71233

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PROFESSIONAL SUMMER

C. S. DRAPER LABORATORY

HYDROFOIL LECTURE DAY

8 JULY 1975

HISTORICAL PERSPECTIVE

Lecture 1

ROBERT J. JOHNSTON

HISTORICAL PERSPECTIVE

R. J. JOHNSTON

1.0 Introduction
- 1.1 Generic Chart of Hydrofoil Development by Ship Type
- 1.2 Hydrofoil Analytical Development

2.0 Surface Piercing Development

- 2.1 Ladder Foils
  - 2.1.1 Forlanini
  - 2.1.2 Bell
  - 2.1.3 Bras D'or No. 1
  - 2.1.4 XCH-4
  - 2.1.5 Monitor (Baker Sailboat)

- 2.2 Schertel Story
  - 2.2.1 VS6
  - 2 2.2 VS7
  - 2.2.3 VS8
  - 2.2.4 PT10
  - 2.2.5 PT20
  - 2.2.6 PT50
  - 2.2.7 PT150

- 2.3 Bras Do'r No. 2
- 2.4 High Pockets
- 2.5 Hybrids
  - 2.5.1 Denison
  - 2.5.2 Rodriquez

3.0 Submerged Foil Development
- 3.1 Richardson
- 3.2 Grunberg (Aquavion)
- 3.3 Hook
  - 3.3.1 Hydrofin
  - 3.3.2 d&/dt (With feelers)
  - 3.3.3 d&/d (Without feelers)
  - 3.3.4 Halobates (With feelers)
  - 3.3.5 Halobates Autopilot Control

- 3.4 Manual and Mechanical Control
  - 3.4.1 Hazard
  - 3.4.2 BIW
  - 3.4.3 Miami 2 Man Craft
  - 3.4.4 Savitsky Flap (Flying Cloud)
  - 3.4.5 Baker High Tail

- 3.5 Lantern
- 3.6 Flying DUKW
- 3.7 Sea Legs

HISTORICAL PERSPECTIVE

1.0 Introduction

1.1 Generic Hydrofoil Development by Ship Type

In trying to outline the background and the history of hydrofoils, one is confronted by the need of classification. A very obvious classification and I think understood by all this audience,, is by surface piercing hydrofoil and incidence controlled hydrofoils or submerged foils. The major categories to which I have broken this presentation has been by these two main headings. The problem comes when one starts to develop the breakdowns within these categories. We could talk to the history of individuals as they have contributed to the hydrofoil program. We could talk down to the breakdown of the hybrids controls, the manual and mechanical controls, the electronic controls systems, etc. The one advantage in being the lecturer in this case is that we will do it my way.

With the number of hydrofoil representatives in the audience, 'this surely can lead to some criticism or some comments as to how they would do it. A presentation of this type opens the door to many sea stories and while very tempted to throw many of them in, time I think will keep me moving along,

1.2 Hydrofoil Analytical Development

One of the observations that has been made of historical presentations has been that we tend to look at the ship crafts that have been built and tested. I suppose we all feel this was where the fun was. However, associated with this particular craft development has been an equally and to me in many cases more important development of analytical methods so that the designer could at least build something that we could have some fun in trying to test, fly, and make worthy of a mission. So this second portion of this discussion really addresses the issue of the major milestones at least in the development of what we can now do analytically with hydrofoil design.

2.0 Surface Piercing Development

2.1 Ladder Foils

I have chosen to start the story this morning on the subject of ladder foils principally because this was where the early development really began. One could cite the patents that seem to parallel the early inventors of aircraft; for an example, the Wright brothers actually received a patent on hydrofoils. It appears in looking at the very early literature that those individuals that were interested in developing airfoils leading to the airplane also were intrigued by the possibility of hydrofoils and their ability to support water craft.

2.1.1 Forlanini

But let's get on to ladder foils. Here we begin the story with the Forlanini Craft. His development started as early as 1904. You can see from the picture what we mean by the ladder foil system. It's a rather complicated structure but it did operate and was aimed at a seaplane development.

2.1.2 Bell

Probably the inventor who has received the most publicity from his early work was Alexander Graham Bell, and the work he did with the ladder system and his craft designated the HD 4. This photograph was taken about 1919 and shows Casey Baldwin at the controls of the particular craft up in the Bras d'Or Lake in Nova Scotia. A very interesting side light is that a Lt. Hunsaker, whom M.I.T. knows as Dr. Hunsaker, evaluated the HD 4 for the United States Navy. His summary was most appropriate, I think, for the time when he said that it's a very interesting development but I can see no application to the United States Navy.

2.1.3 Bras d'Or No. 1

The Bras d'Or which probably very few of you have heard about, but this was an early Canadian craft. I put it in here simply because it shows really a continuation of the Bell configuration under test by the Canadian Navy. You'll hear about another Bras d'Or in a few minutes.

2.1.4 XCH-4

The U.S. Navy, in its early development, work-evaluated another configuration of ladder foils. The XCH-4 had swept wings on a seaplane type hull powered by two Pratt and Whitney aircraft engines with an air propeller drive. The XCH-4 was rather extensively tested in the early 50's by the Navy and for a number of years held the speed record of 78 knots.

2.1 .5 Monitor

All of the ladder foil boats were not aimed at high speed; at least one was aimed at pleasure boating. Here we see a sailboat called the Monitor designed by Gordon Baker and manufactured by the Baker Manufacturing Company. Underway it was reported to have made a maximum speed of 45 knots. I sailed on it at 25 knots and it was quite a thrill. As you can see it had a ladder foil forward and interesting enough the after system was really a submerged foil. Baker designed a rather interesting mechanical computer to control the aft foil. The- controller input was from a summation of forces from the stays of the mast. This was to prevent a problem of an earlier version of the Baker sailing experiences in which the hydrofoil tended to pitch roll. People often ask how did the U. S. Navy get its name on the sail. I can report that the Navy sponsored the fabrication of the forward foil system. That was their oniy investment in this particular project and was justified under the premise that we were learning how to weld a complicated type foil structure.

2.2 Schertel Story

I think that it is appropriate early in any historical presentation to mention Baron von Schertel. His name is synonymous with modern hydrofoil and also provides what I think is the link with the earliest days of hydrofoil development. His early experience goes back to 1926 when as a young engineering graduate he started to work on hydrofoil configurations. Interesting enough, the Baron's early work was aimed at taking advantage of submerged foil depth stability. He utilized the surface effect which decreased lift when the submerged foils approached the surface. To quote the Baron, "I decided for the fully submerged type, in order to get away as far as possible from the disturbing influence of the water surface in waves." In fact, the Baron relates that he used and studied submerged foils through five test boats. After several disappointing experiences he became convinced that the only promising way to maintain the stability of fully submerged hydrofoils would be through the use of automatic lift control and a submergence depth sensing device. He therefore experimented with several types of depth feelers and concluded that the idea worked well in calm water but was not particularly good in sea waves. The Baron's history indicates he spent eight years and utilized six test boats in this trial effort. He became impatient and in looking for a quicker solution turned from the fully submerged principle to the surface piercing foil. system for which he is known today.

2.2.1 VS-6 and 2.2.2 VS-7

In the late 30's Baron von Schertel teamed up with the Sachsenberg Shipyards in Germany to enter a competition for the German Navy to develop a hydrofoil craft which could be used as a personnel carrier over short distances such as the English Channel. In the competition two boats entered. One was the Schertel-Sachsenberg team and the other was entered by a man by the name of Dr. Tietjens. Those of us who have studied structural mechanics well know the name of Tietjens. The competition was run off between the two crafts and the Schertel-Sachsenberg entry was declared the victor. This competition was called the VS-6 vs. the VS-7. The VS-6 being. the Schertel craft and the VS-7 being the Tietjens craft. Several of the VS-6 model were built in about a 15-ton size but were never put into operation.

2.2.3 VS-8

As the war got underway, Germany had a problem moving tanks quickly from Sicily to North Africa. It is said that Hitler made the decision that a hydrofoil was the solution for this over-the-water rapid transport. He therefore directed against the objections of the Schertel technical staff that they divert their energies from the 15-ton VS-6 to a tank carrier. The outcome was the VS-8 which was an 80-ton, 55-knot craft which had an open-well aft into which a tank could be carried with a range from Sicily- to North Africa. Three of these were built and one was actually tested and and achieved a speed of over 50 knots. When one thinks that this was in the 1941-42 time frame, one could recognize the technical achievement that was accomplished. Two craft were bombed on the ways and were never actually tested. The No. 1 VS-8 had a grounding incident and that was the end of the story of German war effort with hydrofoils.

2.2.4 PT-10

When the war was over, most of the technical team of Schertel and Sachsenberg were captured by the Russians. They spent a number of years in Russia when the early Russian foil development was undertaken. Schertel himself went to Switzerland and formed the company we now know as Supramar. His first commercial boat was called PT-10, which operated on Lago Maggiorre in Southern Switzerland.

2.2.5 PT-20

The PT-10 was followed by the PT-20 which was essentially a 20-ton design craft. At this time the Rodriquez Shipyard in Sicily went to work under a Supramar license and have been the primary producer of the Supramar type craft.

2.2.6 PT-50

PT-20 was followed by the PT-50, which is the most widely-used passenger hydrofoil craft today.

2.2.7 PT-150

PT-150 is the largest of the Supramar types which have been built. I think you can see from looking at PT-20 to PT-150 they have all had a very similar foil configuration.

2.3 Bras d'Or

Carrying on the surface piercing development, probably one of the most significant craft with a total surface piercing system was the Bras d'Or. This was a 180-ton vehicle built by the Canadian Navy and operated rather extensively in the open sea. Much data is available today from this effort which gives us hope for the future in the development of such systems as high-powered gear transmissions and systems development.

2.4 High Pockets

One of the early test craft of the United States Navy using a surface piercing system was High Pockets, designed and built by the Baker Manufacturing Company. It was operated in the late 50's by the U. S. Navy. It created a lot of interest in hydrofoil development.

2.5 Hybrids

We now begin to get into the surface piercing hydrofoil Hybrids. The maritime administration in 1960 developed the Denison, which was an 80-ton craft, gas turbine powered. The prototype of the LM1500 was used in the Denison design for foilborne power. This craft we call a hybrid because she had a submerged tail aft and flaps on the forward surface piercing system which-permitted a pitch stabilization system to be effective in reducing craft motions. Denison was extensively tested by the Maritime Administration. It is now owned by the U. S. Navy but is not operational.

3.0 Submerged Foil Development

3.1 Richardson

Let's now back up and start looking at what we can trace through as a submerged foil development story. We go tack into the early 1909 period when the United States Navy and then Lt., later to become Captain, Richardson did some early test work at the Philadelphia Naval Shipyard on a hydrofoil with a totally submerged foil system. Al though he did have a manual capability to control the incidence to assist him in the stabilization. The craft was not self-propelled but was towed as you can see in the insert photograph.

3.2 Grunberg

One of the earlier developers of a submerged system was a Frenchman named Grunberg. We have had an interesting experience recently in the Hydrofoil Office of having a Mr. Graig come in who was formerly Mr. Grunberg. He is a U. S. Citizen and a retired aeronautical engineer.

We have had some interesting discussions regarding his early development. His system consisted of skis forward which pitch controlled the incidence of an aft submerged foil. The skis not only provided forward lift and some lateral stabilization but were in effect the means of sensing the oncoming wave profile. As the boat was pitched it accordingly changed the angle of attack of the main hydrofoil.

3.3 Hook

One of the early inventors who successfully worked with a submerged foil system was the English inventor, Mr. Christopher Hook. His developments also dated to pre-World War II. I could comment that he continues to bring new thoughts and ideas to the hydrofoil world'. Mr. Hook was probably the firs-t submerged foil system designer to bring his ideas to the forefront in the United States.

3.3.1 Hydrofin

He brought over to this country in the early 1950's a little test craft called the Red Bug, in which a number of interested hydrofoilers participated in trial rtms and became impressed with the stability of the Hook craft. As you can see he used feelers ahead of the craft to sense the oncoming waves which were mechanically linked to the forward submerged hydrofoils controlling the incidences and thereby stabilizing the craft. He had a rather clever override steering system which permitted the craft to bank. The craft was quite maneuverable and quite stable.

3.3.2 D&/dt

His ideas were carried forward by Miami Shipbuilding Corporation. In the D&/dt you see Hook feelers, again mechanically linked to a forward submerged foil system. This is a half-scale model of a landing craft. It is interesting to note that one of the early missions that the U. S. Navy foresaw for the hydrofoil was a LCVP application. D&/dt was also configured with a surface piercing configuration on it. A forward step resistance height sensor was part of the instrumentation. We now begin to worry about the problem of how a craft can sense its height above the water. This technique was used and later applied to larger craft.

3.3.3 Halobates with Feelers

The half-scale dG/dt became the full-scale Halobates. The Hook system was adapted to the Halobates.

3.3.4 Halobates Autopilot Controlled

The Hook configuration with the long feelers led to a comment which could be summed up by saying that if this is the way hydrofoils are to be built we have no use for them in the Navy. The feeler-concept was certainly objectionable. So the feelers went their way. Halobates was reconfigured with a Miami Shipbuilding automatic control sys ten. THis was an analogue control system using a step-resistance on the leading edge of the front foils as a height sensor. This is one of the first marine installations of a gas turbine.

3.4 Manual and Mechanical Control

Stepping back a moment, we come to the efforts that were going along in trying to come up with a mechanical means of trying to control hydrofoil craft rather than pursuing electronic means. In the 1950-1960 time frame electronics were considered quite suspect.

3.4.1 Hazard

One of the earlier mechanically controlled craft was the Water Hazard. It was a little speed boat with a joy stick control, quite similar to an airplane.

3.4.2 BIW

BIW, which stood for Bath Iron Works, was a Gibbs and Cox effort. The craft had a number of interesting features on it. It was probably one of the most versatile test craft the U. S. Navy built during the 1950 time frame. The forward struts were step contact resistance height sensors used to control the flying height of the craft. It had actually two foils, one forward and one aft. They were split in the middle and each half was independently controllable, so that a variety of control systems could be tried. It was on this craft that a lot of testing was done to find out if, in fact, a man can manually control a hydrofoil. We discovered that a man can control a hydrofoil in roll, and even do something about height. Man's responses to pitch are just not quick enough to stabilize the pitch mode of a hydrofoil.

3.4.3 Miami 2-Man Craft

Other test craft were built with manual stabilization systems. The 2-man craft was a hybrid. It had a little feeler forward to take care of the pitch control and the pilot had a manual- control. So now we get into a combination of both mechanical and a manual control system. An interesting little craft, it had a clandestine mission. Everything was capable of being folded, stowed in a torpedo tube and launched at sea.' The craft could travel some 10 miles to a beach head, could then be submerged, the mission presumably performed and the craft return out to the submarine. The big problem here was that the development of a submergible outboard motor did not come along with the hydrofoil development.

3.4.4 Flying Cloud

Commercial application of a mechanical control system is the Flying Cloud, which used the Savitsky Flap as a means of assisting in the stabilization.

3.4.5 Baker High Tail

One of the more sophisticated submerged foil systems with a combination of mechanical and manual control was the Baker "High Tail." A mechanical computer was to solve the motion problem. The inputs from the feeler provided the necessary information to solve the stability problem. Actually the High Tail, while quite stable, was the particular craft from which the Navy concluded that mechanical system was not the way to go. Efforts from that point on were developed primarily toward the electronic control system.

3.5 Lantern

Let's look at some of the first electronic control systems. One of the earliest ones was on Lantern, a test craft built and designed by the Hydrofoil Corporation in the mid 50's. This was a straight adaptation of an aircraft autopilot to a hydrofoil. In many respects a Rube Goldberg, but it did fly and also an interesting craft from its shape. The foils, the struts, and the hull all had the same airfoiled section.

3.6 Flying DUKW

Another monstrosity came along when we decided to fly a World War II DUKW - wheels and all. This was an adaptation of the Miami Shipbuilding autopilot.

3.7 Sea Legs

The big breakthrough came when the Gibbs and Cox Corporation, under a U. S. Navy contract developed and demonstrated "Sea Legs." Here was a totally submerged foil system using the Canard configuration, with a sonic height sensor and electronic automatic control system. The autopilot was developed in the Draper Laboratory here at MIT and proved to the Navy that the technology of hydrofoils now could be adapted to mission oriented ships. It made a coast-wise run from New York to Annapolis beating the time of an accompanying PT boat by several hours. The world of hydrofoils began to see practical applications of the principle.

3.8 High Point - PCH-1

The Navy Hydrofoil Advanced Development Program began in 'FY 1960 when HIGH POINT was authorized. The decision to begin the program in 1960 was based on the judgment that sufficient knowledge and experience had been accumulated to demonstrate that submerged-foil hydrofoils were feasible and could provide the Navy with a significant improvement in high-speed, all-weather mission capability.

HIGH POINT was built by Boeing and delivered in October 1963 and her first year of trials, consisting of 53 foilborne hours, indicated the need for modifications. Trials of HIGH POINT were resumed in September 1966. During the next year almost 80 hours of foilborne operation were made in calm water and in seas in excess of state 4. These trials began to restore Navy confidence in the capabilities of HIGH POINT although the operations were restricted to speeds less than 40 knots to alleviate cavitation effects. Foilborne operating hours were rapidly added in 1968. This experience demonstrated the capability to operate the craft and to gather data.

In the spring of 1969, after modifications to eliminate cavitation problems, HIGH POINT rough water trials were conducted in the Pacific Ocean some 25 miles off the coast at Neah Bay. The speed restrictions were removed and HIGH POINT was operated at design speed and in rough water. HIGH POINT further demonstrated the capability to take off and fly at 36 knots on either side of its two foilborne engines. A number of mission demonstrations were also interspersed with craft performance trials. HIGH POINT added *over* 100 hours of foilborne operating time during the first half of 1971 and went on to accumulate a total of over 700 hours by the time her MOD-1 conversion was authorized.

Operational experience showed that major strut-foil and propulsion problems required a redesign. A 1966 design study led to detailed design changes, denoted MOD-1. These changes incorporated advanced technologies to improve on the MOD-O design, correct deficiencies and achieve an acceptable level of performance and reliability. After delivery of MOD-1 in 1973 PCH-1 has become the workhorse of the Navy's R&D community. PCH-1 has now accumulated over 1100 hours of total foilborne time,

3.9 Fresh-l

Another developmental test craft explored the interest in the high-speed hydrofoils. FRESH-l, a high-speed test bed built by the Boeing Company, now holds the speed record in excess of 80 knots.

3.10 Little Squirt

Designers were intrigued with the thought that waterjet could, in fact, propel1 a hydrofoil boat. The Boeing Corporation built LITTLE SQUIRT, which put together a submerged foil system, automatic control sys tern, and the waterjet for the first time.

3.11 Plainview (AGEH-1)

PLAINVIEW, designed by Grumman in 1962, incorporated features which extended the state of the art when delivered in 1970. The most significant of these features are:

- The largest hydrofoil ship in the world (320 tons)
- The largest high-speed aluminum hull (212-foot overall length)
- The large subcavitating foil loading (1460 psf)
- The largest vehicular hydraulic system (3600 psi and 1000 gpm)
- The highest power ZEE-drive transmission system (two 15,000-hp units)
- The largest and fastest high-speed supercavitating propellers (5.2-foot diameter and 1700 rpm)
- The highest design sea state capability at high speed.

Final contract delivery trials on PLAINVIEW were conducted in March 1970. During 25 hours of operation at over 40 knots the struts and foils were shown to be free of cavitation damage. PLAINVIEW was put in a post-shakedown availability in the last half of 1970 to correct deficiencies, primarily in the hydraulic sys tern. Hullborne trials were conducted for the first half of 1971 during which machinery deficiencies were corrected. In July 1971 PLAINVIEW began to fly with regularity and conducted smooth water trials interspersed with a variety of mission trials.

PLAINVIEW conducted its first rough water trials in December, 1972. It also made the first launchings of a missile from a hydrofoil. Because of continued system component deficiencies, PLAINVIEW is now in a major overhaul.

3.12 Commercial Submerged Foils

3.12.1 Dolphin

The Dolphin was designed and built by the Grumman Corporation. This 88-passenger craft was operated in the Canary Islands and the Virgin Islands. It used a conventional foil system and employed a geared propeller drive.

3.12.2 Jet Foil

This Canard configured, waterjet propelled, 200-250 passenger hydrofoil is a current product of the Boeing Company. These craft are in operation in Hong Kong and the Hawaiian Islands.

3.13 Patrol Gunboat Hydrofoils

In response to a requirement for a high-speed hydrofoil gunboat, established by the Chief of Naval Operations in 1963, *two* Patrol Gunboat Hydrofoils (PGH) were authorized in the FY 1966 shipbuilding program. TUCUMCARI (PGH-2), designed and built by Boeing, was delivered to the Navy in February 1968. FLAGSTAFF (PGH-1), designed and built by Grumman, was delivered in September 1968. Both craft were assigned to the Pacific Fleet for operational evaluation.

3.13.1 Flagstaff

FLAGSTAFF, PGH-1, has a conventional foil configuration similar to PLAINVIEW with 70 percent of the lift provided by the forward main foils and 30 percent by the smaller after foil. Lift control is effected by varying the angle of attack of the foils. This is called incidence control. Foilborne propulsion is provided by a single, variable-pitch, supercavitating propeller located on the after end of the pod of the after strut/foil system. The prime mover is a 3200-hp Rolls-Royce Tyne gas turbine which drives through a right-angle bevel gear transmission. Hullborne propulsion consists of two Buehler waterjets, each powered by a 160-hp General Motors diesel engine. The three identical foils are of subcavitating design and are made of solid forged aluminum.

3.13.2 Tucumcari

The Boeing-built TUCUMCARI, PGH-2, is a canard configuration with a 31/69 load distribution and flap control system. The foils are of subcavitating design and the main foils incorporate anhedral to supply more directional stability and to reduce their tendency to ventilate in banked turns. Foilborne propulsion is provided by a waterjet system consisting of a Byron-Jackson pump driven by a 3200-hp Bristol-Proteus gas turbine. Water inlets are located at the juncture of each main strut and foil. Hullborne propulsion is provided by a single Buehler waterjet driven by a 160-hp General Motors diesel engine.

Operational evaluation tests on the PGH's were conducted by the Operational Test and Evaluation Force in the San Diego and Long Beach operating areas from 7 October 1968 until 8 April 1969. AT the end of the operational evaluation the two craft went into a restricted availability to prepare them for- deployment to Vietnam. In August 1969, FLAGSTAFF and TUCUMCARI were deployed to Southeast Asia. The craft were assigned to Market Time Forces with a variety of missions and based in Danang. The deployment was considered militarily successful with the ships showing their ability to remain operational in a remote combat area. Their superior utility compared to displacement craft of similar size was demonstrated.

After return to the states in February 1970, FLAGSTAFF was assigned to operate with Coastal River Squadron One at San Diego as part of the Pacific Amphibious Forces. She currently continues to conduct technical and mission operations in this assignment.

Following the deployment in Vietnam, TUCUMCARI (PGH-2) was sent to Europe for a NATO tour and demonstration. From April 1971 until October 1971 TUCUMCARI operated in European waters. She visited seven different NATO countries performing numerous demonstrations and VIP presentations. The underway refueling experiences under many different situations and sea conditions were most gratifying. A number of combat exercises demonstrated the potential effectiveness of hydrofoils ships. These exercises influenced the decision of NATO to proceed into a program to procure a fast patrol hydrofoil, later designated the PHM. The 390 hours of foilborne time logged during TUCUMCARI's deployment further contributed to the hydrofoil community's confidence in their potential.

After returning from Europe, TUCUMCARI was assigned to Coastal River Squadron Two, Atlantic Amphibious Forces. In November 1972, while conducting night exercises with 2nd Fleet, TUCUMCARI flew into a submerged coral reef north of Vieques Island. The ship was salvaged and transported to her home base at Norfolk, Virginia and was removed from service on 7 November 1973 after a decision to forego repair of the damage caused by the grounding. The hull, struts, and foils were transported to NSRDC and are being used for structural and material tests.

3.14 Pegasus PHM-1

In 1970 NATO indicated a need for a fast, seaworthy missile ship to operate in the Mediterranean, North Sea, and Baltic waters. Comparisons were made between planing hulls, catamarans, hydrofoils, and hovercraft.

A hydrofoil was identified as best meeting the requirements, based on the proven U. S. Navy technology, and the PHM program was launched in FY 1971. Italy, Germany, and the United States have become partners under a Memorandum of Understanding. Boeing has engineered and constructed the U. S. Navy lead ship PEGASUS. The U. S. variant of PHM is a 231-ton ship equipped with a 76 mm gun and a HARPOON missile system. Italian and German variants will be equipped with alternate mission suites. The PHM will add a new dimension to the U. S. Navy and NAM forces.

BIBLIOGRPAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.1.1 - HYDROFOIL LIFT SYSTEM-FLUTTER

DATE	DOCUMENT
Nov 1958	Aeronautical Research Council-London (U) Hydro-Elastic Stability of Hydrofoil Struts Hilborne, D.V. TR-3172
Jan 1962	Grumman Aerospace Corp. (U) Experimental and Theoretical Investigation of Hydrofoil Flutter Baird, E.F. Squires, C.E. Caporali, R.L. Rpt-62-55
Sep 1967	Naval Ship Research and Development Center (U) Hydroelasticity with Special Reference to Hydrofoil Craft Abramson, H.N. Chu, W.H. Rpt-2557 AD 682946
Feb 1973	Naval Ship Research and Development Center (U) Bending Flutter and Torsional Flutter of Flexible Hydrofoil Struts Besch, P.K. Liu, Y.N. Rpt-4012 AD 757645
Apr 1974	Naval Ship Research and Development Center (U) Hydroelastic Design of Subcavitating and Cavitating Hydrofoil Strut Systems Besch, P.K. Liu, Y.N. Rpt-4257 AD 780776

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.1.2 - HYDROFOIL LIFT SYSTEM-STEADY LOADS

DATE	DOCUMENT
1945	National Advisory Committee for Aeronautics (U) Summary of Airfoil Data Abbott Von Doenhoff Stivers Rpt-824
May 1953	California Institute of Technology (U) Theory for Hydrofoils of Finite Span Wu, T.Y. CIT-26-8 N6ONR-24426(NR)062-083 AD 018348
1954	Gibbs and Cox, Inc. (U) Hydrofoil Handbook, Volume II, Hydrodynamic Characteristics of Components NONR-507 (00) AD 089681
1954	Gibbs and Cox, Inc. (LJ) Hydrofoil Handbook, Volume I, Design of Hydrofoil Craft NONR-507 (00) AD 089648
1955	National Advisory Committee for Aeronautics (U) Theoretical and Experimental Investigation of the Lift and Drag Characteristics of Hydrofoils at Subcritical and Supercritical Speeds Wadlin, K.L. Shuford, C.L. McGehee, J.R. NACA-1232
1958	Hoerner (Published by the Author) (U) Fluid - Dynamic Drag - Practical Information on Aerodynamic Resistance Hoerner, S.F.
1960	Bureau of Ships (U) Approximate Analysis of Lifting Forces on a King Near a Free Surface Panchenkov Translation No. 825

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.1.2 - HYDROFOIL LIFT SYSTEM-STEADY LOADS CONTINUED

DATE	DOCUMENT
Mar 1965	Journal of Ship Research (U) Lifting Surface Theory of a Fully Submerged Hydrofoil Nishiyama, T.
Oct 1965	David Taylor Model Basin (U) Steady Two-Dimensional Pressure Distributions on Arbitrary Profiles Brokett, T. Rpt-1821 AD 622769
Oct 1965	David Taylor Model Basin (U) Effect of Distortion of Subcavitating Foil Contours on Cavitation-Inception Velocity Moekel, G.P.
1966	(U) Wing of Arbitrary Aspect Ratio Near a Barrier Panchenkov Yukhimenko JPRS 62385
1970	Kazan University (USSR) (U) Problem of Movement of a Section Under the Free Surface of a Liquid
Jun 1974	Naval Ship Research and Development Center (U) Comprehensive Evaluation of Six Thin-Wing Lifting Surface Computer Programs Wang, H.T. Rpt-4333 AD 785228

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.1.3 - HYDROFOIL LIFT SYSTEM-UNSTEADY LOADS

SORTED BY PUBLICATION DATE

DATE	DOCUMENT
1949	National Aeronautics and Space Administration (U) General Theory of Aerodynamic Instability and the Mechanism of Flutter Theodorsen, T. NACA-496
Jan 1957	David Taylor Model Basin (U) Hilbert Problem for an Airfoil in Unsteady Flow Leehey, P. Rpt-1077
1957	Addison-Wesley (U) Aeroelasticity Bisplenghoff Ashley Halfman
May 1963	General Dynamics/Convair (U) Flapped Hydrofoils in Waves, Subcavitating Flow, Tech. Report Conolly, A.C. GDC-63-032 NONR-3180(00) AD 409551
Jun 1964	Massachusetts Institute of Technology (U) Unsteady Loads on Hydrofoils Including Free Surface Effects and Cavitation Widnall, S.E. Rpt-64-2 NONR-1841(81) AD 603246
Jul 1968	Naval Ship Research and Development Center (U) Unsteady Lift and Hinge Moment Characteristics of the AGEH Main Foil and Strut Assembly O'Neill W C. Rpt-280; AD 840551
Nov 1970	Naval Ship Research and Development Center (U) Unsteady Lift Force on a Restrained Hydrofoil in Regular Waves Steele, J.M. Rpt-3386 AD 717338

DATE	DOCUMENT
Nov 1970	Naval Ship Research and Development Center (U) Unsteady Loads on a Two-Dimensional Hydrofoil Pattison, J.H. Rpt-3245 AD 717953
Dec 1972	Grumman Aerospace Corp. (U) Interim Report on Optimization of Forward Foil Lift Control for AG(EH) Hydrofoil Craft - Vol 1: Hydrodynamics Wright, H.R. Jr. Rpt-HCG-72-19(I) N00014-71-C-0160

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.2 - HYDROFOIL CONTROL SYSTEMS AND CRAFT SIMULATION

DATE	DOCUMENT
May 1953	Massachusetts Institute of Technology (U)Design and Test of a Longitudinal Control System For a Hydrofoil Craft Hastings, B.T. Penny, F.W. Baker, J.B. FCL-7203-T-16 N5ORI-07889 AD042960L
Aug 1954	Massachusetts Institute of Technology (U)Design and Test of a Turn Control System for Hydrofoil Craft (U) Slagle, G.M. FCL7203-T-17
May 1955	Massachusetts Institute of Technology (U)Automatic Control of a Variable-Incidence Hydrofoil Craft-Final Report Barnes, F.A. Connors, J.L. Slade, M. FCL-7203-R12 N5ORI-07899 AD078942
May 1955	Massachusetts Institute of Technology (U)Ultrasonic Altimeter For An Hydrofoli Craft Ehrman, L. FCL-7203-T19 N5ORI-07889
Nov 1958	David Taylor Model Basin (U)Theoretical Prediction of the Longitudinal Motions of Hydrofoil Craft Ogilvie, T.F. RPT-1138 AD206647
Dec 1958	Gibbs and Cox, Inc. (U)Five-Ton, Autopilot-Stabiiized Hydrofoil Research Craft-Automatic Control and Stabilization System (Sea Legs) Browne, R. Rosenbaum, G. RPT-14131/S1/1/1-500 NONR-1366(00) AD315030

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.2 - HYDROFOIL CONTROL SYSTEMS AND CRAFT SIMULATION CONTINUED

DATE	DOCUMENT
Aug 1959	Miami Shipbuilding Corp. (U)Installation and Evaluation of the Electra-Hydraulic Autopilot, Thrust Cell, and Rear Foil Angle Adjust Mechanism in Hydrofoil Landing Craft ("Halobates") Final Report Keller, J.W. Wright, H.R. Hutchinson, R.J. R-128 NOBS-4207
Aug 1962	Massachusetts Institute of Technology (U)Study of Hydrofoil Boat Dynamics Wang, s. Lou, Y.K. REMARKS: Theory and Experiment
Jan 1963	Supramar, Ltd. (U)Tests with the Experimental Boat ST-3A with Air-Controlled Fully Submerged Foils Von Schertel, H. Munch, 0. DeWitt, H. RPT-N4 AD830764L
Dec 1966	Naval Training Device Center (U)Hydrofoil Simulation Equations-Mathematical Model Report Vol. I Foilborne Equations of Motion Jamieson, J.J. TR-1630-2-1 N61339-1630 AD649 331
Dec 1966	Naval Training Device Center (U)Hydrofoil Simulation Equations Study-Mathematical Model Report-Vol. III Equations and Methods For Simulation of Realistic Seas Farris, W.E. TR-1630-2-3 N61339-1630 AD649311
Dec 1966	Naval Training Device Center (U)Hydrofoil Simulation Equations Study-Mathematical Model Report Vol. II Equations and Methods for Simulation of Hull Lift, Drag and Pitch Moment Jamieson, J.J. TR-1630-2-2 N61339-1630 AD649 332

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.2 - HYDROFOIL CONTROL SYSTEMS AND CRAFT SIMULATION CONTINUED

DATE	DOCUMENT
Dec 1966	Naval Training Device Center (U)Hydrofoil Simulation Equations Study-Final Report Hydrofoil Simulation Equation of Motion Jamieson, J.J. TR-1630-3 N61339-1630 AD649365
Feb 1967	Boeing Company (U)AG(EH) Linear Analysis Report D2-133019-1 NOBS-62(A) AD380238L
Feb 1968	Boeing Company (U)Analog Computer Predictions of AGEH Foilborne Behavior-Preliminary D2-133040-1 NOBS-62(A)
Jan 1971	Bolt Beranek and Newman, Inc. (U)Unsteady Hydrodynamics and Control of Hydrofoils Near a Free Surface Smullin, J.I. Bender, E.K. RPT-1970 N00014-70-C-0032 AD716681
Jan 1973	Charles Stark Draper Laborator) (U)Hydrofoil Universal Digital Autopilot (HUDAP)-Phase I Final Report Dogan, P.P. Gamber, F.S. Decanio, F.T. RPT-745 N00014-67-A-0204-0060
May 1974	Charles Stark Draper Laboratory (U)Hydrofoil Universal Digital Autopilot (HUDAP)-Phase II-Final Report Gamber, F.S. Medeiros, R. R-817 N00014-74-C-0009 ADA005523
Oct 1974	Supramar, Ltd. (U)Experimental Investigation of 60KT Air-Fed Hydrofoils (233 PP) Von Schertel, H. RPT-NS N68171-73-C-0054

BIBLIOGRAPHY OF SIGNIFICANT ANALYTICAL MILESTONES

5.1.4 • HYDROFOIL LIFT SYSTEM • STRUTS

Date	DOCUMENT
1959	National Aeronautics and Space Administration (U) Exploratory Study of Ventilated Flows about Yawed Surface-Piercing Struts Breslin, J.P. Skalak, R. Memo-23-59W AD 214068
Sep 1965	Journal of Ship Research (U) Unified Lifting-Line Theory of Fully Welled Hydrofoils Nishiyama
Nov 1970	Lockheed Missiles and Space Co. (U) An Experimental Study of the Effects of Waves on the Ventilation of Surface Piercing Struts Waid, R.L. LMSC/D029678 N00014-70-C-0096 AD 721375
Jun 1972	Naval Ship Research and Development Center (U) Effect of a Proturbence and Aspect Ratio on the Inception of Ventilation on a Surface-Piercing Strut in Cavitating Flow Rothblum, R.S. Dailey, N.L. Pattison, J.H. T&E-SPD-479-H-02
Nov 1973	Naval Ship Research and Development Center (U) Experimental Investigation of the Ventilation and Force Characteristics of One NACA-16 and Two Blunt-Based Parabolic Surface-Piercing Struts Dailey, N.L. T&E-SPD-479-H-07
May 1974	Hovering Craft and Hydrofoil (U) Effect of Roughness, Wettability and Speed on the Ventilation Characteristics of Surface Piercing Hydrofoil Struts Rothblum, R.S. McGregor, R.C. Swales, P.D. Paper

BIBLIOGRAPHY OF SIGNIFICANT MILESTONES

5.3 - HYDROFOIL STATE OF THE ART REVIEWS

DATE	DOCUMENT
Nov 1953	Society of Naval Architects and Marine Engineers (U) Appraisal of Hydrofoil Supported Craft Buermann, T.M. Leehey, P. Stilwell, J.J. REMARKS: Presented at meeting in New York, 11-12-53
1958	National Research Council of Canada (U) Hydrofoil Boats-Their Development, Theory and Application Schertel, H. TT-723
Nov 1958	Gibbs and Cox, Inc. (U) Consideration of Size-Speed-Power in Hydrofoil Craft Hoerner, S.F. 14131/S1/1 (l-502) NONR-1366 (00) AD214011
1959	Naval Research Establishment (U) Potential Characteristics of Hydrofoil Craft and Their Realization Eames, M.C. Draft Paper REMARKS: An Excellent Paper
Dec 1962	Bureau of Ships (U) Hydrofoils-A "State of the Art" Summary (Paper) Oakley, O.H. REMARKS: Papers
Mar 1964	Royal Institution of Naval Architects (U) Progress Report on Hydrofoil Ships Lacey, E.R. Vol. 107, No. 1
May 1965	Society of Naval Architects and Marine Engineers (U) Observations and Comments cn Hydrofoils Myers, G.R. Paper-A REMARKS: May 13/14, 1965, Spring Meeting, Seattle, Wash. Author affilated with Boeing Co.

BIBLIOGRAPHY OF SIGNIFICANT MILESTONES

5.3 - HYDROFOIL STATE OF THE ART REVIEWS CONTINUED

DATE	DOCUMENT
Flay 1967	American Institute of Aeronautics and Astronautics (U) U.S. Navy Hydrofoil Development Program-A Status Report Ellsworth, W.M. AIAA-67-351 AD685568 REMARKS: Undated-See NSRDC TN SDD-OH50-62 Nov 1970
Nov 1970	Naval Ship Research and Development Center (U) U.S. Navy Hydrofoil Development Program Status Report Ellsworth, W.M. O'Neill, W.C. TN-SDD-OH-50-62 AD685568
Dec 1971	Inter-plan Corp. (U) Over-the-Water Program Design-Vol. l-Summary Krzyczkowski, R. UMTA-INT-RDC-8-71-1 DOT-UT-10018 REMARKS: A Comprehensive Analysis of commercial applications of Hydrofoil, ACV, SES
Dec 1971	Interplan Corp. (U) Over-the-Water Program Design-Vol. 2-Technology and Operating Experience Krzyczkowski, R. UMTA-INT-RDC-8-71-1 DOT-UT-10018 REMARKS: A Comprehensive Analysis of commercial applications of Hydrofoils, ACV, SES
1973	California Institute of Technology (U) Hydrofoils and Hydrofoil Craft Acosta, A.J. Paper-8041 AD760230
Oct 1974	Naval Ship Research and Development Center (U) Large Hydrofoil Advanced Development Program Johnston, R.J. O'Neill, W.C. Tech Note SDD 11-C-16