100 YEARS OF OVERCOMING ARCHIMEDES PRINCIPLE

By

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ABSTRACT

Professor Georg Weinblum in introducing dynamic lift to his students, used to say that the major deterrent to advances in Naval Architecture was Archimedes Principle. This paper discusses how the theory of hydrofoils, for the past century, has been used to overcome this principal. The discussion starts with some of the earliest hydrofoil inventions. It continues by outlining how hydrofoils have developed into today's modern military and commercial vehicles. The paper concludes by suggesting ways in which hydrofoil technology may be used in the future.

INTRODUCTION

Even though the concept of hydrofoils is older than the concept of airplanes, the transportation needs that can be filled with a hydrofoil are limited, compared to the potential of aircraft. The development of airplanes proceeded at a much faster pace, however, the significant contributions made by some of the very early inventors of hydrofoil principles are worth recognition and comment.

This paper will review the work of some of the individuals who first used hydrofoils to lift their craft from the water surface. This paper is divided into several parts. Very Early Years start with the inventors of the late 1800s who had obtained patents as early as 1869. Then the first successful "Flying Hydrofoils" in the form of hardware, rather than only paper patents, are described. Bell-Baldwin developments in Canada follow, highlighted by the HD-4. The first U.S. Navy hydrofoil, CAPT. Richardson's dinghy, built about 1909, and the work of von Schertel, Tietjens and Grunberg will take us into the World War II time frame.

The paper continues with the post WW II era and describes how the U.S. Navy reluctantly became supportive of the hydrofoil principle. From this reluctant start, the U.S. Navy began a series of patrol craft developments leading to the present day PHMs. A brief review of other nations military vehicles is presented. At the same time, hydrofoils came of age in the commercial world and a number are successfully operating around the world today. The paper concludes by taking a look at what may be ahead for the next 100 years.

An appendix organized by sections of the paper list the principle dimensions and major characteristics of the craft mentioned in the paper.

EARLY HYDROFOILS

Farcot and Other Inventors

According to Leslie Hayward[1], who has written a most comprehensive history of hydrofoils in a 14 part series in "Hovering Craft and Hydrofoils", the first evidence of the use of hydrofoils on a boat or ship was in a British patent of 1869. It was granted to Emmanuel Denis Farcot, a Parisian, who claimed that "adapting to the sides and bottom of the vessel a series of inclined planes or wedge formed pieces, which as the vessel is driven forward will have the effect of lifting it in the water and reducing the draught". There were numerous patents during the ensuing years, all claiming, by a variety of means, to lift the vessel either partially or fully out of the water to improve speed and motions in waves. Such patents were exemplified by inventors and experimenters like Horatio Phillips, C. E. Emery, Count de Lambert, and the Meacham brothers.

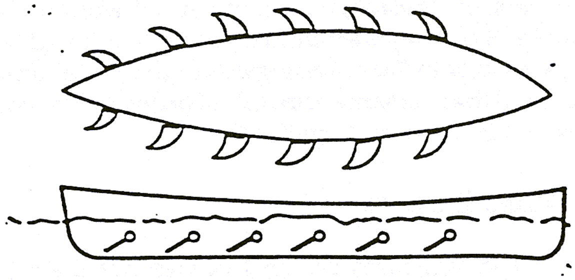

Fig. 1 - Rendering From 1869 Patent by E. D. Farcot

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Phillips' invention of 1881 was to be applied to "torpedo boats and equally so to steam launches and other vessels propelled at high speed". The object of the invention was to "ensure an even keel by which means the resistance would be reduced and the speed thereby increased". His patent went on to describe the fitting of "plates" and the adjustment of same to obtain the desired result.

In 1890 C. E. Emery of Brooklyn, New York, filed a patent using retractable foils, again applied to the sides of a vessel. These foils were of the ladder type and retracted flush with the surface of the ship. They were retracted or extended to be used as a water brake, or for maneuvering.

Count de Lambert, a Russian residing at Versailles, applied for patents as early as 1891. He employed a plurality of foils (or lifting planes) on each side of the vessel, each individually adjustable to raise the hull in the water as speed increased. As in the case of Napier, the location of these primitive foils did not make it possible to lift the vessel completely clear of the water.

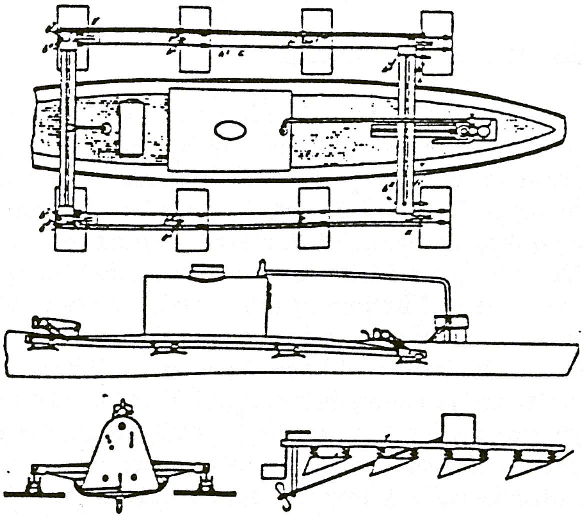

Fig. 2 - Count de Lambert's Hydrofoil (1891-1904)

Hayward describes the work of the Meacham brothers, of Chicago, who commenced work on hydrofoils in 1894. They were influenced by Sir Hiram Maxim's experiments in "aerial navigation" about that time, and believed that the same principle of lifting planes could be applied to "water navigation".

<u>Meacham Brothers</u>

The Meacham brothers carried out their experiments on the Chicago Drainage Canal during 1897 with tests on a 14 ft. long and 30 inch beam craft. Foils were fitted at the bow and the stern along with two small balancing foils, one on each side of the hull, as can be seen in the accompanying sketch. It is interesting to note that the foils were fully submerged and incidence controlled.

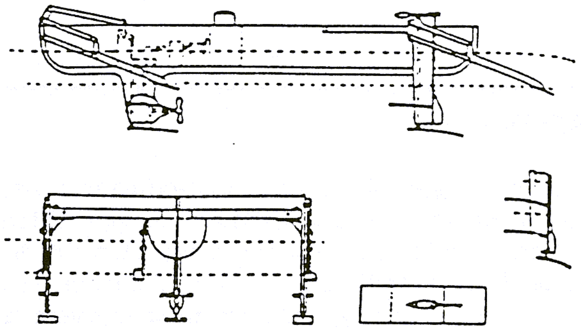

Fig. 3 - Meacham's Hydrofoil Designs (1895-1906)

A surface feeler was connected to the forward foil to provide some stabilization in waves. By 1906 the Meacham's design became more refined with controls on both fore and aft foils, and each supporting strut had two ladder foils with the upper foil fixed and the lower foil controllable through a linkage system to the surface feeler.

The Meachams became involved in a patent suit with a Mr. S. A. Reeve. The brothers applied for a patent in 1896 but Reeve had applied for a patent a year earlier on the subject of swinging links adjusting a pivoting foil to a desired position (Figure 4).

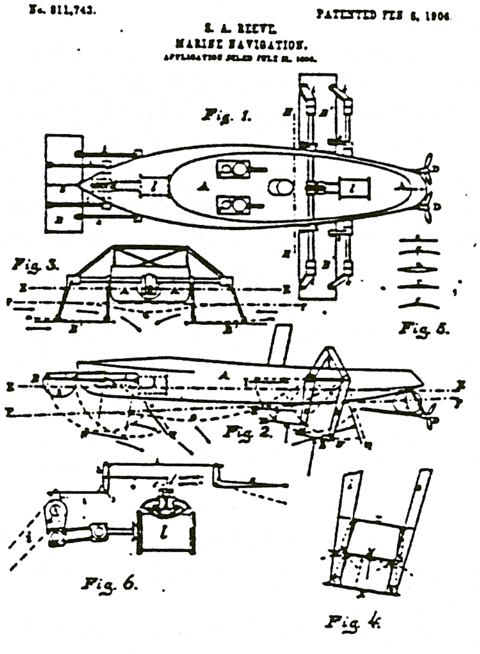

Fig. 4 - Reeve's Design of Swinging Links Adjusting A Pivoting Foil

Mr. Reeve won the judgment in 1904. At least the outcome was quite amicable as Reeve ultimately assigned his patent to the Meacham brothers. The Meachams' interest in hydrofoils continued until at least 1913 when they designed a manual control for the aft foil while retaining the same forward foil control as their 1894 concept (Figure 5). This latter concept of manual control would eventually prove to be an unwise decision as hydrofoils became faster. It is also interesting to note that from 1906 to 1913 they changed from a "conventional" foil system to a "canard," although these definitions would not be used until years later.

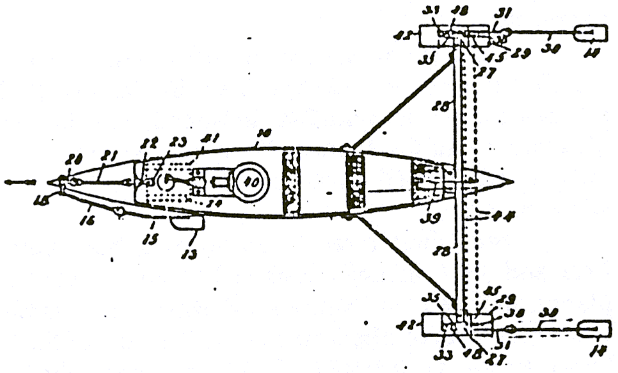

Fig. 5 - Patent Drawing of Meacham's Beam Craft

It is no coincidence that much of the serious hydrofoil work started at about the same time of early powered flight. Interestingly, according to Hayward[1], it had been reported that the Wright brothers experimented with a catamaran hull supported by hydrofoils. However, this is a statement that Hayward had been unable to prove, but from a letter by Wilbur Wright, to Capt. Richardson of the U.S. Navy, there is a suggestion that experimental foils were tried on the 1903 *Wright Flyer* about 1906 to 1907.

Forlanini

Enrico Forlanini was an Italian engineer whose interests included airships, aircraft and helicopters. His hydrofoil developments started in 1898 with a series of model tests from which he arrived at several simple mathematical relationships. These allowed him to proceed with the design and construction of a full scale craft; see Figures 6 and 7.

Forlanini's designs were characterized by a "ladder" foil system. You can see from a drawing of his concept and a copy of an old photograph what is meant by this aptly named ladder foil. The craft weighed about 2,650 pounds and had a 60 hp engine driving contrarotating airscrews. Although designed to fly at a speed of 56 mph, records, according to Hayward, show that during tests on Lake Maggiore, Italy in 1906 a speed of 42.5 mph was obtained.

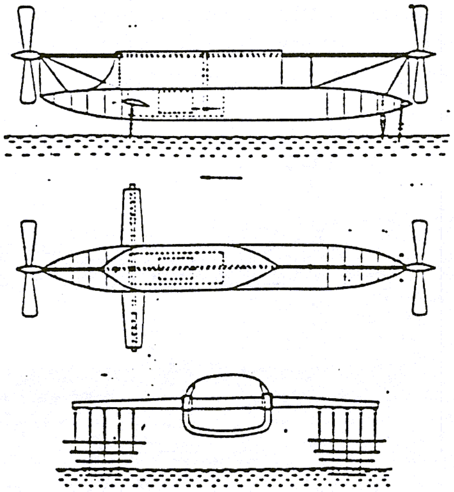

Fig. 6 - Drawing of Forlanini's Hydrofoil

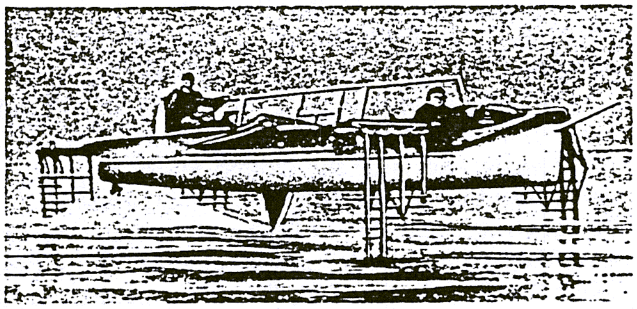

Fig. 7 - Forlanini's Hydrofoil on Lake Maggiore in 1906

Although the foil system was a rather complicated structure, Forlanini's craft operated well and represented an advancement in the state of the art. He obtained a number of British and American patents on his ideas and designs, most of which were aimed at seaplane applications.

Guidoni and Croco

Another Italian, Guidoni, in the 1910 to 1921 time frame was involved in the development of hydrofoil seaplanes. He mounted foils beneath the floats of seaplanes to reduce the impact loads and improve the landing characteristics of such craft in rough water. The aircraft Guidoni worked with usually became airborne at well below 50 knots. According to Hayward, Guidoni's work was based on that of Croco, who in 1907 experimented with marine craft supported by simple monoplane dihedral foils (Figure 8), but had little success in applying them to flying machines. Guidoni's ladder foil system was finally successful in executing the first take-off and landing of a hydrofoil seaplane in 1911. This was because he adopted Croco's dihedral foil feature which avoided the sudden transition from one foil to the other under varying speed conditions.

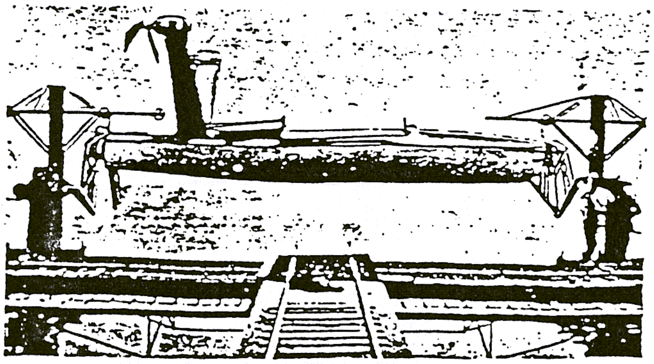

Fig. 8 -A Rendering of CROCO's Hydrofoil (1907)

Alexander Graham Bell

Although we see that the hydrofoil had it beginnings in Italy, probably the inventor who received the most publicity from his early work with hydrofoils was an American living in Canada: Alexander Graham Bell.

Born in Scotland in 1847, Bell went to Canada in his early years and later the United States to pursue his career as a teacher and scientist. On Cape Breton Island he constructed his famous laboratory and workshops described in detail by Arseneau[2]. One building served as Bell's boat building facility; there was another building which served as the home of Canada's first aircraft manufacturing company, the Canadian Aerodrome Company.

According to A. E. Roos[3], Alexander Graham Bell's attention to hydrofoils in 1906 was due, in part, to a report by one of the Meacham brothers in Scientific American. In connection with Bell's work on airplanes, he was concerned with the possibility of taking off and landing on water, which he considered safer than land. His experiments did not get underway until 1908, a year after the Wright brothers had considered a similar solution, as mentioned earlier. Foil sections were developed empirically by Bell's colleagues Frederick W. (Casey) Baldwin and Phillip L. Rhodes, a New York naval architect. Experiments with small scale models and full scale craft continued for about five years but were interrupted by a world tour that Bell and Baldwin undertook in 1911. They visited Forlanini in Italy where they witnessed tests on his 1.6 ton hydrofoil on Lake Maggiore. It is understood that Bell purchased some of Forlanini's patents.

The design that Baldwin produced for this hydrodrome (as Bell's hydrofoils were called) series reflected Bell and Baldwin's view that the vessel was a hybrid, and as such consisted of two distinct parts. One section was for progression through the air, and functioned for all intents and purposes like an aeroplane, with all parts, wherever possible, designed to constitute aerofoils. This included the main hull, as it was only useful for support in the water while at rest and once underway and out of the water should have as low a resistance to air as possible. The other section of the craft was comprised of the foils and these were designed primarily for lifting effectiveness in water and compactness.

During the winter months when inclement weather interfered with the work in Canada, Bell experimented on Biscayne Bay, in Miami, Florida. He did his work out of the Monroe Boatyard located in Cocoanut Grove. Most of this work in Miami was experimenting with models.

Bell's first three hydrodromes, built between 1911 and 1914, actually looked like abbreviated aeroplanes, and their trial runs were described as resembling unsuccessful take-offs from water. The first of the three hydrodromes built prior to the HD-4 was also the fastest of these three, managing 50 mph using a 70 hp Gnome engine as a power plant. The subsequent two hydrodromes, even though they supposedly encompassed improvements ascertained from Bell's and Baldwin's previous work, did not exceed this speed.

Work on the design of the HD-4 was started in 1917. Bell had decided to make this Baldwin's project and did not interfere with Baldwin's design, but gave the latter his full support. Once the proposed vessel had been roughed out on paper, a scale model was produced in 1917 for testing. This model was larger than usual, being 17 feet long and 2-1/2 feet in diameter, since Bell believed that anything smaller would not provide accurate enough data to proceed to a full scale vessel. The results he obtained from this unpowered vessel convinced them to proceed with the construction of the HD-4.

The HD-4, once finished in 1918, had a simple yet imposing appearance. Its main hull was a 60 foot long cigar-shaped cylinder with a maximum diameter of 5.75 feet. On either side of the hull in the cockpit area, which was approximately one third of the way back from the bow, there extended out a sponson to the end of which was attached a 20 foot long pontoon of the same design as the hull. Each sponson served as a base support for an engine bed structure, with the two beds being interconnected with a Phillips blind arrangement above the cockpit. The sponsons also served as the point of attachment for the main foil sets which were located directly below them. There were three foil sets on the HD-4. At the front there was a preventer set, the main purpose of which was to prevent diving and ride clear of the water once the vessel was up on its foils. A second set composed of two banks of foils, one bank under each sponson, functioned as the main load bearing foils and forward two points of the three point support system once the vessel was underway. At the rear of the vessel, just forward of the stern, was a third nest of foils that functioned as the third point of the three point support system, and also as the rudder, for these foils were constructed to pivot on a vertical axis. All foil sets, except for the preventer, were designed so that once underway there would be continuity of lift, or as Bell described it, "continuity of reefing." Bell argued that to obtain continuity of reefing, the foils could not extend horizontally in the lateral direction but had to slope upwards away from the center line of the boat, so that the foils on either side of the boat would form a dihedral angle. In such a system a hydrofoil comes gradually out of the water instead of leaping out like a whale. If successive foils are then so spaced that the lower end of one foil is at the same level as the upper end of the next foil below it, the lift will be continuous as the foils leave the water, or, to use Bell's phrase, continuity of reefing will result.

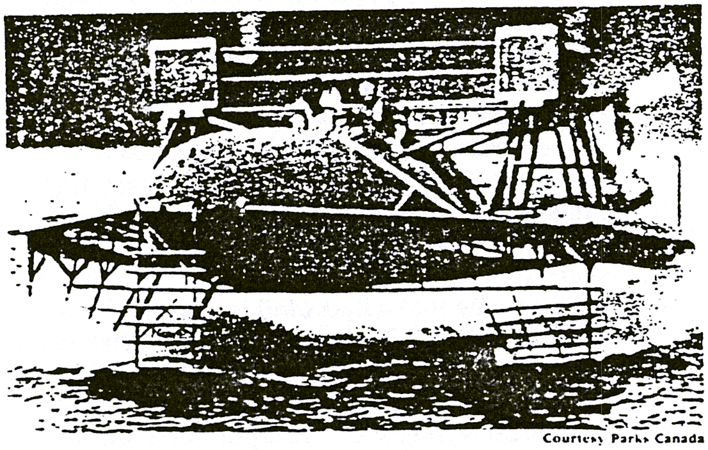
Courtesy Parks Canada

Fig. 9 - Bell-Baldwin HD-4 Hydrofoil on Bras d'Or Lake

The HD-4 had been designed to use two Liberty engines, with air propellers as sources of thrust, that were to be obtained on loan from the U. S. Navy. Unfortunately, these were not available during the war years, and Bell and Baldwin had to settle initially for the loan of a pair of second-hand Renault engines. Even with these engines on board the HD-4 managed to "fly" at 53.7 mph in 1918, once the start-up problems had been solved. A report outlining the results with these engines and a set of line drawings of an HD-4 type of craft were forwarded to the U.S. Navy in 1919. It was hoped that this action would lead to an order from the Navy for a hydrofoil craft, or at the very least, the loan of two Liberty engines for future trials.

One of the pictures of the HD-4, taken to document its design and trials, shows Bell's colleague, Casey Baldwin, at the controls of the HD-4 in 1919 on the Bras d'Or Lake in Nova Scotia, at which time they achieved a world speed record of 61.5 knots; see Figure 9. Notice that there is a set of three airfoils attached above the hull to provide aerodynamic damping to motions in choppy water, an idea which was originally proposed by Forlanini.

Over an extended period from 1918 both Bell and Baldwin made repeated attempts to interest the U.S. Navy Department in their work. It was in this connection that a young Lt. Cdr. Jerome Hunsaker, whom many Aeronautical Engineering students at M.I.T. later knew and admired as Professor Hunsaker, evaluated the HD-4 for the U.S. Navy. It was reported[4] that he said: "Its a very interesting development, but I can see no application to the U.S. Navy". In spite of this comment, the U.S. Navy and its many staunch supporters of this concept, much later proceeded along the long path to bring the hydrofoil to its present state.

Captain Richardson's Dinghy

The U.S. Navy, however did show an interest, although very limited, earlier than the Bell-Baldwin proposals. It was about 1909 that a young "Naval Constructor", Holden C. Richardson, fitted a set of submerged foils to a dinghy - a humble beginning to say the least. Under tow, as can be seen from the photograph, Richardson's dinghy took off and flew at six knots on the Schuylkill River in Philadelphia[5,6]. He was one of the few Naval officers who believed that hydrofoils could be applied to practical seagoing craft during the period when the U.S. Navy had written them off. Captain Richardson's early interest was inspired, in part, by Forlanini; they both were interested in using hydrofoils as landing gear for seaplanes.

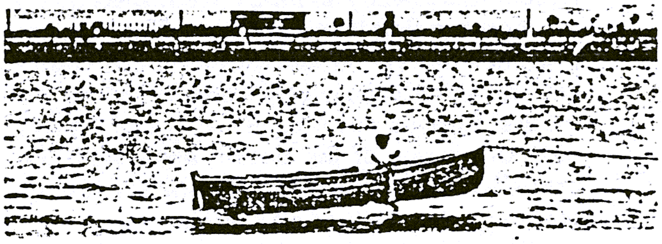

Fig.10 - Captain Richardson's Dinghy (1909)

In Richardson's experiments, his craft was fitted with a set of foils consisting of a fixed ladder foil forward and a controllable foil aft; see Figure 10. The incidence angle and the foil tips could be manually controlled. Roll control, banking into a turn, and maneuverability were achieved by this foil tip control, much in the same way as warping of aircraft wing surfaces was done during that time period. Richardson's efforts in hydrofoil supported craft continued until about 1911. In that year he received a patent for a speed boat powered by twin air propellers with controllable fore and aft fully- submerged foils.

Baron von Schertel

The early years of the hydrofoil story would not be complete without a tribute to the genius, determination, and deep-rooted faith of Baron Hanns von Schertel. The gap in hydrofoil development subsequent to the Bell era was filled by "The Baron", as he was affectionately called, who began to experiment with hydrofoil craft in 1927. Much credit for developing the hydrofoil from an unstable, unreliable, "calm-water-only" craft to today's safe, fast, and efficient mode of water transportation must be accorded to von Schertel.

As was the case of so many of his predecessors, von Schertel started his experimental work obsessed with finding a solution for the problems of the flying boat landing gear. In the period of eight years he tested all foil configurations which appeared promising - both surface piercing and fully submerged. He originally gave preference to the fully-submerged system to get as far away as possible from the disturbing influence of the water surface waves. Von Schertel had hoped that the surface effect would be strong enough to stabilize the foil at a certain immersion depth. In Reference 7, he describes his experiences as follows:

> "The first trial runs at the Berlin lake "Wannsee" with a boat powered by a very obsolete air-cooled aircraft engine and propelled by an air screw, finished catastrophically. The old engine did not provide enough power for take off. When I noticed that the steering control was nearly ineffective I cut off the ignition, but the engine was already so much overheated that it went on running by self ignition. The boat approached more and more the numerous, frantically escaping boats which had gathered around me and I had to count myself very lucky that I did not hit one of the fleeing boats with the propeller. The adventure finished with me crashing into an island on the lake.
>
> This experience taught me to abandon the traffic-endangering airscrew and to use a water propeller for the next experiments. Several crashes with the second craft due to ventilation made it clear that the surface effect stability would not be feasible for sea going hydrofoils. We know that the Russians succeeded later in making use of the surface effect for stabilizing the immersion of foils with a small lift coefficient operating in calm inland waters. They accepted the jerks that occasionally occurred when the foils came too near to the water surface in the wake of passing ships.
>
> For the following two boats I applied a mechanically-operated depth sensor which activated the angle of attack or the deflection of flaps. The foils had been arranged in a canard configuration. With this appliance the experimental boat could fly in good weather, but it had already failed in a slight seaway.
>
> With an improved sixth test boat in which a device was provided to compensate for the lift changes, I had my first success. The boat operated very nicely and attained a speed of 36 knots with less than 30 hp. This was eight years after I started my experimental work. How-ever, it did not yet come up to my expectations under heavier sea conditions and there was no doubt for me that the development of a satisfactory working depth sensing device would require a still longer time. Therefore, it is understandable that I became impatient and wished to find a quick solution. I abandoned the fully-submerged foil system for the seventh test built boat in 1935, in which all acquired experiences had been incorporated. The craft was provided with a V-shaped front and aft-foil with trapezoid outer portions. She performed fully satisfactorily under all-weather conditions on the Rhine River. With only 50 hp she carried seven persons at a speed of nearly 30 knots. This craft proved for the first time that a hydrofoil is a fast and economical means of transportation and that its seaworthiness could no longer be doubted. This attracted representatives of the German Navy, Air Force, Ministry of Transportation and Finance, and finally brought about the partnership of Gotthard Sachsenberg, with his shipbuilding organization."

In 1937, after a demonstration trip from Mainz to Cologne on the Rhine River, the Cologne-Dusseldorf Steamship Co. placed with Gebruder Sachsenberg A.G. at Dessau, the world's first order for a commercial hydrofoil boat.

To be on the safe side, the Schertel-Sachsenberg syndicate decided to build a larger test boat. It was completed at the outbreak of World War II and was later demonstrated to the German Navy. The war however, prevented the fulfillment of the original order[8].

During WW II von Schertel and the shipbuilder Sachsenberg collaborated in the construction of a number of hydrofoil boats for the German Navy. In 1941 they launched the 17-ton VS-6, a mine laying hydrofoil. It was 52.5 feet in length, was powered by two Hispano-Suiza gasoline engines of 1560 hp each and was capable of speeds up to 47 knots.

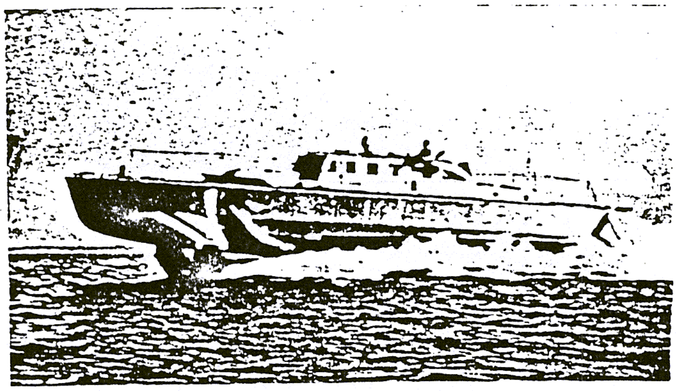

Fig. 11 - The von Schertel-Sachsenberg VS-6 Hydrofoil

In 1943 the 80-ton VS-8 was launched. This relatively large hydrofoil was 150 feet long and was designed to carry tanks and supplies to support Rommel's North African campaign. The VS-8, although originally designed for a top speed of 45 knots, was actually limited to 37 knots. This was because the only engine that could be made available at the time was a Mercedes-Benz diesel with 1800 hp. The underpowered craft was stable in head seas but came off the foils in some tests in following waves. Furthermore, in 1944 it suffered a casualty due to sabotage and was eventually beached.

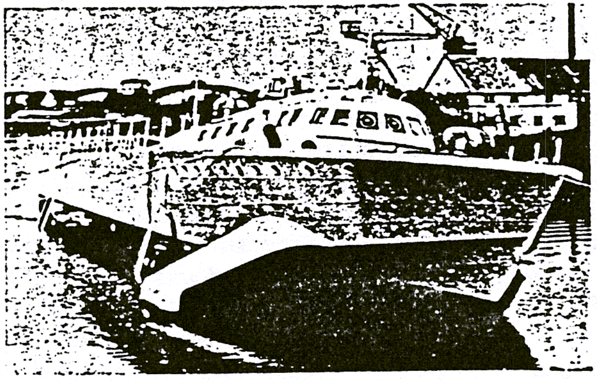

Fig. 12 - The von Schertel-Sachsenberg VS-8 Hydrofoil

Tietjens

Another famous name in the hydrofoil story is that of Professor Oscar Tietjens, who had patented a new type of foil system. Figure 13 shows his surface piercing hoop system which was first tested on a small speed boat at Philadelphia (probably on the Schuylkill River) in 1932. The 500 lb. craft reached a speed of about 25 mph with only a 5 hp motor[1].

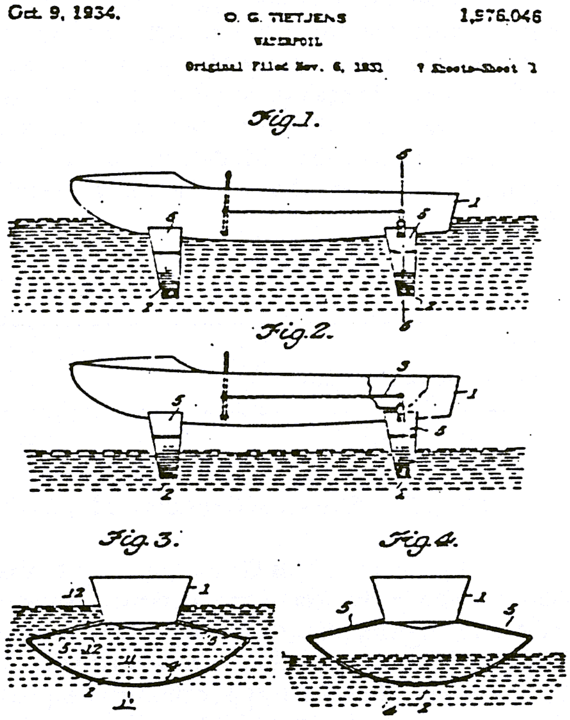

Fig. 13 - Patent Drawing of O. Tietjens' Hoop Foil

Tietjens later returned to Germany where he continued his hydrofoil development work in parallel with von Schertel. The VS-7 hydrofoil, a 17-ton craft with a hoop foil system, was built in Schleswig, Germany, at the Vertens Shipyard. The VS-7 was built to the same displacement and had the same power as von Schertel's VS-6. The two boats were placed in competition under the auspices of the German Armed Forces. Although the VS-7 attained a speed of about 50 knots compared to the 47 knots of von Schertel's VS-6, the stability and maneuverability of Tietjen's hydrofoil was much poorer than that of the VS-6, and had difficulty with take-off.[8]

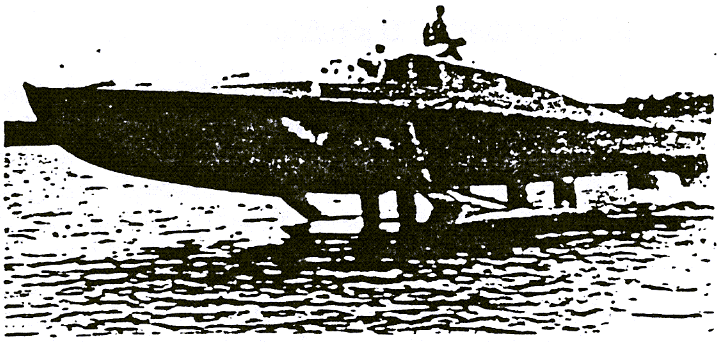

Fig. 14 - Tietjens VS-7 Hydrofoil

Grunberg

Wsevolode Grunberg, a Russian National residing in France, conceived a submerged foil system which had a single main lifting foil with forward floats or surface riders. These planing floats adjusted the angle of attack of the main foil, controlled foil submergence, and provided roll stability. Models of this craft, shown in Figure 15, were tested in the Saint-Cyr model basin in France.

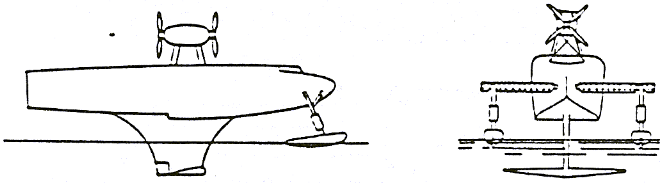

Fig. 15 - A Sketch of Grunberg's Hydrofoil

In the late 1930s Grunberg came to the United States at the invitation of the National Advisory Committee for Aeronautics (NACA) to demonstrate his hydrofoil design principle.[5] NACA was actually interested in Grunberg's ideas for application to seaplanes. Mr. Grunberg worked with NACA as a French citizen providing the necessary information so that a model could be built and tested at Langley, VA.

As one of the ironies of wartime security, classification of the project prevented Grunberg, a foreign citizen, from seeing the results of the model tests. Grunberg left the U.S. and reentered as an immigrant, changed his name, and became a U.S. citizen. He has been honored as Waldemar Craig, a life member of the International Hydrofoil Society of the North American Association. It wasn't until years after World War II, when all interest in hydrofoil landing gear for seaplanes had ceased, that Mr. Craig found out how really successful the NACA model tests had been.

PROGRESS AFTER WW II

U. S. Experimental Hydrofoils

At the conclusion of World War II, several spirited, inventive individuals pursued the concept of hydrofoil supported craft. At the same time some of the German mine-laying hydrofoils were brought to England for experimental purposes. William P. Carl and Robert Gilruth, who during the war years, had met on assignment to NACA, conducted experiments on foil design and built a hydrofoil supported sail boat. Christopher Hook started building small scale submerged foil boats using surface feelers as stabilizing devices. The Canadian Navy began experimenting with a ladder type foil system on the MASSAWIPPI R-100, see Figure 16. The U. S. Navy's position remained that they could see no useful mission for these craft.

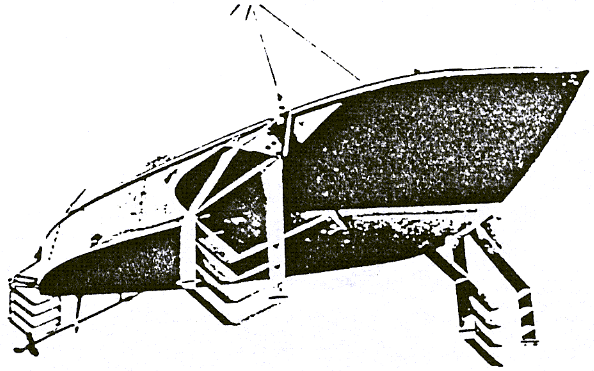

Fig. 16 - MASSAWIPPI R-100

The first change in this attitude came from the U.S. Navy's Bureau of Aeronautics. Seaplanes in the late 1940s and early 1950s were still of naval interest and effort was placed on improving the rough water take-off and landing characteristics. Hydrofoils, based on their past history of use on aircraft, became a candidate for investigation. At about this same time, Dr. Vannevar Bush became the scientific advisor to the President of the United States. Dr. Bush was concerned with the transportation of war supplies to overseas destinations in case of the break out of hostilities. With the success of World War II submarines in disrupting sea shipments, he became interested in high speed surface ships as cargo carriers. Based on some erroneous data regarding potential foil lift and drag, he concluded that the hydrofoil was a possible contender for this mission. Dr. Bush proposed, supported, and received government finances for a 3000 ton, destroyer type hydrofoil. With this impetus, the U. S. Navy reluctantly instigated a program of hydrofoil development. The program was conducted out of the Office of Naval Research and was supported by the Bureau of Ships and the Bureau of Aeronautics.

The non-governmental organizations selected to pursue the large, fast ocean transport consisted of Bath Iron Works as the potential builder, Gibbs and Cox as the designers, and the Hydrofoil Corporation of America as the basic research organization. The Hydrofoil Corporation of America was formed by Dr. Bush in Annapolis, Maryland. Bath Iron Works never became very active in the effort, but the first test craft designed and tested by Gibbs and Cox was designated BIW, see Figure 17. This craft used submerged foils which could be positioned at different locations on the hull. It was the first craft to employ an electronic Automatic Control System (ACS) with forward struts holding step resistance measuring devices for height control.

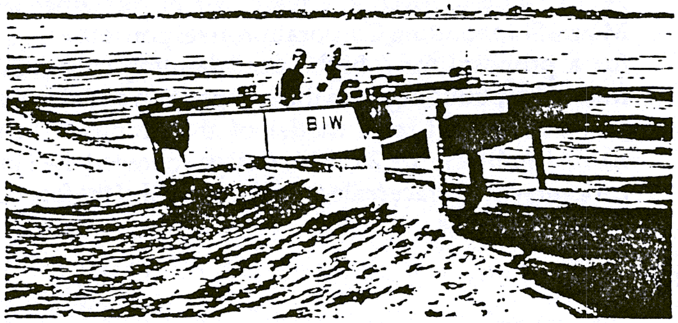

Fig. 17 - The BIW Hydrofoil

The Hydrofoil Corporation of America also built a test draft named the Lantern HC-4, see Figure 18. This craft used submerged, incidence controlled foils with a modified Sperry aircraft autopilot for the ACS. As can be seen from Figure 18, the hull, struts and foils all used the same symmetrical foil section.

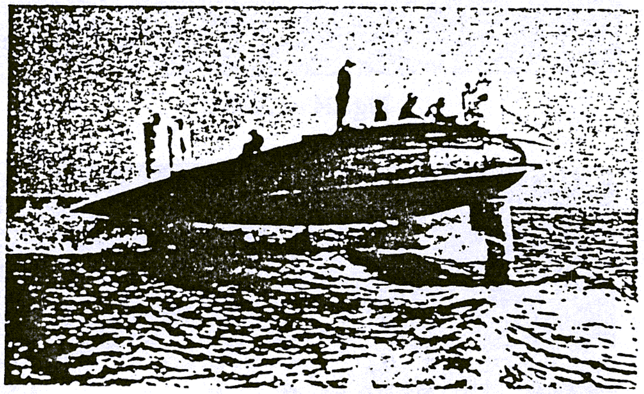

Fig. 18 - LANTERN HC-4

William Carl, working within his family's company, John H. Carl and Sons, was the prime support for the Bureau of Aeronautics. He was joined by Robert Gilruth and Professor Ken Davidson in this effort. As such, experimental devices and models were built and utilized to provide the basis for the design and construction of the XCH-4, see Figure 19. In 1954 this craft attained a speed of 78 knots. But by now the interest in Navy seaplanes was waning. Bill Carl formed his own company, Dynamic Developments, Inc. and began the pursuit of commercial vehicles. The first vehicle was a sport boat which could be purchased in kit form or a complete runabout. This led to the development, design, and construction of the first ocean going hydrofoil for the Maritime Administration named the DENISON, see Figure 20. On this project the Grumman Corporation acquired part interest in Dynamic Developments to pursue their interest in hydrofoils and to support the DENISON project. After the successful trial of DENISON, Grumman acquired all of Dynamic Developments and molded the organization into the parent company. This was the beginning of Grumman's involvement in designing and constructing hydrofoils.

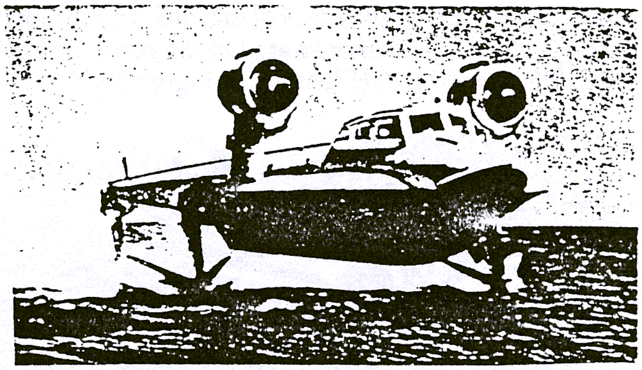

Fig. 19 - XCH - 4

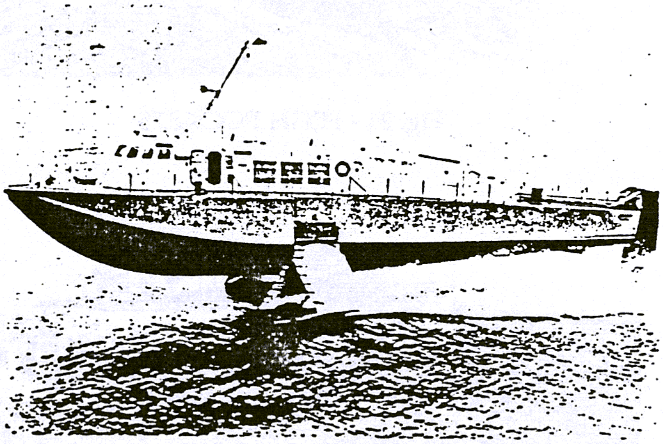

Fig. 20 - DENISON

Another early developer in the U. S. hydrofoil program was Gordon Baker, a mathematician and designer of mechanical computers of some renown. He became president of his family's company, Baker Manufacturing Company, a supplier of farm water systems. To keep his technical skills active, he became involved in the design of hydrofoils. His first designs were small runabouts using self stabilizing, surface piercing, V-foils. His success with these craft led to the design, construction and test for the U. S. Navy of HIGH POCKETS see Figure 21. HIGH POCKETS used the same V-foils as the smaller commercial versions with the addition of a helm driven device that changed the inboard and outboard angles of attack to provide banking in turns. This drive made the craft highly maneuverable. HIGH TAIL, shown on Figure 22 was another test craft built for the Navy to evaluate a mechanical computer for controlling foils. HIGH TAIL used three V-foils, one forward and two aft in an airplane configuration. Improved ride quality was obtained by using inputs from surface riding feelers. A single ahead feeler, the anticipator, and two, one port and one starboard, trailing feelers, the regretors, were used as sensors. The output of these sensors was fed to the mechanical computer which controlled the angle of attack of the foils. The summation of this effort was demonstrated in the construction of a LCVPH named HIGH LANDER, Figure 23.

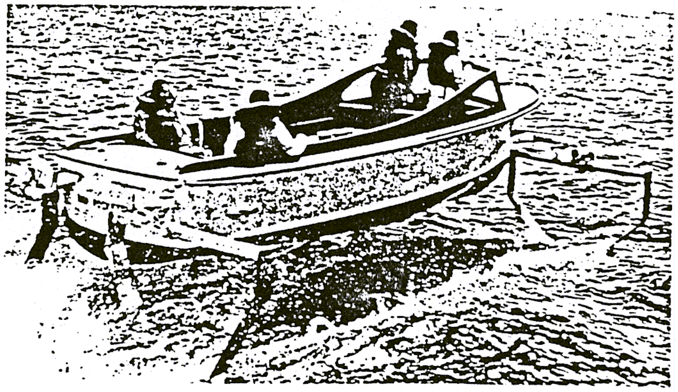

Fig. 21 - HIGH POCKETS

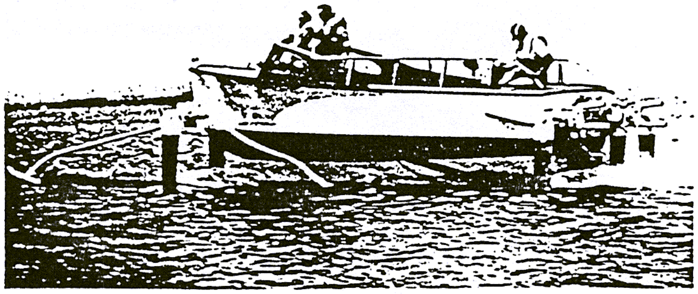

Fig. 22 - HIGH TAIL

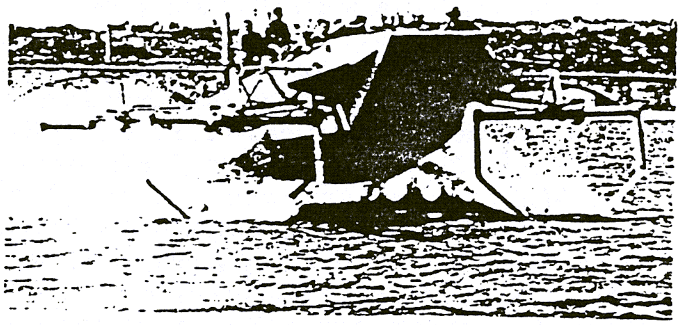

Fig. 23 - HIGH LANDER

Christopher Hook brought his small runabout, ICARUS, equipped with submerged foils controlled by the use of surface feelers, to the United States; see Figure 24. Using the ICARUS as a model, Mr. Hook teamed with Miami Shipbuilding Corporation in response to a request for a proposal for a high speed landing craft LCVP. Miami Shipbuilding won the competition and designed and built a half-scale model of the proposed LCVP named $\partial\alpha/\partial t$, Figure 25. This design followed the Hook concept with surface feelers for the control of the forward. submerged foils.

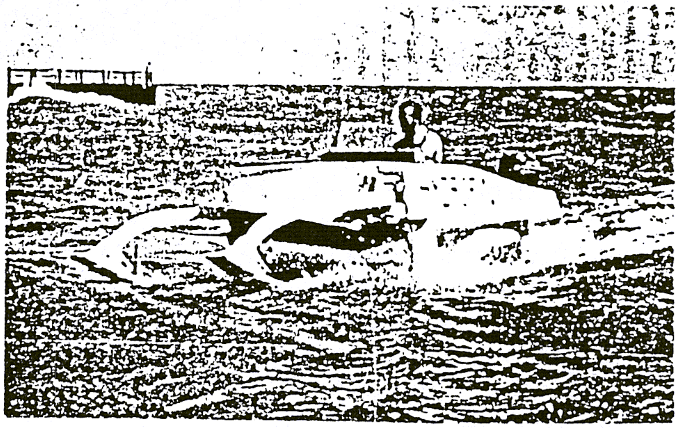

Fig. 24 - ICARUS

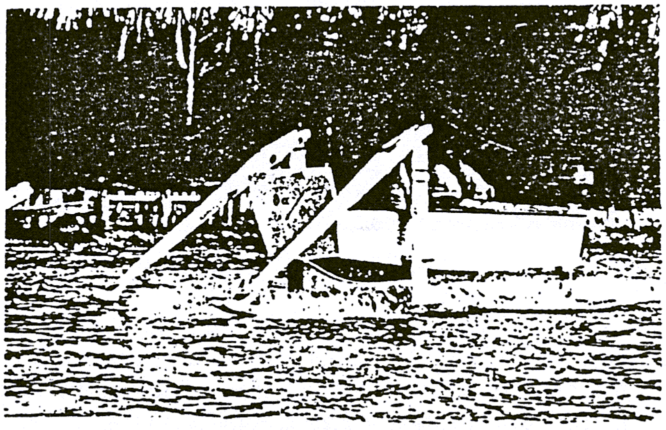

Fig. 25 - LCVP $\partial\alpha/\partial t$)

With $\partial\alpha/\partial t$ proving the concept, the Navy gave the go-ahead to proceed with a full scale, foil supported LCVP. The result of this effort was the construction of HALOBATES LCVP(H). Figure 26 shows HALOBATES with surface feelers which became quite large and ungainly in the full scale version. This was recognized early in the design process and an automatic control system(ACS) development was started with the objective of replacing the feelers after test data was available from the full scale trials with the feelers. Accordingly the ACS was completed and replaced the feelers to produce a more feasible landing craft. This configuration is shown in Figure 27. At the same time as the installation of the ACS the Hall Scott gasoline engine was replaced with a Navy supplied gas turbine. This was the first gas turbine installation in a U. S. Navy vehicle.

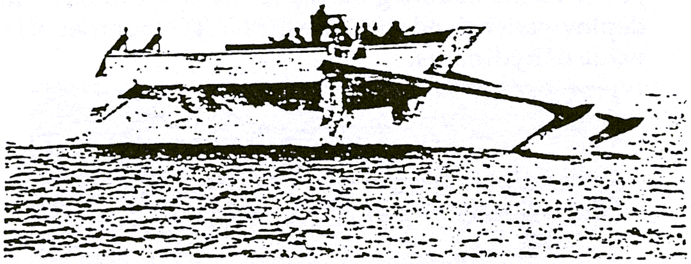

Fig. 26 - HALOBATES With Surface Feelers

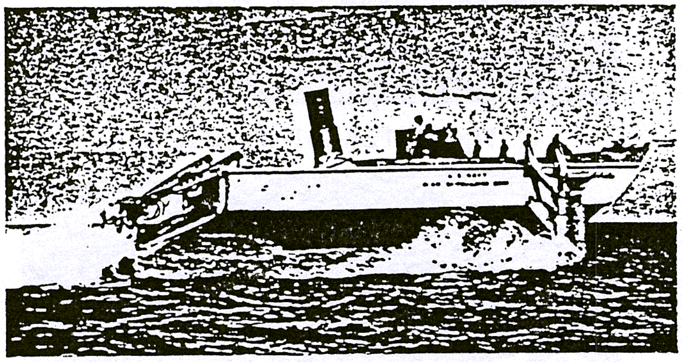

Fig. 27 - HALOBATES Without Surface Feelers

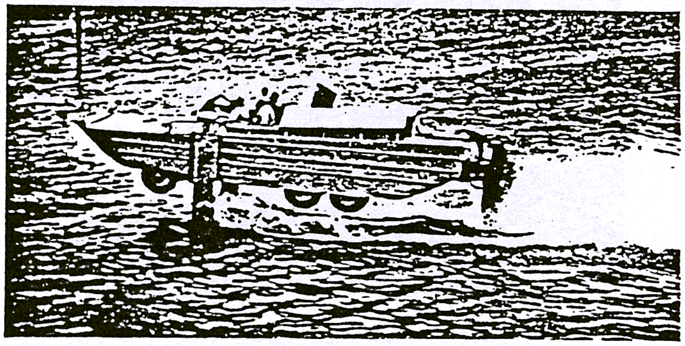

Fig. 28 - Flying DUKW

The U. S. Army, watching the success of the Navy's LCVP(H) program, became interested in increasing the water speed of their amphibian, the DUKW. Under contract with the U. S, Army Ordnance Corp, a DUKW was fitted with foils, a Miami Shipbuilding ACS and a gas turbine. The design and conversion was done by Miami Shipbuilding. The vehicle was named the FLYING DUKW, Figure 28. The result was an increase of water speed from 5 knots to over 30 knots. Trials of the vehicle were conducted in the Miami area. Several minor automobile incidents occurred on the causeway paralleling Government Cut as the drivers became excited upon seeing this wheeled amphibian flying in and out of the Port of Miami. Follow on flying amphibians were built for the U.S. Marine Corp by Lycoming and Food Machinery Corporation.

U. S. NAVY PATROL HYDROFOILS

After the learning experience that Gibbs and Cox had with the afore-mentioned BIW test craft including a rudimentary ACS, they undertook the design of a more sophisticated test craft for the U. S. Navy. This craft was a modified Chris-Craft hull fitted with fully submerged foils in a canard arrangement. The Draper Lab of MIT developed the ACS using a sonic height sensor. This craft was completed in 1957 and named SEA LEGS, Figure 29. SEA LEGS was moved by a sea voyage from New York to Annapolis. On this trip it continually out ran an accompanying PT boat. From Annapolis the hydrofoil was brought to Washington, D.C. and there demonstrated to senior naval officers. These events finally convinced the Navy that the hydrofoil had a practical mission as a patrol vessel.

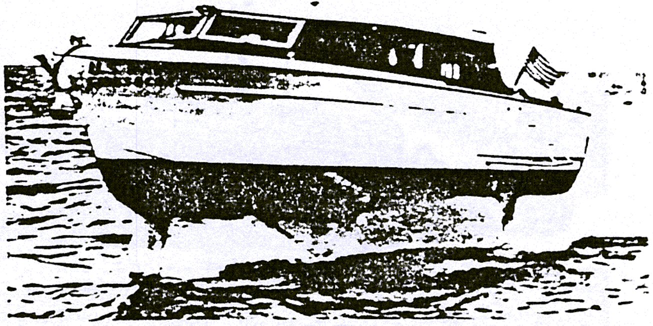

Fig. 29 - SEA LEGS

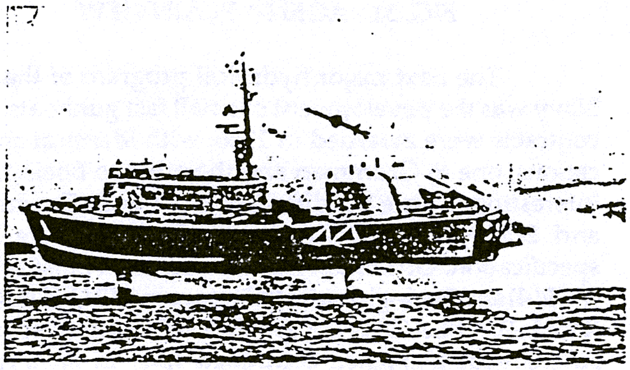

Fig. 30 - HIGH POINT (PCH-1)

In late 1957 the Bureau of Ships started a design study based on the mission of a patrol craft with ASW capabilities. This was the beginning of what was to be named HIGH POINT (PCH-1), Figure 30. The detailed story of this craft from concept to retirement after 21 years of service is completely and excellently related in reference (8).

After the contract design of PCH was completed, the Navy turned its attention to a larger and faster ocean going hydrofoil. The ship was to be initially capable of 50 knots with the designed capability to be converted to a 90 knot vessel. Grumman was awarded the design contract with an option to build and test the ship. Grumman was supported by Newport News as the hull builder and outfitter and General Electric as the supplier of the propulsion system. The contract design and specifications were accepted by the Navy in 1962 with the ship being designated AGEH-1. The Grumman estimate to build and test exceeded the Navy's budget and the design was put out to bid. Puget Sound Bridge and Drydock Co. won the competition and was awarded the contract to build in 1963. After many problems, delays and increases in cost, the Navy took delivery in 1969. The ship was named PLAINVIEW (AGEH 1), see Figure 31. A more detailed story of the trials, successes and tribulations of PLAINVIEW is contained in Reference (9).

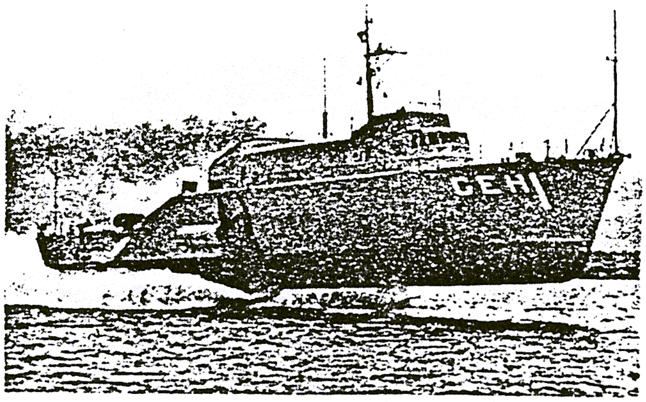

FIG. 31 - AGEH-1 PLAINVIEW

The next major hydrofoil program of the U. S. Navy was the development of small fast gunboats. Two contracts were awarded in 1966, with identical specifications, one to Grumman and the other to Boeing. It is interesting to note the differences between Grumman's and Boeing's designs although both met the same specification. Grumman's craft was named FLAGSTAFF (PGH-1) and Boeing's hydrofoil was named TUCUMCARI (PGH-2). FLAGSTAFF (Figure 32) employed three submerged, incidence controlled foils in an airplane arrangement. TUCUMCARI (Figure 33) also had three submerged foils but with flap control and in a Canard arrangement. TUCUMCARI was waterjet propelled and FLAGSTAFF was geared and propeller driven. After Stateside trials and evaluation both hydrofoils were deployed to combat in Vietnam, After Vietnam FLAGSTAFF and TUCUMCARI returned Stateside. FLAGSTAFF was assigned for further trials and tests including foil resistance to underwater shock from explosions and the capability of firing a large gun from the foredeck. In the meantime TUCUMCARI was sent to tour NATO nations demonstrating the capability of hydrofoils. This deployment helped convince the NATO countries of the value of hydrofoils.

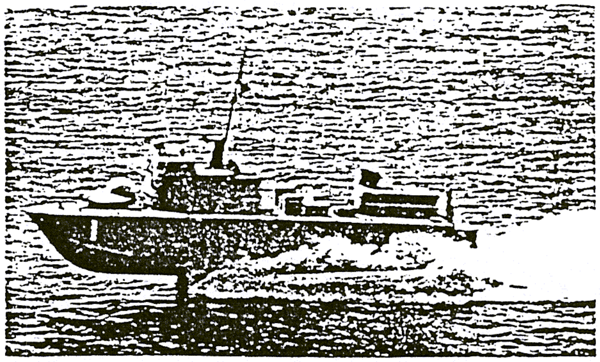

Fig. 32 - FLAGSTAFF (PGH-1)

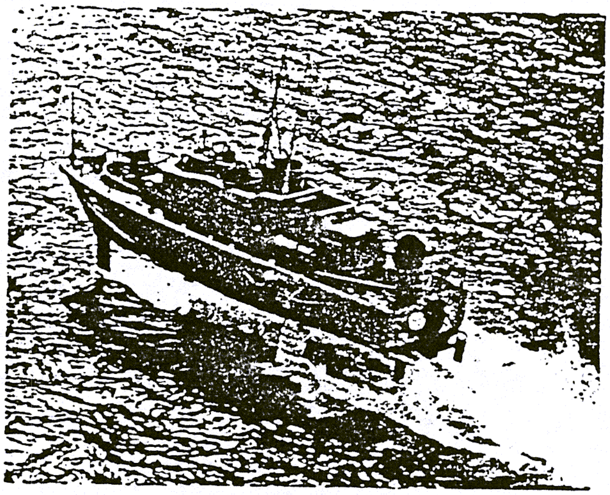

Fig. 33 - TUCUMCARI (PGH-2)

Following this experience with the two gunboats, the U. S. Navy entered into a NATO program to build larger, missile carrying hydrofoils. This was the PHM program. In 1973 a contract was awarded to Boeing to design and build two PHMs. Germany and Italy were cooperating and funding partners in this NATO venture, but dropped out after the design phase. The first ship of the PHM class was delivered to the Navy after completion of operational evaluation in 1977 and was named PEGASUS (PHM-1), Figure 34. Many features of the PHM are similar to TUCUMCARI including waterjet propulsion, Canard configured foils controlled by flaps and forward strut steering. However instead of two after foils with over-the-side retraction, a full span, over-the-stern retraction is used. Six of the PHM's now form a squadron based in Key West, Florida. They have proven to be quite successful in drug interdiction missions.

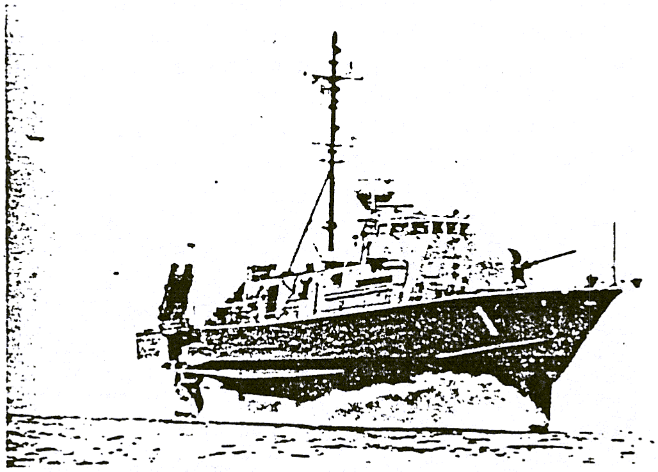

Fig. 34 - USS PEGASUS (PHM-1)

FOREIGN MILITARY HYDROFOILS

From the early interest in hydrofoils in the USA, the Canadian Navy has cooperated fully and effectively in the development of the U.S. Navy's hydrofoil program. Results from the previously mentioned MASSAWIPPI trials as well as laboratory data were shared with the U.S. The culmination of the Canadian effort was the construction and test of the BRAS D'OR FHE-400, see Figure 35. This ship used surface piercing foils and was designed for an ASW mission. BRAS D'OR achieved speeds in excess of 60 knots.

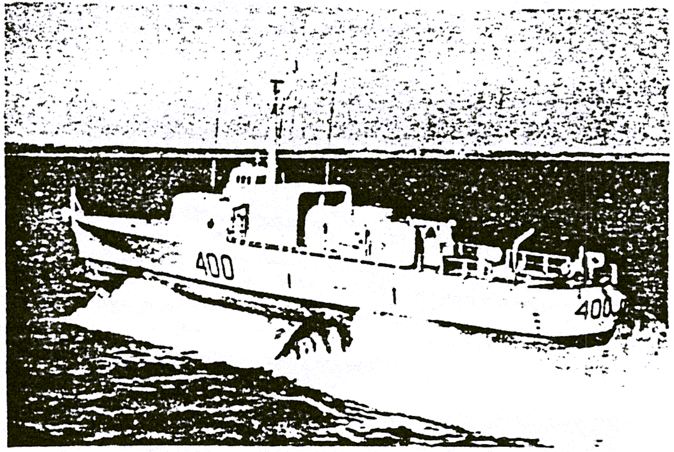

Fig. 35 - BRAS D'OR FHE-400

Italy's military interest in hydrofoils resulted in the construction and deployment of the NIBBIO class missile-carrying gunboats. There are six ships in this class all commissioned in the 1981 to 1983 time frame. The design of these hydrofoils is a derivation of Boeing's TUCUMCARI but with greater payload. These ships carry OTOMAT missiles and a 76 OTO Malara gun, see Figure 36. More details of this class of hydrofoils are contained in reference (10).

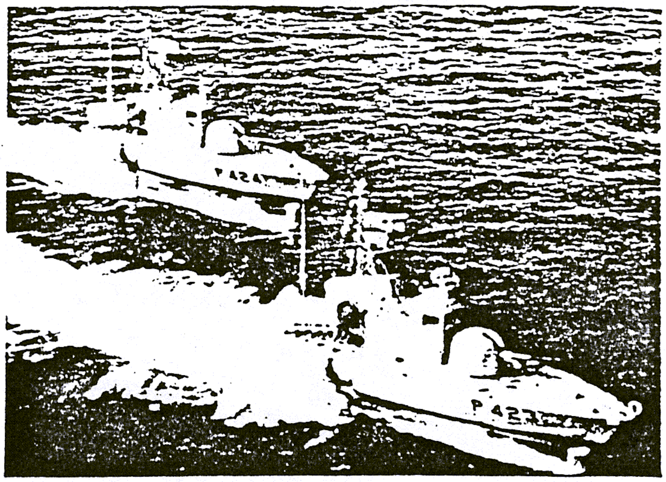

Fig. 36 - Two of the NIBBIO ClassHydrofoils

Israel has three missile carrying hydrofoils in their Navy. The design and construction of the first of these ships was undertaken by Grumman. The design of this class is based on the U. S. Navy's FLAGSTAFF. The first ship of this class was built by Grumman in the United States in Lantana, Florida and was named SHIMRIT (Figure 37). The other two hydrofoils of this class, LIVNIK and SNAPRIT, were built at the Israeli Shipyards, Inc. in Haifa. This class of hydrofoils is noted by the radome which is an indication of the high tech nature of the ships.

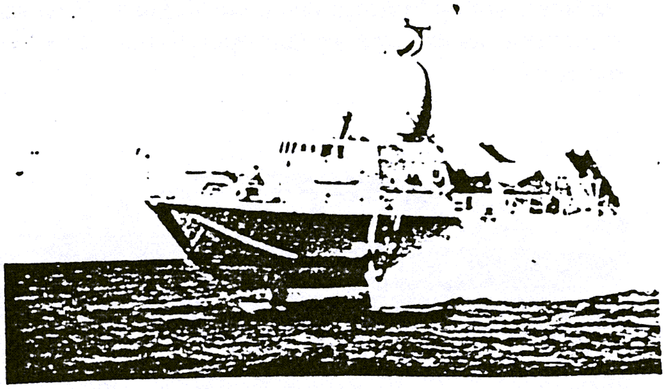

Fig. 37 - SHIMRIT

In 1979 The British Navy purchased a modified JETFOIL from Boeing and named the ship HMS SPEEDY (Figure 38). As can be seen from the figure the superstructure was modified considerably. However the fundamental elements of the craft in terms of propulsion system, foils and ACS were essentially the same as JETFOIL. One exception is that two GM Diesels were installed to drive directly into the foilborne propulsion gearboxes and in turn the waterjets. This provided more economical, low speed, hullborne operations. Fisheries protection was the major role in which SPEEDY was evaluated, although evaluation of other mission applications were made.

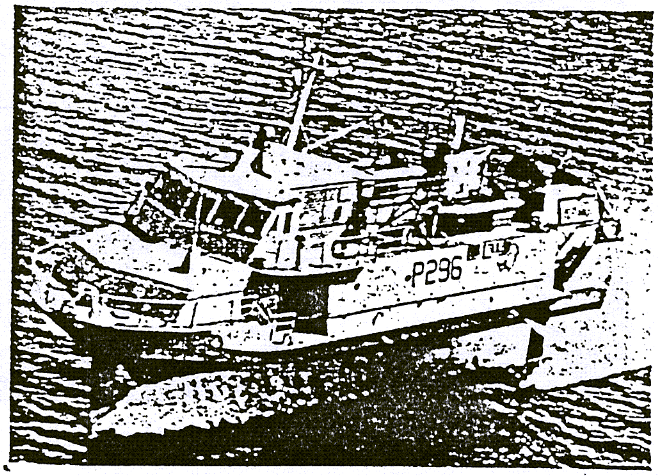

Fig. 38 - HMS SPEEDY

COMMERCIAL HYDROFOILS

In the late 1940s Baron von Schertel assembled in Zurich, Switzerland several members of the German team that had designed and built the German Navy's World War II hydrofoils. In 1952, with this team he organized a design company named Supramar to develop commercial hydrofoils. Their first vehicle was designated PT-10 and was named FRECCIA D'ORO (Figure 39). That same year Supramar introduced this 32 passenger, surface piercing hydrofoil on Lake Magiore. This craft is recognized as the world's first operational, commercial hydrofoil.

Fig. 39- FRECCIA D'ORO (PT-10)

The PT-10 was followed by the PT-20 design, a 72 passenger hydrofoil. The Leopoldo Rodriquez Shipyard in Messina, Italy, headed by Carlo Rodriquez, entered into a license agreement to build this craft. The shipyard built the craft and introduced it on the Straits of Messina in 1955. This PT-20 was named the FRECCIA del SOLE (Figure 40), and it continued to operate across the Straits until 1990. In the meantime Supramar continued to develop larger designs and to license other companies to build them in several different countries. The PT-50 (Figure 41) was one of the most popular and the PT-150 (Figure 42) was the largest they developed.

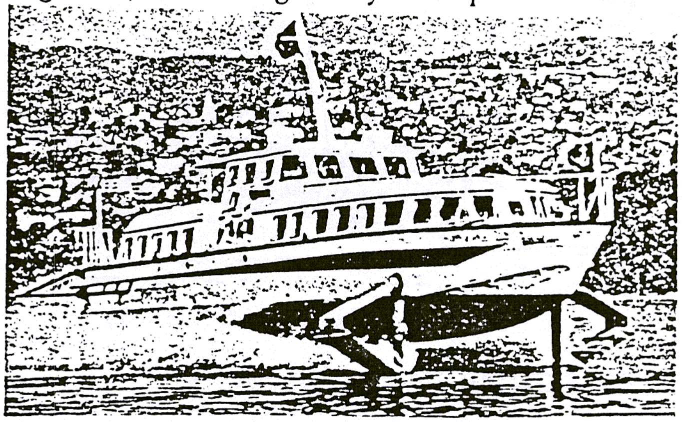

Fig. 40 - FRECCIA Del SOLE (PT-20)

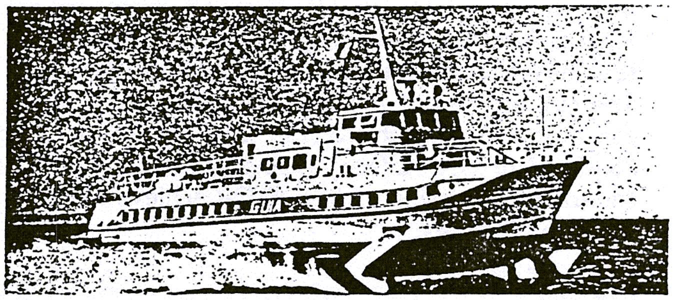

Fig. 41 - PT-50

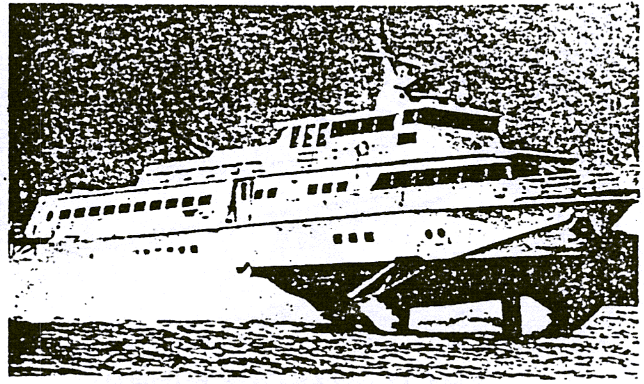

Fig. 42 - PT-150

Rodriquez continued to build under the Supramar license up to 1971. At which time the Rodriquez staff had developed their own design and started to build these designated by the letters RHS. The series of Rodriquez hydrofoils include the RHS 70-100-140-160 and the largest, the RHS-200 (Figure 43). All of these had variations depending upon the customers requirements. Of all of these the RHS-160, Figure 44 has been the most popular. The shipyard changed its name to Rodriquez Cantieri Navali SpA and can now point to over 200 of hydrofoils delivered and operated throughout the world. A good evaluation of the RHS-200 can be found in reference (11).

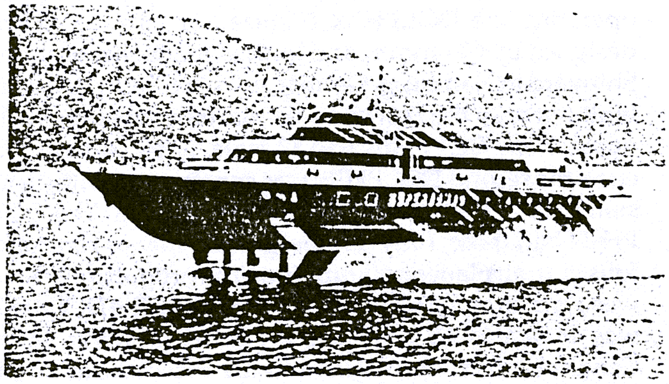
Fig. 43 - RHS-200

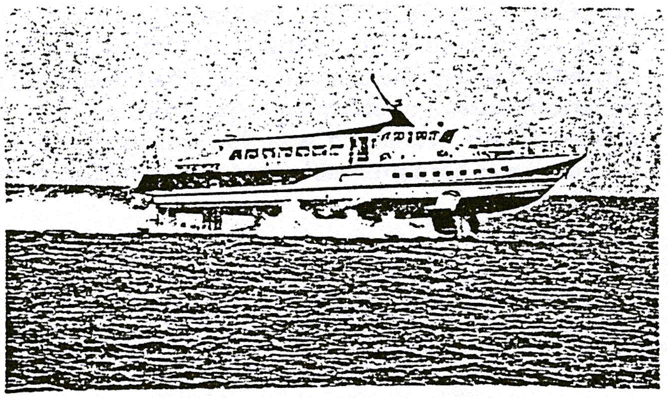
Fig. 44 - RHS-160

Russia has also been a producer and user of hydrofoil passenger vessels. Until recently little has been known about the scope of the Russian effort. However they did export several vehicles which operate in various locations throughout the world. The RAKETA (Figure 45), was the first of the Russian hydrofoils to be exported. This craft is a surface piercing hydrofoil using shallow draft foils that depend upon the loss of lift as a foil approaches the water surface to help stabilize it. The RAKETA is primarily designed for calm water operations such as in rivers or sheltered lakes. The KOMETA (Figure 46) is larger hydrofoil based on the RAKETA design with the addition of a midship foil to improve rough water performance. The latest export model is the CYCLONE (Figure 47), which is a larger version of the KOMETA using waterjets for propulsion.


Fig. 45 - RAKETA

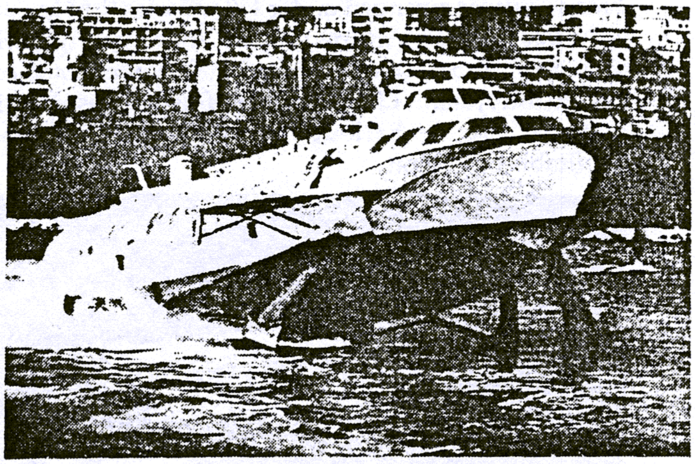
Fig. 46 - KOMETA

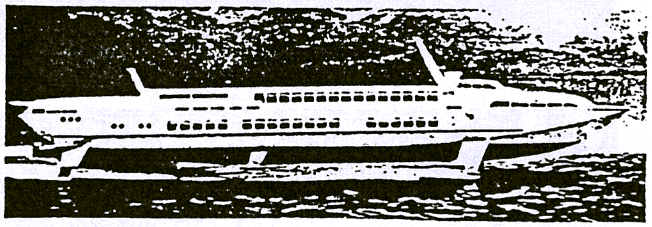
Fig. 47 - CYCLONE

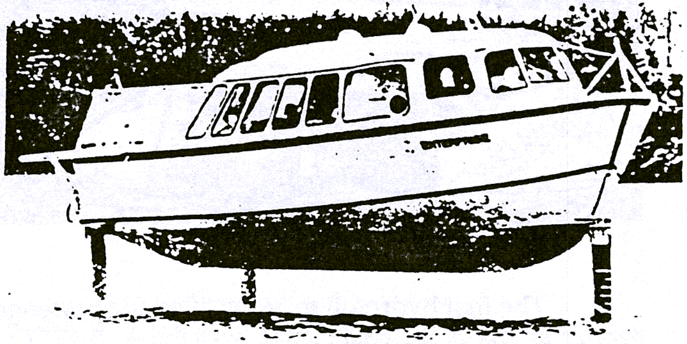
Fig. 48 - ENTERPRISE

In the United stated one of the first passenger hydrofoils to be certified by the U. S. Coast Guard was the ENTERPRISE, (Figure 48). This submerged-foil vehicle was designed by Marine Systems Corporation of Miami, Florida and built by Sewart Seacraft of Morgan City, Louisiana with final assembly taking place in Miami. The craft was designed to run between Wall Street, Manhattan and Atlantic Highlands carrying 27 passengers. ENTERPRISE operated on this route and in the Chicago area on Lake Michigan.

In 1965 a hydrofoil named the VICTORIA (Figure 49) was placed in service between downtown Victoria, British Columbia and Seattle, Washington. The VICTORIA was designed by Gibbs and Cox and constructed by Maryland Shipbuilding and Drydock Co. Financing was arranged under Title XI with the Maritime Administration. Victoria had a Canard configuration with fully submerged, non-retractable, incidence controlled foil system. Like most one-of-kind transportation systems, with no back-up, the VICTORIA was not a profitable operation.

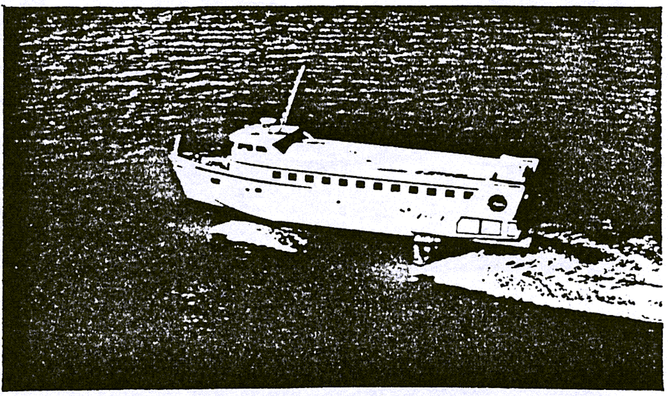

Fig. 49 - VICTORIA

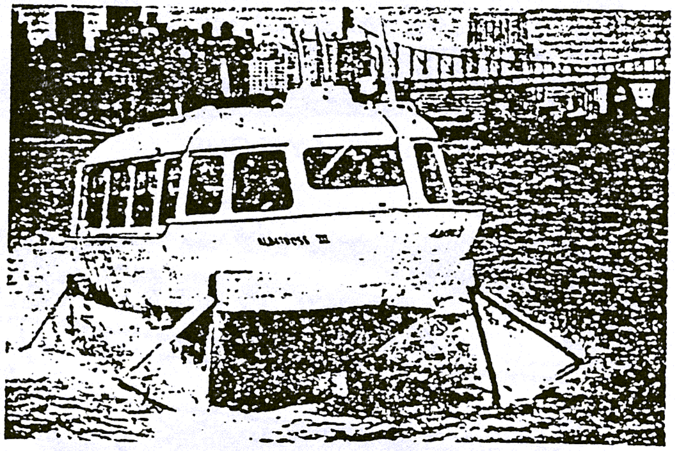

Fig. 50 - ALBATROSS

The first hydrofoil to be certified for passenger service by the U. S. Coast Guard, was the ALBATROSS (Figure 50). The designer was Helmut Koch who placed the first unit in service between Newport Beach and Catalina Island in California. The ALBATROSS carried 28 passengers and was later built in series to transport people to the 1964 New York World Fair. The route was from downtown Manhattan to the World's Fair Marina in Flushing Bay. Twenty of these craft were eventually built and operated in various locations in the U.S. and overseas.

In the late 1960s Grumman evaluated the potential market for commercial hydrofoils by building and operating the DOLPHIN (Figure 51). This craft was designed by Grumman and built at the Blohm and Voss Shipyard in Hamburg, Germany. Two DOLPHINS were built but only the first one was placed in operation. The number one DOLPHIN had 88 seats. After some experience, the second DOLPHIN was constructed with provision for 110 seats, but was never completed. The DOLPHIN had three, fully-submerged, incidence controlled foils in an airplane configuration. The propulsion system was a gas turbine, geared, propeller drive. The DOLPHIN was evaluated in Hamburg on the Elbe, River, in the Canary Islands, from Miami to the Bahamas, in Puerto Rico, and in the U. S. Virgin Islands. For the operation out of Miami, the DOLPHIN was granted a waiver to the Jones Act, was certified by the U. S. Coast Guard and carried a US flag. The original design had been built to American Bureau of Shipping requirements. The conclusion of this evaluation was that this type and size hydrofoil was not a profitable venture for the Grumman Corporation.

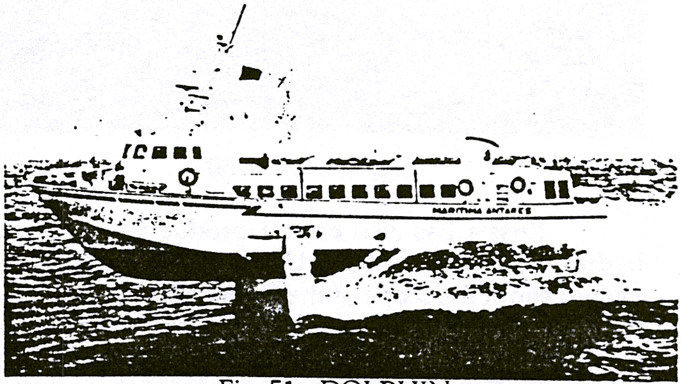

Fig. 51 - DOLPHIN

The most ambitious undertaking in the US commercial market was made by Boeing when they designed, built and marketed the JETFOIL (Figure 52). This passenger hydrofoil with seating variants from 200 to 300 passengers is canard configured, with flap controlled submerged hydrofoils. Two gas turbines driving a waterjet provide the propulsion. This craft has proven to be one of the best high speed waterborne vehicles from the viewpoint of speed and ride quality in rough water.

Boeing produced 28 JETFOILs before discontinuing U.S production. The JETFOIL is now built and marketed under Boeing license to Kawasaki of Japan.

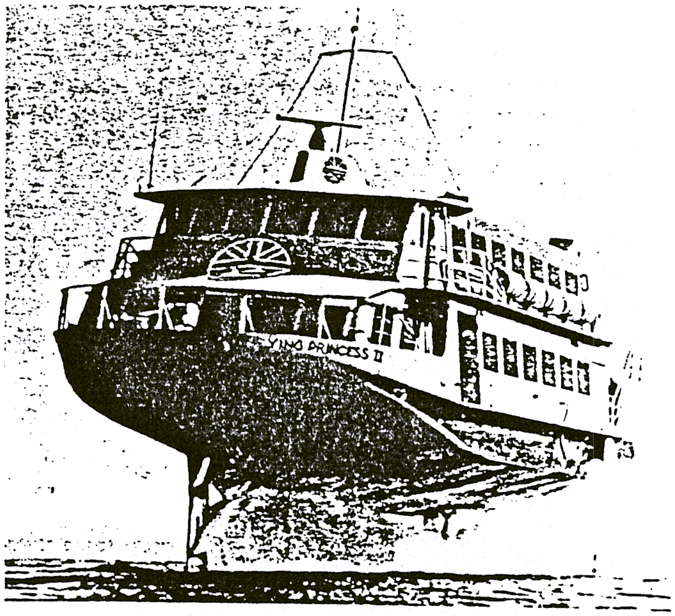

Fig. 52 - JETFOIL

Limited space in this paper does not afford us the luxury of describing many other U.S. Navy hydrofoil feasibility designs and the more recent commercial hydrofoils employing catamaran hulls. However, these and Rodriquez designs employing fully-submerged foils and hydraulic transmissions are treated in Reference 12.

THE HYBRID HYDROFOIL CONCEPT

Investigations of Hybrid Surface Ship forms were started at the David Taylor Research Center (DTRC) in the 1970s under the Hybrid Marine Interface Vehicles Program. One objective of this program was to explore the advantages to be realized through conceptual hybrid surface ship platforms. The U.S. Navy studies were oriented toward military applications. These included a full range of missions utilizing various size ships from small patrol craft to 4,000 ton frigates. This work has been well documented in the literature; the latest paper being one presented at the High Performance Marine Vehicle Conference in June 1992.[13]

Compared to the conventional mono-hull, and even the hydrofoil, air cushion vehicle, surface effect ship, and small water-plane area twin hull (SWATH) "advanced vehicle" forms, Hybrid Ship concepts are relatively new. A vehicle having more than one source of sustention (or lift) simultaneously over a major portion of its operational speed envelope has been referred to as a "Hybrid Marine Interface Vehicle". Because of its advantages, the Hybrid Hydrofoil, and its forerunners, Hydrofoil Small Waterplane Area Ship (HYSWAS) and the Extended Performance Hydrofoil (EPH) concepts, have received considerable attention by the U.S. Navy, and to a lesser degree, the U.S. Coast Guard.

A Hybrid Hydrofoil consists of a conventional monohull form with the addition of a long, slender, single strut and lower body added to its keel. The lower body buoyant lift is augmented by the dynamic lift from a fully-submerged foil system. Foil dynamic lift comes into play at speeds of about 12 to 15 knots and above, at which time the upper hull is lifted from the water surface leaving only the small waterplane of the single strut at the interface. The foil automatic control system maintains pre-determined flying height and provides a stable platform in waves. The foil surfaces are sufficiently powerful to counter roll, pitch and heave motions that would be imparted to a conventional monohull in waves. Propulsion of a Hybrid Hydrofoil is provided by one or more prime movers in the upper hull, either driving through a mechanical Z-drive, or an electric transmission system, to one or more propellers on the stern of the lower hull. An alternate arrangement is to place the entire propulsion system in the lower hull, thereby eliminating a Z-drive requirement.

Hybrid Hydrofoil Applications

The investigations of Hydrofoil Small Waterplane Area Ship (HYSWAS) were aimed at designing a two thousand ton ship with seventy percent of the weight supported by buoyancy and thirty percent by its foils, see Figure 53. Since the HYSWAS was a cross between a fully-submerged hydrofoil and a demi-SWATH (Small Waterplane Area Twin Hull) ship, analytical investigations were largely a product of the technologies of the two parent designs.

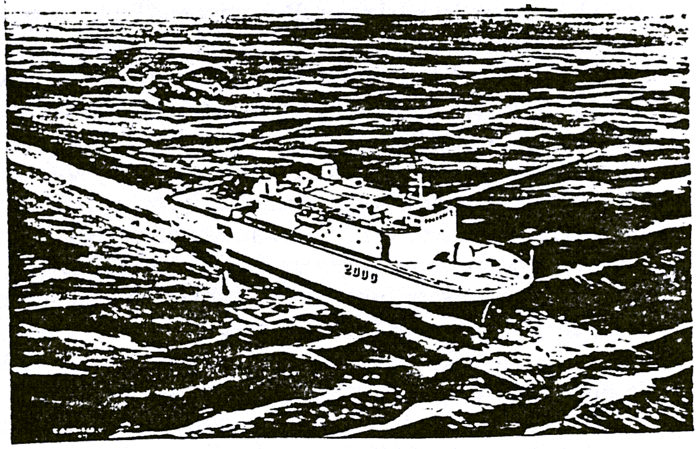

Fig. 53 - 2000 Ton HYSWAS

Results showed the potential for maximum speeds greater than 40 knots, a 4000 mile range at 20 knots, and favorable hydrodynamic and propulsive efficiencies at low, as well as at high, speeds. Other important results of this research showed that the ship could be hydrostatically stable when hullborne, and that there was adequate control available to operate in a seaway.

As a result of work done at DTRC, the Ecole Nationale Superieure De Techniques Avancees performed a study of the HYSWAS concept which was reported by Renvoise and Bourgougnon. The study sought a novel solution to overcoming the shortcomings of conventional monohull war-ships with the specific objectives to (1) obtain increased speed without loss of endurance, and (2) obtain improved platform motions to ensure the ship's effectiveness regardless of weather conditions. After a discussion of limitations of conventional ships, parametric studies of HYSWAS were described in terms of foilborne drag and static stability along with secondary parameters of demi-hull submersion, number of struts per demi-hull, and length of strut.

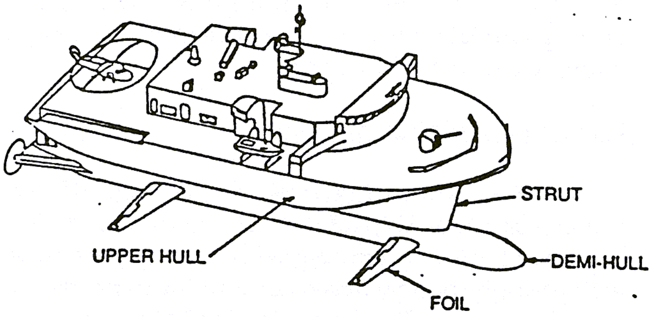

Figure 54 - French HYSWAS 4000

The French study concluded with a description of a 4,000 ton HYSWAS (Figure 54) feasibility design including arrangements, propulsion system, foils, weights, and estimated price. Renvoise and Bourgougnon point out the benefits derived from the foils, namely, not only support of the upper hull above the waves, but stabilization (or motion control) when foilborne and hullborne. Takeoff speed is projected to be 20 knots. Motion study results showed that in a seaway with 5 m waves, both head on and broadside, the mean foilborne lower hull submersion can be maintained as soon as the speed is greater than 25 knots. HYSWAS 4000 carries a total of 1,400 tons of fuel in a combination of the upper hull, strut, and lower hull; the predominant portion of this is in the lower hull. Estimated performance is 45 knots maximum, with a sustained speed of 42 knots. Practical hullborne speeds range up to 25 knots. Range is estimated to be 6,000 nautical miles at 20 knots and 3,000 n miles at 40 knots.

USCG Hybrid Hydrofoil Designs

During the early phases of planning for a new patrol craft, the USCG explored several "advanced vehicle" design options including a Hybrid hydrofoil design. As a starting point, DTRC and Grumman Aerospace Corp. investigated the feasibility of basing the design on an existing 95 ft. USCG patrol craft. With conversion of the propulsion system to larger diesels, incorporation of a Z-drive (based on the Israeli SHIMRIT), addition of a long slender strut, lower hull and fully-submerged foil system, a feasible design was achieved. The resulting Hybrid provided greater range, higher speed and improved seakeeping without any reduction in other ship capabilities.

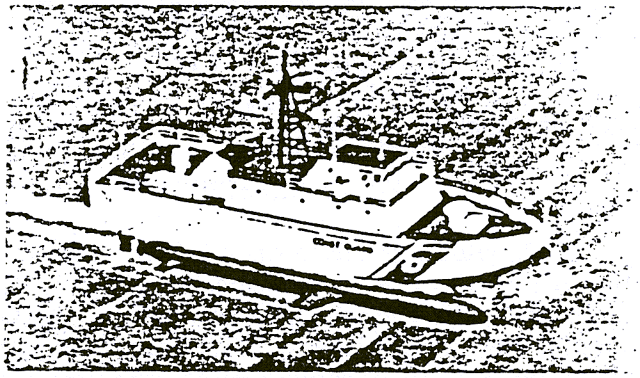

Figure 55 - Rendering of USCG Hybrid Hydrofoil Concept

The USCG then provided DTRC with a new set of specifications for a similar patrol craft with enhanced capabilities over that of their existing 95 ft. craft. A completely new upper hull was designed and appendages added to generate a future generation USCG Hybrid Hydrofoil patrol craft as seen in Figure 55.

PHM Hybrid Variant

This Hybrid Hydrofoil concept built upon the PHM experience and provided substantial improvements in hullborne and foilborne range. It also provided the capability to operate efficiently in the hullborne mode in the 15- to 20-knot speed regime, as well as a major increase the ship's weight-carrying capability. The concept (shown in Figure 56) was suggested as an alternative design approach that may be appro-priate for mid-life conversion of the PHM-1 Class ships or follow-on procurement to a more demanding performance specification. The PHM Hybrid Variant consisted essentially of the current PHM hull with changes to the foil system, hullborne and foilborne propulsion systems, and although not essential for this concept, modification of the ship service power unit.

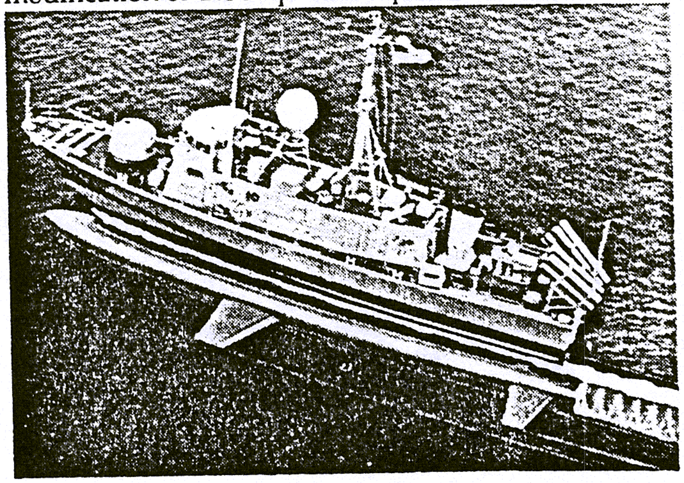

Figure 56 - PHM Hybrid Hydrofoil Variant

The 475-ton Hybrid Hydrofoil was projected to have more than a 50 per cent improvement in hydrodynamic and propulsive efficiency. This led to hullborne and foilborne range improvements, and the potential for promising benefits for fuel/military payload tradeoffs. By-products of this innovative design were low foilborne wake signature, potential for sonar installation in the lower hull's nose section, mine-sweeping capability, increased military payload potential, reduction of weight constraints, refueling cycle improvements, long-range ferry operations, and the possibility of current PHMs and a Hybrid Hydrofoil operating as a team wherein the latter serves as a "tanker" for today's PHMs.

Hybrid Hydrofoil Combatant

This conceptual Small Hybrid Hydrofoil Combatant is a 2,000 to 3,000 ton frigate-size ship with improved motions, higher calm and rough water speed, and high speed endurance when compared to conventional monohulls and SWATH ships. In the foilborne mode, 70% of the total lift is provided by a long, slender, single strut and lower single body. Buoyant lift is augmented by the dynamic lift from a fully submerged foil system. Foil dynamic lift comes into play at speeds greater than 12 to 15 knots, at which time the upper hull is lifted from the water surface leaving only the small waterplane of the single strut at the interface. Propulsion options for this hybrid form include prime movers driving through a mechanical Z-drive, an electric drive to one or more propellers on the stern of the lower hull, or the entire propulsion system in the lower hull. The concept is illustrated in Figure 57.

Benefits of a combatant in this form are seakeeping, mobility in terms of range, endurance, and maneuverability, speed greater than 40 knots, and relatively low signatures.

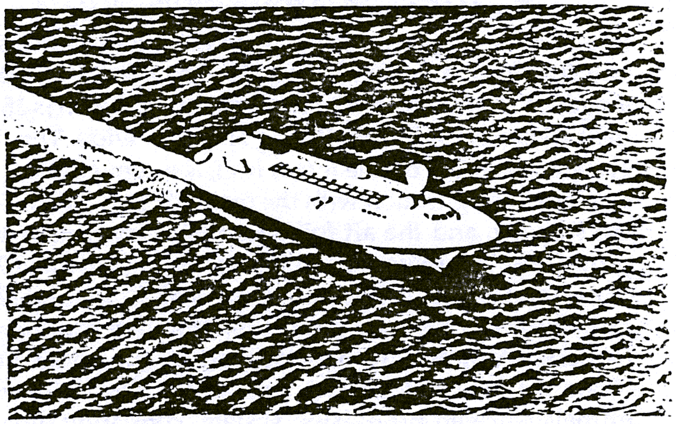

Figure 57 - Hybrid Hydrofoil Combatant

Hybrid Hydrofoil Multimission Deployable Vehicle

A Hybrid Hydrofoil Multimission Deployable Vehicle (HH-MDV) feasibility design was carried out at DTRC to satisfy a particular set of requirements. A Multimission Deployable Vehicle (MDV) would be deployed from the well deck of a Carrier of Large Objects (CLO) and operate approximately 150 nm in advance of the battle force on three to five day missions. It would have the capability to act as an independent LAMPS III platform to extend its mission duration, and therefore the MDV has a landing, refueling, and rearming capability. The HH-MDV (shown in Figure 58) would be outfitted with a modular Anti-Submarine Warfare (ASW) system payload which could be substituted for another mission payload while in the well deck of the CLO.

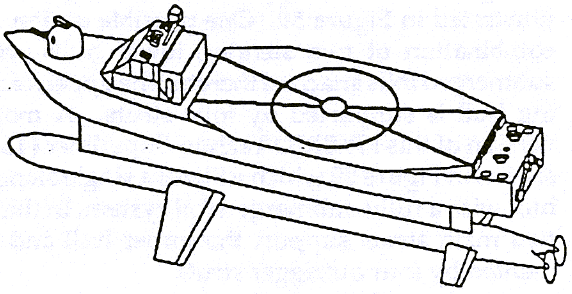

Figure 58 - Hybrid Hydrofoil Multimission Deployable Vehicle

Through removable mission modules, the MDV could play a variety of roles from ASW to drug interdiction operations. The MDV would have a maximum speed of approximately 45 knots through SS-3 and be mission capable through SS-5.

The 416 L ton HH-MDV feasibility design has an upper hull with an overall length of 124 ft, a strut 3 ft thick and 90 ft long, a lower hull 7 ft deep by 8 ft wide with a length of 130 ft. The upper hull maximum beam is 28 ft, the helicopter deck is 66 ft long and 40 ft wide. The foil system, mounted on the lower hull, is a conventional or airplane configuration with the main foil just forward of the ship c.g. and the aft foil about 18 ft forward of the propellers. The main foil, which normally provides 67% of the total dynamic lift, has a span of 45 ft. Buoyant lift from the lower hull and strut at full load in the foilborne mode is from 40% to 50% depending on upper hull clearance selected by the operator. The foilborne propeller-driven propulsion system, consisting of two Allison 571KF gas turbine engines, planetary gear reduction, and short shafts is located completely within the lower hull. Two small retractable outdrives and a bow thruster provide low speed hullborne and maneuvering capability.

Kawasaki Techno-Superliner

Japanese research is spearheading a project to develop a high-speed cargo carrying ship and is well underway. "Techno-Superliner '93", a five year project, was started in 1989 and is being generously funded with about 10 billion Yen. The objective of the project is to produce a set of workable basic designs by the end of 1993 for a ship capable of speeds of 50 knots, carrying a payload of 1,000 tonnes, with an endur-ance of 500 n miles, and sufficiently seaworthy to maintain a regular service.

Several different approaches to a viable ship form have been taken and it is noteworthy that a Hybrid ship form has been included. Of the latter, several configurations have appeared in the literature and are illustrated in Figure 59. One possible design utilizes a combination of two slender, lower hulls with fully-submerged foils attached thereto. The upper, cargo carrying hull is supported by four struts. A more recent version of this HYBRID Techno-Superliner (TSL) is also shown in Figure 59 which utilizes a single slender lower hull with a fully-submerged foil system. In this version, two main struts support the upper hull and are augmented by four outrigger struts.

Several papers have been published on the Techno-Superliner project, including elements of the design and test program. The authors pointed out that one of the excellent features of TSL concept is its superb seaworthiness. As an ocean liner, it will be required to sail regularly 98% of the time on a year-round basis on routes around Japan and from Japan to South East Asia. An investigation on probability of occurrence of wave condition on these routes shows that the significant wave height that the TSL will encounter is 6 meters and the maximum wave height may be as high as 12 meters.

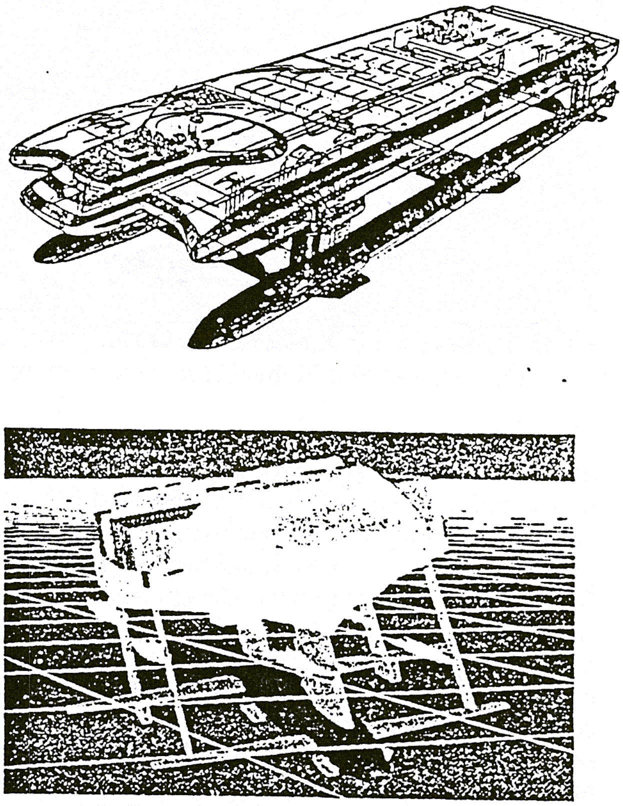

Figure 59 - Hybrid Techno-Superliner Designs

To determine general performance characteristics of the Hybrid TSL, a self-propelled, 1/20-scale model of TSL maneuvered manually by a crew, was tested at a sheltered open sea under conditions corresponding to the above sea criteria. The results showed that in waves, TSL has a good course keeping ability and an excellent turning ability of about six times the ship's length.

Kawasaki's results indicate that the Hybrid TSL concept is the most suitable large high-speed liner. The combination of the fully submerged buoyancy and the fully-submerged foil dynamic lift gives a high degree of seaworthiness, less motion and vibration characteristics, and a high yearly operational rate. A final goal of the Techno-Superliner Project in Japan is to establish the fundamental technology for construction of a Hybrid Techno-Superliner which will be realized as a large ocean going liner in the near future.

THE DAVID TAYLOR RESEARCH CENTER ADVANCED SHIP DATA BANK

The major challenge facing both government and industry is the problem of managing the deluge of paper that is generated in the development of complex systems such as advanced ships which embody concepts such as hydrofoils, air cushion vehicles, surface effect ships, high-speed planing craft, small water plane area vehicles (called SWATH Ships), etc. The Systems Department at the David Taylor Research Center established an Advanced Ship Data Management System (ASDMS) for advanced vehicles in the 1970s.

The Advanced Ship Data Management System (ASDMS) is a complete information system containing a compilation or data base of technical documents, a data classification system for identifying various subject matter contained within a document, an interactive computer Retrieval Program for searching the data base and a reference center that provides for storage, reading, viewing, and reproduction facilities. The information in the documents has been subject classified according to bibliographic data as well as subject matter contained within the document, and this information is input into a computerized Data Base.

The Advanced Ship Data Bank maintains and provides interactive access to computer facilities so document searches can be performed. The "heart" of this data management system is a subject classification system based upon terminology in common use in the Navy and is described in detail in a User's Manual[14]. The hierarchical subject coding structure of this common terminology provides for either broad or narrow document searches. The search results are in the form of a computer listing containing selected bibliographic information on each document. The collection of material in the Data Bank is in the form of technological reports and technical papers. The ASDB provides copies of all documents to authorized users either on a permanent retention or loan basis. The Data Bank has converted many of its documents to microform, copies of which can be permanently retained by the user.

ACKNOWLEDGMENTS

It is realized that a number of hydrofoil vehicles and their designers and builders have been left out of this paper. There is no intention to discredit these efforts. Some of them made important contributions to the development of the hydrofoil principal. In the interest of meeting SNAME rules for the length of papers, the authors have attempted to include those individuals and vehicles which are benchmarks of the progress made in the last one hundred years.

REFERENCES

1. Hayward, L., "The History of Hydrofoils", Hovering Craft and Hydrofoils, Vol. 4, No. 8 (May 1965) - Vol. 6, No. 6 (Feb 1967).
2. Arseneau, Dr. D.F., "Bell's Work in Baddeck", Paper dated January 7, 1982, Presented at 1982 Annual Meeting of the Association for the Advancement ofScience, Washington, D.C.
3. Roos, A.E., "The Artifact as Historic Document: A. G. Bell's and F. W. Baldwin's Hydrofoil Boat", Parks Canada Research Bulletin No. 153, March 1981.
4. Johnston, R.J., "Historical Perspective", Hydrofoil Lecture Day, Massachusetts Institute of Technology Professional Summer, July 8, 1975.
5. Johnston, R.J., "History of U.S. Involvement in Developing the Hydrofoil", Paper Presented at 1st International Hydrofoil Society Conference, Ingonish Beach, Nova Scotia, Canada, July 27-30, 1982.
6. Richardson, H.C., "Hydrovane-Boat," U. S. Patent No. 1,095,166 (April 28, 1914).
7. Von Schertel, Baron Hanns, "European Development of Hydrofoil Craft Technology", Paper Presented at the 1st International Hydrofoil Society Conference, Ingonish Beach, Nova Scotia, Canada, July 27-30, 1982.
8. Ellsworth, W.M., "Twenty Foilborne Years - The U.S. Navy Hydrofoil HIGH POINT, PCH-I", David Taylor Research Center, 1987.
9. Johnston, Robert J. and O'Neill, Wm. C. "A Ship Whose Time Had Come and Gone" Paper Presentation at A1AA/SNAME Advanced Vehicle Conference, Baltimore, MD, 2-4 October 1979.
10. King, James H. "The Evolution of the Nibbio Class Hydrofoils from Tucumcari", First International Hydrofoil Society Conference, Ingonish Beach, Nova Scotia, Canada, July 1982.
11. Rieg, Donald F. and King, James H. "Technical Evaluation of the RHS-200 for High Speed Ferry Application and U.S. Coast Guard Missions" DTNSRDC Report SDD-83/10, December 1983
12. Meyer, John R. and Dr. James R. Wilkins, Jr., "Hydrofoil Development and Applications", Intersociety High Performance Marine Vehicle Conference, Arlington, VA, 24-27 June 1992.
13. Meyer, John R., "Hybrid Hydrofoil Technology Applications", Intersociety High Performance Marine Vehicle Conference and Exhibit, 24-27 June 1992, Arlington, VA.
14. Advanced Ship Data Bank Management System (User's Manual), David Taylor Research Center, Bethesda, MD, January 1979.

APPENDIX
TABLE OF CRAFT CHARACTERISTICS ORGANIZED BY PAPER SECTION

CRAFT	L O/A M(FT)	HULL BEAM M(FT)	DISPLACEMENT TONS	SPEED KNOTS.	
		EARLY HYDROFOILS			
FORLANINI	-	-	1.6	37.0	
BELL HD-4	18.3 (60)	1.8(6)	4.9	61.5	
VS-6	16.0 (52.5)	-	17.0	47.0	
VS-7	-	-	17.0	50.0	
VS-8	45.7 (150)	-	80.0	37.0	
		PROGRESS AFTER WW II			
BIW	6.1 (20)	1.5 (5)	0.8		
LANTERN	10.7 (35)	6.7 (22)	10.0	18.0	
XCH-4	16.2 (53)	-	7.4	78.0	
DENISON	31.9 (104.6)	7.0 (23)	79.0	60.0	
HIGH POCKETS	7.3 (24)	2.3 (7.5)	2.7	35.0	
HIGH TAIL	7.3 (24)	2.3 (7.5)	2.7	30.0	
HIGHLANDER	12.2 (40)	3.5 (11.5)	14.0	40.0	
HALOBATES	10.8 (35.5)	3.6 (11.7)	13.8	34-40	
DUKW	-	-	-	30.0	
		U.S. NAVY PATROL HYDROFOIL			
SEA LEGS	8.5 (28)	2.4 (8)	4.7	30	
HIGH POINT (PCH-1)	35.4 (116)	7.3 (24)	126.0	40+	
PLAINVIEW (AGEH-1)	64.6 (212)	12.3 (40.2)	320.0	50+	
FLAGSTAFF (PGH-1)	22.6 (74)	6.1 (20)	69.0	40+	
TUCUMCARI (PGH-2)	21.9 (72)	5.9 (19.5)	57.0	40+	
PEGASUS (PHM-1)	39.3 (129)	8.6 (28.2)	240.0	40+	
		FOREIGN MILITARY HYDROFOILS			
MASSAWIPPI	13.7 (45)	-	7.5	45.0	
BRAS D'OR (FHE-400)	46.0 (151)	6.6 (21.5)	200.0	60.0	
NIBBIO	22.8 (75)	7.0 (23)	61.5	40+	
SHIMRIT	25.9 (85)	6.1 (20)	105.0	52.0	
SPEEDY	27.4 (90)	9.4 (31)	120.0?	45.0	
		COMMERCIAL HYDROFOILS			PASSENGERS
PT-10	-	-	7.0	35.0	32
PT-20	20.8 (68.1)	4.4 (14.3)	32.5	32.0	62
PT-50	27.7 (91)	5.4 (17.8)	68.3	32.0	150
PT-150	37.8 (124.1)	7.5 (24.6)	165.0	36.5	200
RHS-70	22.0 (72.1)	4.8 (15.8)	31.5	32.4	69
RHS-160	30.9 (101.5)	6.2 (20.4)	85.0	38.0	205
RHS-200	35.8 (117.5)	7.0 (23)	120.0	35.0	300
RAKETA	26.9 (88.4)	5.0 (16.4)	27.0	32.0	58
KOMETA	35.1 (115.2)	4.9 (16.1)	60.0	32.0	120
CYCLONE	44.2 (145)	12.6 (41.3)	143.0	43.0	250
ENTERPRISE	12.2 (40)	4.3 (14)	8.0	36.0	27
VICTORIA	19.8 (64.9)	4.9 (16)	40.0	37.0	75
ALBATROSS	10.4 (34.1)	3.4 (11.1)	6.0	28.0	21
DOLPHIN	21.3 (70)	5.5 (18.7)	55.0	50.0	88
JETFOIL	27.4 (90)	9.5 (31)	117.0	45.0	263