seventeen (17) as itemized by Table 2.

Table 2 HMS SPEEDY Manning

| NO. | RANK | DUTIES |
|---|---|---|
| 1 | Commanding Officer | In command |
| 3 | Officers | Watch officers - navigation - alternate - helmsman O.O.W. |
| 3 | Senior Ratings | Flight Engineer/maintenance |
| 1 | Senior Rating | Seaman, navigation watch-keeper |
| 3 | Junior Ratings | Senior Technical, watchkeeper, lookouts, messenger |
| 1 | Junior Rating | Communications |
| 1 | Junior Rating | Cook |
| 1 | Junior Rating | Steward |
| Total: 17 | | 4 Officers, 4 Senior Ratings, 9 Junior Ratings |

Crew accommodations are being provided on the lower deck. The Commanding Officer's quarters will be located just forward of the entry door on the starboard side and the remaining four officer's quarters will be just aft of the entry door on the same side. Nine bunks and lockers will be provided for Junior Ratings just aft of the port entry door and sleeping quarters for the Senior Ratings will be just aft from the Junior Ratings. Heads, shower facilities, galley, wardroom and rating's messing facilities are also being installed. Figure 12 shows the layout of the crew accommodations.

## Performance

Table 1 provides a summary of HMS SPEEDY's characteristics, however it is believed that some additional performance data are of interest.

### Foilborne Performance

Takeoff and cruise performance are of interest. Gearbox limits are 4500 shaft horsepower (SHP) for takeoff and intermittent operation and 3750 SHP for continuous cruise. Interpolation between waterjet pump RPM and engine SHP may be made from the relationship.

$$\text{SHP Takeoff} = 0.424 \left(\frac{Np}{100}\right)^3$$

$$\text{SHP Cruise} = 0.43 \left(\frac{Np}{100}\right)^3$$

Subsequent data is provided in relation to pump RPM, the measured parameter in JETFOIL operation.

Figure 13 shows takeoff requirements of pump RPM versus displacement for a two minute or three minute takeoff duration from engine idle speed to 35 knot speed under normal throttle advance. Takeoff at maximum displacement of 115 long tons is less than two minutes under calm conditions.

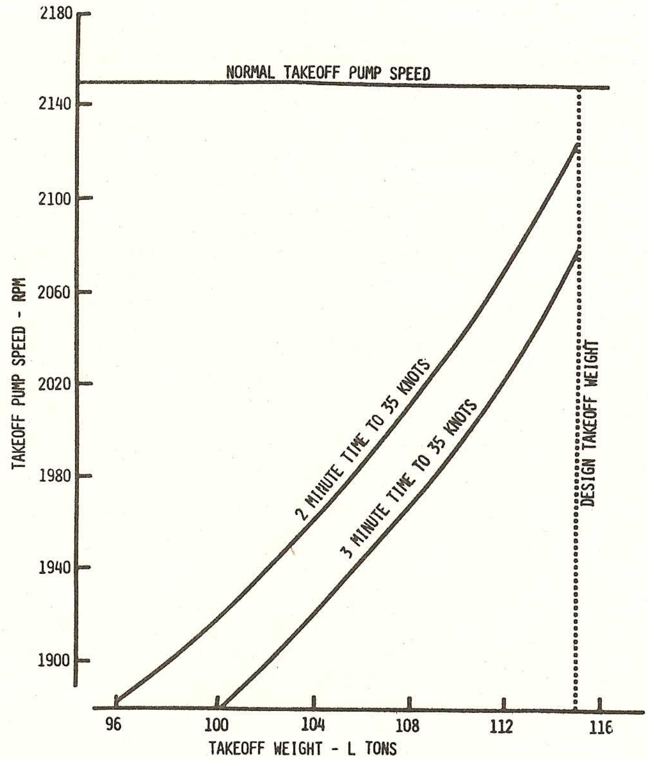


Fig. 13 "Pump RPM vs Displacement for Takeoff"

Figure 14 and Table 3 provide takeoff correction values for the effect of wind and sea conditions. These corrections applied to appropriate values from Figure 12 allow prediction of takeoff capability in service conditions.

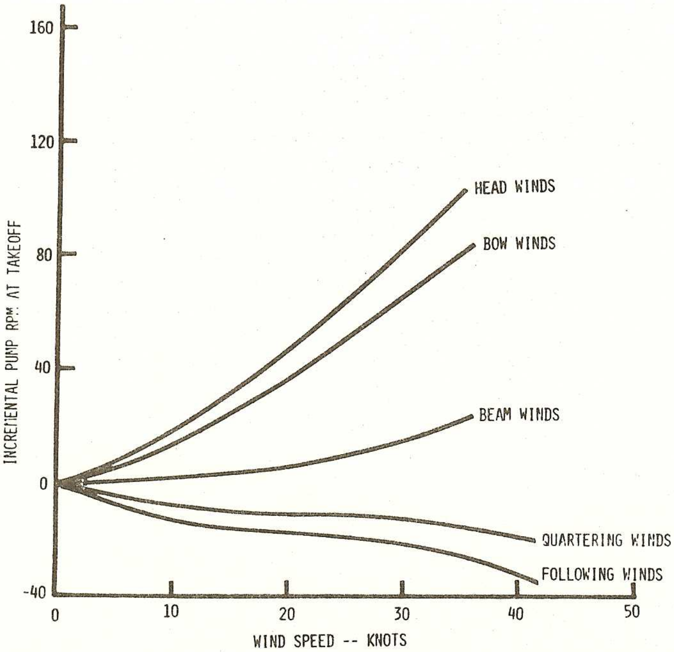


Fig. 14 "Effect of Wind on Takeoff Performance"

Table 3 Effect of Seas on Takeoff Performance

| SIGNIFICANT WAVE HGT - FT. | HEAD | BOW | BEAM | QUARTER | FOLLOWING |
|---|---|---|---|---|---|
| 1 | +20 | +12 | 0 | 0 | 0 |
| 3 | +20 | +12 | 0 | -30 | -40 |
| 5 | +40 | +35 | * | * | * |
| 7 | +150 | +130 | * | * | * |

INCREMENTAL PUMP RPM REQUIRED FOR TAKE-OFF DUE TO WAVES

*No data available, use "0" increment in calculations.

Figure 15 shows the relationship between speed, displacement, pump RPM and total fuel flow for calm conditions. From this chart it is seen that at 105 ton average displacement (60 percent fuel load) and normal cruise power at 1975 RPM, the calm water speed is estimated at 43 knots, the total fuel flow is 538 gallons/hour corresponding to 12.5 gallons/nautical mile. Figures 16 through 19 provide correction values for fuel flow and speed to be added to calm condition values for the effect of wind and waves in service conditions.

For an average displacement of 105 tons, in calm conditions, and with a 24.7 ton (7929 U.S. gallons) full load of available fuel and at 1975 pump RPM (43 knots average) the maximum range is 635 nautical miles without reserve and 570 nautical miles with ten percent reserve allowance. Correction to the values for service weather conditions may be obtained from Figures 18 and 19.

## Hullborne/Foilborne Performance

Hullborne performance is based on using the CODOG system in the diesel power mode at a nominal displacement of 105 long tons corresponding to 60 percent available fuel load. Performance values are predicted estimates based on nominal data measured from JETFOIL coupled with nominal engine performance and estimated application losses.

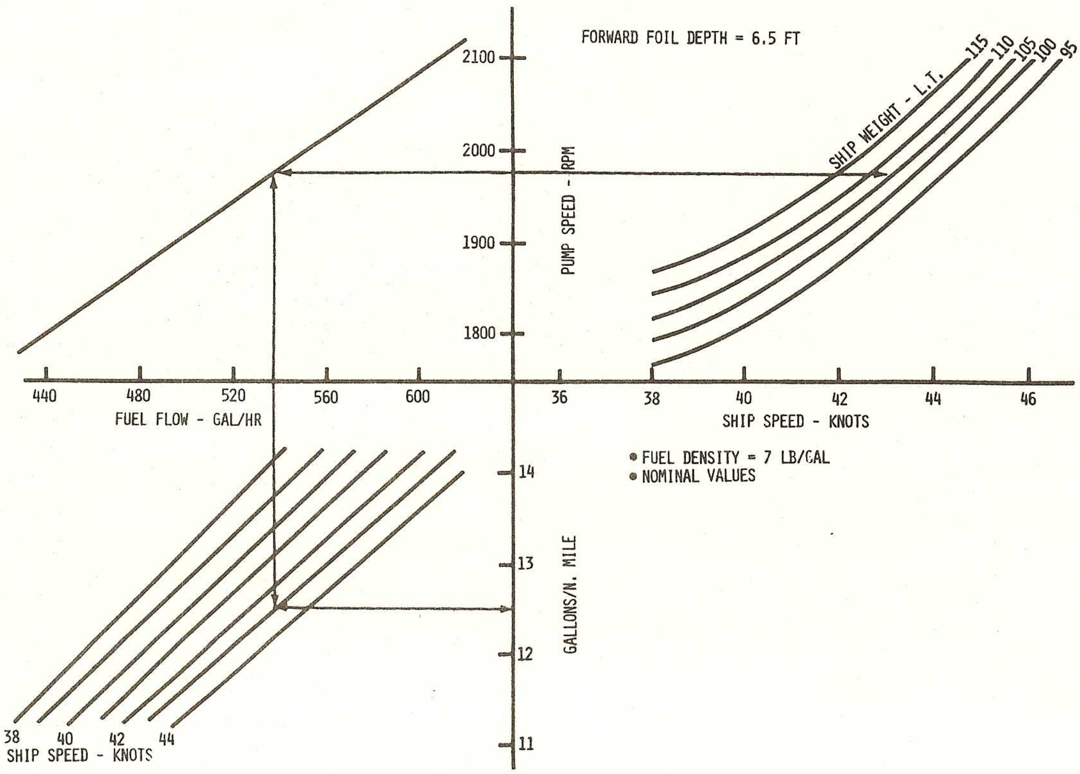


Fig. 15 "Calm Water Foilborne Cruise Performance"

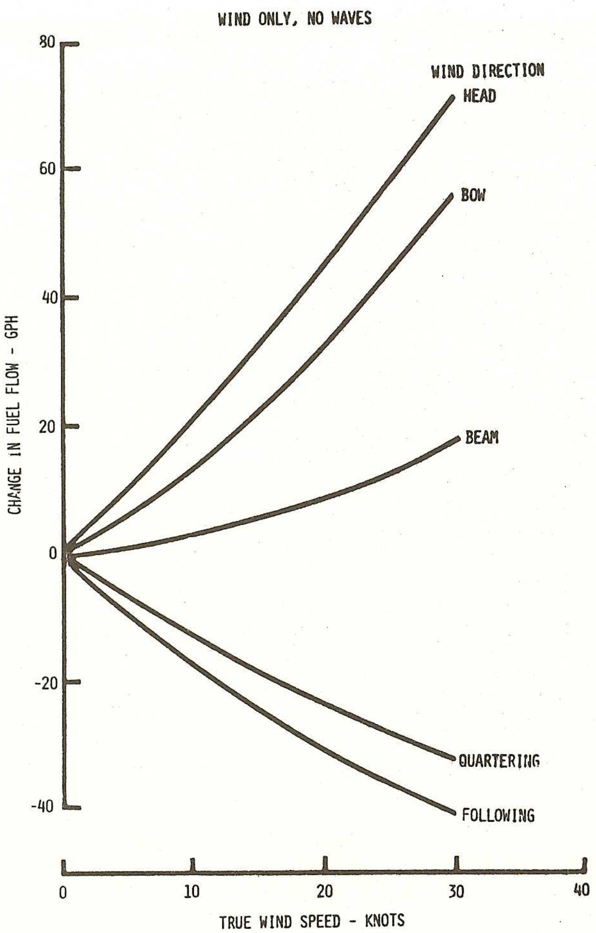


Fig. 16 "Effect of Wind on Foilborne Fuel Flow"

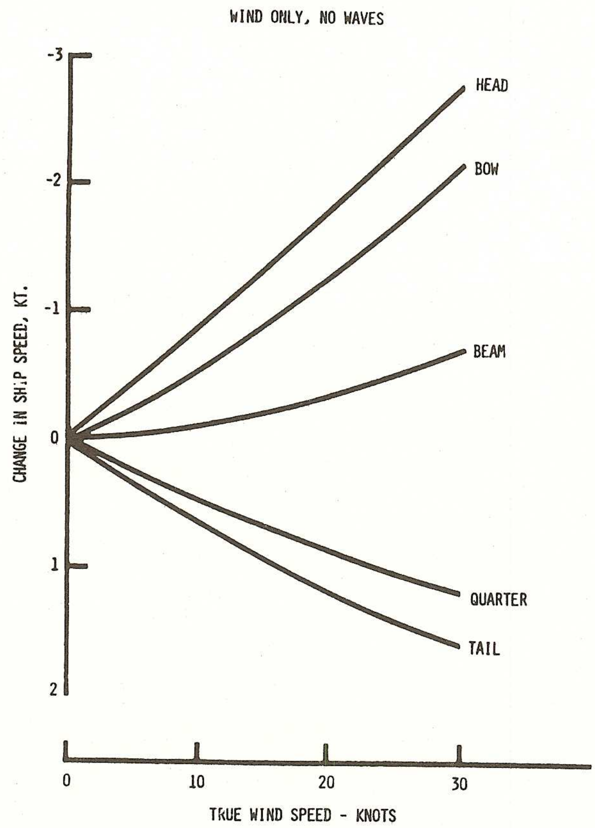


Fig. 18 "Effect of Wind on Ship Speed"

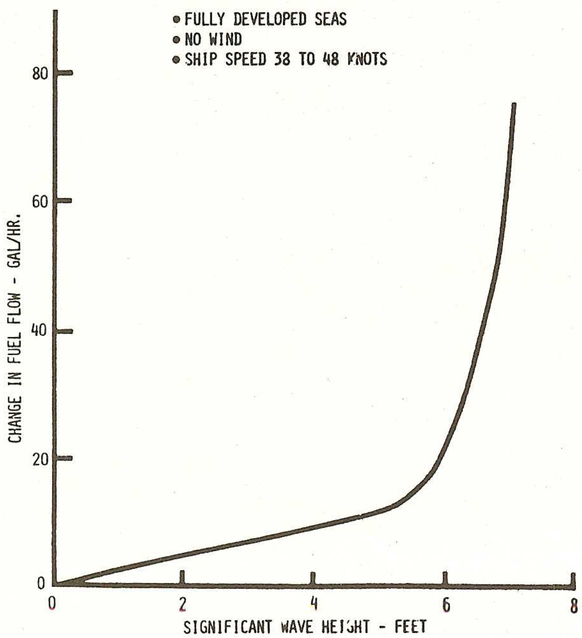


Fig. 17 "Effect of Seas on Foilborne Fuel Flow"

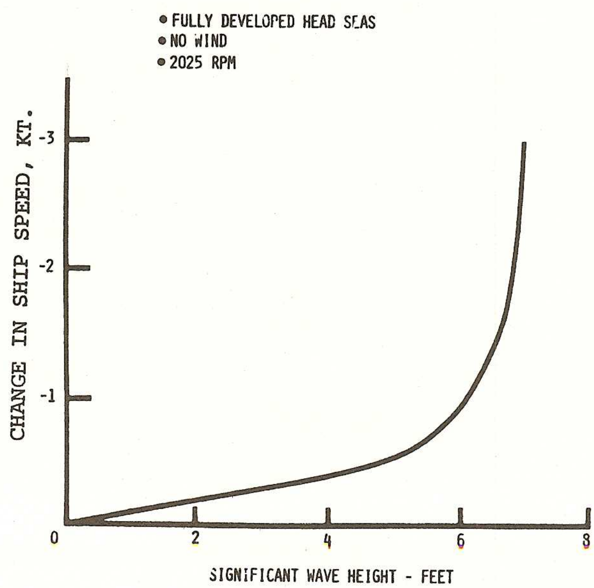


Fig. 19 "Effect of Seas on Ship Speed"

Figure 20 shows the predicted hullborne speed-power characteristics for operation with either one or both of the available diesels in calm water conditions. With two-engine operation at recommended continuous cruise rating the speed is 7.1 knots. Maximum continuous power is available for additional thrust if and when required for maneuvering or other situations. Approximate propulsion pump RPM's are shown for reference to the main propulsion system.

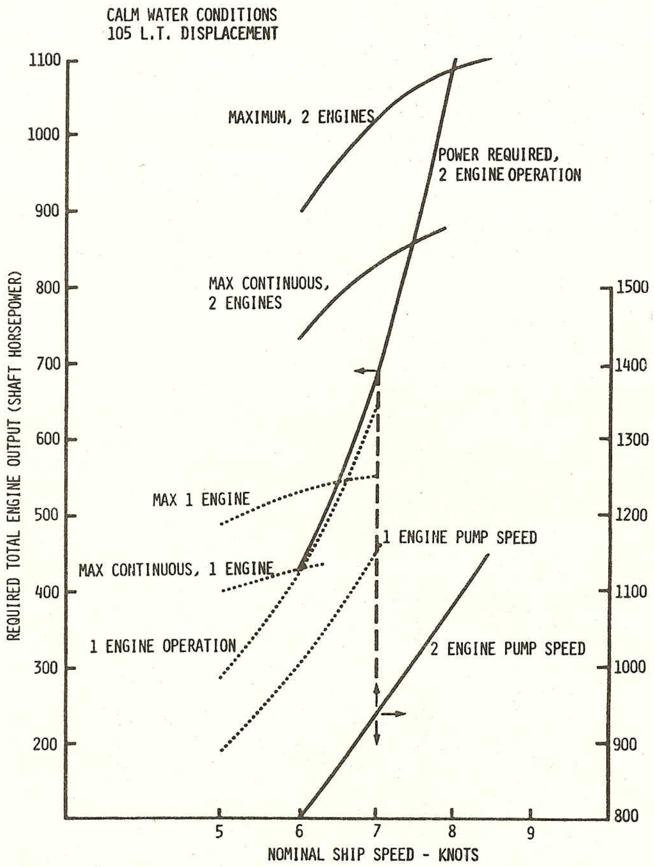


Fig. 20 "Hullborne Power Requirements"

Figure 21 shows the predicted range and endurance for combination foilborne and hullborne operation in average bow sea conditions with 1.5 meter waves and 20-knot winds. Foil borne range is based on 40-knot cruise speed under these conditions. Hullborne power includes 25 percent margin over calm conditions. Useable fuel is 22.2 tons based on 24.7 tons full load available less ten percent reserve. Foilborne performance includes control system primary hydraulic power extraction from the main propulsion plant. Hullborne performance is based on control systems hydraulic power supplied from a diesel generator set operating at 65 BHP corresponding to 30 kW average electrical plus average hydraulic power.

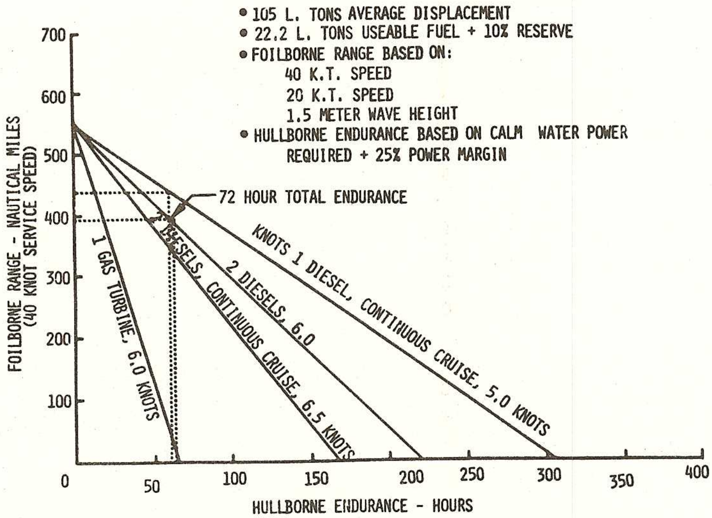


Fig. 21 "Hullborne/Foilborne Performance"

Significant range/endurance capabilities include:

- Maximum foilborne endurance is 13.75 hours for 550 nautical mile range at 40 knots.
- For a 72-hour trip, one diesel hullborne operation at continuous cruise power will provide 11 hours of foilborne endurance for 440 nautical mile range with the balance of 61 hours at 5 knots hullborne.
- For 6 knots sustained hullborne speed using both diesels the available foilborne endurance is 9.9 hours for 395 mile foilborne range during a 72-hour total trip.

## Summary

Data obtained from commercial JETFOILS, demonstrations by the FLYING PRINCESS and studies conducted show that the Boeing JETFOIL may be more productive than vessels presently conducting the UK fisheries patrol mission. Figure 22 shows that continuous foilborne operation, averaged over all headings, is possible 90% of the year in the North Atlantic. In the Winter months continuous foilborne operation is possible for 85% of the time in the North Sea and 72% in the North Atlantic. In both cases, during roughly half of the remaining time, the vessel could operate foilborne but with occasional involuntary landing. The crew effectiveness would be limited duration of the hullborne operation in these high seas. The percentage of foilborne time could further be increased by selection of a favorable heading.

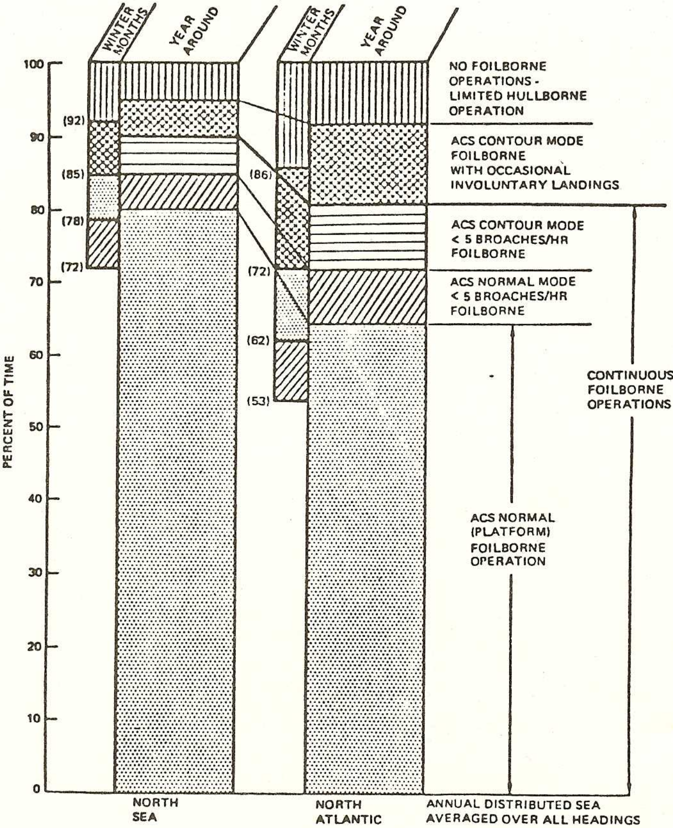


Fig. 22 "Weather Limits to Foilborne Operation - North Sea and North Atlantic"

HMS SPEEDY will be delivered to the Royal Navy in April 1980 to prove its capability in the fisheries patrol as well as its ability to satisfy other offshore missions.