Hydrofoils – Then and Now

A Century of Development

By John R. Meyer

Actually, it has been MORE than a century. It was as early as 1869 that a patent 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. Count de Lambert, a Russian residing at Versailles, applied for patents as early as 1891. He employed several foils (or lifting planes) on each side of the vessel, each individually adjustable to raise the hull in the water as speed increased. However, the location of these primitive foils did not make it possible to lift the vessel completely clear of the water.

We really begin the Hydrofoil story with Enrico Forlanini, 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. Forlanini's designs were characterized by a "ladder" foil

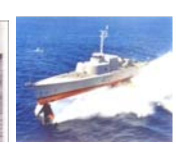
Forlanini's Hydrofoil

The HD-4

V-6 Hydrofoil

Massawippi R-100

Saunders-Roe 103



Bras D'or

system. One can see from a copy of an old photograph (page 1) what is meant by this aptly named ladder foil. Forlanini's model experiments had shown him that lift was proportional to the square of speed, therefore less foil area was required as speed increased. He conveniently obtained this decrease in foil area with the ladder scheme. The craft weighed about 2,650 pounds and had a 60-hp engine driving contra-rotating airscrews. Although designed to fly at a speed of 56 mph, records show that during tests on Lake Maggiore, Italy in 1906 a speed of 42.5 mph was obtained.

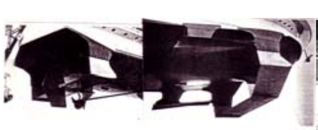
An inventor who received the most publicity from his early work with hydrofoils was an American living in Canada: Alexander Graham Bell. Although Bell, and two colleagues, Frederick W. (Casey) Baldwin and Phillip L. Rhodes, designed and built several hydrofoils, it was the HD-4 that made its mark in history. With two Liberty engines installed during the summer of 1919, the HD-4 set an official speed record of 70.86 mph on 9 September 1919. Although major external modifications were made to try to improve the performance of the HD-4, the speed of 70.86 mph was not officially surpassed.

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. One example of his many designs was the von Schertel-Sachsenberg VS-6 Hydrofoil.

In Canada there was a rekindled interest in hydrofoils resulting in a 45-foot, 5-ton craft built at Lake Massawippi in Quebec, Canada, and was based on Baldwin's later designs. After a series of rough water demonstration trials, the craft was transferred to the Naval Research Establishment at which time she became officially known as the R-100. However, the unofficial name of MASSAWIPPI was the one that prevailed throughout this hydrofoil's life. The MASSAWIPPI was instrumented for quantitative trials to collect data for the design of larger, operationally capable ships.

As a result of successful trials of the R-100, the Canadian government decided to fund another test craft to be built by Saunders-Roe in England. It was designated the R-103. This 17-ton craft, had several design features which were important at that period of hydrofoil development. These included an aluminum hull, as opposed to the wooden construction of the R-100, and built-up foils and struts of aluminum sheet riveted over aluminum ribs and stringers, compared to the solid construction heretofore. Also, a right-angle bevel gear transmission, housed in a propulsion appendage supported by a single, centrally located strut, drove propellers on each end of the pod. This represented a significant departure from the long inclined shaft used in the R-100. Power was provided by two 12-cylinder Rolls Royce Griffon gasoline engines rated at 1,500 hp.

Much later, a Canadian requirement for a hydrofoil centered about the Anti-Submarine Warfare role that demanded an extremely versatile ship. Michael Eames, in his paper reviewing hydrofoil developments in Canada, pointed out that an alternative to improving sonar range (on large ships) is to provide a significantly larger number of sonars economically - the so-called "small and many" concept. Hull construction of BRAS D'OR commenced in 1964, but during construction, on 5 November 1966, there was a disastrous fire in the main machinery space that almost caused termination of the program. In spite


Alexeyev Foils


Raketa


Sputnik


Metor


Cyclone


RHS-140

of the delays and cost increase, however, the ship, designated FHE-400 and named BRAS D'OR, was completed in 1967. Subsequently the FHE-400 underwent a series of trials and Fleet demonstrations.

While these hydrofoil developments were going on in the U.S. and Canada, several European shipyards have produced hydrofoil craft for the commercial market. In Russia, by contrast with the U.S. and the rest of the west, there have been several thousand hydrofoils operating in the Soviet Union on a commercial basis on the many rivers, canals and lakes of this vast country. This may be more understandable when one realizes that there are 150,000 rivers and 250,000 lakes and, at the time, relatively few automobiles and fewer roads in the Soviet Union. Krasnoye Sormovo in Gorki is one of the oldest established shipyards in the Soviet Union. In addition to building displacement craft of many kinds for the Soviet River Fleet, the yard has constructed the world's widest variety of passenger hydrofoils. Many of these are equipped with the so-called Alexeyev shallow-draft submerged-foil system developed by Dr. R.Y. Alexeyev starting near the end of 1945. The system was specifically designed for operation on smooth, but open and shallow rivers and canals. The basic principle underlying Alexeyev's foil system is the immersion depth effect (or surface-effect) for stabilizing foil immersion in calm water by the use of small lift coefficients.

The Alexeyev system consisted of two main horizontal foil surfaces, one forward and one aft, with little or no dihedral, each carrying about one half the weight of the craft. A submerged foil loses lift gradually as it approaches the water surface from a submergence of about one chord length. The effect prevents the submerged foil from rising completely to the surface. A planning sub-foil of small aspect ratio is used as a means of providing take-off assistance and preventing the hydrofoil from settling back to the displacement mode. The planing sub-foils are located in the vicinity of the forward struts arranged so that when they are touching the water surface, the main foils are submerged approximately to a depth of one chord. The system was first tested on a small launch powered by a 77 hp converted automobile engine.

Subsequent to this, a large number of commercial and military hydrofoils were built including Raketa, Strela, Sputnik, Meteor, Kometa, and Cyclone, to name only a few. Many military hydrofoils were designed and built in Russia including the largest hydrofoil in the world, the Babochka, exceeding the size of the US Navy Plainview by a considerable margin. The Babochka was preceded by Pchela, Turya, and Sarancha.

At the same time, major Western European manufacturers include: Gustoverft of the Netherlands; Westermoen of Norway; Vosper Thornycroft of Great Britain; and Rodriquez of ltaly. There will probably be little argument however, that the most successful commercial hydrofoils designed and built in Western Europe were those produced by Rodriquez Centieri Navali of Messina, Italy. Among others, the RHS series of commercial hydrofoils are most notable, for example RHS-70, RHS-110, RHS-140, RHS-150, RHS-160 and the RHS-200.

The RHS series hydrofoils grew in size and ventured into waters which subjected their inherently stable surface-piercing foils to forces not previously felt under the benign environment offered by rivers, lakes, and coastal regions. During this evolution it was realized that some degree of motion control was required to provide an acceptable ride to hydrofoil passengers. Hence, the introduction of Rodriquez's Seakeeping


Sea Legs


Little Squirt


Tucumcari


Plainview


PHM in Seattle


PHMs in Formation

Augmentation System (SAS) that has been successful in alleviating heave, pitch, and roll motions in rough water.

During the early 1950s, the naval architectural firm of Gibbs and Cox of New York had assembled with U. S. Navy support, a technical team for the design of a versatile hydrofoil test craft. It was built by Bath Iron Works, and aptly named BIW. The craft, 20 feet long with a 5-foot beam, displaced about 1800 pounds and had a 22-hp outboard engine. BIW was successful in testing different foil arrangements, different control schemes including manual, mechanical and electronic, and different height sensors used in the control system. The most important outcome of this work was the potential for an electro-hydraulic autopilot and the decision to design and build SEA LEGS. A foil system was added and propulsion system changes were made. An electronic autopilot stabilization system, developed by the Draper Laboratory at the Massachusetts Institute of Technology, was installed to control the fully-submerged foil system. This electronic autopilot contained 160 vacuum tubes! SEA LEGS made its first flight in 1957 and demonstrated its excellent seakeeping performance in rough water up to speeds of 27 knots.

From this success, the U.S. Navy was deeply involved in hydrofoil test vehicles, such as Little Squirt, the Hydrodynamic Test System (HTS), and the Foil Research Experimental Supercavitating Hydrofoil, known as FRESH-1. Also several “developmental” hydrofoils were designed and built by the Boeing Company and Grumman/Lockheed Shipbuilding. These included High Point (PCH-1), Flagstaff (PGH-1), Tucumcari (PGH-2) and Plainview (AGEH-1). These ranged in sizes from Flagstaff’s 57 Ltons to that of Plainview at 320 Ltons, and clearly demonstrated the capabilities and potential applications of hydrofoils for military use. These developments led to the generation of a NATO program out of which the US Navy hydrofoil, PHM (Patrol Hydrofoil Missile) was designed and built by the Boeing Company’s Marine Systems group. Although the NATO plan was to build a total of 26 ships, only six were eventually constructed and placed in service subsequent to a decision by Germany and Italy to withdraw from the project. The PHM ships were to be named after constellations. With about 88 to choose from, the Navy decided on USS PEGASUS (PHM-1), USS HERCULES (PHM-2), USS TAURUS (PHM-3), USS AQUILA (PHM-4), USS ARIES (PHM-5), and USS GEMINI (PHM-6). Commissioning dates ranged from July 1977 to November 1982.

Subsequent to construction, each ship underwent a series of trials in the Puget Sound area. Following the launching ceremonies the PHMs were transferred to the Navy's David Taylor Research Center Hydrofoil Special Trials Unit (HYSTU) Detachment at the Puget Sound Naval Shipyard in Bremerton, WA. The USS PEGASUS departed San Diego, CA on 4 June 1979, set a speed record transiting the Panama Canal, and arrived at her first East coast home port at Little Creek, Norfolk, VA on 3 July. At that time the plan was to have the entire Squadron of PHMs at that location. However, the plan was later changed. Rather than have the PHMs operating too close to sources of major support afforded by one of the largest Naval bases on the East Coast, the ships and it's Mobile Logistics Support Group were put to the test of self reliance by selecting the most southern U.S. outpost, namely, Key West, Florida. Also, the Caribbean was increasingly becoming a focus of the U.S. Navy's Atlantic Fleet. The success stories of PHMs operating out of the PHM Squadron are numerous and would take many pages to adequately describe. In addition to its operations with the US Navy Fleet, basing the PHM Squadron Two in Key West, and particularly at Trumbo Point, established an ideal situation for drug busting in the Caribbean Basin. In addition to the obvious geographic area, is the fact that the U.S. Coast Guard Station was also located on an adjacent


Westamarin Foilcat


DBH


Grumman HYD-2


Olympia


QUEST

pier. In any such exercise utilizing the PHMs, it was necessary that Coast Guard personnel be present to play an active role in apprehending personnel and confiscating illegal materials. Nicknamed "El Terror Gris que Vuela" (The Grey Terror That Flies) by drug smugglers of the Florida Keys, the PHM's drug interdiction efforts were most impressive.

In spite of plans to improve the PHM ships by upgrades and modifications to extend their foilborne range, The US Navy decided to decommission the ships in 1993. A ceremony, which I attended, was a sad day for hydrofoilers; a day when an entire class of US Navy ships was decommissioned and placed in “mothballs” and later auctioned off or scrapped. One PHM (AQUILA) was purchased by a private party, transited hullborne up the Mississippi River to Missouri where its owners plan to use it as a “dive boat”.

From then on, the US Navy’s hydrofoil efforts centered on a series of “paper studies” consisting of designs ranging in sizes from 615 Ltons to 2,400 Ltons. Examples are a Corvette Escort, Developmental Big Hydrofoil (DBH), PCM (a patrol missile-carrying hydrofoil), and the Grumman HYD-2 at 2,400 Ltons.

During the 1990s, commercial hydrofoil development enjoyed a rebirth with new designs from Japan, Norway, Sweden, Russia, Italy and the United States. In Russia, more recent designs include the Cyclone, a larger, double decked derivative of Kometa. It seats 250 passengers, cruises at 42 knots, and employs a sonic/electronic automatic control system. A more recent design was Olympia that was a culmination of development of larger hydrofoils capable of operating on more open sea routes.

The Boeing Jetfoil went into production in the mid-1970s and it saw service in many parts of the world. At the time it was the most technologically advanced of all commercial hydrofoil designs. With its water-jet propulsion system and fully-submerged foils, it operated at a cruise speed of 45 knots in heavy seas, and with superior ride comfort. Kawasaki obtained a license from Boeing to build the Jetfoil in Japan around 1989. Many of them are still operating in the Hong Kong area. Also in Japan, Mitsubishi designed and built several passenger hydrofoils called Rainbow that operated in and around that country.

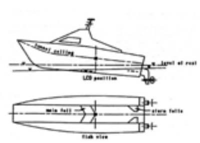
In Sweden and Norway hydrofoil designs with a catamaran hull and foils suspended by relatively short struts were employed on routes in the Baltic. Foilcat 2900, built by Westamarin, is one example. Navatek Ships, Ltd. of Honolulu Hawaii re-launched the 45-knot, 149 passenger vessel offering the design for construction in the United States. The Westamarin Foilcat 2900 vessel was re-flagged American for use in Hawaii as part of a commuter ferry demonstration sponsored by the State of Hawaii Department of Transportation.

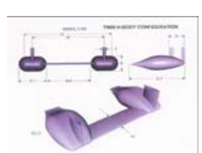
In Italy, Rodriquez introduced the Foilmaster in 1994. It is an example of Rodriquez’s attempt to carefully integrate the design of the propeller screw and the foil profiles to maximize performance while retaining the relative simplicity of aft-mounted screws driven by angle shafts.

As a result of the hydrofoil developments described here, some very creative work on hybrid variations of hydrofoils has taken place. 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". Compared to other hullforms, Hybrid Ship concepts are relatively new. The concepts described


HYSWAS Model


AliSWATH


HYSUCAT


Blended Bodies


HYSWAC X 515


Superfoil 40

here have one characteristic in common, namely the use of foils to provide dynamic lift to augment buoyant lift. The forms include HYSWAS, Foil Assisted Catamarans, Lifting Bodies/Blended-Wing Concepts, and Tail Draggers.

The Hydrofoil Small Waterplane Area Ship (HYSWAS) concept was an outgrowth of hydrofoil and SWATH developments at the Naval Surface Warfare Center, Carderock Division, Bethesda, Maryland, USA during the 1970s and 1980s. This hybrid vehicle concept consists of a single submerged hull with a fully-submerged foil system and an upper hull structure supported above the water surface by a single, thin, longitudinal strut. In the low-speed (hullborne) mode, sustention is provided by buoyancy of the submerged hull, the strut, and a small segment of the upper hull. As speed increases, the dynamic lift of the foil system raises the upper hull above the water and the waterplane area on the strut becomes small. At this point, the lower hull and submerged strut provide about 70 percent of the total lift (through buoyancy) and the foil system provides about 30 percent of total lift. The US Navy sponsored a program in the 1990s to design and build a demonstrator of the concept called QUEST. Maritime Applied Physics Corporation of Baltimore, Maryland, USA designed, constructed, launched and successfully tested the 27-foot vehicle weighing 12 Ltons. QUEST was capable of operating at almost 35 knots in 6-foot seas.

Very recently Rodriquez has developed a concept called Aliswath that bears a resemblance to the HYSWAS concept. It has been reported that this large vehicle and passenger ferry is to be launched later in 2007.

A major portion of the work on Foil Assisted Catamarans has been carried out by Dr.- Ing K.G.W. Hoppe, SAIMENA, Division of Marine Engineering, Department of Mechanical Engineering, University of Stellenbosch, South Africa. The hybrid consisting of a catamaran with fully asymmetrical demi-hulls and a single hydrofoil spanning the tunnel between the demi-hulls was named Hydrofoil Supported Catamaran or HYSUCAT. Many versions of this concept, referred to as Foilcats, have been designed and built by a variety of companies for commercial use as passenger ferries.

Lifting Bodies/ Blended Wing Body (BWB) concepts have been promoted by Navatek who has been developing and testing various configurations of lifting bodies and foil systems, separately and in combination, since 1996 with successful demonstrations of the technology on their Midfoil and Waverider test craft. Working with commercial Computer Fluid Dynamics (CFD) programs, and with assistance from California State University, Long Beach, Navatek has developed the next evolution of lifting body technology, the BWB. The main objective of the BWB is to enhance the seakeeping and high-speed payload capacity of a range of existing or planned vessel designs.

A “tail dragger” features foils forward on the vessel, but no foil aft, so the stern drags in the water. The catamaran, Superfoil 40, an example of a “tail dragger”. It was constructed by Almaz Marine Yard, designed by the St. Petersburg branch of the British company "MTD" (Marine Technology Development). It is claimed to be the fastest passenger ferry at a speed about 55 knots (more than 100 km/hour). Now it will take only 50 minutes to travel from Tallinn to Helsinki.

John R. Meyer has authored numerous technical reports and papers on the subjects of hydrofoils and Hybrid ships and craft. Subsequent to his retirement from the Naval Surface Warfare Center, Carderock Division in Bethesda, Maryland, USA, in 1996, he has consulted with several companies on these subjects, and has pursued a career in High Performance Marine Vehicle consulting. He has served as President of the International Hydrofoil Society and is editor of the Society’s Quarterly Newsletter (www.foils.org). He has authored several books that are available on CDs, namely: “Ships That Fly” (http://themeyers.org/ShipsThatFly/index.html), and “Hybrid Ships and Craft-A New Breed” (http://themeyers.org/ANewBreed/). Details of the hydrofoils and Hybrid vehicles described in this article (and many more) can be found in these two books on CD.