PATROLLING CANADA'S COASTLINE: THE HYDROFOIL RECONSIDERED

by Sub-Lieutenant Peter Dalton

The Canadian Navy has been tasked, in conjunction with the Coast Guard and the ships of the Department of Fisheries and Oceans, to carry out sovereignty patrols and to enforce fisheries, customs and pollution regulations over literally millions of square miles of ocean off Canada's coasts. The sheer vastness of this area of responsibility makes this a daunting mission, but the difficulties are greatly compounded because of fleets that are completely inadequate to the tasks.

The Navy simply has too few vessels to effectively carry out all of its naval operational commitments as well as the sovereignty-protection roles in this enormous reach. Then too, the use of extremely sophisticated warships tends to be gross 'overkill' for most of the patrolling and regulation-enforcement jobs; vessel capabilities are under-utilized, and their use is comparatively very expensive because of the large crews and heavy fuel consumption, and indeed because of the greatly increased wear on the ships and their equipment. Only in the use of their shipborne helicopters can any real advantage be found in employing a frigate or destroyer for economic zone patrols.

The Coast Guard is in reality in an even worse position. Most of their ships are too slow to be effective. Only their Type 500 search and rescue cutters are capable of 17 knot speed; the remainder of this fleet by and large fall into the 11 to 13 knot range. The Fisheries and Oceans fleet is similarly handicapped. Only the motor-vessel *Louisbourg* can make good 19 knots. There are a few 16 knot ships, but the bulk of the fleet are limited to 14 knots or less[1]. Since most freighters and many fishing vessels are capable of speeds greater than many of their potential pursuers, how, one might wonder, are these vessels to catch let alone stop a ship intent on avoiding capture?

Aerial surveillance is, of course, a valuable means of supplementing and even directing the few vessels engaged in offshore patrols. Unfortunately, the number of planes available for these operations have been cut severely with the phase-out of the *Tracker*. But, aircraft of any type have a very fundamental limitation: they can locate and photograph suspected violators of Canadian law, but they cannot do anything about enforcement.

Simply put, the protection of our marine resources and enforcement of our maritime laws requires the presence of a capable vessel! But, if what we have now is either inappropriate or inadequate, what characteristics must be looked for in a vessel for it to be suitable and effective.

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Characteristics of a Patrol Vessel

For the wide variety of patrolling and enforcement tasks that must be done in all sea conditions, the ideal patrol vessel must have a number of characteristics. It must be capable of undertaking extended patrols, independent of support. It must have a high speed capability for chase and capture, and it must have fuel efficiency for on-station endurance. All-weather, open-ocean capability and survivability cannot be compromised, and habitability should not be sacrificed. (This latter factor means that vertical accelerations in rough sea should be limited to 1/4 g or less — a difficult thing to achieve in small vessels.) Crew size should also be as small as possible, to keep costs as low as possible.

These characteristics are difficult for any conventional ship designer to meet. Size requirements imposed by the need for all-weather, open-ocean capability also call for large crews, large engines, and greater construction and operating expenses.

Hydrofoils, however, do have most of the characteristics

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wanted in our ideal patrol vessel.

It is, of course, true that hydrofoils have not gained wide acceptance in Western navies and coast guards, but that is almost certainly because of past errors in matching vessel design with mission roles. A mis-match of vessel characteristics to intended use in the past contributed to poor performance ratings for hydrofoils, overly complex systems, high maintenance costs, and thus a reluctance to exploit the advantages of this type of ship. There have also been misperceptions about foil strength, sea-keeping capability and offensive and defensive weapons effectiveness.

It is contended, however, that it is now time for a serious re-evaluation of the hydrofoil as an off-shore patrol and enforcement vessel for Canada.

Evaluation of Experience with Hydrofoils

Civilian experience with hydrofoils has an important role in this debate because of technology transfer and because commercially-run craft provide a well-documented and relatively long source of operational experience[2]. The continued existence of hydrofoil ferries successfully argues that this type of vehicle is a viable alternative to conventionally-hulled high speed craft. Their use by non-military organizations also indicates that while costs may indeed be higher than those for a conventional ship, they are within manageable (i.e. profitable) limits[3]. Though navies seldom select ships based primarily on such economic attributes, the potential life-cycle costs of operating a vessel, and the ability of private concerns to support these craft, argues that navies can maintain a hydrofoil type of craft within acceptable budgetary limits.

The former Soviet Union makes the most extensive use of hydrofoils, both militarily and commercially, of any country. Their craft, primarily used in close coastal and riverine applications have been(for the most part) of remarkably simple design, though their newest additions seem to follow the American trend towards greater complexity and abilities[4]. But what went wrong with Western naval experiments with hydrofoils?

Early Canadian Developments

Canadian involvement with hydrofoils dates from the first decade of the century, when Alexander Graham Bell and K.C. Baldwin developed successful, experimental models which they tested at Baddeck Bay, Cape Breton Island. These inventors discovered that their designs promised advantages over conventional hull forms when, during an early towed testing of the foil system, strain on the tow rope fell dramatically to less than eleven pounds. This indicated a very low co-efficient of friction while foil-borne, and offered the promise of high speed without significant drag.

Lieutenant-Commander Ted Clayards was one of the first Canadian naval officers to recognize the potential of the hydrofoil in anti-submarine warfare. His article in the 1960 RCAF Staff College Journal, 'Hydrofoil Craft - New Hope for NATO's ASW Problems', set out some of the vessels' most important features in an attempt to convince senior officers of their promise[5]. He argued that the advent of the nuclear-powered submarine demanded that a high-speed surface vessel be developed to counter this threat. The hydrofoil which Clayards advocated, and which Canada later constructed as the *Bras d'Or*, was built for just such a perceived danger. What the NATO navies required was a craft capable of exceeding the speed of a nuclear-powered submarine, even in high sea states[6]. The desired vessel would combine the speed of the PT boat with the sea-keeping capabilities and endurance of a destroyer-sized craft.

HMCS Bras d'Or, during trials in 1970.

Canada developed hydrofoil technology in the 1960s as a contribution to a much larger Allied research effort which included Britain and the United States[7]. The three countries agreed to cooperate in the development of a high speed marine craft[8]. The British concentrated on air-cushion vehicles, and the Canadians upon surface-piercing design hydrofoils. Meanwhile, the Americans split their efforts between a submerged (retractable) foil system and their hovercraft projects.

The American Experience

The US Navy entered into hydrofoil building with specific features in mind. Their operational models were all designed for fast-attack requirements, although weapons and sensor configurations were varied. Their requirements appeared to require the use of a retractable foil system, as this would allow the craft to enter and dock in virtually any harbour. This capability would also allow for the dispersed deployment of the vessels, which would enhance their ability to respond quickly to any perceived threat.

The series of vessels that emerged from the American naval flirtation with hydrofoils are arguably the most complex, expensive, and poorly designed of all military hydrofoils[9]. The initial mission plan conceived for these vessels had them deploying from a harbour in foil-borne condition, transiting to a specific location, performing their mission and returning. In this scenario, the craft would become hull-borne only to enter and exit confined locations, such as a berth, or if the sea-state became too severe to continue in foil-borne mode. Sea conditions for becoming foil-borne were thus never a major design consideration[10]. A coast-guard role was tested by the *High Point*, and the whole PHM class (Patrol Hydrofoil-Missile) is currently engaged in coast-guard type activities, though still operating under naval control. (They are also the only hydrofoils now being operated by the USN.) The tasks they must now do requires a combination of foil and hull-borne operation (for pursuit and for boarding), which dictates a 'take-off' capability under conditions which were never given much priority in the original designs.

US Navy hydrofoils (the PHM class (*Pegasus*), PCH (PCH-1 *High Point*), and PGH-2 (*Tucumcari*) all employed some manner of foil retraction system; and even the much larger experimental vessel, AG(EH)-1 *Plainview* (290 tons standard, 328 tons max) utilized a retraction system.

All revealed defective characteristics. The disconnect couplings on *High Point's* foilborne drive system was a source of continual trouble[11], and corrosion and pitting of the pivot points was an ongoing maintenance concern. US Navy stability parameters could not be met with the foils in their retracted position, so these requirements were waived for hydrofoils, as, it was argued, one would not want to retract the foils in higher sea states due to their dampening effect. The retraction systems were of necessity very complex, incorporating drive elements, controls for variable incident flaps, and a mechanical link (port to starboard) to ensure simultaneous retraction of the parallel units. These and other critical technical problems, including cavitation, plagued American hydrofoils, and contributed to generally poor performance.

A problem common to hydrofoils is their gross fuel inefficiency at what are normal cruising speeds for conventional warships. This is, however, only a problem when combined operations and station keeping are to be required, but this factor may have contributed to the mis-use of the American hydrofoils, and may account for the general decline in interest in hydrofoil type vessels in the US. The USN's focus on long-distance power projection and the carrier battle group often meant that vessels were regarded and judged with respect to their ability to fit into such task groups. Given the USN's inclination toward large ships and extended, unsupported (by shore facilities) deployments such as those typically assigned to a carrier force, hydrofoils were less than ideal vessels.

The Canadian Experience: The *Bras d'Or*

Canada's role in hydrofoil development—to investigate surface-piercing designs—was a logical course, as the ASW role necessitated a hydrofoil which would spend most of its deployment hull-borne, with the ability to transition into foil-borne mode in most sea-states. With the state of technology existing in the 1960s, control of a fully-submerged-foil, open-ocean vessel was, in fact, exceedingly difficult, as discussed above.

The results of experimentation with the *Baddeck* and the *RX*, two experimental craft, suggested to Defence Research Establishment Atlantic scientists that a 'canard' configuration was the way to go when using surface-piercing foils. Because the forward foil was inherently inefficient as a lifting unit, it was decided to keep this as small as possible, and to locate the centre of gravity of the boat close about the aft foils, which were far better equipped to support loads[12]. The advantages of a small forward foil were not limited merely to foil efficiency; because the forward unit had to pivot in two dimensions (rake and steering), bearing loads were a critical factor. Minimizing the size of the forward foil thus helped keep bearing loads within engineering limits.


The *USS Aquila* an US Navy PHM-class hydrofoil.

Too many firsts were probably attempted with *Bras d'Or* for her ever to be acceptable as an operational vessel. Hull construction methods, hydraulic control systems which pushed the limits of available technology, and the use of new and untried materials caused delays and breakdowns, and raised questions about the overall reliability of hydrofoil ships. Per-unit costs, if based upon her construction price tag, would have been prohibitive[13].

Bras d'Or indeed suffered from an unfair financial accounting system—which attributed a multitude of developmental projects (and an extensive rebuilding after a fire) to *Bras d'Or's* basic costs. The price tag of $53 million dollars was cited in a Parliamentary Committee in 1974[14].

After *Bras d'Or* was laid up in October, 1971 (following the discovery of severe cracking in the replacement centre foil element), several inquiries were made during meetings of the Standing Committee on External Affairs and National Defence in 1974-5. One member several times questioned the disposition of the hydrofoil, encouraging the Navy to take a stand and either reactivate the program or 'just cut it up for scrap'. He also pressed the Navy to examine the possibility of using the *Bras d'Or* in the role of fisheries surveillance work 'because a fast ship of this type might be useful in carrying out a count on the foreign ships that are operating on our continental shelf'[15].

What was suggested was a diversification of mission objectives for *Bras d'Or*. This was a logical position to take, as the 1971 Defence White Paper had indeed shifted emphasis from ASW to sovereignty protection. The Navy was, unfortunately, struggling with the new priorities assigned in the White Paper, and considered three other projects to be of higher priority. Before any further funds could (or would) be spent on the *Bras d'Or*, the Navy wanted to (a) Replace the *Argus*, (b) Replace ASW frigates with multi-purpose vessels, and (c) Develop a heavy-ice capability[16].

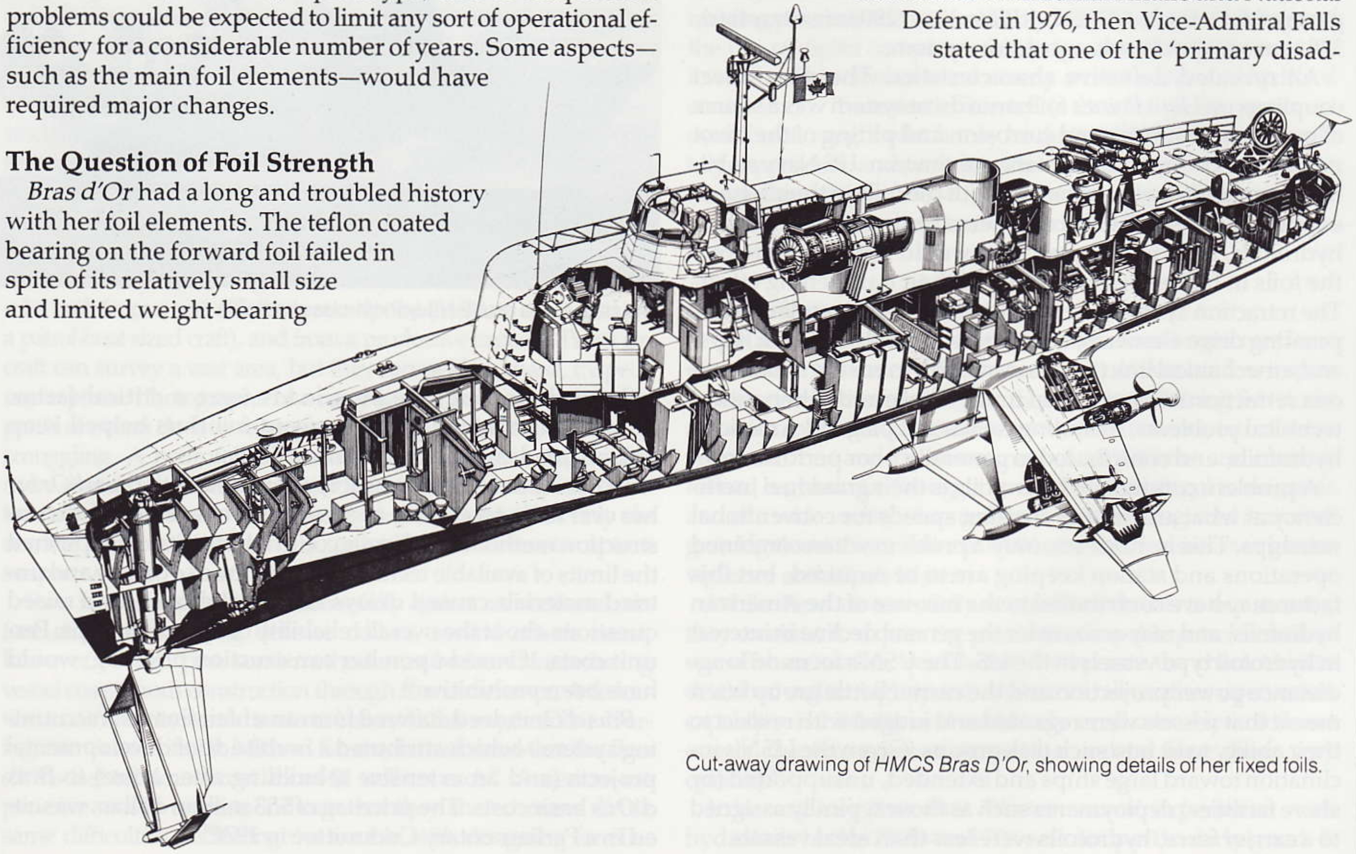
Bras d'Or was theoretically capable of carrying out the fisheries missions envisioned in the Standing Committee. Her range was estimated at over 6,000 nautical miles (while towing a Variable Depth Sonar body), and she was supposed to be able to remain on station for a fourteen day deployment[17]. *Bras d'Or* was, however, a prototype, and developmental problems could be expected to limit any sort of operational efficiency for a considerable number of years. Some aspects—such as the main foil elements—would have required major changes.

The Question of Foil Strength

Bras d'Or had a long and troubled history with her foil elements. The teflon coated bearing on the forward foil failed in spite of its relatively small size and limited weight-bearing character. The main foil elements were constructed of 18 percent nickel maraging steel, a relatively new, high strength material which, it was later discovered, had very poor corrosion resistance properties[18]. Sea water gained access to several of the foil elements and attacked welds, accelerating cracking attributed to residual welding stress. The cracking of *Bras d'Or's* foil units led to the belief that the foils were not strong enough to perform satisfactorily, and that no foil could be made strong enough to survive impact with large debris.

Several sources, however, refuted any such notions, including an account in the 1968-69 edition of *Janes's Surface Skimmer Systems*, which relates how the *Tucumcari* (a US Naval hydrofoil, smaller than *Bras d'Or*) 'struck debris several hundred times and splintered every log it hit, including one 25 ft. long, 18 in. diameter timber weighing 1 1/2 tons'[19]. The Boeing *Jetfoil*, built to commercial standards, was able to slice 'unimpaired through a log 2 feet in diameter'[20]. The *USS High Point* had perhaps the most severe collision with a submerged object, a deadhead estimated at 3 feet in diameter. The impact caused damage to the forward steerable strut, a salt water inlet pipe, and a fibreglass fairing—minor when one considers the size of the vessel, the fact that it was travelling at 42 knots, and the damage likely to have occurred to a conventional hull at that speed[21].

Canadian Naval Staff, however, seem to have chosen to overlook the evidence of survivability and stamina demonstrated by foil systems. During questioning by the Standing Committee on External Affairs and National Defence in 1976, then Vice-Admiral Falls stated that one of the 'primary disad-



Cut-away drawing of *HMCS Bras D'Or*, showing details of her fixed foils.

vantages is of course its vulnerability to floating objects—ice and that sort of thing'. This in spite of strong evidence to the contrary developed from *Bras d'Or*'s own trials, and those of the American vessels just cited. In fact, long experience with hydrofoils has shown them to have an excellent capability in coping with debris, and that their ability to withstand impact damage is actually superior to a conventionally hulled vessel[22]. In direct contradiction to Falls' stated concerns was a study conducted by Supramar (a company long involved in commercial hydrofoil manufacturing and design), which noted that ice patches 2 to 3 inches thick were easily transited by a small sixteen-ton hydrofoil. This information had been presented 11 years *prior* to the concerns expressed by Admiral Falls.

Bras d'Or Trials Limited

Though trials of *Bras d'Or* were intended to prove the fixed foil concept, to detect design faults for correction in production runs, and to test proposed systems for a hydrofoil class, only the first of these objectives was met with any degree of completeness. The second task—discovery of design error—was an ongoing operation with no specified goals. The third assignment was never allowed to proceed. A committee formed from members of the Canadian Forces Maritime Warfare School[23] concluded that because 'the FHE-400 (Bras d'Or) is not considered to be representative... continuation of tactical trials for this vehicle would serve no useful purpose.' The group chose to focus upon limited trials of Variable Depth Sonar towing capabilities at various speeds, to examine potential weapons systems, and to investigate 'the feasibility of increasing the hull-borne speed to 18 knots'[24].

The conclusion one can draw from this last suggestion is that Naval Staff wanted a vessel capable of travelling in formation with conventional ships. As was the case with the American hydrofoils, the Naval authorities were trying to incorporate a capability quite incompatible with basic design criteria. The Canadian hydrofoil had two effective speed ranges—the lower range utilizing an efficient diesel prime mover for extended cruising, and an upper range which relied upon a gas turbine. Speeds beyond the capability of the diesel and below foil take-off were the most inefficient and fuel hungry, and yet this was precisely the range which the Maritime Warfare Committee was suggesting should be exploited!

Other Naval Hydrofoils

Several other navies have of course employed hydrofoil vessels successfully, most commonly as some form of patrol craft. Russia has the largest hydrofoil combatant fleet in the world[25]. The Italian, and Japanese navies both employ some adaptation of an American design. Typical of this arrangement is the *Sparviero* (P420) class, in service with the Italian Navy, which is an improved version of the USN's *Tucumcari*. This vessel, which is used primarily for coastal patrol operations, has successfully demonstrated the missile capability of a small hydrofoil combatant. The first of the class was commissioned in 1974, with the *Condor* (P426), the last of the production run, joining the fleet in 1983. Also manufactured in Italy is the *Pat 20* fast patrol hydrofoil. Utilizing surface-piercing foils, this relatively small (20.9 meters, 28 tons) craft has been sold to several countries, including the Philippines. A passenger ferry version is also manufactured which uses the same simple, inclined shaft, diesel driven propulsion unit[26]. Both the *Pat-20* and the *Sparviero* are employed in contraband patrol and coast-guard duties.


Italian Navy hyrofoil of the *Sparviero class.*

Future Prospects

What does the future hold for the hydrofoil?

Canadian, American, and other nations' experiences with a variety of models, propulsion methods, and foil configurations have by now amply demonstrated the strengths and weaknesses of this type of craft. On the basis of past experience, it is evident that hopes for speeds in excess of 55 knots cannot be justified because of the additional high costs. Equally clear is the need to examine mission requirements, and to allow them to dictate the performance characteristics of vessels to be constructed. Just as it is unreasonable to expect an ASW frigate to perform well in an air defence role, it should not be expected that a hydrofoil designed as a missile attack craft will be ideal for executing a coast guard role.

What roles might a hydrofoil fulfil?

The original concept of an ASW platform is no doubt still valid, as the decline in the Russian threat has not eliminated or reduced the number of submarines operating throughout the world. The possibility that nuclear navies might sell off early generations of their nuclear-powered submarines, as is common practice with surface ships, could pose a very real threat to our coastal sovereignty. Though down-sizing of fleets is now in vogue, and some credible arguments may be advanced for a reduction in the number of large capital ships, the submarine threat is actually increasing as quieter and more sophisticated craft join not only the Russian Navy, but also those of second and third world navies[27]. As Truver has noted in his article 'Tomorrow's Fleet,' 'quantity has a quality all of its own', an argument that, in conjunction with the desire to cut costs and reduce overall force numbers of capital ships, speaks in favour of the *Jeune Ecole's* 'small and many' approach to naval forces.

Bras d'Or, hull-borne.

Hydrofoils are not, nor could they ever be, a replacement for frigates, destroyers and larger capital warships. They are, however, an economical alternative for many of the less demanding roles these larger craft now perform, and they hold the promise of accomplishing some of these tasks more quickly and effectively. This is undoubtedly, where the hydrofoil is needed most.

Establishing and protecting sovereignty and exclusive economic zones demand a visible and effective presence. Declining fish stocks argue for an increased capability for monitoring and enforcement of economic exclusion zones. American experience has very clearly demonstrated the threat posed by smuggling operations, and has revealed a clear role for a high-speed, all-weather interception vehicle capable of extended deployment. As argued earlier, destroyers and frigates are very unsuitable for this type of role, both from a cost-efficiency standpoint (fuel and crew costs vs. a patrol-boat sized craft), and from a productive capacity. Patrol aircraft can survey a vast area, but they can neither board, inspect, nor capture. Photographs of a rusty-hulled foreign trawler on a patch of ocean do little to stop overfishing, and even less to stop smuggling. A hydrofoil fleet could cover a larger zone, deploy more vessels for the cost of major ships, and move between contacts much more quickly—increasing the likelihood of not only observing illegal activities, but also providing the means to capture suspect vessels.

For a hydrofoil to compete successfully against conventional surface craft for declining defence dollars, several criteria must, however, be met. First, some method must be found for reducing vessel costs—from construction through to maintenance. A reduction in complexity would seem to be key to this requirement. During interviews with Dr. Michael Eames, he estimated that the *Bras d'Or*'s last ten knots cost about $1 million each[28]. American experience would seem to indicate that they shared many of the same difficulties, including the trouble with designing for 60+ knots. Reducing the vessels top speed to the fifty-knot area would no doubt be a major step in reducing initial construction costs. Another area where improvement is essential, if long-range patrol activities are to be a common mission is vessel endurance. Here, increases in fuel efficiency[29], coupled with reductions in machinery weight, can contribute significantly to enhanced range and greater payload.

Past research and development has already broken most of the ground necessary to build an effective hydrofoil class of ships, and most major shipyards now have the experience and infrastructure necessary to make such craft[30]. 'Off-the-shelf' components, which have some proven 'track record' are probably best employed in the building of a hydrofoil, which is of itself a significant test of engineering skills and limits. As *Bras d'Or*'s unfortunate experiences with hydraulic systems and an insufficiently tested steel type clearly demonstrated, control of vessel costs can escalate wildly when this is not a firmly established principle.

Previous hydrofoil projects may also now be used to more closely estimate vessel construction costs, while now current shipyard building practices, such as familiarity with aluminum welding and the use of digital computers for design and tool operation, will lower the costs of what was formerly an exotic aspect of hydrofoil construction. 'Transport efficiency' (a measure of the portion of overall craft weight which may be dedicated to crew, cargo, military equipment and fuel) has also shown significant improvements through successive generations of hydrofoils—virtually doubling between the *Denison* and *PCH-1*, to use American examples[31].

Conclusion

The need to protect our marine resources and to enforce Canadian laws in the waters off our coasts will not become less important anytime in the future. Quite the contrary. Declining fish stocks argue for an increased capability for surveillance over our offshore economic zone and for enforcement of our fisheries and environmental regulations. Smuggling—of drugs, of illegal immigrants and of a wide variety of contraband—is increasing, and is an ever growing threat to our national well-being that requires ever greater vigilance and efforts to stem.

While these are essentially non-military threats to our security, they continue to require the presence of capable patrol vessels in our offshore waters, vessels that incorporate the characteristics described earlier: high speed; endurance; all-weather, open-ocean capability; habitability and a relatively small crew. Hydrofoils are one of the few types of vessel that indeed have these very qualities[32].

It is certainly true that Western naval experience with hydrofoils in the 1960s and 70s was not particularly good. It is also true that today they tend to be looked at in light of that early, experimental experience. But hydrofoil technology has matured greatly over the past 20 years, in large part because of civilian applications.

If for no other reason than to eliminate unnecessary wear and tear on our frigates and destroyers, but indeed also because they can do the necessary job better and at far less cost, we need to give hydrofoils another serious look. ☐

NOTES

1. *Jane's Fighting Ships 1991-2.*
2. The Far East Hydrofoil Company, which uses primarily the Boeing *Jetfoil* (though some Supramar vessels remained in service up to 1984), had only cancelled seven out of 2,500 scheduled crossings, for a 99.8 percent reliability factor. Overhauls consist of annual overhauls of the main engines, with a 10,000 hour (four year) period between major servicing (according to a Boeing company reprint from *High-Speed Surface Craft*).
3. Commercial hydrofoils have been operating with considerably more success than their naval counterparts. Hydrofoil ferries have the advantage of being constructed with only one mission in mind, and civilian vessels are usually constructed along much simpler lines than their naval counterparts, with lowered expectations for top speed and manoeuvrability.
4. The *Sarancha* and *Babochka* (330 and 400 tons) are the largest naval hydrofoils currently in service. Both employ a combination of surface-piercing forward and submerged rear foils to attain speeds estimated at 50+ knots. The *Sarancha* has been fitted out as a missile attack craft, while *Babochka* is configured for an anti-submarine role with torpedoes and sonar fits.
5. One of the features which Clayards extolled was the difference in per-unit costs between a destroyer (approximately $30 millions) and the estimated costs of hydrofoils ($5 millions). Both figures are for 1960 dollar values. (Clayards, Interview).
6. K. Harbaugh and W.H.G. Fitzgerald, 'Hydrofoil Operations and Development Experience 1952-1964', SNAME Hydrofoil Symposium, 13-14 May 1965. The Society of Naval Architects and Marine Engineers, New York.
7. Canada's assigned area of study were to: (1) establish in practice the feasibility of an ocean-going hydrofoil of the proposed size and characteristics. (2) evaluate the prototype as an ASW weapons system (The RCN Hydrofoil Programme, a presentation paper by DeHavilland and the RCN, 11 Feb, 1964).
8. J.H.W. Knox, Cdr. in 'Testing and Initial Sea Trials of HMCS Bras d'Or', a presentation paper given in Ottawa, Ontario on 13 January, 1970 to the Eastern Canadian section of The Society Of Marine Architects and Marine Engineers noted that the meeting which confirmed this division took place in Halifax, N.S. during January of 1960.
9. K. Harbaugh of Supramar, a world leader in hydrofoil construction and design, noted that 'problems involved in stabilization are of far greater magnitude' with a submerged foil system. They also noted the necessity for complex control, hydraulic and sensing systems for the operation of a fully submerged foil system (SNAME conference papers, 13-14 May, 1965).
10. The greatest power requirement for a hydrofoil is during the 'take-off' phase, and the additional drag imposed by higher sea states increases hull resistance, necessitating even more power beapplied to the propulsion unit. During an interview with Dr. M. Eames, one of Canada's foremost authorities on hydrofoils, he confirmed the low emphasis placed on regaining foil-borne configuration under open ocean conditions inherent in American designs.
11. Wm. M. Ellsworth, *Twenty Foilborne Years: The U.S. Navy Hydrofoil Highpoint PCH-1*. United States Navy, David Taylor Naval Ship R & D Centre: Contract #N00600-81-D-0252-FD36 and FD40.
12. Tom Lynch, in an interview (January 8, 1992, Halifax, N.S.) and Dr. Eames in 'A Review Of Hydrofoil Development In Canada'—a presentation paper given to the First International Hydrofoil Society Conference, Ingonish, N.S.: July 27-30, 1982 confirmed this decision.
13. Commander J.H.W. Knox, 'Testing and Initial Sea Trials of HMCS *Bras d'Or*'. A paper given in Ottawa, Ontario on 13 January 1970 to the Eastern Canadian Section of The Society Of Marine Architects and Marine Engineers.
14. The price tag hung on *Bras d'Or* included $3 million for scale models and tests, $7 million for the post-fire rebuild, $1 million for a slave barge, $3 million for trials and logistics facilities and $10 million for fighting equipment, most of which was never fitted (Lynch, *Warship International.*, 134) This attachment of costs continued to misrepresent the true price of *Bras d'Or*; even as she was given over to a museum the press exaggerated her costs and utility, calling the ship a $53 million white elephant' (*Globe & Mail*, 25 May, 1983, 1-2).
15. *House of Commons Debates*, 17/10/74, 1: 22-3 and 25/11/75, 30: 6.
16. Dr. M. Eames, 'A Review of Hydrofoil Development In Canada'. A presentation given to the First International Hydrofoil Society Conference, Ingonish, N.S., 27-30 July, 1982: 1-15.
17. *FHE 400 Hydrofoil Operator's Confidential Handbook*, The DeHavilland Company of Canada, Downsview, Ontario. (Revised July, 1966). Maritime Museum Of The Atlantic Archives, Call #623.812314 D32A.
18. American hydrofoils were making wide use of HY-80 steel (with yield strength of 275,000 lbs) and were considering HY-130 (yield 450,000 lbs) and Titanium (yield 625,000 lbs), especially where cavitation damage was likely to occur. All three of these options offer superior corrosion resistance properties to the steel used on *Bras d'Or*, and all possess the strength necessary to satisfy the Canadian craft's design needs. G.A. Starr, 'Titanium For High-Speed Hydrofoils-A Cost Value Study'. A presentation given in Seattle, Washington, 13-14 May, 1965 to The Society of Naval Architects and Marine Engineers.
19. *Jane's Surface Skimmer Systems 1968-69*, page 190.
20. In a *Newsweek* article by A.J. Mayer and W.J. Cook, 'Boeing's New Flying Boats', 8 November 1976.
21. Ellsworth, *Op. Cit*.
22. Dr. Michael Eames, 'Advances in Naval Architecture For Future Surface Warships', RINA conference, 1980.
23. Members were Captain R.H. Falls, Commander D. Mainguy, Lieutenant-Commander D.D. Peacocke, and Mr. D.M. Murray, D.R.B. (Memorandum MCW 8000-1 Sub 1 Vol. 2 14 March, 1966) (Falls 1-2).
24. Captain R.H. Falls, 'Minutes of Meeting to Discuss FHE Tactical Study on 10 March, 1966', Confidential (Declassified) Memorandum, MWC 8000-1 sub 1 Vol. 2, addressed to CDS. This increased speed would be consistent with the upper limit of 'economical cruising speed' for a destroyer/frigate. Desire for this specific speed seems to indicate an attempt to equate the hydrofoil with a conventional ship, and conventional ship characteristics.
25. The *Turya* class, with close to 30 in service, is not a 'true' hydrofoil, as the stern of the vessel remains in contact with the water—eliminating the need for complex gearing systems. Foilborne, the majority of the vessel's hull and weight are carried by a single main foil. The *Matka* class is another of the transom draggers, able to reach 45 knot speeds as the single fixed foil reduces the wetted hull area, lifting most of the forward end clear.
26. The use of an inclined shaft eliminates the 'Z' drive common to American and Canadian hydrofoil designs. Though mechanically simpler, this method does not optimize the angle at which the propeller operates.
27. Outside of the 'nuclear' navies, advances in diesel and air-independent technologies are promising a limited range, but very quiet submarine. See Truver's article 'Tomorrow's Fleet' in *Proceedings*, Vol 177 July 1, 1991.
28. i.e. the cost to exceed 50 knots.
29. Presently available intercooled recuperative engines (a gas turbine variant) can boost efficiencies by about 30Ç over the estimates originally developed for *Bras d'Or*, a figure which may be translated directly into increased range. E.J. Walsh 'US Surface Navy Plans Ahead to 2020.' *Armed Forces Journal* July, 1989.
30. Aluminum welding techniques were still in their infancy when *Bras d'Or* was built, necessitating a major training program for MIL staff. The demands of *FHE-400's* design also forced DeHavilland to expand its drafting and engineering department's use of the 'new' digital computers.
31. J.R. Meyer, *Hybrid Hydrofoil Technology and Applications: Presentation to NATO Working Group 6*. Bethesda Maryland: David Taylor Research Centre, November 1991.
32. The *PGH, Tucumcari*, through designed for a sea-state 4 operated successfully during her trials period in a sea-state 6. This is with a craft displacing a mere 62 tons at full load.
33. Other vessel types are discussed in Eames' 'Advances in Naval Architecture for Surface Warships,' including hovercraft (S.E.S.), displacement ships, SWATH, Planing hull and Wing-In-Ground-Effect vehicles. Of this group, only the SWATH concept has been developed for open-ocean operation. Air cushion, or Surface Effect Ships are presently too small for deep sea, all weather operation, and Eames (with other experts) does not foresee anything less than a multi-thousand ton size as viable in such operations (106).