PROCEEDINGS

25TH

ANNIVERSARY CELEBRATION AND CONFERENCE

OF THE

INTERNATIONAL HYDROFOIL SOCIETY

FORT RICHARDSON ROOM
ARMY-NAVY COUNTRY CLUB
ARLINGTON, VIRGINIA

JUNE 14 - 16 1995

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WELCOMING REMARKS

On behalf of the Board of Directors of the International Hydrofoil Society, I welcome all members, their guests and colleagues to this 25th Anniversary Celebration and Conference commemorating the founding of the Society in 1970.

It was during a Board meeting in June 1994 that a suggestion was made to celebrate this event. This single remark has generated hundreds of volunteer-hours of effort on the part of many Board members, other IHS members, and fellow colleagues to finally bring us to this point - the opening session of a two and one half day Conference.

Not only have the authors worked hard to generate their papers in a timely fashion for inclusion in the Proceedings along with their presentation materials, but many have worked behind the scene to organize the myriad of details necessary to accommodate the IHS here at the Army-Navy Country Club. We are indebted to John King and George Jenkins for the privilege of meeting here. Papers Chairman, Barney Black, is to be complemented and thanked for his dedicated effort in this capacity. His numerous E-mail messages have found their targets worldwide. Bill Hockberger took on the task of assembling and organizing a Panel Program for Friday morning. His tireless efforts and leadership in this role are recognized and appreciated.

My personal thanks to all of you for your support to make this Conference program so broad and yet so deep. I am confident that at the closing on Friday you will all join me in the clamor.

Not since the First North American International Hydrofoil Society Conference in Nova Scotia in 1982 have we met, as an independent group, to hold meetings and discussions on our favorite topic on the scale that we attempt today. It is therefore my honor and privilege to open this Conference with a hope and desire that much will be gained by all of us as we proceed with the Program before us during the next several days.

John R. Meyer, President
June 14, 1995

INTERNATIONAL HYDROFOIL SOCIETY (IHS), A REVIEW OF THE FIRST TWENTY-FIVE YEARS

by
Robert J. Johnston
Presented 14 June 1995

AUTHOR

Robert J. Johnston is a long-time member of IHS having joined in the mid-seventies. He was a charter member of the North American Chapter of IHS and was the fifth president of the Society. His involvement with hydrofoils started when he was on active duty with the US Navy and fulfilled the assignment of Hydrofoil Project Officer. His interest in hydrofoils led to his resignation from a Regular Naval Officer and a transfer to the Naval Reserve. He is a retired Captain of the US Naval Reserve. Following his Navy resignation, he joined Miami Shipbuilding Corporation as a vice-president in charge of their hydrofoil development. This responsibility included the construction and evaluation of several submerged hydrofoil vehicles, principally in the amphibious application. He later became President of Miami Shipbuilding Corporation. In 1960, he joined the Grumman Corporation's marine group. He was a program manager for the Maritime Commission's *DENISON*, the design of the US Navy's *PLAINVIEW* (AGEH-1), the design and construction of the *FLAGSTAFF* (PGH-1), and the commercial hydrofoil *DOLPHIN* program. He became Grumman's Director of Marine Programs. In 1973, he returned to the US Navy when appointed Technical Manager of the Hydrofoil Development Program at the David Taylor Naval Ship Research and Development Center (DTNSRDC). In 1982, he left DTNSRDC and formed Advanced Marine Systems Associates, Inc., a consulting organization that undertook specialized studies in high-speed waterborne transportation for the US Government, municipalities, and private investors. He is now retired and works at maintaining his golf handicap.

ABSTRACT

This paper traces the development of the International Hydrofoil Society from its London conception, its formation as a Charity under the laws of England, the addition of a North American Chapter, and its transition to a not-for-profit corporation under the statutes of the United States. The story is primarily about the people who have made this all happen, survive, and prosper for twenty-five years. In a sense, it describes a great respect and friendship that the author has enjoyed with the characters of this review.

INTRODUCTION

It was the fall of 1982 and the location was the Royal Yacht Club on the Isle of Wight. We had arrived at the dock by the Red Funnel Lines' hydrofoil from Southampton. This Club is noted by the principal berthing space, right next to the Clubhouse, always being reserved for Her Majesty the Queen's use. The occasion was a dinner party being given by Royal Yacht Club member, CDR Mark Thornton D.S.O., D.S.C., R.N. (Ret.) honoring Sir Christopher Cockrell. Sir Christopher had been knighted for his pioneer invention of the hovercraft concept. Also present at this dinner were executives of British Hovercraft Corporation, Robert L. Trillo Eur. Ing., editor of Jane's *High Speed Marine Craft* and my wife, Marcia, and myself.

Marcia had been granted special privileges not only to join the group in the main dining room, but also to overnight with me in the Clubhouse. The Royal Yacht Club had severe restrictions on women in the dining room and in using the Club's facilities. A verandah had been constructed for Queen Victoria's use so all the women could stay outside. The evening meal was excellent and the chatter was filled with much banter and nostalgia, particularly between Mark and Christopher. Much of the banter related to the beginnings of the International Air Cushion Engineering Society and the International Hydrofoil Society. It seems that Sir Christopher had used Mark's idea of a hovercraft society and had taken over from Mark as the originator. Not to be outdone, Mark had proceeded with the founding of IHS.

As the toasts of the evening proceeded, a note of sadness became apparent. We toasted the Queen and the President and then personal toasts took place between Mark and Christopher congratulating each other on their accomplishments. I shall never forget Mark's toast to Christopher including the words "Christopher, this will be our last meal together." Mark was dying from lung cancer and a few months later, he was gone. This was the end of the beginning of IHS.

THE BEGINING

And so to the beginning... During the 1960s, many individuals in the United Kingdom as well as in other parts of the world, began to show interest in use of high-speed ferries. To an island nation such as England, the use of fast ferries was particularly attractive. Much attention was paid to Sir Christopher Cockrell's work with hovercraft, although the initiation of this attention was difficult to achieve. Christopher once said that to make an advance in the marine field, one had to have infinite patience and a very understanding wife. CDR Mark Thornton, a retired Royal Navy Officer, had recognized the advantages of high speed marine craft and he, therefore, used his efforts to help promote the hovercraft concept. Christopher and Mark worked together and became quite good friends.

With the formation of the British Hovercraft Corporation, the role of Mark Thornton diminished, and he turned his attentions to the growing interest in hydrofoils. It must be said that CDR Mark Thornton was the instigator of IHS. In 1965, he organized the British Hydrofoil Association, Ltd., which was the forerunner of IHS. At the same time, Countess Juanita Kalerghi, who was the editor and founder of the trade magazine *Hovering Craft and Hydrofoil*, encouraged and supported Mark's efforts to found a hydrofoil society. These two individuals, the founders of IHS, had very interesting backgrounds.

Mark Thornton joined the Royal Navy as a midshipman while just a boy. His entire career was in the R. N., rising to and retiring as a Commander. His love of ships centered on the destroyers as the fastest ships in the Royal Navy. During World War II, then Lieutenant Commander Thornton, was assigned command of the *HMS PETARD*. While the *PETARD* was on patrol in the Eastern Mediterranean in October, 1942, the *PETARD* sank a German submarine, the U-559. Mark had extensively trained his crew to capture a U-boat. When the damaged submarine surfaced, a boarding party, trained for such action, went on board. While they couldn't save the submarine, they did manage to retrieve signal books and a decoding machine which enabled the allies to decode German messages. For this accomplishment, CDR Thornton was decorated by the Royal Navy. Mark's Executive Officer, who led the boarding party, and a sailor were lost in the action. More details of this story are contained in reference (1). After Mark's retirement from the Navy, he devoted his time and energies to advancing the cause of hovercraft and hydrofoils.

Juanita Masur was born in the Transvaal Province of South Africa, where she spent her early life. Her mother was Hungarian, although born in the USA, and her father, family name Masur, was a true South African pioneer. Juanita attended college at Witwatersrand University, where she earned a BA degree in political philosophy and economics. She displayed an interest in journalism while in college by becoming editor of the school's newspaper. Juanita considered the South African rules of apartheid unfair, resulting in loss of educated personnel. So she, with some of her classmates, ran a secret nighttime school teaching blacks to read and write. Upon graduation, Juanita's future was focused on journalism. She undertook assignments with the magazines *Democrat* and *South African Opinion*. These assignments resulted in her appointment as sub-editor of the *Johannesburg Sunday Express*. Her interest in politics was centered on General Smuts' United Party. Juanita was selected for the post of organizing secretary of women's groups for the party. During World War II, Juanita assisted her mother in the administration of the camp of 90,000 German and Italian prisoners of war. Recognizing that among the prisoners were doctors and educators, the two women, mother and daughter, organized hospitals and schools staffed by these trained professionals. For these efforts Juanita's mother was honored by the Italian Government.

In 1951 Juanita was selected to represent South Africa at an International Conference of Women in Athens, Greece. While in Greece she met and later married Count Nicholas Kalerghi Mavrogeri, Director of the Ministry of Justice, President of the Martial Court, and legal adviser to the Hellenic Royal family. From this marriage she was titled Countess Kalerghi. While living in Greece she accepted a commission from Quentin Reynolds to prepare a special issue on Greece for the *United Nations World*. This commission led to a teaching position at the University of London which included the editing of the University's Education Journal. In 1961 Juanita made the decision to organize and edit a magazine in the rapidly expanding field of waterborne transportation, and with this *Hovering Craft and Hydrofoil* came into being. The name was later changed to *High Speed*

Surface Craft. Juanita eventually sold her interest and retired as editor of the magazine, which is now known as *Fast Ferry International*.

During the late 1960s, Mark, with Juanita's support, started the effort that led to IHS. A steering committee was formed to initiate IHS as a Charity. Mark Thornton was the chairman, and organizational meetings were held in Juanita's place of business. Other members of this committee included Derek Deere, Alan Buckle of Lloyds Register, Michael Eames, and the sailing enthusiast, James Grogono. This effort resulted in the Society being registered as a Charity in 1970 in the United Kingdom. The laws regulating a Charity in the United Kingdom are similar to those for a not-for-profit corporation in the United States. The registration identified the management of the Society as a governing council headquartered in London, England.

On October 20, 1970, at the Institute of Mechanical Engineers in London, the Inaugural Meeting of the International Hydrofoil Society took place. Presiding at this meeting was Baron Hanns von Schertel, who had been elected as the first President. This honor to Baron von Schertel recognized his contributions and inventions related to the development of the hydrofoil. The Baron had at that time spent almost fifty years in developing and perfecting the Schertel hydrofoil system. For much of this effort, he had been supported by an inheritance from his mother. His father was a titled Baron in Germany and his mother was a United States citizen who was heiress to her father's US brewery. They had been married at the turn of the century when it was very popular for wealthy American women to go to Europe to meet and sometimes marry titled Europeans. From his mother's wealth, Schertel was able to finance his many tries at developing a workable hydrofoil system, see reference (2). After he had achieved a performing hydrofoil system and had patented it, he teamed with a German shipbuilder, Sachsenburg, to obtain several building contracts for the German Navy.

Their first Navy contract was to build a trial vessel designated the VS 6 to compete against VS 7, a hydrofoil based on Dr. O. Tietjen's system. The VS 6 proved to be a superior design, and further contracts were awarded to the Sachsenburg Brothers Shipyard during World War II. Two Schertel-Sachsenburg craft were built for the German Navy, the VS 6 which was to be used as a mine layer, and the VS 8 which was planned for carrying tanks between Italy and Africa. This latter design was abandoned after being damaged by Allied bomb raids.

Following WWII, Baron von Schertel moved to Switzerland and formed Supramar, a company devoted to the design of hydrofoil passenger boats. In 1953, the Schertel design PT 10, a twenty-passenger hydrofoil, inaugurated service on Lake Maggiore between Ascone, Switzerland and Stasa, Italy. This was the first passenger hydrofoil to be placed in service. Other larger passenger hydrofoil designs were developed by Supramar and were licensed to be built in a number of countries throughout the world. With this background, it was only fitting that Baron von Schertel be honored with first Presidency of IHS.

BARON HANNS VON SCHERTEL, IHS PRESIDENT 1970 TO 1974

Inaugural Meeting

The October 20, 1970 inaugural meeting of IHS was quite successful with fifty members and guests attending. CDR Mark Thornton opened the affair by introducing Baron Schertel as the first IHS President. The Baron's presidential address began by recognizing the representatives from other Societies and Institutions. As president, he promised to contribute his utmost to the successful development of the Society, although handicapped somewhat by living some distance away from London in the Swiss mountains. He congratulated CDR Thornton for having taken the idea and perseveringly employed his initiative to found the Society. He emphasized that the Society was an international technical society and that the main aims of the organization were to advance the study and research into the science and technology of hydrofoils, both power and sail. The Baron expressed hope that our new Society would succeed in transforming "Cinderella" (hydrofoil) craft to a favorite known to the broad public. He pointed out that it took almost fifty years to go from the first flight of Forlanini in 1905 on the Lake Maggiore to the introduction of the first public hydrofoil transportation on that same lake.

Also on the agenda of the inaugural meeting was a paper presented by Mr. Urushidani of the Hitachi-Zosen of Japan. The title was "Nine Years of the Hitachi-Supramar Boat," see reference (3). His paper discussed the experience of Hitachi-Zosen in building the Supramar PT 20 and learning the operational and maintenance techniques to make a commercial hydrofoil successful. This paper stated that the capital cost of their PT 20 was $380,000 US.

Shown at this meeting was a film made by the National Film Board of Canada of the Canadian Forces hydrofoil ship Program, *BRAS D'OR*. The concluding paper was given by Mr. John Fowler of the Amateur Yacht Research Society (AYRS) discussing the experiments made during the past few years with foilborne sailing boats.

First IHS Council

Preceding the inaugural meeting, the Steering Committee worked out the final details for the formation of IHS and completed its efforts. The following participants on the Steering Committee agreed to become members of the first Council:

- Baron Hanns von Schertel, President
- A.M. Gonnella, Boeing Company, Vice President
- CDR Mark Thornton, Chairman
- Derek Deere, Technical Editor
- Michael Eames, Head of Canadian Defense Board's Hydrofoil Program
- James Grogono, Surgeon, Sail Hydrofoils
- Miss J. Kalerghi, Editor *Hovering Craft & Hydrofoil*

During the Baron's time as President of the Society, the Council met several times a year. Meetings were scheduled as issues arose that required action and as developments occurred in the life of the Society and hydrofoils. Several meetings of the Society were held where technical papers were presented and discussed. In March 1971, Michael Eames presented a paper at a Society meeting on the *BRAS D'OR* program. At a Council meeting at the same time, Michael was elected Vice-President of the Society.

The Council placed much importance in establishing a Society library. By the end of the Baron's presidency, approximately three hundred documents had been indexed. It is interesting to note that from the beginning of the Society, interest was expressed in the sponsorship of a technical book on hydrofoils. The first planning was for a book titled *The Handbook of Hydrofoils*. Fifteen sections were planned including theory, design, economics, seakeeping, sailing hydrofoils, and history. This handbook concept has remained an objective during the life of the Society.

In November 1971, a winter meeting of the Society was held. Baron von Schertel gave a review of the first year's progress of the IHS. During that year, the Society was legally finalized as an English Charity. The membership increased to about one hundred. Interest in military hydrofoils was demonstrated by Germany, Italy, Canada, Japan, USSR, and the United States -- all having on-going developments. The US Navy's *TUCUMCARI* (PGH 2) had been visited by several members while operating in Germany. The FLAGSTAFF (PGH 1) had been outfitted with a six-inch gun and accurately fired while foilborne. Professor S. Schuster, Director of the Berlin Towing Tank, gave the principal paper "Research on Hydrofoil Craft" at this meeting.

The 1972 meeting of the Society was on the subject of "Hydrofoil Sailing." Allan J. Alexander and James Grogono presented papers and led discussions on this subject. Also on the agenda was a US Navy film showing the *TUCUMCARI* and *FLAGSTAFF* operating foilborne.

PETER DOREY, PRESIDENT 1974 to 1977

Peter Dorey was the Managing Director of Condor Ltd, located on Guernsey, one of the Channel Islands of the United Kingdom. Condor Ltd started in 1964 with one hydrofoil, *CONDOR 1*, a Rodriquez built, Supramar designed PT 50. They continued to add Rodriquez hydrofoils to their fleet and became the largest passenger carrier between the Channel Islands and the coast of France. Condor used the Port of St. Malo as their primary destination. However, during March to November, service was provided to the mainland of England.

The Society considered it most appropriate to have a hydrofoil operator as president, following the presidency of a designer and developer of hydrofoils. The Society was quite pleased when Peter Dorey agreed to accept the role of President. Peter was a very interesting and likable personality. His family interests were much broader than transportation. They owned dockyard facilities where the upkeep and maintenance of their hydrofoils were performed. Also, they owned hotels and other real estate on the Islands. They catered to the summer time and holiday visitors to the Islands.

Guernsey was an interesting place to visit. The Channel Islands are exempt from British taxes. As can be expected, this makes the Islands an attractive location for individuals and corporations to avoid taxation. However, to support the local government, the citizens are required to undertake certain tasks. When visiting the Islands, you may find your host off for a few days working on the roads or performing other civic duties.

Peter Dorey was a conservative manager. Although starting rather early in hydrofoil transportation, he studied and experienced the performance of hydrofoils along with their reliability and maintenance requirements before committing to their acquisition. The first PT 50 was actually assigned to Condor for a trial period prior to making the decision to purchase. Another example of his conservatism was experienced by Grumman. Before the management of Grumman would support the *DOLPHIN* hydrofoil program, they required that ten potential customers be identified and committed to the program. This commitment was based on the *DOLPHIN* being produced with the predicted performance and cost. Condor became one of the committed ten. When Peter agreed to this, he said he would take number ten off the production line. His wisdom in wanting to experience the performance, reliability, and cost factors of owning and operating a craft for Condor's fleet was clearly demonstrated.

Peter Dorey became the second President of the Society on January 14, 1974 at the Annual General Meeting in London. In his acceptance remarks to the members, he gave a special vote of thanks to the outgoing president Baron von Schertel, the Chairman of the Council, Mark Thornton, and to Juanita Kalerghi for her support of IHS. President Dorey, in his address, spoke on the status of the hydrofoil industry, stating that it was a growth industry. He further discussed the advantages of the hydrofoil over other vehicles, particularly the open sea passenger comfort.

During Peter Dorey's presidency of IHS, time had lost the details of all of the meetings of the Society and its Council. One of the known facts is that Dott. Ing. Leopoldo Rodriquez became the vice-president and that the Council, with Mark Thornton as Chairman, and changes in the membership, continued to function effectively. Periodic Newsletters followed the first one that was issued in 1971. While not always achieved, the goal was to publish a spring, summer, autumn, and winter Newsletter. Information was also provided to the members by the *Hovering Craft and Hydrofoil* publication. The number of documents in the IHS library continued to grow. Some progress was reported in the development of the *Hydrofoil Handbook*, as authors of chapters were solicited and changed when authors withdrew.

During May 1974, Countess Kalerghi organized an International Hovering Craft and Hydrofoil Conference and Exhibition at Brighton, England. Cosponsors were IHS, UK Hovercraft Society, Institute of Marine Engineers, Royal Institute of Naval Architects, and the Institution of Production Engineers. IHS sponsored and manned a booth at the

Exhibition. During one evening of the Conference, a general meeting of the IHS members was held, which was primarily a social occasion.

Again in the Spring of 1976, Juanita Kalerghi sponsored and organized a High Speed Surface Craft Conference and Exhibition in Amsterdam, Holland. This conference was well received in the technical and operational communities of these craft. Individuals from many countries attended including commercial and military representatives. The papers presented were well received and honors were awarded to the authors of the outstanding papers. LCDR Robert E. Nystrom, USN, Officer in Charge of the Navy's Hydrofoil Special Trials Unit, and a member of IHS, presented a paper on the experiences of this trials unit. The paper was judged the outstanding hydrofoil paper and LCDR Nystrom was so honored. Russian representatives were present at this conference. This was one of the few times that an interchange of ideas was made between representatives of countries of NATO and Russia during the cold war. The United States representatives were somewhat surprised to learn the extent of knowledge of the Russians regarding the US military hydrofoil program and its participants.

In conjunction with the Conference, a meeting of the IHS members attending was held. Peter Dorey organized and hosted this meeting at the Amsler Hotel in Amsterdam. While the evening meeting was primarily social, this was considered the annual meeting of the Society for 1976. President Dorey provided a review of the IHS status and conducted such business that needed attention. Peter's hosting capabilities were demonstrated as outstanding. After a day of technical meetings, that evening of the Society's meeting was most relaxing and worthwhile.

One of the issues that Mr. Dorey undertook was to get the British Government to take more interest in hydrofoils. From one of Peter's papers, reference (4), these words are taken. "From the very birth of the hovercraft industry, however, there has always been a hydrofoil lobby which fought against the allocation of such substantial funds towards hovercraft development whilst nothing of any consequences was allocated to hydrofoils.

"There has been, and still is, a great deal of misunderstanding and lack of appreciation of the true capabilities of hovercraft and hydrofoils as individual vehicles. I have said on occasions, and do feel strongly, that hovercraft have a worthwhile future but like every vehicle that ever was, they have their limitations and also have severe problems both operationally and financially.

" . . . Perhaps it is a fact that one of the greatest sources of strength of the (commercial) hydrofoil industry is its lack of reliance on government funds. Decisions which are taken by commercial hydrofoil designers and builders have to be right to the best of their knowledge and ability or it becomes extremely expensive for them . . . One of the greatest spurs to success in any activity is personal risks whether financial or by reputation."

Peter Dorey was a member of a Working Party formed by the British Government to assess the virtue and importance of commercial hovercraft and hydrofoils. The Working Party's report included reference (4), part of which is quoted above. This report was submitted to the Minister of Technology in November, 1968, but was never published. A number of questions were raised about it in the House of Commons but the replies were always evasive. Peter was a strong believer that commercial hydrofoils had their place in waterborne transportation.

Peter Dorey was also an enthusiastic sailboat owner. One of his greatest joys was in racing his sailboat, an ocean racer. Generally, members of the Dorey family were the crew. Their many trophies represented the success of their sailing endeavors. One of the major races was the Fastnet Race sponsored by the British Sailing Association. This was an open sea event held off the southwest coast of England. In the summer of 1979, a Fastnet was scheduled when the weather predictions were not favorable. The race was started in spite of these predictions. As the race proceeded, storms hit the fleet with increasing winds and seas. Several boats were lost or damaged and there were fatalities including the life of Peter Dorey. Peter was on deck, reefing and trimming the sails while trying to maintain the heading of the boat into the sea. He had taken proper precautions, wearing a harness to prevent being swept overboard. However, a large wave crashed into the boat, tearing the harness loose from its fastenings and Peter was swept overboard. As he disappeared into the gloom, he shouted to his son “save yourselves and the boat. Don’t come about.” A tragic end to a young man’s life.

DOTT. ING. LEOPOLDO RODRIQUEZ PRESIDENT 1977 TO 1981

In 1977, IHS, with the desire to alternate the honor of the presidency between a person with a technical background and an individual with operational experience, elected Dott. Ing. Rodriquez as president. At that time, Leopoldo was the technical manager and principal naval architect of Rodriquez Cantieri Navali of Messina, Italy. This shipyard had produced the largest number of hydrofoils of any organization in the free world. Their hydrofoils were operating in a number of countries throughout the world. The yard was under the direction of Leopoldo’s uncle, Carlo Rodriquez, who in 1953, had started the construction of their first hydrofoil, a PT 20, under license from Supramar. The yard continued to build Supramar PT series vessels until the early 1970s.

In 1970, Carlo Rodriquez made the decision and directed his nephew Leopoldo to investigate the introduction of electronic seakeeping systems into a new design. Using the experience of Hamilton Standard, a US company with a background in automatic control systems for hydrofoils, Leopoldo initiated the new design. Surface-piercing W-foils were used to replace the V-foils of the Supramar PT hydrofoils. The W-foils had trailing edge flaps in both the bow and rear foils -- these flaps being controlled hydraulically by the electronic seakeeping system. The result was reduced motions of heave, pitch, and roll in a heavy sea. This new design proved to be well fitted for longer sea routes so that larger hulls and increased passenger capacity were required. The new series was designed RHS.

In 1976, the first RHS 160 was launched, marking a productive success for the Rodriquez shipyard and a tribute to Leopoldo’s engineering skills. This hydrofoil, over thirty meters long and with a capacity of over two hundred passengers, was able to navigate sea conditions that had been previously believed to be prohibitive for surface piercing hydrofoils.

Quite early in his presidency of the IHS, Leopoldo pursued an idea that had been on his agenda for some time. Prior to his election as president, he had been an active supporter of the Society, attending Council meetings in the role of vice-president. Leopoldo had recognized that the members of the Society from the United States and Canada outnumbered the balance of the membership. His ambition was to organize a North American Chapter of IHS. At that time, IHS had about 125 members. In this regard, he solicited the support of Robert J. Johnston. Bob, in turn, bounced the idea off other prominent hydrofoilers including William Ellsworth, Associate Technical Director of DTNSRDC, James Schuler of the Naval Sea Systems Command, Michael Eames of Canada, CAPT. John King, USN, Chief of Naval Operations PHM Administrator, Walter Wohleking, Manager of Grumman's hydrofoil program, William M. Schultz of Boeing Marine Systems, and Harlow Longfeller from Boeing. The basic idea of a North American Chapter in general was considered to have merit, and a decision was made to pursue the matter further.

On April 16, 1978, in conjunction with an AIAA Advanced Vehicle Conference in San Diego, California, a dinner meeting was held at the Admiral Kidd Officers Club. A significant number of members of IHS attended this meeting with the objective of inaugurating the North American Chapter. President Rodriquez addressed the meeting which included the following remarks:

"As the newly elected President of the International Hydrofoil Society, let me express my happiness in finding new friends pursuing the same aim of the Society -- to advance the study and research into the science and technology of hydrofoils, both power and sail. . . .Bob (Johnston) for sure told you that we are working very closely to establish the Society's Chapter on this side of the world. I am sure that with your efforts, the North American Chapter can be realized for the common benefit of every hydrofoiler in the world."

With the inaugural meeting of the North American Chapter having made the decision to proceed, the necessary steps were undertaken to formalize the Chapter. LCDR William C. Stolgitis, USN, then serving as hydrofoil program officer at DTNSRDC and a member of IHS, held a law degree. His talent was most helpful in undertaking the legal effort to register the North American Chapter of IHS (NAC-IHS) as a not-for-profit corporation under the statutes of the State of New York. The Certificate of Incorporation was signed on April 14, 1980. This process was materially assisted by the efforts of William Schultz in providing guidance in forming the rules and regulations of NAC-IHS. Mr. Schultz had experience in the formation of a not-for-profit corporation for a ferry boat organization. At that time, Bill Schultz was a vice-president of the Boeing Marine Systems Far Eastern Division.

The governing rules of NAC-IHS required an annual meeting to be held where a board of directors would be elected. In the spring of 1981, in conjunction with the annual meeting of the American Society of Naval Engineers, a dinner meeting of NAC-IHS was held where the first board was elected. These first, board members are identified in the addendum of this paper. The board then elected the officers of the Chapter. The officers elected were Robert Johnston, President, William Stolgitis, Vice-President, and John King, Secretary-Treasurer. It should be noted that John King has faithfully, loyally, and competently undertaken the chores and responsibilities of secretary-treasurer since the inception of the Chapter and continues to function in this capacity with IHS in 1995. The Chapter was formed with fifty charter members.

In the meantime, the IHS Council held periodic meetings, managing the affairs of the Society and issuing periodic Newsletters from London. On November 28, 1978, Mr. T. Pellinkof relieved Mark Thornton as Chairman of the Council. Mark then became Vice President of the Society. Juanita Kalerghi remained a strong supporter of the Council and the Society. It was a pleasure to learn that Juanita was married to Nat Rothman, an English barrister, during September, 1980. In June 1980, in conjunction with an exhibition and conference held in Brighton, England, and sponsored by Juanita Kalerghi and her magazine, a dinner meeting of the IHS members attending was held. President Rodriquez presided where he reviewed the state of the Society and informed the Non-North American members present about the formation of the new Chapter. The members in turn honored Leopoldo Rodriquez and Mark Thornton for their contribution to the Society.

DAVID C. H. LIANG, PRESIDENT 1981 TO 1985

In March 1981, an IHS general meeting was held at the Royal Institute of Naval Architect in London. At this meeting, the selection of David Liang as President was announced. His selection was in keeping with having a sequence of an operator and a developer of hydrofoils alternate as president. David's father had established the Hong Kong Macao Hydrofoil Company in 1964. When his father died in 1977, David became responsible for managing his family's interests. These interests included not only the hydrofoil company but also an old established shipping and ferry company, hotels, other real estate holdings, as well as interests in other small businesses in Hong Kong. In this regard, he was the "Tai-Pan" of the Liang family assisted by his brothers. The China interest in the link between Macao and Hong Kong placed particular importance on the hydrofoil company.

In his acceptance address to the Society, David Liang paid homage to his illustrious predecessors, Baron Von Schertel, Peter Dorey, and Leopoldo Rodriquez. He discussed the importance of hydrofoils to areas of densely populated regions with a large ratio of working commuters. Using Hong Kong as an illustration, he pointed out that, in 1980, close to five million people traveled between Hong Kong and Macao. In addition, feeder services using hovercraft were being introduced between Hong Kong and the People's Republic of China. He encouraged the continual development of bigger, more cost-efficient craft to address the growing requirement for fast, waterborne transportation. David Liang's aims for the IHS included broadening the membership to encompass a wider cross section of people including mariners, designers, shipbuilders, and transportation consultants. He also expressed hope to have the Society issue the handbook of hydrofoil technology during his tenure which would be useful to both operators and manufacturers. He stated that the IHS library then contained over three hundred publications and is located at the Royal Institute of Naval Architects in London.

At the Spring 1981 meeting of the Society, three technical papers were presented:

- "Hydrofoils in Hong Kong," by Kenny Tham, Technical Mgr of Hong Kong Macao Hydrofoil
- "Future Ship's Bridges and Navigation Systems" by CAPT. I. S. S. Mackay, Royal Navy
- "A New Self Controllable Pitch Propeller" by John Coxon

In September 1981, in conjunction with the AIAA's Marine Conference celebrating the AIAA's Fiftieth anniversary, a meeting of IHS was held in Seattle, Washington. During the three-day AIAA Conference, members of IHS attending were invited by Boeing to attend the christening and launching of the *USS AQUILA* (PHM-4). President David Liang came from Hong Kong to attend the IHS meeting and to give an address at the IHS dinner. He gave a very interesting talk on the problems in achieving commercial viability of high speed waterborne transportation.

In July 1982, the NAC-IHS organized a meeting of the Society at the Keltic Lodge, Ingonish Beach, Nova Scotia, Canada. The planning committee for this meeting was co-chaired by Mike Eames of Canada and Bob Johnston of the United States. Eighty-five members and guests of the Society attended this event. The Parks Canada Bell Museum, in nearby Baddeck, provided support and facilities for the Society's use. A special tour of the Museum was arranged where Bell-Baldwin hydrofoil HD-4 replica is located. Descendants of Alexander Graham Bell, who spend their summers around Baddeck, invited the Society to a beautiful Canadian salmon picnic lunch. The meeting lasted three days with papers of technical and historical interest presented. One of the historical highlights was the reading by Juanita Kalerghi of a paper prepared by the Society's first president, Baron Van Schertel, reviewing his lifelong hydrofoil experiences, reference (2). The Baron was in attendance, but his health prevented his presentation of the paper. This was the last paper ever written by the Baron.

President David Liang attended this meeting and was the principal speaker at the banquet. The province of Nova Scotia had assisted in arranging the banquet meal. In words of the Governor, he stated that he wanted the many visitors to have an outstanding Nova Scotia dining experience. The members all agreed that he had accomplished his objective. The evening began with the members being piped into dinner by a charming lass on her bagpipes. From then on, the evening was filled with much banter and fun. When it came time for the President's address, he showed his paper to the toastmaster, Bob Johnston. It was a rather carefully prepared, complex discussion on the subject of commercial hydrofoil operations. David's remarks to Bob were that he didn't think the paper was in keeping with the spirit of the evening. So in lieu of his prepared speech, he gave a spontaneous, humorous talk on the lighter side of hydrofoil experiences. His talk topped off a delightful evening.

During David Liang's term as president of the Society, changes took place within IHS and the expanding world of hydrofoils. In competition with the Hong Kong Macao Hydrofoil Company, the Far East Company of Hong Kong acquired Boeing-built Jetfoils. This competition along with the demands of the Liang family's businesses curtailed David's travels to various meeting of the Council in London and the North American Chapter. David stayed in touch with both organizations and suggested an IHS meeting in Hong Kong. This never came to be, much to the regret of many of the membership. In addition to the continuing growth of commercial hydrofoils, several nations were now operating and acquiring military hydrofoils. The US Navy's fleet of PHMs became active and fulfilled their assigned roles with success. Italy built and operated a squadron of *SPARVIERO* Class, hydrofoil missile craft, developed from the successful Boeing-built *TUCUMCARI*. Israel contracted with Grumman for the construction of missile carrying, surveillance hydrofoils. The lead ship was built in the US and follow production was in Israel.

On November 21, 1982, CDR Mark Thornton died. Juanita Kalerghi was elected as the Chair of the Council which she held until IHS was incorporated in the US. To assist Juanita, the North American Chapter undertook to put out an occasional Newsletter to all IHS members. It is interesting to note that the aim of the Society to publish a *Hydrofoil Handbook* was of high priority but proved difficult to achieve. With the undertaking of the Newsletter responsibility, the NAC also assumed the task of publishing a *Hydrofoil Textbook*. The name was changed from "Handbook" to "Textbook" with the aim of making it attractive to schools of naval architecture and marine engineering. Dennis Clark, as a member of DTNSRDC's advanced hydrofoil program, agreed to head a publishing committee with Michael Eames as editor.

From 1980 to 1982, Robert Johnston continued as President of NAC-IHS. In 1981, Dr. James Wilkins was elected Vice-President, succeeding LCDR William Stolgitis. Dr. Wilkins, as a Captain in the US Navy, had been the PHM program manager. In 1982, Dr. Wilkins was elected President of NAC-IHS, and CDR Ronald Adler was elected Vice-President. Ronald Adler owned and managed a consulting firm specializing in naval logistics and mission analysis. His expertise in this field had contributed substantially to the US Navy's advance vehicle program. James Wilkins and Ron Adler were re-elected to their respective capacities, serving from 1982 to 1984.

The 1984 annual meeting of the NAC was held in April at the Army-Navy Country Club in Arlington, Virginia. Ronald Adler was elected President and Raymond Hoop, Vice President. Raymond was a long-time supporter of all aspects of the US Navy's hydrofoil program, working as a team leader for the contractor, Wheeler Industries. He was a charter member of NAC. During all of these officer changes within NAC, John King continued as the loyal Secretary/ Treasurer keeping the chapter on a sound financial basis. At this 1984 meeting, CAPT. W. Scott Slocum, USN, was the dinner speaker. CAPT Slocum had just been relieved of the command -- of one of the PHMs. He gave a very informative talk on the activities of the PHM squadron. At this meeting, the Captains of the PHMs and their Squadron Commodore were made honorary members of the Chapter.

CAPTAIN ROBERT J. JOHNSTON, PRESIDENT 1985 TO 1987

By letter dated February 3, 1985, the IHS Council informed Robert Johnston that he had been elected the fifth President of IHS. At that time, he was the president of Advanced Marine Systems Associates, Inc., a consulting organization, specializing in high speed waterborne transportation studies. He had been a member of IHS since the 1970s while working on several military and commercial hydrofoil projects. The 1985 announcement letter stated the following: “Your dedication to the aims and goals of the Society, along with the efforts of you and your North American colleagues to formulate the North American Association, have been the basis of our selection for you to become the Fifth President of the International Hydrofoil Society.” This recognized the effort put forth by several members in forming and activating the North American Chapter. The appointment went on to state the following: “Our first request to you as President is to undertake the transfer of the management responsibilities of the International Hydrofoil Society from London to North America. This would require the formation of a new governing Council to govern our society’s activities, and to conduct annual council meeting.” The letter was signed by Juanita Kalerghi, Chairman of Council.

Robert Johnston’s primary aim as president, therefore, became to make the transition as smooth as possible. An interim council was formed with Ron Adler, the President of NAC, as the chairman of the interim council. The members of the interim were William Ellsworth, Raymond Hoop, George Jenkins, Juanita Kalerghi, John King, Robert Ripley, James Schuler, William Stolgitis, Donald Wight, and James Wilkins. John King was assigned the responsibility of handling the transfer of assets from London to the United States. William Stolgitis went to work on incorporating IHS as a not-for-profit society under the statutes of the State of New York. The basic format of the North American Chapter’s management was adopted for IHS. A board of directors consisting of nine members replaced the council. The format called for an annual meeting where three members were elected to the board annually for a three-year term. The Board of Directors then elected the officers of IHS to serve a one-year term.

A position of recording secretary was also established. Patsy Jackson had been an active member and participant in the NAC’s affairs since the Nova Scotia meeting where she was in charge of registration. She helped significantly in organizing the annual dinner meetings of the Chapter. Appropriately, Patsy Jackson was officially made the Society’s recording secretary, a position she continues to fulfill.

During this transition period, the North American Chapter continued to function under its elected officers. Periodic board meetings were held with the interim council of IHS to report on the status of the incorporation and to resolve issues that arose. Ronald Adler, President, Raymond Hoop, Vice-President and John King, Secretary /Treasurer were the officers of the Chapter until the annual meeting in April 1986 when, after six years, NAC was phased out and replaced by IHS, managed from North America.

During this transition period, on April 18, 1985, the first president of the Society, Baron Hanns von Schertel died. The Baron was born on January 8, 1902 in Seeshaupt/OBB, Germany and passed away in Stanstad, Switzerland. His obituary was in reference (5).

Also, in December 1985, the Publication *High Speed Surface Craft*, founded in 1961, as *Hovering Craft and Hydrofoil* by Juanita Kalerghi, changed hands. The High Speed Surface Craft Publishing Associates from Capstan Publishing acquired all rights and interests in the publication. Alan Blunden became editor, and David Woodgate, the advertising manager. This publication is known today as *Fast Ferry International*. Messrs. Blunden and Woodgate still hold their original positions.

JAMES L. SCHULER, PRESIDENT 1987 TO 1989

The Certificate of Incorporation was received in time for a formal announcement at the annual spring meeting of IHS. The first North American board of directors was elected by the membership. The Board then elected James Schuler the sixth President of IHS. John King was elected to both the positions of Vice-President and. Secretary/Treasurer. Jim Schuler's selection as President recognized his years of contributions to the Society and to developing hydrofoils. The combination of Jim Schuler and Bill Ellsworth had sustained and advanced military hydrofoils for the US Navy, particularly during the 1960s. The capability of submerged hydrofoil systems had been demonstrated by the performance of *HIGH POINT* (PCH-1). Also the *PLAINVIEW* (AGEH-1) had been built and gave an indication of the use of larger military hydrofoils.

The major questions confronting the US Navy were, what was the role of military hydrofoils and how best can they be manned and maintained? Bill Ellsworth came up with the idea of forming a Hydrofoil Ship Trials Unit (HYSTU) with the two above hydrofoils as the trial ships to address these questions. Jim Schuler, who was the father of hydrofoil development in the US Navy's Naval Sea System Command, used his influence to support HYSTU and to provide the necessary resources. On November 10, 1966, HYSTU was established as a tenant activity at the Puget Sound Naval Shipyard, Bremerton, Washington. The life history of HYSTU is excellently described in reference (6). Jim Schuler continued as a supporter of the development of hydrofoil systems for the US Navy until his retirement. In the meantime, he had become a chartered member of the North American Chapter and a supporter of the aims of IHS.

James Schuler was elected President of IHS again in 1988 with John Meyer becoming Vice President, and John King remaining the Secretary/Treasurer. The Society's annual dinner meetings were well attended and looked forward to by the members. These meetings were semi-technical as guest speakers gave talks on recent developments in both the commercial and military world of hydrofoils. They were also social in nature, giving old friends the opportunity to renew acquaintances and to catch up on what these friends were doing. Work continued on the preparation of a *Hydrofoil Textbook*, with several chapters completed, but the final preparation for publication remained elusive.

Unfortunately, on January 23, 1989, after Jim had retired from the Civil Service and joined Engineering and Science Associates, Inc. of Rockville, Maryland, he suffered a severe heart attack. While the attack proved not to be life threatening, it did cause a severe disability from which Jim has never fully recovered. John Meyer stepped into the role of acting President of IHS. He kept the Society functioning, organizing periodic board meetings and the 1989 annual meeting.

DR. JAMES R. WILKINS, PRESIDENT 1989 TO 1991

At the 1989 annual meeting, James Wilkins was elected the seventh President by the Board of Directors of IHS. John Meyer was reelected Vice-President and John King continued on in his position of Secretary/Treasurer. Dr. Wilkins had retired as a Captain from the US Navy and established Wilkins Enterprise, Inc. in Annapolis, Maryland. His long time interests in the Society and hydrofoils, and his major contribution to the US Navy's Patrol Hydrofoil Missile (PHM) ships as acquisition manager were recognized by his being elected President. One of his early suggested goals, strongly supported by the Board and the Vice-President, was the commitment to publish four Newsletters a year. Bob Johnston volunteered to be the editor, with Patsy Jackson doing most of the work as the Production Editor. This commitment has remained an aim of the Society since that time.

At the annual dinner meeting of the Society in 1990, the above officers of IHS were reelected and commended for maintaining an active program. Renewed hopes were expressed for the publishing of the long awaited *Hydrofoil Textbook* based on Michael Eames' retirement from the Defense Research Establishment Atlantic of the Canadian Navy, giving him time to edit the book. William Ellsworth and Mark Bebar agreed to investigate sources of funding support to help finance the preparation of the missing chapters. Mike Eames believed that the editing process should not start until all the chapters were in draft format.

CDR Charles Luck, USN, the Chief of Naval Operation's platform sponsor for PHMs, addressed the 1990 annual meeting. He stated that the PHMs were operating much as other Atlantic Fleet units. These assets are committed to the national counter-drug effort in the Caribbean. The PHMs have accounted for about one-third of all Navy-assisted drug seizures since 1983. CDR Luck attributed this high success rate to the ships' high speed and maneuverability in the open sea.

JOHN R. MEYER, PRESIDENT 1991 TO PRESENT

At the Spring 1991 IHS Annual Meeting held at Army-Navy Country Club, Arlington, Virginia, the Board elected John Meyer as the eighth President of IHS. Mark Bebar was selected as Vice-President and John King as Secretary/Treasurer. Patsy Jackson was continued in the position of Recording Secretary. John Meyer, a charter member of the North American Chapter, had been and continues to be a strong supporter of IHS. When Jim Schuler was incapacitated by his illness, John stepped into the acting president's role, and did an excellent job in providing continuity to the IHS programs. His long and dedicated service to the Society made it most appropriate that he be selected President.

It must be added that John Meyer has been one of the most active presidents the Society has been privileged to have. He has put the Board of Directors to work, holding meetings on a monthly basis and assigning specific tasks to each member. John has been a strict taskmaster with the editor and production editor of the Newsletter to insure four issues per year to the membership. In fact, he has become, more appropriately, the co-editor of the Newsletter. John had expanded joint meetings of IHS with other related societies such, as the Hovercraft Society and the Society of Naval Architects and Marine Engineers' high-speed surface craft panel. Generally, both a spring and fall meeting of IHS have been held during John's tenure.

John Meyer is recognized as one of the world's leaders in the development of the technology of hybrid marine vehicles. He has, in this regard, studied the improvements realized in combining hydrofoils with other advanced ship concepts. John has been annually selected as President since 1991 and has the recognition of having served as President longer than any of his predecessors. Both Mark Bebar and John King have continued to be elected as Vice-President and Secretary/Treasurer during this period.

One of the highlights of John Meyer's presidency was the Intersociety High Performance Marine Vehicle Conference and Exhibit (HPMV-92) held at the Ritz-Carlton Hotel, Arlington, Virginia, June 24 to 27, 1992. The sponsor of HPMV-92 was the American Society of Naval Engineers assisted by thirteen societies and US Government organizations including IHS. One of our members, William Ellsworth, was co-chairman of the technical program and session organizer for the Plenary Session. President John Meyer was the organizer of the hydrofoil sessions. There were five hundred sixty registrants from sixteen countries with sixty papers presented at the sixteen technical sessions. Twenty-two members of IHS were registered.

The membership of IHS was quite active in the conduct of this Conference. William Ellsworth, James Wilkins, John Meyer, Michael Terry, and George Jenkins were technical session moderators. James Wilkins, John Meyer and Michael Terry co-authored papers presented, see reference (7). Robert Johnston was a panel member for the discussion that took place on the evening of June 24 on the subject "What are the obstacles that impede wider utilization of high performance vehicles and what steps can be taken to reduce or eliminate such obstacles?" A special session was sponsored by IHS on the subject "Hydrofoils -- Where Do We Go from Here?" John Meyer organized this session with Bob Johnston as the discussion leader. This session was well attended, and the discussions were quite lively, highlighted by the remarks of Dott. Ing. C. Buccini of Rodriquez Cantieri Navali and Dr. T. Yagi of Kawasaki. IHS also sponsored a booth at the exhibit which was arranged by William Buckley.

As the downsizing of the US Navy began, the PHMs became issues of survival as a fleet asset. IHS played a significant role in bringing to the attention of the decision makers the record of the PHM squadron in their drug interdiction role. It was pointed out that the value of the drugs captured more than paid for the maintenance and operation of the squadron. Alternative ownership of the PHMs was suggested to the US Coast Guard and the US Customs. This valiant effort on the part of IHS was unable to change the final decision that the US Navy's budget could not support the PHM's role in drug interdiction.

On July 30, 1993, the PHMs were decommissioned. At the ceremony, a message from the US Navy's Chief of Naval Operations, Admiral Frank B. Kelso, II, USN, was read. In part, the message stated " . . . To those officers and men who walk the PHM decks for the last time and participate in the decommissioning ceremonies of the "Flying Gray Terrors," you brought a new dimension to the surface warfare and have served your country well. You have given these proud ships a special honored place in our Navy's history. Land the ship! Well done and Godspeed."

The IHS effort to keep these ships active was spearheaded by Dr. James Wilkins, Chairman of the IHS Congressional Liaison Committee and ably assisted by John King, George Jenkins, John Meyer, and others, see reference (8). This effort of the Society was recognized by asking President Meyer to address the decommissioning ceremony.

At the Annual Meeting in May 1993, the Society initiated the awarding of plaques to honor members for the hydrofoil accomplishments. Plaques were presented to Cavaliere del Lavoro Carlo Rodriquez, posthumously, and to CAPT Robert J. Johnston, USNR (Ret.) for their roles in the development of hydrofoils and their support of IHS. At a special dinner meeting in November 1993, in recognition of their many contributions to the hydrofoil world and to the Society, IHS Award Plaques were presented to Countess Juanita Kalerghi Rothman and William M. Ellsworth. All recipients of the awards and Carlo Rodriquez's family expressed sincere appreciation for this recognition by the Society.

The Society now comes to its Twenty-Fifth Anniversary Celebration and Conference recognizing its existence from 1970 to 1995. The concept of this event has been promoted for some time by President John Meyer. George Jenkins and Mark Bebar are program co-chairs. Barney C. Black, as papers chairman, has done an outstanding job in organizing the papers to be presented. This event will take place at the Army-Navy Country Club, Arlington, Virginia, June 14 to 16, 1995.

It can be reported that the Society is in good health as it starts its second quarter of a century of existence. The leaders of IHS are strong, active and enthusiastic about the future. The membership is at an all-time high, with twelve countries represented. Financially, IHS remains on a sound basis with adequate resources for any unforeseen contingency. The major unaccomplished aim of publishing a handbook or textbook remains to be done.

The early library of IHS is now part of the Royal Institute of Naval Architects' library in London. At the time the transfer of management took place to North America, a substantial data bank was available at DTNSRDC near Washington, D.C. Therefore, the library asset of IHS remained in London. What is left of the DTNSRDC data bank is now under the control of John Meyer and can be accessed through John.

The concept of CDR Mark Thornton of an International Hydrofoil Society, in the opinion of the author, has exceeded his imagination of where and what IHS would be in 1995. It has been an interesting twenty-five years of progress of the hydrofoil concept. The advancement in commercial hydrofoils has grown to large craft carrying several hundred passengers over open sea routes. Military hydrofoils have demonstrated the new dimension they can provide in naval warfare. They stand ready to fulfill their mission when required. One cannot but wonder where IHS and hydrofoils will be in the year 2020.

ADDENDUM

When writing a history mainly about people, the author is certain to neglect someone who was a major participant in the events described. For example, it is known that Dr. Robert MacGregor, professor of Naval Architecture, Glasgow University, was an active member of the London Council, but his tenure could not be determined. The records of the activities of the Council, particularly during the 1970s, were quite limited. Therefore, a number of other individuals must have been neglected in this history. To anyone who has been so treated, please let the author know, and an errata will be issued.

Fortunately, rather complete records were available of the various Boards of Directors of the North American Chapter and IHS after it became a not-for-profit US corporation. The records of the participants on these boards is placed here to acknowledge the important role filled by these members.

Board Members of the North American Chapter

1978-1981	1979-1982	1980-1983	1981-1984
Michael Eames	Victor Beck	H. Lee Barhem	Michael Eames
Charles Rabel	James King	William Stolgitis	William Ellsworth
Martin Reeves	Robert Ripley	Donald Wight	Robert Johnston
Robert Johnston	William Schultz	James Wilkins	Michael Terry

1982-1985	1983-1986	1984-1987	1985-1988
Ronald Adler	Robert Ripley	William Ellsworth	Ronald Adler
Raymond Hoop	James Schuler	Robert Johnston	Mark Bebar
Lou Tedeschi	William Stolgitis	Ronald McWilliams	Raymond Hoop
John King	James Wilkins	Donald Wight	John King
		George Jenkins	

Board Members of the International Hydrofoil Society

Note: Boards of Directors of 1984 - 1987 and 1985 - 1988 of the North American Chapter, listed above, were made Board of Director members of IHS when it was incorporated in the USA.

1986-1989	1987-1990	1988-1991	1989-1992	1990-1993
Juanita Kalerghi	William Ellsworth	Ronald Adler	William Erikson	Jeffrey Benson
John Meyer	Robert Johnston	Mark Bebar	John Meyer	William Buckley
James Schuler	Lanny Puckett	Raymond Hoop	John Monk	William Ellsworth
William Stolgitis	Phil Yarnall	John King	James Williams	Robert Johnston

1991-1994	1992-1995	1993-1996	1994-1997	1995-1998
Mark Bebar	John Meyer	Barney C. Black	Mark Bebar	William Ellsworth
George Jenkins	John Monk	James King	George Jenkins	William Erickson
John King	James Wilkins	Mark Rice	John King	John Meyer
Wade Webster	Phillip Yarnall	Ken Spaulding	Cameron Mixon	Peter Squicciarini

Through all of aforesaid Boards, Patsy Jackson was the Recording Secretary. Her efforts contributed significantly to the maintenance of the Society's records.

ACKNOWLEDGEMENT

In preparing this review of the first twenty-five years of IHS, the author has been materially assisted by several people. **Derek Deere** of Basingstoke, England provided a wealth of material related to the effort and participants associated with the founding of the IHS as a Charity in England. His collection of documents and letters of the beginning years was the source for that part of the story.

Michael Eames sent the author a very helpful collection of documents and letters from his IHS files. This material was most helpful in identifying officers and participants in the early years of the Council and the Society. Mike also wrote the author a letter providing many facts and dates that added to the content of the history. And now, a very sad note must be added that on March 16, 1995, Mike suffered a heart attack and died. A memorial to Mike is in reference (9).

John Meyer, **John King**, and **Jean Buhler** were most helpful in going through their files, Newsletters, and back issues of *Hovering Craft and Hydrofoil* to provide useful information.

While there are gaps in this review, it would not be as complete as it is without the help of the above mentioned individuals. It must be added that any omissions or errors are solely the responsibility of the author.

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ENTERPRISE

Designed and Built by
Marine Systems Corporation
Miami, Florida

for

North American Hydrofoils, Inc.
Chicago, Illinois

by

Jean E. Buhler, Naval Architect

ABSTRACT

Interest in hydrofoils dates back to the end of the nineteenth century but use as a passenger carrying vessel did not become popular until the introduction by Baron Von Schertel of the Supramar PT-10, FRECCIA D'ORO, a 53 foot, 32 passenger craft on Lake Maggiore in 1953.

This paper touches on the author's experiences in the design, building and operating of the 40 foot, 27 passenger vessel, ENTERPRISE, the world's first commercial totally submerged foil hydrofoil craft. It is hard to believe that the events covered herein began over forty years ago and it is harder yet to recall all the details so the paper is primarily a history of trials and tribulations with a few technical details thrown in.

BACKGROUND

Once upon a time, as all good fairy tales start, there was a thin Englishman with a beard who had a patent on an interesting little boat that would literally "fly" over the surface of the water. You have probably heard of him, but you had to meet Christopher Hook to appreciate him. Nevertheless, he brought his single seater, Hydrofin HN-1, as he called it, to this country from England for demonstration purposes in Long Island Sound in 1951 hoping that he could find someone to finance a larger craft. Hook learned that the U.S. Navy was interested but that they could not deal with him since he was not an American citizen unless he became associated with some American shipyard. By strange coincidence, a friend of my father saw the demonstrations and knowing of our family's record performance of building fast craft for the U.S. Navy at Miami Shipbuilding Corporation (MSC) during World War II, suggested Hook get in touch with us.

Hook came to Miami with his partner, Sandy Holt of Stamford, Connecticut, and the HN-1. Although originally powered with an aircraft engine and propelled by air screw, it had been converted to a 10 horsepower Mercury outboard. It had two submerged foils forward and one attached to the extended shaft housing of the Mercury outboard. The angle of incidence of the forward foils were controlled by individual forward reaching surface feelers, which he called "jockeys". Incidence of the aft foil was controlled by pitch or attitude of the craft. In plan form the three foils were tapered and swept, to shed weeds he said. In profile they were circular arcs with a flat bottom, ogival as our propeller designers call them. The forward foils were pivotally mounted to vertical struts and mechanically connected through push rods to the jockey arms. The linkage between the jockey and foil could be regulated by the pilot through a manual control column.

The control column, which also included a steering wheel, was mounted on a double hinged post that could move fore and aft as well as sideways, joystick fashion. Picture, if you will, steadying this loose jointed control column between your bent knees, pulling it back to elevate, moving it sideways to bank and turning the wheel to steer this little craft. It worked well under Hook's command. The craft was painted red, looked like a high speed water spider and was immediately dubbed "The Red Bug", much to Hook's displeasure.

The story was true that the Navy was interested in the craft but "The Rest of the Story" was that the Navy had placed all hydrofoils in the classified information category and since Christopher Hook was a alien, the Navy could not work with him directly, hence needed the U.S. shipyard as an intermediary.

Miami Ship did negotiate a contract with U.S. Navy Office of Naval Research to study and explore (or exploit would have been a better word) the Hook system. Miami Ship hired, on a part-time basis, two University of Miami professors, John D. Gill and Albert W. Hainlin, who were aeronautical engineers, to assist with the analysis. They weighed, measured and ballasted the craft for extensive testing, with Hook at the helm, to establish lift, drag and numerous other non-dimensional coefficients for future scaling to larger models. Hook never could understand why the Navy had to make all these stupid measurements and calculations - the boat already works! Worst of all, he was peeved that he was not allowed to see all the data collected and/or reduced.

By this time it was revealed to Miami Shipbuilding that the Navy was interested in applying hydrofoils to a landing craft; after all, the Navy had not been able to hit the beach at more than five knots since the time of William the Conqueror in the year 1066. The small engineering gang at Miami Ship accepted the challenge but now with the requirement to design and build a 31,000 pound, 36 foot vessel of the Hook configuration, with retractable hydrofoils, thought it wise to make a half scale test vehicle to collect more data.

MSC negotiated a contract with ONR to design, build and test a .46 Froude scale model of the landing craft. Why .46 scale? The Navy offered to furnish a war surplus 50 horsepower Evinrude engine and Froude scale was the only way that this Naval Architect (over the objections of his two aeronautical engineers) knew how to scale down the 40 knot/630 h.p. speed/power requirement of the full size landing craft.

DEE ALPHA DEE TEE

The test craft was named DEE ALPHA DEE TEE (dα/dt) representing lift control by change in angle of attack but for the non-engineers it was known as FAZAY, being Phase A of the hydrofoil adventure. The craft was instrumented with a 15-channel recording oscillograph for noting stresses in the struts, foil angle, control rod forces, craft speed, engine r.p.m., pitch and roll as well as altitude, steering wheel position, etc. The struts were adjustable to represent retraction on the full size craft and the jockeys were straight functional elements for simplicity instead of Hook's "graceful" curves.

A spare height sensing probe was obtained from the Gibbs & Cox test craft, BIW, and consisted of a series of insulated contracts spaced about two inches apart to sequentially measure sea water electrical resistance across contacts. The scheme was used to measure altitude, not control it, although this was the start for future control systems. We have always been aware that one cannot fly a submerged foil system very long without some sort of pitch and altitude information and control. Hook always stated that one could not fly his system out of the water but we had one occasion of flying too high and folding the surface feelers under. The feeler system was designed for the full scale landing craft but we knew from the start that sooner or later they had to be replaced with something more practical. During the test period we also found out that with the struts fully extended the feeler system bottomed out and left us short on lateral stability. Ask Bob Apple, he was aboard when we rolled over.

HALOBATES

During the FAZAY test period, six more engineers were employed by Miami Shipbuilding, including old friend and former associate of the author, world famous speed boat designer, George F. Crouch, as a consultant, to help put together the landing craft design. The resulting vessel looked like an LCVP but it was actually designed from scratch, not converted as frequently stated. It had a built in aluminum alloy framework forward to provide for the hydrofoil mounting and retraction system and an aluminum alloy transom for attaching the cantilevered, retractable foil/strut, steering and drive system. The overall assembly was rather ungainly, to say the least, and Dr. Walton F. G. Smith, founder and Dean of the University of Miami Rosenstiel School of Marine and Atmospheric Science (RSMAS), said it reminded him of the water insect Halobates Sericeus; hence the name. This is a strange group of insects that is found on the surface of the ocean, far from land. What Walton did not tell us was that these animals disappear as soon as a breath of wind causes a ripple on the surface.

With the exception of the feeler system, HALOBATES was a reasonable success but the feelers had to go. Miami Ship then developed an electronic autopilot using insulated electric contacts on the leading edge of the forward struts for altitude input. These did not have "spatial anticipation" as originally deemed necessary, but they did the job adequately. While designing and installing the autopilot, it was decided to replace the Hall Scott gasoline engine with a T-53 gas turbine, making this vessel the Navy's first hydrofoil with electronic autopilot and gas turbine power plant.

Miami Shipbuilding Corporation made a number of other hydrofoil configurations including the Flying DUKW, a conversion of a World War II DUKW, with HALOBATES' type autopilot and T-53 gas turbine, for the U.S. Army. A major effort was then expended on a Navy proposal to design and build the PCH hydrofoil but MSC was underbid by Boeing. The tremendous cost of preparing the bid put MSC in the position where it could no longer tread water. Yacht and commercial repair work continued at the shipyard but it was a type of walk-in trade with no outside salesmen and the yard could not survive without supplemental government work. Several attempts were made in 1960 to merge with a larger company using the loss carry over as an incentive all to no avail.

The engineering department was the first to go with six members defecting to Grumman and the remaining stayed in the Miami area. The complete epoch of Miami Shipbuilding is another adventure tale in its own right but part has been included here as background on experience and crew that were to become the team to design, build and operate ENTERPRISE.

MARINE SYSTEMS CORPORATION

William Niedermair, administrator for MARAD during the initial design phase of H/S DENISON, was a great hydrofoil enthusiast and had had his eye on Miami Shipbuilding for some period of time. Upon hearing of the demise of the MSC engineering staff, he contacted this author about putting together a team to design a hydrofoil craft for the 1962 Seattle World's Fair. He had funding from a prominent yachtsman, Paul W. Adams, attorney from the New York and New Haven firm of Adams, Blanchette & Eyster, but the project was to be financed through a Title XI mortgage.

I recruited John Gill, Oscar Proni, Bill Lane, Lou Baranello and my older brother Ted, all former Miami Ship employees who had had experience in hydrofoil design, plus the remains of the Miami Ship hydrofoil library. The new company was named Marine Systems Corporation (same initials as Miami Shipbuilding Corporation) with Bill Niedermair as President, rented office space from Miami Ship and we were off and running.

The design was to be a 75 foot, 90 passenger vessel powered with two Solar gas turbines and would be operated by another Neidermair company, Northwest Hydrofoil Lines. The design was submitted to Todd Shipbuilding for a budgetary price but the resulting quote was considered much too high. Further, with the foreseeable difficulties in getting Coast Guard approval of this Subchapter "H" vessel with its PCH type integral hull plating/framing, aircraft wiring and many other aircraft design features, the project became ominous and was abandoned.

In the meantime, Marine Systems Corporation (the new MSC) made numerous proposals attempting to interest some prospective operators in high speed passenger service between Miami or Fort Lauderdale and the Bahamas. A number of proposals were made to put hydrofoils on standard aluminum, Coast Guard approved, Subchapter "T" crew boats for the operators of offshore oil industry. There was much interest but no takers. During this period, Edward R. Harris, formerly with Submarine Signal Corporation, joined Marine Systems as President and Bill Niedermair left to pursue his interests in promoting hydrofoil service in Puget Sound through Northwest Hydrofoil Lines.

In 1961, Marine Systems contracted with North American Hydrofoils, Inc., headed by Harry G. Nye, Jr. to design and build a commuter for the run between Atlantic Highlands, New Jersey and Wall Street in Manhattan. The route was considered prime in the 1961 Stanford Research Institute (SRI) study on the "Feasibility of Passenger Hydrofoil Craft in U.S. Domestic and Foreign Commerce" for the Maritime Administration. The vessel was "sized" to meet a 1961, $75,000 purchase price.

ENTERPRISE

Two 40 foot vessels were ordered, to be named ENTERPRISE and ENDEAVOUR, after America's Cup boats. Harry Nye was an ardent yachtsman and Olympic Gold Medalist in the Star class. The hulls were designed of 5086 aluminum alloy plating with 6061-T6 structural extrusions. Foils and struts were of 17-4 PH stainless steel. Power consisted of two Chevrolet Corvette 225 h.p. engines with modified Mercruiser stern drives. The vessels, with their three foil Canard arrangement, were the world's first commercial hydrofoil vessels with fully submerged foil systems. All three foils were provided with 30% flaps of aluminum alloy controlled by a Sperry "Gyrofoil" autopilot. The cabin top was made of cored fiberglass reinforced plastic. The seating and interior decor were products of the aircraft industry.

CHARACTERISTICS AND DIMENSIONS

LENGTH OVER ALL:	40 feet
BEAM:	14 feet
DRAFT, FOILS RETRACTED:	23 inches
DRAFT, FOILS DOWN:	7 feet, 6 inches
POWER:	450 b.h.p.
CRUISING SPEED, SUSTAINED:	42 m.p.h.
TAKE OFF SPEED:	22 m.p.h.
DISPLACEMENT, FULL LOAD:	17,600 pounds
PASSENGERS:	27
CREW:	2
FOIL SECTION:	NACA 64_1-010
FOIL SPAN:	78" fwd., 57.5" aft (ea.)
FOIL CHORD:	14" fwd. & aft
FIXED ANGLE OF ATTACK:	3 degrees
DISTANCE BETWEEN C.P. OF FOILS:	37' - 2"
STRUTS SECTION:	Circular arc
STRUT CHORD:	16"
STRUT THICKNESS/CHORD RATIO:	.12

CONSTRUCTION

The welded aluminum alloy hull was constructed by Sewart Seacraft, Inc. in Morgan City, Louisiana and was shipped overland to Miami for completion and outfitting. In the interim, Marine Systems moved the office to the canal on 20th street where there was a small shop with lathe, drill press, welding machines etc., and an open lot next to the canal. The cast foils and fabricated struts were manufactured by Dwyer Baker Co. in Fort Lauderdale but assembled at the new 20th street shop. Various major components were made in shops about Miami including Miami Ship. The FRP cabin top, wiring, piping, aluminum sheet metal joiner bulkheads and steps were all fabricated in-house along with the engine installation, seating and interior decor installations, by and under the direction of George Banchbach, a former aircraft A & E mechanic and shop foreman.

The hull form incorporated a fine entry forward and a relatively high deadrise (20°) from midships aft to the stern to minimize water impact loads that might occur during take-off, landing or in rough seas. Polyurethane foam was provided in the hull for flotation, to reduce noise and support the 1/16" thick decking installed under the seats in the passenger cabin.

The cabin was arranged with the pilot on a raised platform forward followed by steps to each side to emergency exits. A head was provided with a W.C. and wash basin to starboard. Seating consisted of five rows of triple seats and one double seat to port; five rows of double seats were provided to starboard. Four steps lead to the open after deck main entrance above the engine compartment. Windows were plexiglass and provided with curtains, aircraft style.

The struts were mechanically fastened to the hull. The forward strut was mounted on a transverse trunnion to swing forward for retraction. The after struts, containing the drive shafts and engine water intakes, were attached to barrel-like aluminum alloy structures which were mounted on fore and aft axes for rotation athwartships to retract them. The aft strut assemblies swiveled about vertical axes to provide torque-free dynamic steering. The trailing edges of all three struts were separate from the struts and were used as the control rods from the actuators to the flaps on the foils.

THE CONTROL SYSTEM

Early in the design stage, Ed Canter, electrical/electronic engineer, joined the team to review the HALOBATES autopilot design and set up specifications for the ENTERPRISE configuration. As inferred previously, *it is virtually impossible to fly a totally submerged hydrofoil system* without some sort of stability control system – it is inherently unstable.

Sperry-Piedmont contracted to build the system and dubbed it the Gyrofoil (TM) Automatic Stability Console. Two young enthusiastic engineers at Sperry, Henry Harris and Robert Smith, both of whom had experience in determining the control requirement and performance prediction for the LV(H), the PC(H) and the AG(EH) were assigned to the project. They later published a paper on the installation and successful operation of Gyrofoil in ENTERPRISE entitled "Practical Experiences with Hydrofoil Craft" in 1964 in the Naval Engineers Journal.

The control computer is a completely transistorized unit which accepts information from three sources: 1) motion sensors which provide data on actual craft altitude and pitch, 2) pilot controlled inputs related to desired altitude and pitch, and 3) transducers which indicate the position of the flaps. The control computer processes this information to produce flap angle order necessary to maintain the desired performance.

The altimeter measures the altitude of the boat from the keel to the water line by sensing elements located on the leading edge of the forward strut. The sensing elements are spaced two inches apart, thereby giving an incremental step output, over a total effective range of 40 inches. Angular orientation of the craft in roll and pitch is sensed by a Sperry aircraft vertical gyro and an aircraft roll rate gyro is also employed.

Command controls for the pilot, located on the console, are altitude order, roll trim and pitch trim as well as sensitivity adjustments for each command control.

Although steering is accomplished manually, a turning control on the console gives the pilot the ability to regulate, through the flaps, the roll to yaw coupling so that coordinated banked turns can be accomplished automatically at any speed and turning radius.

The controls are relatively simple although it is necessary for the pilot to develop a technique for adjusting to light and full loads and passengers moving fore and aft or crowding to one side. It is also well for the pilot to be alert for semi-floating oil drums, tires or other debris and to remember the long glide angle if it is necessary to stop on a dime.

COAST GUARD APPROVAL

Plan review by the Coast Guard seemed painful and interminable at the time but considering the nature of the craft, its small size and unusual (no rules in the book) features, the time consumed is believable – much better than it would be if submitted today! Normally, Coast Guard would like plans submitted for approval all at one time but this was impossible since many of the details were yet to be conceived. The first submittal on April 26, 1962 consisted of Inboard and Outboard Profiles along with a set of Specifications. Forty-seven days later the plans were returned stamped "Approved" and the specifications were marked "Examined". In July and August a second and third batch of plans were submitted and returned on September 1st. In November 1962 a final batch of plans and Design Notes were submitted and returned in January and February 1963.

There were 179 plans drawn of which 67 were submitted to Coast Guard along with 24 Technical Notes and Calculations. Of the plans, 53 were returned marked "Approved", four were returned for revisions, 13 were stamped "Examined". One was marked "Abrogated", whatever that means. Of the notes, 19 were marked "examined" and five were stamped "Approved."

Plan review was not the only hurdle; there were the C.G. Inspections too:

8th District, New Orleans, for the hull.
7th District, Miami, for machinery, electric and assembly.
3rd District, New York, for inclining and trial runs.
Headquarters, Washington, for initial and final trials off Sandy Hook, New Jersey and issuance of Certificate.
9th District, Chicago, for inspection, demonstration and route change.

There were also the numerous trips to Washington to "argue the point" such as aluminum versus stainless steel hydraulic tubing, the "Equipment List" and "Affidavits", seat belts and the FAA recommended (C.G. disapproved) fold down seat backs.

For the final test we were required to write a flight test program with every imaginable maneuver, then go out and take the test with Coast Guard personnel aboard. The final test, which I was not keen on doing, was to make a sharp banked turn at high altitude to surface the aft outboard foil, ostensively to demonstrate that the craft would not roll over. As it turned out, the foil surfaced, ventilated and gently slipped back into the water, resurfaced, re-ventilated and slipped back in again and again in a gentle loping action.

OPERATIONS

ENTERPRISE was launched in April 1963 in Miami and initial testing was conducted in Miami during the next three months but the owners were anxious to get the craft into the intended operating area for debugging and further testing. On July 15th it was loaded aboard a Kenosha trailer and transported to Atlantic Highlands, New Jersey. Coast Guard approval and certification of the craft was granted for a route in New York Harbor in November 1963. The certification process took longer than planned leaving very little time during the remainder of 1963 to prove or disprove the SRI route prediction. The balance of the year was taken up with demonstrations and short excursion rides in the Atlantic Highlands area.

Marine Systems and North American Hydrofoils merged in the fall of 1963 to become General Hydrofoil Corporation, with a Marine Systems Engineering Division and a North American Hydrofoil Operating Division. The merger brought the building, financing and operating organizations into one company and based on the response from those who had had a flight on ENTERPRISE, General Hydrofoil Corporation estimated that the New York market might require as many as 30 boats.

For the 1963–1964 winter, ENTERPRISE was shipped south to Miami, launched and flown as a hydrofoil across the Gulf Stream to the Bahamas for operation on a route between West End, Grand Bahama and Freeport/Lucaya for the developing casino traffic. Unfortunately, early in the season, the crew committed the cardinal sin in hydrofoiling of flying in very shallow water and went aground on a reef.

The accident changed the outlook and complexion of General Hydrofoils Corporation. The 30 boat program was shelved and the Marine Systems crew laid off. Captain Murray was summarily fired. Buhler volunteered to go to Freeport to salvage what he could for North American Hydrofoils, brought ENTERPRISE back aboard an LCT to Miami and with the help of George Banchbach, Ed Canter and brother Ted, made repairs. In April '64, ENTERPRISE successfully passed a flight test in the ocean off Miami Beach to the satisfaction of the Coast Guard and was soon afterward shipped overland back to Atlantic Highlands, New Jersey.

During the next month there were many demonstration and excursion trips including flights to the World's Fair and Playland in Rye, New York. The crew took particular delight in literally flying circles around AQUARIUS VII, the "competitor". The Atlantic Highlands base was well established with cooperation and enthusiasm from the local citizens, however, schedules and projected routes did not materialize. The major difficulty was the operator's inability to successfully make an arrangement for berthing facilities in New York; high fees, the union and politics.

North American Hydrofoils decided to move the operation to Lake Michigan, another prospective area in need of more modern transportation, and with which the President of North American Hydrofoils was more familiar, financially and politically. ENTERPRISE was flown up the Hudson, through the Mohawk River/New York Barge Canal, Lake Ontario, Welland Canal and Lakes Erie, Huron and Michigan to Chicago, where she was based for the balance of the summer. Operations consisted of demonstrations, short excursion trips and charter flights back and forth across Lake Michigan. Shore facilities, routes and schedules were never established and the operation closed at the end of the summer season.

TRIALS AND TRIBULATIONS

The best history of the craft is in the flight logs which not only include the aircraft pre-flight check off lists and mundane technical details of control settings, in-flight adjustments and reactions but also cover guest lists, routes flown, interesting incidents and events and usually end with a "grief list". The log is too long to quote in detail but some of the more interesting events are worth mentioning.

ENTERPRISE was launched on April 13, 1963 with the usual fanfare in the Tamiami Canal adjacent to the 20th street shop. Struts were retracted, meaning struts, foils and power train, so that we did not run aground along the unknown edges of the canal. Good move because our inexperienced towboat operator bounced us against every dock until we got to the Miami River. Once down the river, struts were extended and the engines were cranked up. Four days were spent taxiing, checking and adjusting and finally all agreed on a high speed taxi run. Roll and pitch control order produced the desired effects. Then it was bow up, a little more throttle and plunk! We had hit a manatee and knocked off the forward foil. A built-in safety feature but it was then back to the drawing board for reevaluation.

By May 5th we were back in business with a new foil (borrowed from sistership ENDEAVOUR). First take off and great flight, no seats except for the pilot and no interior furnishings. For the next several weeks the orders were to complete the interior, between trial flights with the Sperry representatives and Sewart Seacraft, the hull builder. The Navy pushed for a trial flight and of course the owners wanted to get the boat up to New Jersey, finished or not. We shipped it overland by Kenosha on July 15th.

The Kenosha trip cannot be overlooked without some comment. The boat was 14 feet wide and when a highway load is over eight feet wide, one needs a special permit and escort vehicle with a sign atop saying "wide load". I trailed 200 feet behind as the escort vehicle: 65 miles an hour watching the Kenosha trailer with one of the dual wheels overhanging the pavement! Most exciting was the Annapolis bridge on route 301; 14 feet wide load, six inch clearance to the bridge uprights and 24 foot roadway! What a driver!

Along the way we had a scheduled stop for a display and walk through viewing on the Kenosha trailer with boarding ladders borrowed from the airport, all for the Navy in Washington on 17th street opposite the Navy building.

The first flight out of Atlantic Highlands was on July 31st to the Battery in Manhattan followed by many demonstration trips to 23rd Street on the East River. In the meantime we were debugging, installing a new steering system, checking in with the Coast Guard in New York and making modifications demanded by Coast Guard in Washington. About this time came our first encounter with fog. We had a compass aboard but up until now piloting was generally watching the horizon for channel markers and land marks with an occasional look at the compass. However, our compass was an aircraft unit with the lubber line on the near edge of the compass card instead of the far side that I was used to. As a result, I had a hard time learning to turn the steering wheel in the right direction.

The ultimate episode was coming out of the fog to find a big black billboard with large white letters "Isbrandtson Lines" painted thereon. Instantly I realized that this was a freighter crossing our bow and yes, I made a tight coordinated turn in plenty of time.

On August 23rd, we made a trip to Oyster Bay, Long Island to visit Bill Carl and tour the H/S DENISON. Upon our return to Atlantic Highlands that evening we struck a 4' x 4' wooden pallet and demolished the altitude sensor on the forward strut. Needless to say, we returned to Atlantic Highlands on the bottom. Fortunately, we had a spare on hand so it was a quick trip to the shipyard on Staten Island for repairs and back to home base for a Navy demonstration on August 28th.

The next two weeks included crew training, demonstrations to Gibbs & Cox and a gang from DeVaval, a sample commuter run for a Coast Guard officer and fourteen 20-minute demonstration flights carrying 256 passengers from the Atlantic Highlands base. September 19th was an official flight for the USCG trial board.

On September 20th, while passing under the Verrazano Bridge, we heard a tremendous thump right behind us followed with a plume of water as though we had just set off a depth charge. It was not until a year later while reading a book "The Bridge" by Gay Talese about the building of the Verrazano-Narrows Bridge that I learned (page 69) that the construction crew had dropped a 1000 pound cable clamp that just missed us. Who says hydrofoiling isn't exciting?

November 4th was the big day – final USCG official tests. Beautiful sunny day, glass smooth water, one could see the foils under water. As one of the antics for the Coast Guard we removed the foredeck hatch cover so one could stand within the opening, waist at deck level and peer over the side to watch a vortex peel and curl off the forward foil tip. Captain Bob Price (USCG) took his turn looking about the time we flew through the wake of the S.S. ILE DE FRANCE, which caused us to touch down momentarily, but got the Captain thoroughly soaked in his dress blues. His trial board thought it was a riot but the Captain was not so pleased. Nevertheless, ENTERPRISE passed all the tests and was awarded the certificate.

On November 11th I turned over the command to Captain Arthur Murray who had been aboard in training for all of the flights since arrival in New Jersey. Murray, with the owner's representative and guests, left shortly thereafter with ENTERPRISE on a promotional trip to Woods Hole which, in itself, turned out to be an interesting adventure in rough weather, making demonstration flights, delivering the U.S. Mail to Martha's Vineyard, and assisting in a rescue along the way. Upon their return to Atlantic Highlands winter had set in; there was no more boating interest and the gang decided to retreat to Florida.

The 1964–1965 winter season and return to Atlantic Highlands was summed up previously but the prospect of going to the Great Lakes posed a new problem. Our altitude sensing device was based on the electric conductivity of sea water. Fresh water conductivity would be another order of magnitude less or if pure enough, non-existent. What to do? We made a flight up the Hudson to West Point on ebb tide taking water samples and measuring the electrical resistance thereof to advise our electronic engineer, Ed Canter. In three weeks Ed shipped us some new printed circuit cards with more sensitivity for the altimeter circuitry which seemed to be satisfactory so we were off for our trip to Chicago.

The Mohawk River/New York Barge canal passage was interesting through innumerable locks and trading demonstration flights with canal police for the privilege of flying at 30 mph instead of the mandatory idling pace. We emerged at Oswego into Lake Ontario and flew on to Niagara Falls with a fuel stop in Rochester. We locked through the Welland Canal with a 535 foot freighter, a night passage, emerging at Port Colborn in Lake Erie, where we met John Meisner, shipping magnate, who owned a Russian sport hydrofoil and with whom we traded demo flights.

In Lake Erie the new altimeter cards worked satisfactorily except that every time the radio transmitter was activated, the craft suddenly lost six inches in altitude. At Detroit, demonstration flights were made for the President of Chrysler Motors and my old University of Michigan professor, Louis A. Bayer.

Upon our arrival at Mackinack Island we were swamped with visitors and managed to provide a number of demonstration flights. The next day we faced small craft warnings so we elected to stay in port but Harry Nye, our President, was anxious to push on to Chicago and suggested that we just stick our nose out and proceed hull borne. George Manifold, first mate and relief Captain, said he did not think it was "prudent" and chose not to venture out. Harry said "we are going to try it but if you don't wish to go, you don't have to". George moved off bag and baggage and Harry Nye, George Banchback and I put out to sea. It was rough and we were covered with spray. I applied full bow up pitch and a little more throttle. That eliminated the spray and made the ride much smoother. Before we got to the Mackinack Bridge I realized that we were almost flying. I set controls for a little more altitude and less pitch; we were flying and one hour and 38 minutes later we were in Charlevoix.

After re-fueling we made a three hour 45 minute flight to Frankfort for more fuel, then a one hour 50 minute flight to Ludington where we put in for the night. In the morning it was fuel up, a demonstration flight and departure for a four hour 38 minute flight to Benton Harbor. Again, it was load fuel, make a 20 minute demonstration and off for a two hour ten minute flight to Belmont Harbor in Chicago. Total flying time from Mackinack to Chicago: 16 hours.

In Chicago we operated from the Windella dock next to the Wrigley building and the Chicago Yacht Club, Munroe Street Station, making half hour excursion trips out into Lake Michigan. On August 29th and 30th we made fly-by demonstrations for the Sixth Annual Lake Shore Park Water Show, then took a designated spot in the center of the "arena" as the "target" for the Blue Angels demonstration. Later, we had the privilege of flying the Blue Angel pilots for a demonstration of our own. They told us flying in ENTERPRISE was more fun than flying their jets.

On the weekend of September 4-7, we chartered to a number of wives of yachtsmen in the Tri-State Race. We were able to fly within the fleet without making a ripple on the water so the wives could watch their husbands "work."

Excursion flights and charter flights to Benton Harbor and Michigan City continued throughout the month but the weather was turning cold and Harry was ready to put ENTERPRISE in storage for the winter. There were two last memorable flights at the beginning of October, namely, a demonstration with Adlai Stevenson and his son, John Fell Stevenson, aboard and, at long last, the day Harry "soloed."

SUMMARY/CONCLUSIONS

The overall system was perhaps a few years ahead of itself, and built on minimum financing. State of the art electronics were applied, i.e., transistors, diodes and printed circuits, etc., were used but the circuit boards were made in-house without gold-plated contacts and other reliability factors that have evolved through the present electronics "explosion". The Sperry Gyrofoil had no vacuum tubes and was possibly the most reliable (although not perfect) part of the stability system; the Marine Systems Corp. altimeter was fragile and both Gyrofoil and altimeter were subject to stray currents and changes in resistance.

Conservatism, i.e., not taking a chance with a one and only craft, and "economic distress" precluded exploring ultimate limits of controls and structure. Roll control was a little weak. The leading edge strut altimeter was damaged several times by debris in the New York harbor. The engine cooling system was marginal and prevented operating at full power for more than 15 minutes at a time. This made the difference of going 30 knots in lieu of the design speed.

The transmission, likewise, was marginal. The Mercruiser stern drive units had been modified slightly and the manufacturer, Kiekhaufer, not only voided the warrantee but took no interest nor furnished any help or comfort with the units.

The cabin ventilation was inadequate although air-conditioning on the subsequent boats would have solved that problem. A "porta-potty" in the head is not for commercial application. In spite of the numerous other weight saving attempts, the all up weight, like many other boats, was 2000 pounds over design (18%) making full load performance marginal.

Coast Guard approval procedures seemed interminable and like harassment at the time. The assurance of safety was not objectionable but internal Coast Guard disagreement over this first of kind was apparent.

Counting on the reliability of one boat is a disaster; the customers will walk away or not come back tomorrow if they have to wait while you change a set of spark plugs. The doubting Thomases far out number the enthusiasts who are willing to bear with you in getting a new and novel system into full swing. Shore facilities, shore connections, alternative emergency transportation arrangements, public relations and public education can have a greater part in success/failure than technical items. The SRI and other studies hypothesizing on best commuter routes, talk of percentage utilization but seemed to neglect deadheading and off business hours, mechanical failures and maintenance periods. Political pressure could and did have a great influence on operational success.

Maintenance and training cannot be ignored. These vessels are flying machines and must be serviced accordingly. Low power, dirty bottom and foils, malfunctioning Gyrofoil resulted in "no take off". For the extra fare (over conventional boat or bus travel) the public expects extra service – no waiting. The extensive preflight routines and check lists all require time. Spare parts were minimal and for the most part were borrowed from ENDEAVOUR.

A training manual and program was established although the first students had the advantage of having had a member or two of the design team along at all times to help with the troubleshooting. Subsequent students did not have the initial enthusiasm and esprit de corps.

Many have asked "Why the Canard (tail first control system) arrangement which has not been overwhelmingly successful in aircraft?" The answer is twofold: lesser crash consequences in surfacing a side foil (as experienced with HALOBATES), and the cost of developing a single new power train such as the Cabi–Cattaneo units used on HALOBATES and the FLYING DUKW. Also asked, "Why use gasoline for fuel and why the Mercruiser?" Answer: much lighter weight than diesel and the already existing Mercruiser inboard/outboard unit was in the right power range.

EPILOGUE

ENTERPRISE was shipped in the spring of 1969 from Chicago to Newport Beach, California. In June, while the author was present checking out and setting up for the demonstrations in the area, ENTERPRISE was sold to the MOHU Corporation. In August it was shipped to City Island, New York without ever having been put in the water in California. At City Island in October 1969, Buhler and Center overhauled the electro/hydraulic control system, checked out the entire craft, then launched and made several flight tests.

Work on the second vessel, ENDEAVOUR, was resumed in 1965 by a new group, Hydro–Marine International, Inc. in Miami with financing from Paul W. Adams. Before the vessel was finished, however, she was put into wet storage. Interest was revived in July, 1969 under the ownership of MOHU Corporation. The author performed an Inclining Experiment for the benefit of the USCG then shipped the vessel to City Island for completion. The author made an inspection trip to City Island in 1970, conducted a flight test and re–initiated the Coast Guard certification process although certification was never completed.

In 1974 ownership of both vessels passed on to the Great Alaska Corporation in care of Charles F. Willis, Jr., President and/or International Hydrolines in care of Ira Dowd. Later in 1974 Ed Canter and I inspected ENDEAVOUR in Fort Lauderdale and quoted on making repairs. We never heard anything further.

In 1979 I came across ENDEAVOUR in Sarasota, Florida in the hands of Captain Shannon who had removed the Gyrofoil console and was installing foot pedals to control the hydraulics to provide roll, pitch and altitude. I tried to explain to Captain Shannon that the boat cannot be flown "by the seat of the pants" but he insisted that he could make it work. I asked him to call me when he had it flying - he never called! I learned later that he had removed the struts, foils, gasoline engines and transmissions and converted the vessel into a conventional boat for sightseeing purposes. I heard nothing further of the fate of ENTERPRISE.

Yes, we were 30 years ahead of ourselves.

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Mr. Buhler was born and raised in Eastern Pennsylvania but at an early age (5) was introduced to the sea through a voyage to Europe with his parents on the French Line S.S. PARIS. In prep school he built boat models, as do most boys, and on summer vacations learned a little about real live boating. In 1935 he moved to Miami with his family where shortly thereafter the family became involved in a boat yard. Summer vacations became jobs in the boat yard where he learned boat building from the bottom up-scraping barnacles, that is.

During the three years he attended Stevens Institute of Technology studying mechanical engineering he continued working summer vacations at the boat yard but now he was employed as a junior draftsman. In the summer of 1939 while engaged as the loftsman for the U.S. Navy Motor Torpedo Boats, PT-1 and PT-2, his immediate boss convinced him that he should transfer from Stevens to the University of Michigan to become a Naval Architect.

Upon graduation from U. of M. he rejoined the boat yard, which by this time was known as Miami Shipbuilding Corporation and he became involved in the design and building of the 63-foot Aircraft Rescue Boat. By the end of WWII he had advanced to Principal Naval Architect.

At the close of the war he joined W. Starling Burgess in a Damage Control Research Project at Stevens Tech but returned to Miami Ship upon the death of Starling Burgess. It was during this period at Miami Ship that he became acquainted with Christopher Hook and hydrofoils and has been "hooked" on hydrofoils ever since. The decade that followed is covered in this paper.

Mr. Buhler is currently a Naval Architect with a private practice in Miami although his recent activities in stability work have taken him half way around the world. He is a life member and Past Commodore of the Biscayne Bay Yacht Club in Miami. He is a Life member of SNAME, Past Chairman of the SNAME Southeast Section and in 1988 was the first recipient of the SNAME Distinguished Service Award.

He is married to Phyllis A. Buhler, a sailor in her own right, for the past 40 years. They have a son, Phillip, who is an Admiralty Lawyer and lives in Jacksonville, Fla. with his wife Gloria and one son.

"An Overview of Advanced Marine Vehicles - A Video"

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Department of Mechanical Engineering
Seattle, Washington
June 1995

For Presentation at :

International Hydrofoil Society (IHS)
25 th Anniversary Celebration and Conference
14 - 16 June 1995
Arlington, Virginia

Biography

Professor Calkins' professional engineering career includes industrial, governmental, academic, and consulting experience in research and development and engineering design. Responsible for planning, development, and management of various engineering programs, including contract administration, project engineering, design, test and evaluation. His technical specialties include Computer-Aided Design and Engineering (CAD/CAE), interactive computer graphics, aeronautical engineering, naval architecture and marine engineering and vehicle system design and analysis.

Abstract :

The video which accompanies this text, "**History of Advanced Marine Vehicles,**" was originally prepared for presentation at the AIAA 6th Marine Systems Conference in Seattle, Washington in 1981 at the AIAA 50th Anniversary. The video includes Hydrofoils, Air Cushion Vehicles (ACV), Surface Effect Ships (SES') and Small Waterplane Twin Hulls (SWATH) which were in existence in 1981. The following are data sheets that describe each of the craft shown in the video and are as complete as possible. There are, however, gaps in the data sheets for the ACV's. The video is a composite of films supplied courtesy of :

Boeing Marine Systems
Grumman Aerospace Corp.
Lockheed Missals & Space Co.
Bell Halter Inc.
David Taylor Naval Ship R & D Center

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HYDROFOILS

Forlanini Hydrofoil
Bell / Baldwin HD-4
Sea legs
HC-4
Hydrodynamic Test System (HTS)
HS Denison
RHS 140
Fresh 1
Little Squirt
PCH-1 High Point
PGH-2 Tucumcari
Swordfish
PGH-1 Flagstaff
Dolphin
AG(EH)-1 Plainview
Jetfoil
PHM

AIR CUSHION VEHICLES (ACV)

Viking
SK-5
Voyageur
LACV-30
AALC Jeff (A)
AALC Jeff (B)

SURFACE EFFECT SHIPS (SES)

Bell 100B
BH-110
Rodolf

SMALL WATERPLANE TWIN HULL (SWATH)

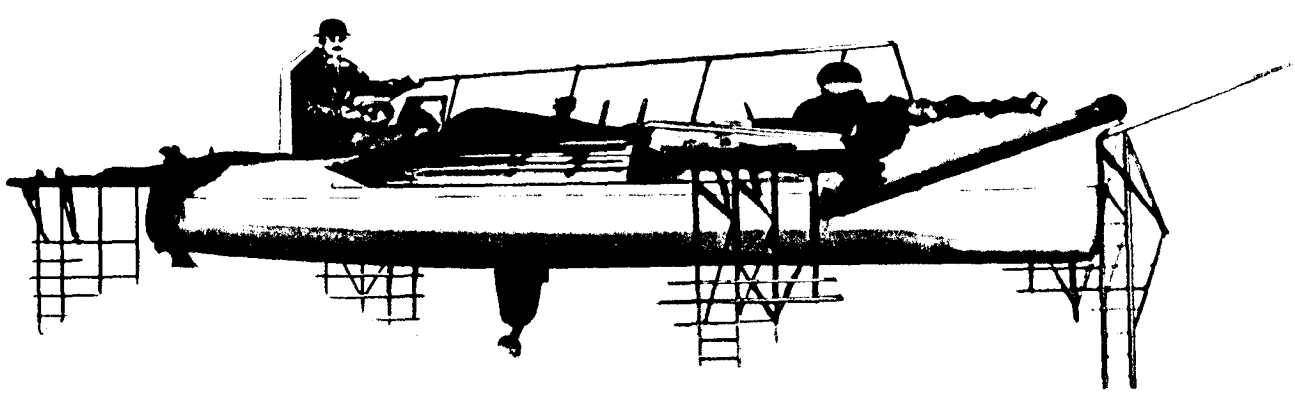
SSP Kaimalino

Vehicle	**FORLANINI**

Description

Worlds first successful manned hydrofoil

Class	Hydrofoil Surface piercing ladder foils
Manufacturer	Enrico Forlanini
Year	1898 start 1905-1911
Location	Lake Maggiore, Italy
Dimensions	
Length, Overall	
Beam	
Weights	
Gross	1.6 tons
Empty	
Useful Load	
Powerplant	
Type	
Manufacturer	
No.	
SHP(ea)-max	
SHP(ea)-cont.	
Propulsion	
Performance	
Max Speed	38 kn
Cruise Speed	

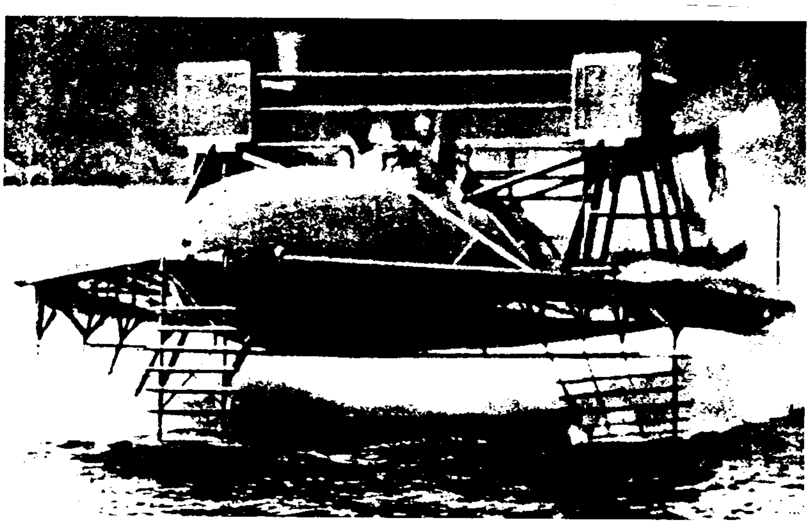


Vehicle **HD-4**

Description

Designed and built by Alexander Graham Bell and Casey Baldwin
Established speed record in 1919 / record until 1962

Class	Hydrofoils Surface Piercing Ladder foil systems
Manufacturer	Bell-Baldwin
Year	1919
Location	Baddeck, Nova Scotia
Dimensions	
Length, Overall	60 ft
Beam	
Weights	
Gross	11,000 lb
Empty	
Useful Load	
Powerplant	
Type	Piston Internal Combustion
Manufacturer	Liberty aircraft engines
No.	Two
SHP(ea.)-max	350 hp ea.
SHP(ea.)-cont.	
Propulsion	Twin Airscrews / Propellers
Performance	
Max Speed	70.85 mph
Cruise Speed	

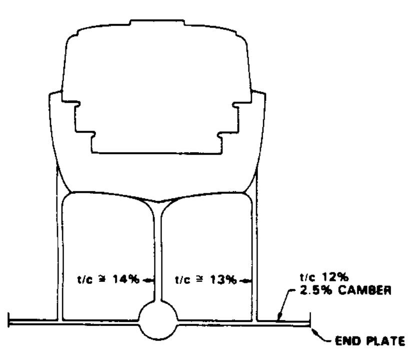


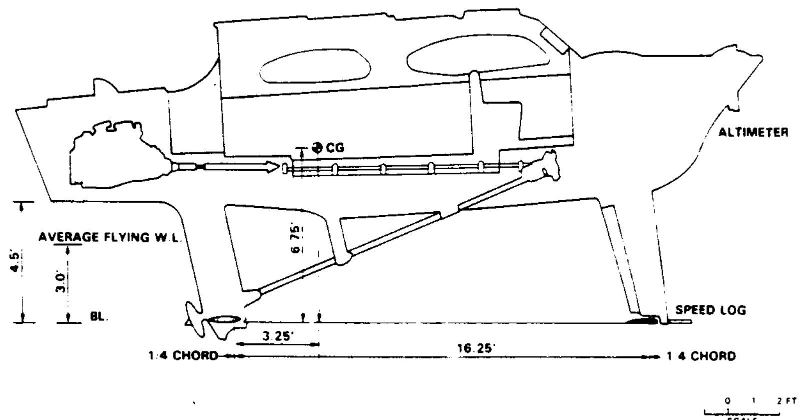
Vehicle SEA LEGS

Description

Used modified Chris Craft hull
V-drive and angled shaft
Electronic autopilot

Class	Hydrofoil Fully Submerged
Manufacturer	Sutton & Brown
Year	1957
Location	Annapolis, MD
Dimensions	
Length, Overall	28.5 ft
Beam	9 ft
Weights	
Gross	5 tons
Empty	
Useful Load	
Powerplant	
Type	Gas internal combustion engine
Manufacturer	Chrysler marine
No.	One
SHP(ea)-max	235 hp
SHP(ea)-cont.	
Propulsion	19 in Propeller
Performance	
Max Speed	23 kn
Cruise Speed	

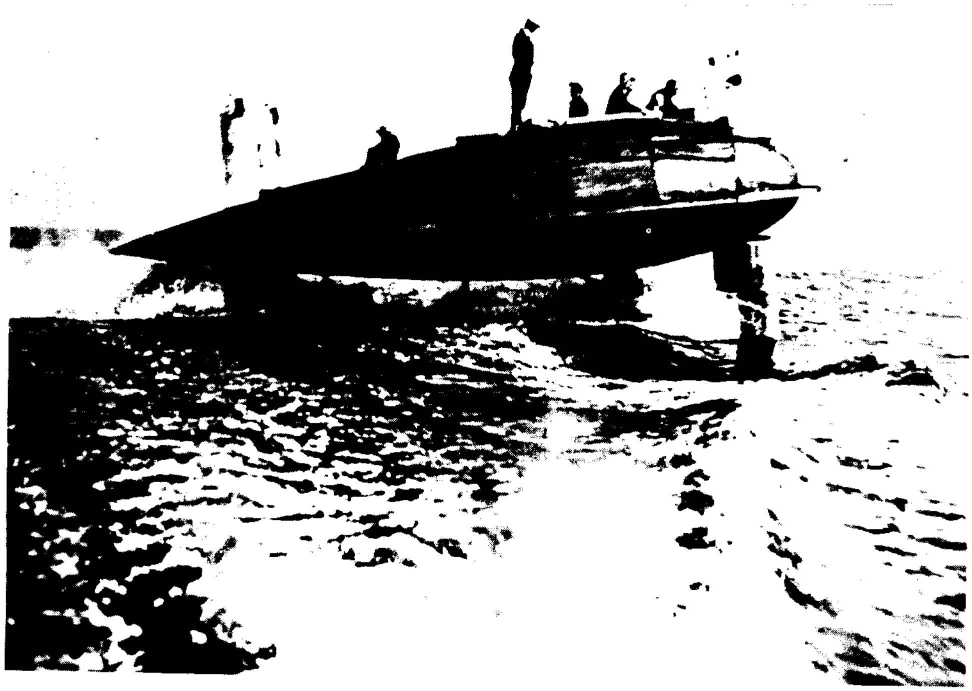




Vehicle	**HC-4 LANTERN**

Description
Dr. Vannevar Bush designed

Class	Hydrofoil Fully Submerged
Manufacturer	Hydrofoil Corporation of America
Year	1952
Location	Annapolis, MD
Dimensions	
Length, Overall	36 ft
Beam	22 ft
Weights	
Gross	22,000 lb
Empty	
Useful Load	
Powerplant	
Type	
Manufacturer	
No.	
SHP(ea)-max	
SHP(ea)-cont.	
Propulsion	
Performance	
Max Speed	18 kn
Cruise Speed	



Vehicle — **HYDRODYNAMIC TEST SYSTEM (HTS)**

Description

Three point hydroplane / Plywood construction
Two forward planing sponsons / One aft Planing ski
Test model hydrofoils to 80 kn

Class — Three point hydroplane

Manufacturer — Boeing Advanced Marine System Organization
Year — 1961
Location — Seattle, WA

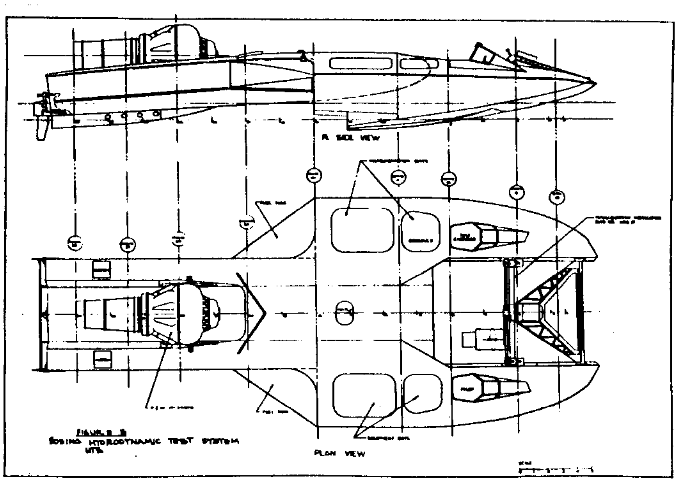
Dimensions
- **Length, Overall** — 38 ft -0 in
- **Beam** — 17 ft-0 in

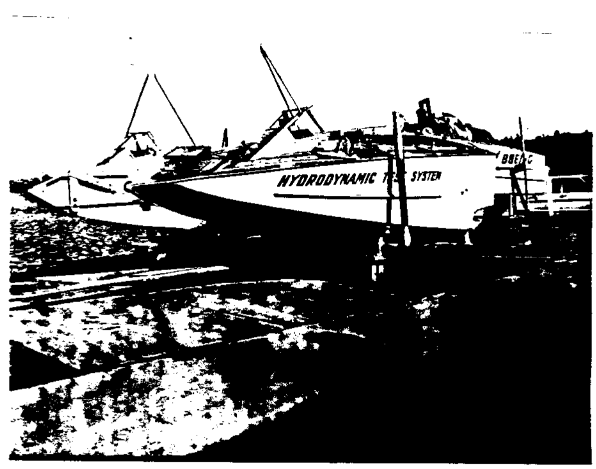
Weights
- **Gross** — 14,000 lb
- **Empty**
- **Useful Load**

Powerplant
- **Type** — Turbojet
- **Manufacturer** — Pratt & Whitney J-48 jet Engine
- **No.** — One
- **SHP(ea)-max** — 7,200 lb Thrust
- **SHP(ea)-cont.**

Propulsion

Performance
- **Max Speed** — 145 kn without model hydrofoil
  80 kn with model hydrofoil



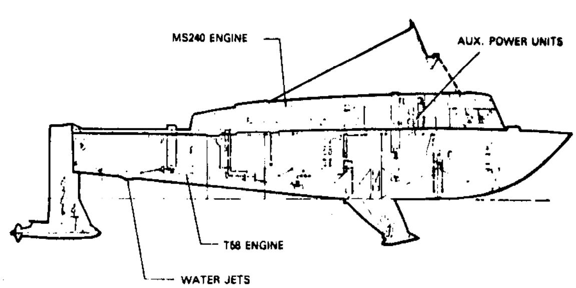


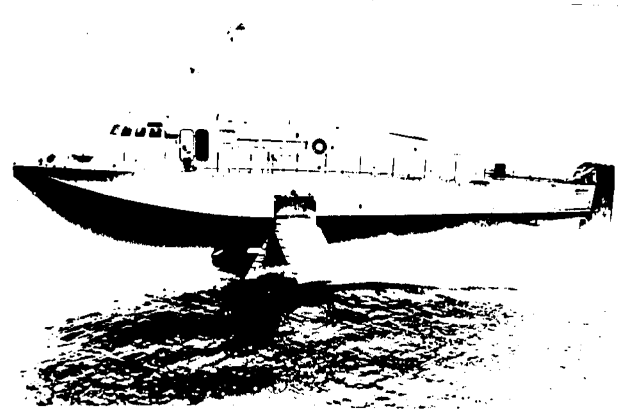
Vehicle **HS DENISON**

Description

Funded by Maritime Administration / 1960
Operate 1962
Fully submerged foil aft
Two forward 85 % of weight
One foil aft = 15 % weight

Class	Hydrofoil Surface Piercing
Manufacturer	Grumman Aerospace Corporation
Year	1962
Location	Bethpage, Long Island, NY
Dimensions	
Length, Overall	104.6 ft
Beam	23.0 ft
Weights	
Gross	95 tons
Empty	52 tons
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	General Electric MS-240
No.	One
SHP(ea)-max	14,000 shp
SHP(ea)-cont.	
Propulsion	Supercavitating propellers
Performance	
Max Speed	60 kn
Cruise Speed	55 kn



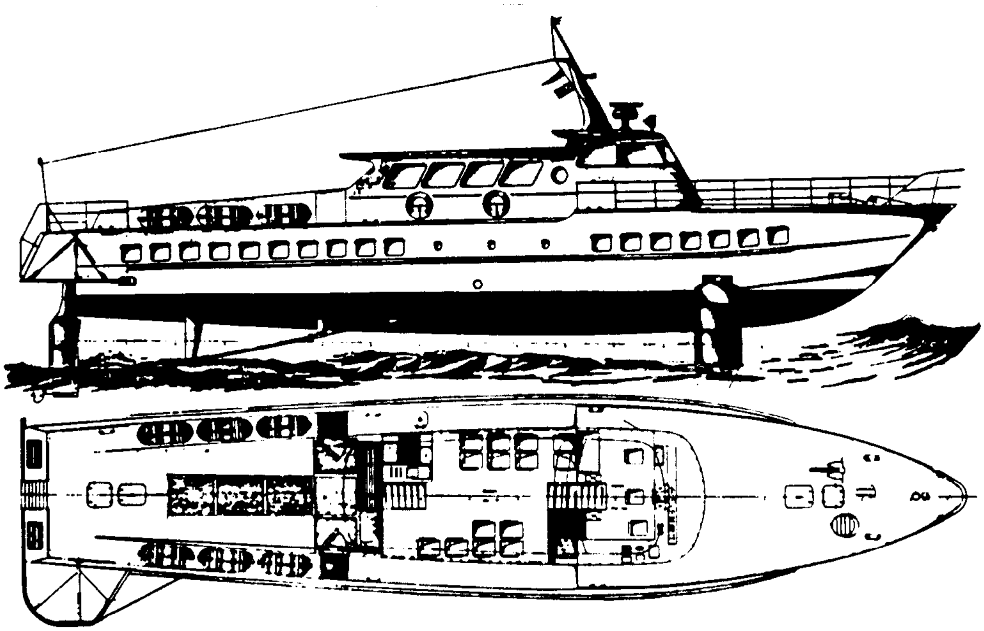


Vehicle	**RHS 140**

Description

Riveted hull construction
125 to 140 passengers

Class	Hydrofoil Surface Piercing V-foils
Manufacturer	Cantiere Navaltechnica SpA
Year	1977
Location	Messina, Italy
Dimensions	
Length, Overall	94 ft - 1.5 in
Beam	35 ft. - 2.25 in
Weights	
Gross	65 tons
Empty	52.5 tons
Useful Load	12.5 tons
Powerplant	
Type	Diesel
Manufacturer	MTU 12V493 Ty 71
No.	Two
SHP(ea)-max	1,350 hp 1500 rpm
SHP(ea)-cont.	
Propulsion	Two three-bladed propellers
Performance	
Max Speed	36.0 kn
Cruise Speed	32.5 kn

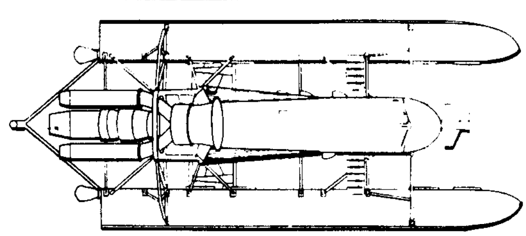


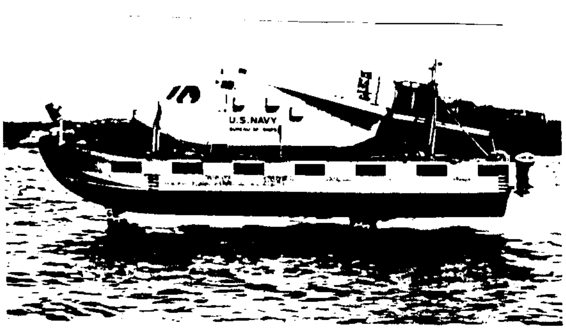
Vehicle **FRESH-1**

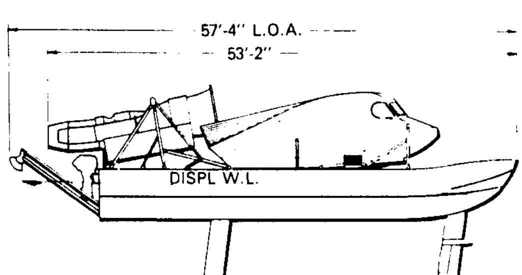
Description

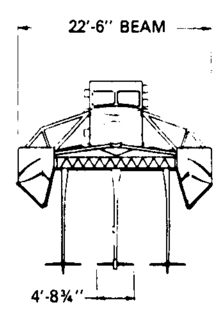
High Speed Hydrofoil Test Craft
Canard and conventional foil arrangements
Launched as canard February 1963
Twin-Hulled / Two hulls and central cabin
June 1961 / Contract awarded by BuShips
July 1963 / Acceptance trials

Class	Hydrofoil Fully Submerged (ACS)
Manufacturer	Boeing Advanced Marine Systems Organization (AMSO)
Year	1963
Location	Seattle, WA
Dimensions	
Length, Overall	47 ft - 4 in
Beam	22 ft - 6 in
Weights	
Gross	16.5 tons
Empty	12.4 tons
Useful Load	4.1 tons
Powerplant	
Type	Turbofan
Manufacturer	Pratt & Whitney
No.	One
SHP(ea)-max	18,000 lb Thrust
SHP(ea)-cont.	
Propulsion	Turbofan
Performance	
Max Speed	80 - 100 kn
Cruise Speed	

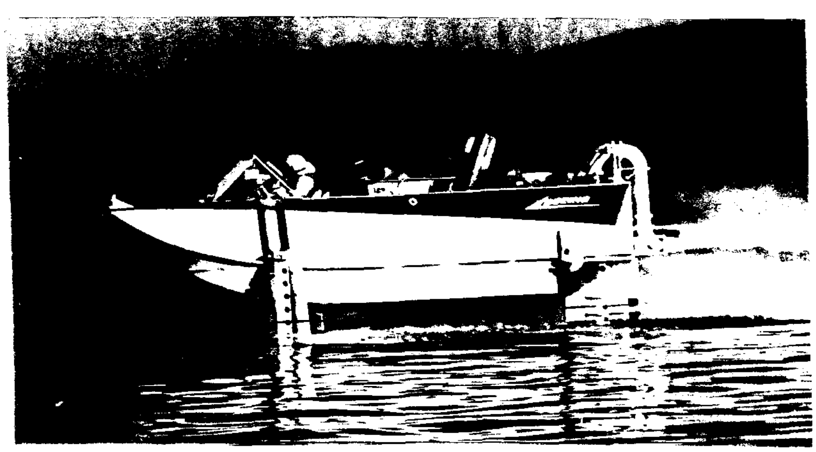








Vehicle	**LITTLE SQUIRT**
Description	
Water jet research vehicle Plywood construction	
Class	Hydrofoil Fully Submerged (ACS) Airplane Configuration
Manufacturer	Boeing Company
Year	1962
Location	Seattle, Washington
Dimensions	
Length, Overall	22.0 ft
Beam	11.25 ft
Weights	
Gross	2.65 tons
Empty	2.28 tons
Useful Load	0.37 tons
Powerplant	
Type	Gas Turbine
Manufacturer	Boeing 502
No.	
SHP(ea)-max	425 shp
SHP(ea)-cont.	
Propulsion	Centrifugal Pump / Waterjet
Performance	
Max Speed	48 kn
Cruise Speed	

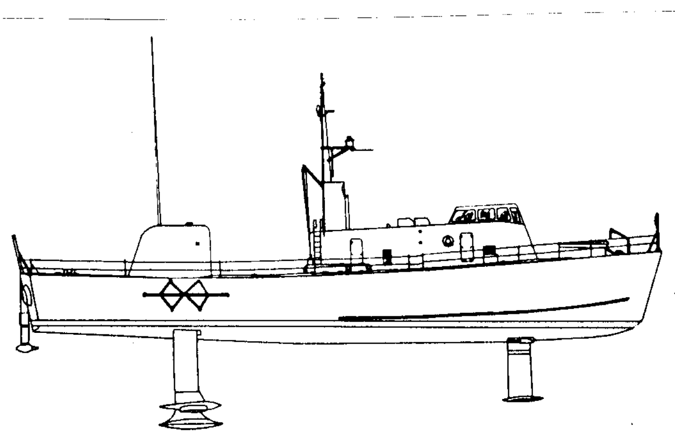


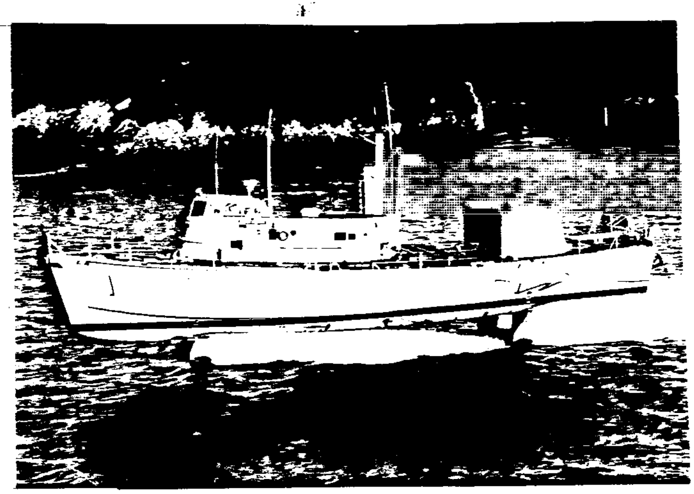
Vehicle	**PCH-1 High Point**

Description

General design specified by US Navy Bureau of Ships
Detail design and construction by Boeing
Constructed : January 1961
Accepted by Navy : August 1963
Major modification and overhaul in 1972

Class	Hydrofoil Canard / 68% lift aft / 32% fwd Fully Submerged, Fixed Incidence
Manufacturer	Boeing Advanced Marine Systems Organization
Year	1961
Location	Seattle, WA
Dimensions	
Length, Overall	115 ft - 9 in
Beam	30 ft - 0 in
Weights	
Gross	127.2 tons
Empty	99.6 tons
Useful Load	27.6 tons
Powerplant	
Type	Gas Turbine
Manufacturer	Proteus
No.	Two
SHP(ea)-max	4,250
SHP(ea)-cont.	3,800
Propulsion	Propellers / Four
Performance	
Max Speed	50 kn
Cruise Speed	30-40 kn



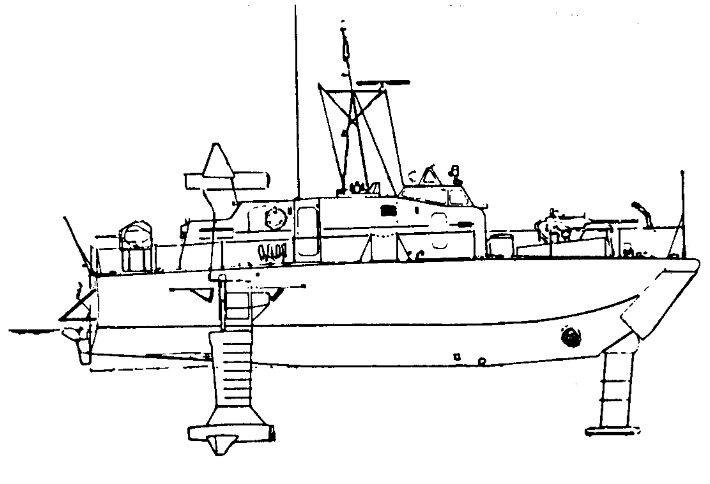


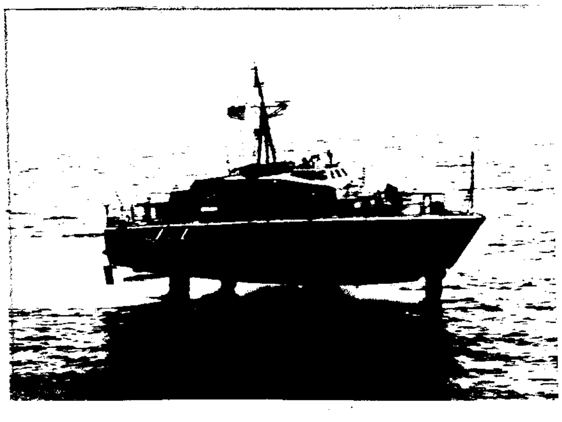
Vehicle **PGH-2 TUCUMCARI**

Description

Patrol Gunboat Hydrofoil
Contract let 1966
Delivered March 1968
Ran aground seven miles east of Puerto Rico in November 1972
Deactivated 1972

Class	Hydrofoil
Type	Fully Submerged Canard
Manufacturer	Boeing Marine Systems
Year	1968
Location	Seattle WA
Dimensions	
Length, Overall	80 ft - 4 in
Beam	35 ft - 4 in
Weights	
Gross	64.0 tons
Empty	40.8
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	Rolls Royce Proteus
No.	
SHP(ea)-max	3,200 hp
SHP(ea)-cont.	
Propulsion	Centrifugal Pump / Waterjet Twin inlets
Performance	
Max Speed	50 kn
Cruise Speed	



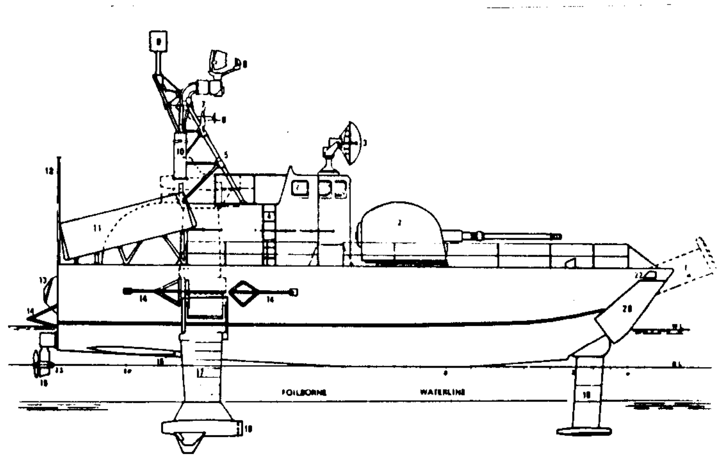


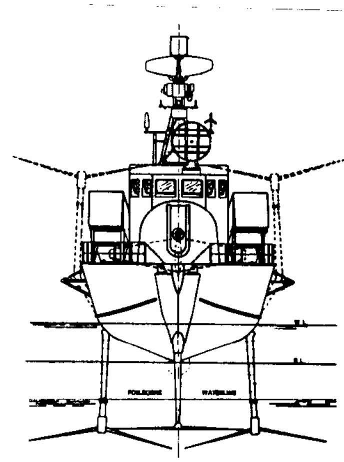
Vehicle SWORDFISH

Description

Alinavi formed in 1964 to develop, manufacture and market advance military marine systems
Missile launching hydrofoil gunboat
Based on Boeing fully submerged hydrofoil technology
Improved version of Boeing Tucumcari PGH-2
October 1970 /contract by Italian Navy for design and construction of hydrofoil missile craft
Swordfish delivered July 1974

Class	Hydrofoil Fully Submerged (ACS)
Manufacturer	Cantieri Navali Riuniti, SpA
Year	1974
Location	Genoa, Italy
Dimensions	
Length, Overall	75 ft - 4 in
Beam	35 ft - 4 in
Weights	
Gross	64 tonnes
Empty	
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	Rolls Royce Proteus 15M/553
No.	One
SHP(ea)-max	4,500 - 5,000 shp
SHP(ea)-cont.	
Propulsion	Centrifugal Pump Waterjet
Performance	
Max Speed	45- 50 kn
Cruise Speed	



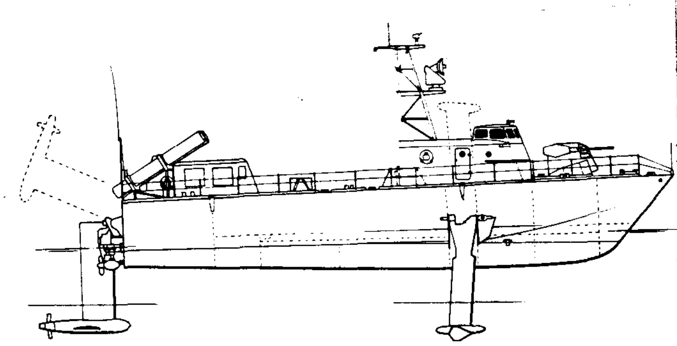


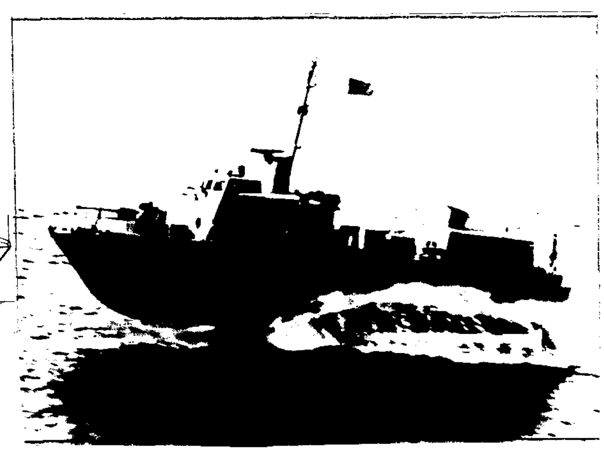
Vehicle	**PGH-1 FLAGSTAFF**

Description

Launched January 1968
Trials July 1968
Placed in service September 1968 / West Palm beach

Class	Hydrofoil Fully Submerged Incidence control 70% forward / 30% aft
Manufacturer	Grumman Aerospace Corporation
Year	1968
Location	Bethpage, New York
Dimensions	
Length, Overall	86 ft - 6 in
Beam	21 ft - 5 in
Weights	
Gross	67.5 long tons
Empty	
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	Rolls Royce Tyne MK 621/10
No.	One
SHP(ea)-max	3,550 shp
SHP(ea)-cont.	
Propulsion	Three blade supercavitating propeller One
Performance	
Max Speed	40 kn
Cruise Speed	



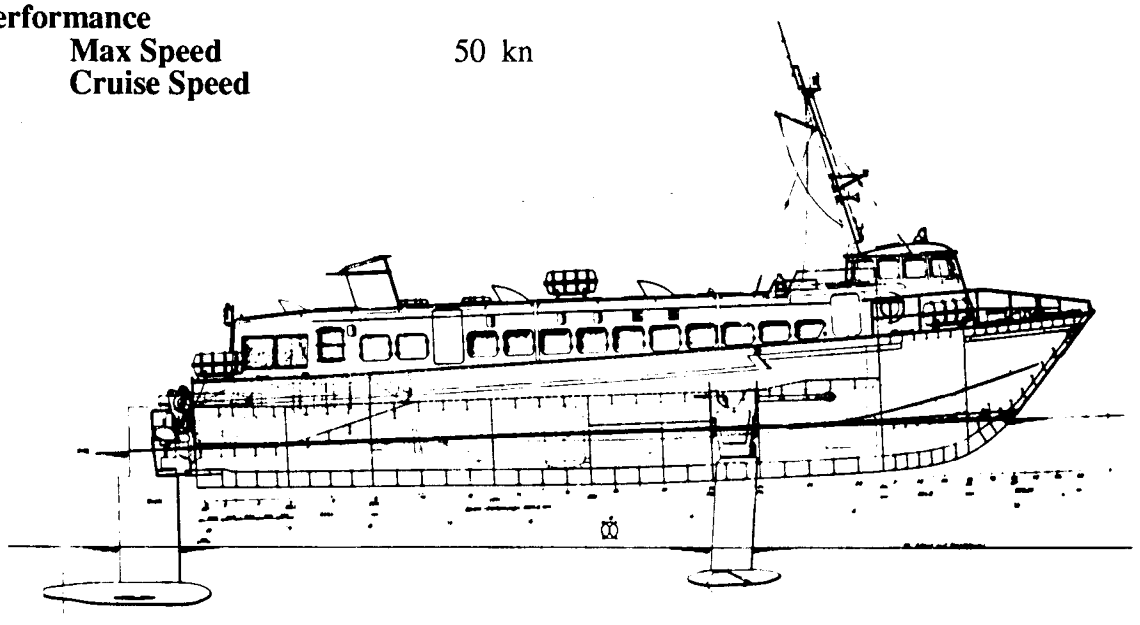


Vehicle	**DOLPHIN**

Description

116 Passengers
Built by Blohm and Voss / Hamburg

Class	Hydrofoil Fully Submerged (ACS) Airplane configuration 70% Fwd / 30% Aft
Manufacturer	Grumman Aerospace Corporation
Year	1970
Location	Bethpage, NY
Dimensions	
Length, Overall	42 ft - 8 in
Beam	15 ft - 3 in
Weights	
Gross	67 tons
Empty	50 tons
Useful Load	10 tons
Powerplant	
Type	Gas turbine
Manufacturer	Rolls Royce Tyne 621
No.	One
SHP(ea)-max	3,600 shp
SHP(ea)-cont.	
Propulsion	KaMeWa controllable pitch propeller
Performance	
Max Speed	50 kn
Cruise Speed	

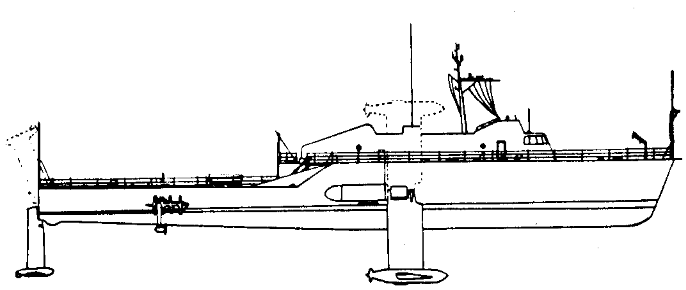


Vehicle	**AG(EH)-1 PLAINVIEW**

Description

Auxiliary General Experimental Hydrofoil (AGE)
Built by Lockheed Shipbuilding & Construction Co. / Seattle, Washington
Detailed design & construction contract / June 1963
Launched June 1965
Maiden Flight March 1968
Delivered to US Navy March 1969
Last flight July 1978

Class	Hydrofoil Fully submerged 90% forward / 10% aft Incidence Controlled
Manufacturer	Grumman Aerospace Corporation
Year	1965
Location	Bethpage, New York
Dimensions	
Length, Overall	219 ft - 0.5 in
Beam	70 ft - 0 in
Weights	
Gross	290 to 328 long tons
Empty	265 tons
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	General Electric ML 1500
No.	Two
SHP(ea)-max	
SHP(ea)-cont.	14,500 shp ea.
Propulsion	Two 4 bladed supercavitating Propellers
Performance	
Max Speed	42 -50 kn
Cruise Speed	

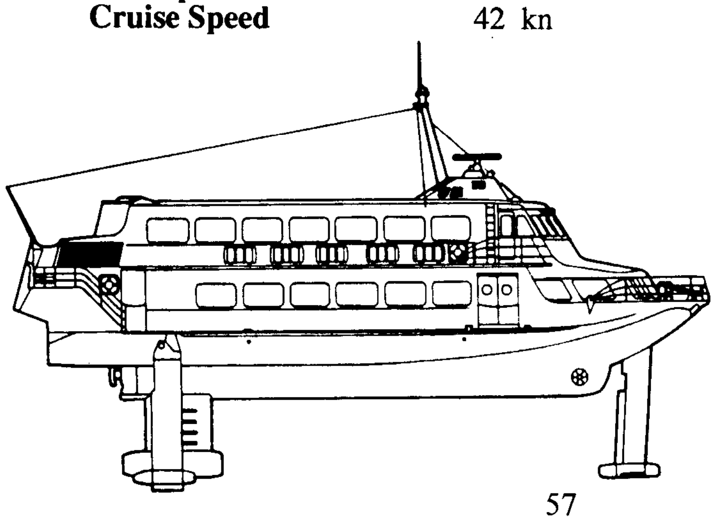


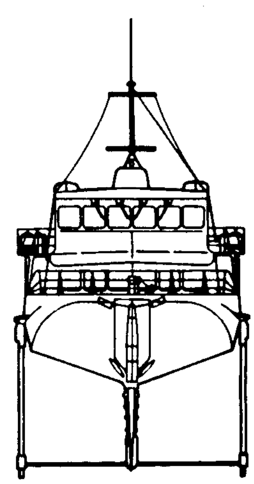

Vehicle	**JETFOIL**

Description

Commercial hydrofoil
190-250 passengers
Keel laid January 1973
Launched March 1974

Class	Hydrofoil Fully submerged Canard 15-5 PH steel
Manufacturer	Boeing Marine Systems
Year	1974
Location	Seattle, Washington
Dimensions	
Length, Overall	90 ft - 0 in
Beam	31 ft - 0 in
Weights	
Gross	110 tons
Empty	
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	Allison 501 K20
No.	Twin
SHP(ea)-max	3,300
SHP(ea)-cont.	3,710
Propulsion	Rocketdyne Powerjet 20 Waterjet
Performance	
Max Speed	50 kn
Cruise Speed	42 kn



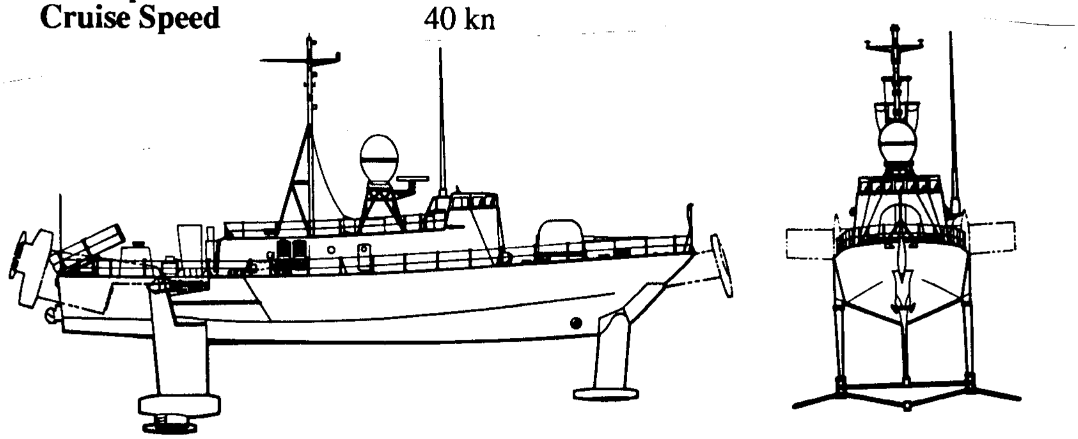


Vehicle	**PHM**

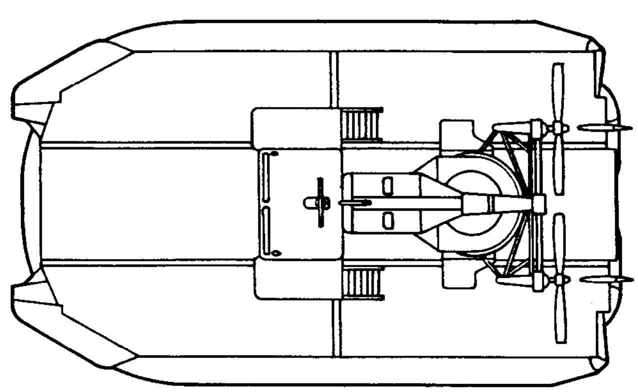
Description

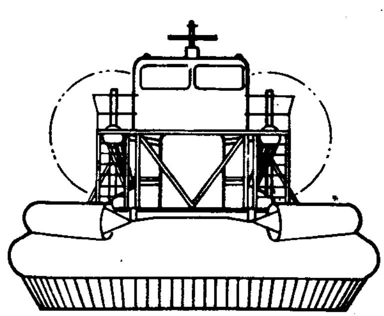
Patrol Combatants - Missile Hydrofoils
US Navy awards contract to Boeing for preliminary design
USS Pegasus Launched June 1974
First Foilborne flight February 1975
Commissioned into service July 1977
First squadron : Pegasus, Aquila, Aries, Gemini and Hercules

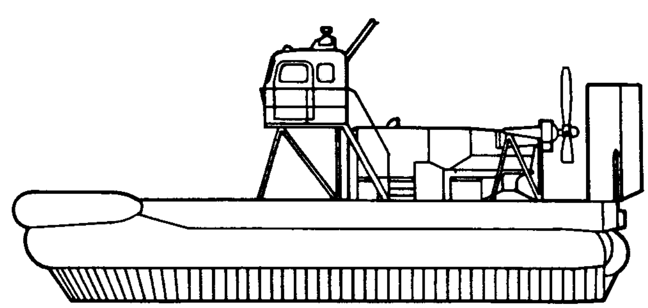
Class	Hydrofoil Canard Foils 17-4 PH Stainless Steel Struts : 17-4 Stainless steel
Manufacturer	Boeing Marine Systems
Year	1974
Location	Seattle, Washington
Dimensions	
Length, Overall	131 ft - 2 in
Beam	28 ft - 2 in
Weights	
Gross	231 tons
Empty	
Useful Load	
Powerplant	
Type	Gas Turbine
Manufacturer	General Electric LM 2500
No.	Single
SHP(ea)-max	18,000
SHP(ea)-cont.	
Propulsion	Waterjet / Rocketdyne
Performance	
Max Speed	50 kn
Cruise Speed	40 kn



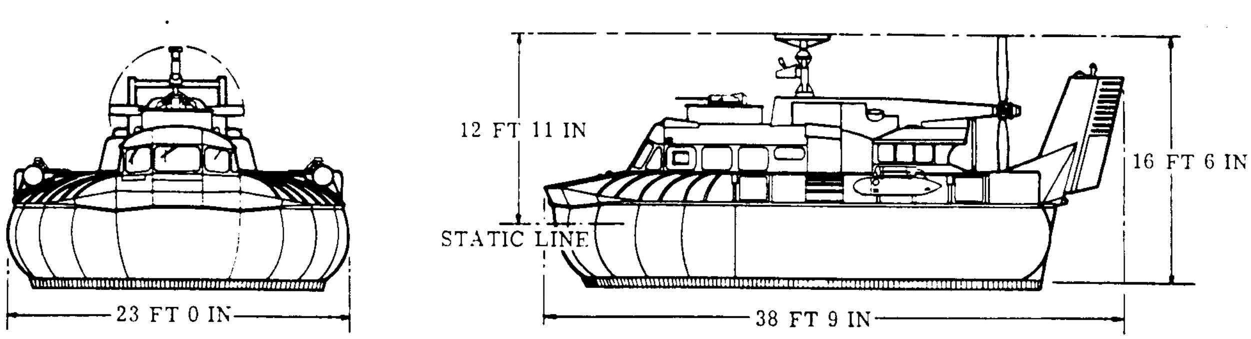
Vehicle	**VIKING**	**Model 7501**
Description		
Inshore search and Rescue craft Used by Canadian Coast Guard		
Class	Air Cushion Vehicle (ACV)	
Manufacturer	Bell Aerospace Textron, Canada	
Year	1969	
Location	Ontario, Canada	
Dimensions		
Length, Overall	44.5 ft	
Beam	26.0 ft	
Weights		
Gross	32,500 lb	(16.25 tons)
Empty	20,685 lb	(10.34 tons)
Useful Load		(6-7 tons)
Powerplant		
Type	Gas Turbine	
Manufacturer	UACl ST6T-75 Twin-Pac	
No.	One	
SHP(ea)-max	1,700	
SHP(ea)-cont.	1,300	
Propulsion	One 7 ft - 0 in dia lift fan Two 9 ft - 0 in dia 3 blade propellers	
Performance		
Max Speed	57 mph	
Cruise Speed		







Vehicle	**SK-5**
Description	
US Army use in Vietnam	
Class	Air Cushion Vehicle (ACV)
Manufacturer	Bell Aerospace Co.
Year	1970
Location	Buffalo, New York
Dimensions	
Length, Overall	38 ft - 10 in
Beam	23 ft - 9 in
Weights	
Gross	17,000 lb
Empty	9,857 lb
Useful Load	
Powerplant	
Type	
Manufacturer	General Electric LM 100
No.	One
SHP(ea)-max	1,250 shp
SHP(ea)-cont.	
Propulsion/Lift	Three blade Hamilton Standard propeller (9 ft dia) Centrifugal lift fan (7 ft dia)
Performance	
Max Speed	60 kn
Cruise Speed	

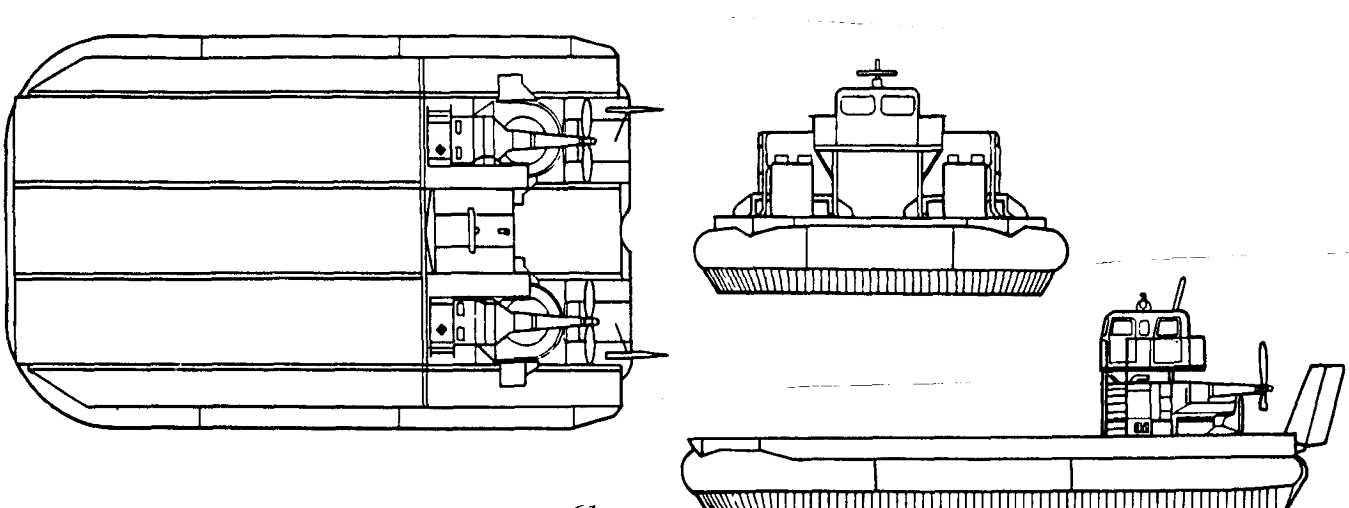


Vehicle VOYAGEUR

Description

1967-68
Cargo ACV
Model 7380
Amphibious
Haul payloads up to 25 tons over Arctic terrain

Class	Air Cushion Vehicle (ACV)	
Manufacturer	Bell Aerospace, Canada	
Year	1967	
Location	Ontario, Canada	
Dimensions		
Length, Overall	64.8 ft	
Beam	36.7 ft	
Weights		
Gross	90,000 lb	(45.0 tons)
Empty	35,720 lb	(17.86 tons)
Useful Load		(27.14 tons)
Powerplant		
Type	Gas Turbine	
Manufacturer	Pratt & Whitney ST-75 Twin-Pac	
No.	Two	
SHP(ea)-max	1,300 shp	
SHP(ea)-cont.		
Lift & Propulsion	Hamilton Standard propeller 9 ft dia - Two 12 blade / 7 ft dia centrifugal lift fan - Two	
Performance		
Max Speed	54 mph	
Cruise Speed		

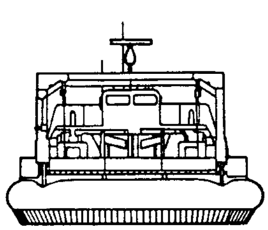


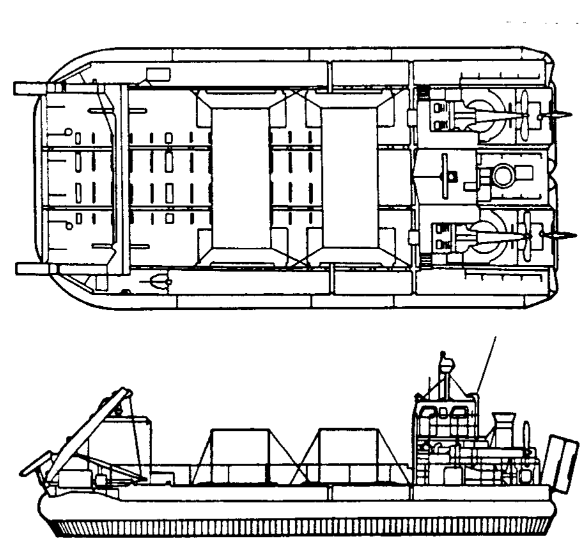
Vehicle **LACV-30**

Description

Stretch version Voyageur for Surf & Ice use
Lighter Over The Shore (LOTS)
Lighter, amphibious air cushion vehicles
High speed amphibious vehicle
September 1979 / Sign contract
US army Mobility Equipment R&D Command

Class	Air Cushion Vehicles	(ACV)
Manufacturer	Bell Aerospace Textron	
Year	1981	
Location	New Orleans, LA	
Dimensions		
Length, Overall	76 ft - 6 in	
Beam	36 ft - 8 in	
Weights		
Gross	115,000 lb	(57.5 tons)
Empty		
Useful Load		
Powerplant (Lift & Propulsion)		
Type	Gas turbine	
Manufacturer	Pratt & Whitney ST6T Twin Pac	
No.	Two	
SHP(ea)-max	1,800 shp ea	
SHP(ea)-cont.	1,400 shp ea	
Propulsion/Lift	Two Hamilton Standard 3 bladed Propellers one each Twin Pac 7 ft dia / 12 blade lift fan	
Performance		
Max Speed	46-56 mph	
Cruise Speed		



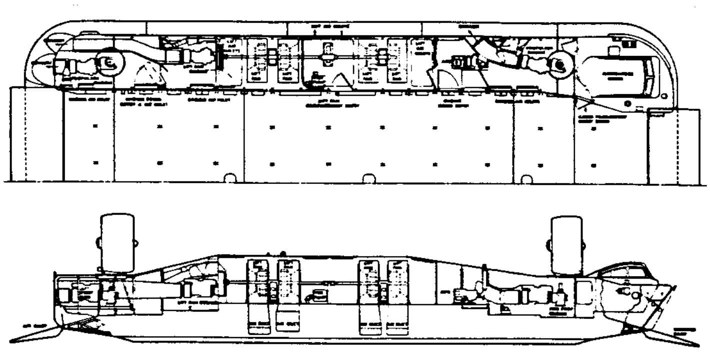


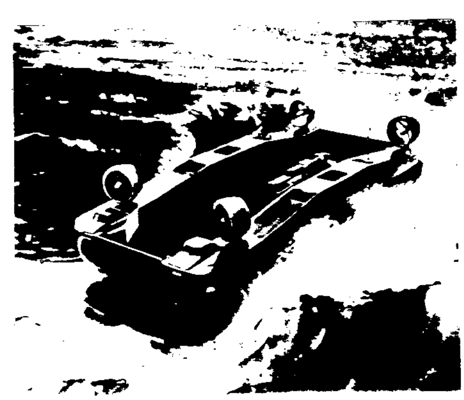
Vehicle	**AALC JEFF(A)**

Description

Difference between Jeff A&B = structure/skirts/power/control
US Naval Ship Systems Command / 1970 / Awarded contract
Construction - Todd Shipyards 1974
Hull complete 1976 / Hover 1977 / Deliver to US Navy / Panama City / Trials / June 1979

Class	Air Cushion Vehicle (ACV)
Manufacturer	Aerojet-General
Year	1976
Location	El Monte, CA
Dimensions	
Length, Overall	96 ft - 1 in
Beam	48 ft - 0 in
Weights	
Gross	340,000 lb (170 ton)
Empty	180,000 lb (90 ton)
Useful Load	120,000 lb (60 ton)
Powerplant (Lift)	
Type	Gas Turbine
Manufacturer	Avco Lycoming TF40
No.	Two
SHP(ea)-max	3,750 shp
SHP(ea)-cont.	
Powerplant (Propulsion)	
Type	Gas Turbine
Manufacturer	Avco Lycoming TF40
No.	Four
SHP(ea)-max	3750 shp
SHP(ea)-cont.	
Propulsion	Eight 4 ft dia Lift fans Two 7 ft - 5 in dia Shrouded Propellers
Performance	
Max Speed	50 kn

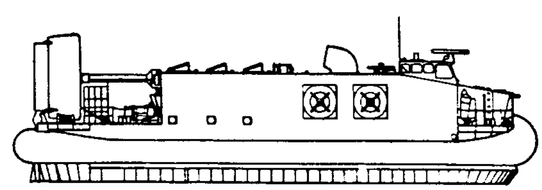


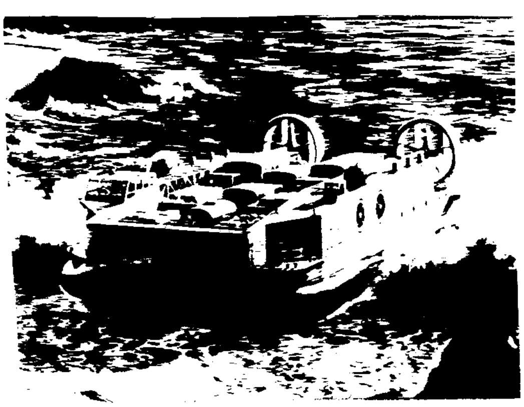


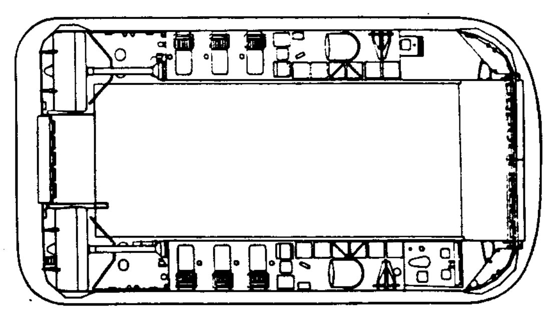
Vehicle	**AALC JEFF (B)**

Difference between Jeff A&B = structure/skirts/power/control
Awarded contract / March 1971
Completed March 1977
Panama City April 1977
Overwater trials December 1977

Class	Air Cushion Vehicle (ACV)	
Manufacturer	Bell Aerospace Textron	
Year	1977	
Location	New Orleans, LA	
Dimensions		
Length, Overall	86 ft - 9 in	
Beam	47 ft - 0 in	
Weights		
Gross	330,000 lb	(165 ton)
Empty	210,000 lb	(105 ton)
Useful Load	120,000 lb	(60 ton)
Powerplant (Lift & Propulsion)		
Type	Gas Turbines	
Manufacturer	Avco Lycoming	
No.	Six	
SHP(ea)-max		
SHP(ea)-cont.		
Propulsion	Lift - Four 5 ft dia centrifugal impellers Two 11 ft - 9 in dia Hamilton Standard ducted propellers	
Performance		
Max Speed	50 kn	





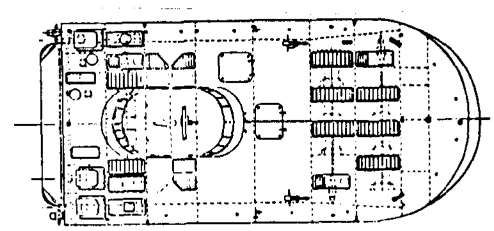


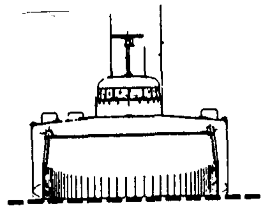
Vehicle SES-100B

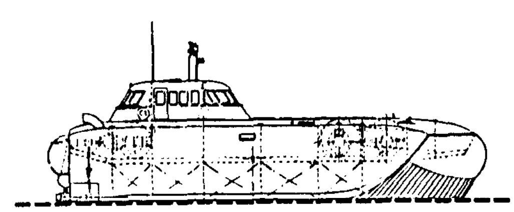
Description

US Surface Effect Ships Project Office awarded contract to Bell in January 1969
Construction began in September 1969
Launched July 1971 / Craft preparation for trials early 1971.
Test & Evaluation / 1972 / Lake Pontchartrain, Louisiana
Transferred to Naval Coastal Systems Lab at Panama City, Florida / May 1973

Class	Surface Effect Ship (SES)
Manufacturer	Bell Aerospace Textron
Year	1971
Location	New Orleans, LA
Dimensions	
Length, Overall	77 ft- 8.5 in
Beam	35 ft - 0 in
Weights	
Gross	105 tons
Empty	
Useful Load	10 tons
Powerplant	
Lift	
Type	Marine Gas Turbine
Manufacturer	United Aircraft ST6J-70
No.	Three
SHP(ea)-max	620 shp @ 2200 rpm
SHP(ea)-cont.	580 shp
Propulsion	
Type	Marine Gas Turbine
Manufacturer	P & W FT 12A-6
No.	Three
SHP(ea)-max	
SHP(ea)-cont.	
Propulsion	Marine propellers / Two
Lift	Centrifugal Fans
Performance	
Max Speed	90 kn





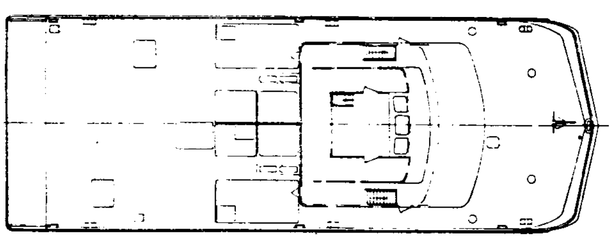


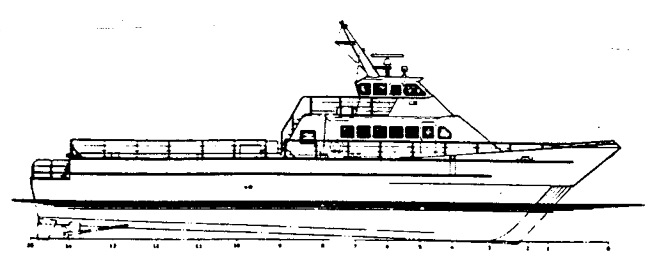
Vehicle	**BH-110**

Description

Demonstration Craft / Crew Boat / Passenger Ferry / Patrol Boat
Offshore Oil rig / Gulf of Mexico
120 passengers or 40 ton cargo

Class	Surface Effect Ship (SES)
Manufacturer	Bell Halter
Year	1978
Location	New Orleans, Louisiana
Dimensions	
Length, Overall	100 ft - 0 in
Beam	39 ft - 0 in
Weights	
Gross	107 tons
Empty	80 tons
Useful Load	18 tons
Powerplant (Lift)	
Type	Diesel
Manufacturer	Detroit Diesel Allison 8V92TI
No.	Two
SHP(ea)-max	445 hp
SHP(ea)-cont.	
Powerplant (Propulsion)	
Type	Diesel
Manufacturer	Detroit Diesel Allison 16V149TI
No.	Two
SHP(ea)-max	1,335 hp @ 1900 rpm
SHP(ea)-cont.	
Propulsion	Marine propellers / Two
Lift	Centrifugal Fans
Performance	
Max Speed	40 kn on cushion 19 kn off cushion



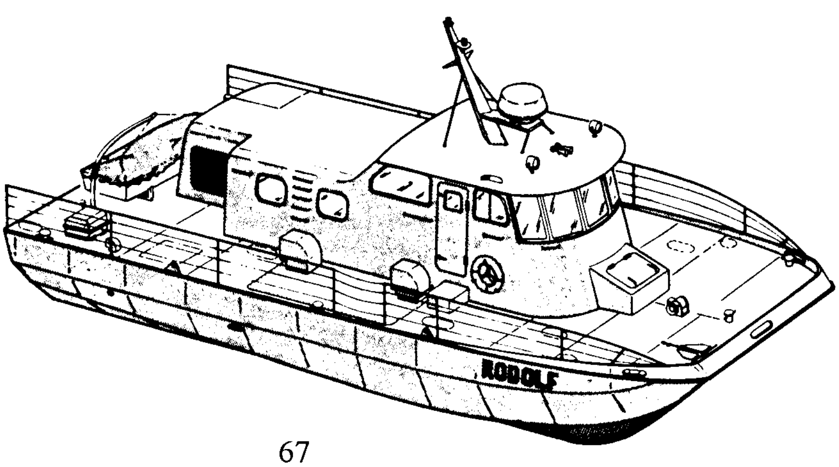


Vehicle	**RODOLF**

Description

Hydrographic Survey Boat
US Army Corp of Engineers (Portland)

Class	Surface Effect Ship (SES)
Manufacturer	Bell Halter
Year	Late 1977
Location	New Orleans, Louisiana
Dimensions	
Length, Overall	48 ft-0 in
Beam	24 ft-0 in
Weights	
Gross	18.7 tons
Empty	16.7 tons
Useful Load	2.0 tons
Powerplant (Lift)	
Type	Diesel
Manufacturer	Detroit Diesel 4-53
No.	One
SHP(ea)-max	105 shp @ 2600 rpm
SHP(ea)-cont.	
Powerplant (Propulsion)	
Type	Diesel
Manufacturer	Detroit Diesel Allison 8V92N Marine Diesel
No.	Two
SHP(ea)-max	
SHP(ea)-cont.	
Propulsion	Twin propeller
Performance	
Max Speed	35 mph
Cruise Speed	

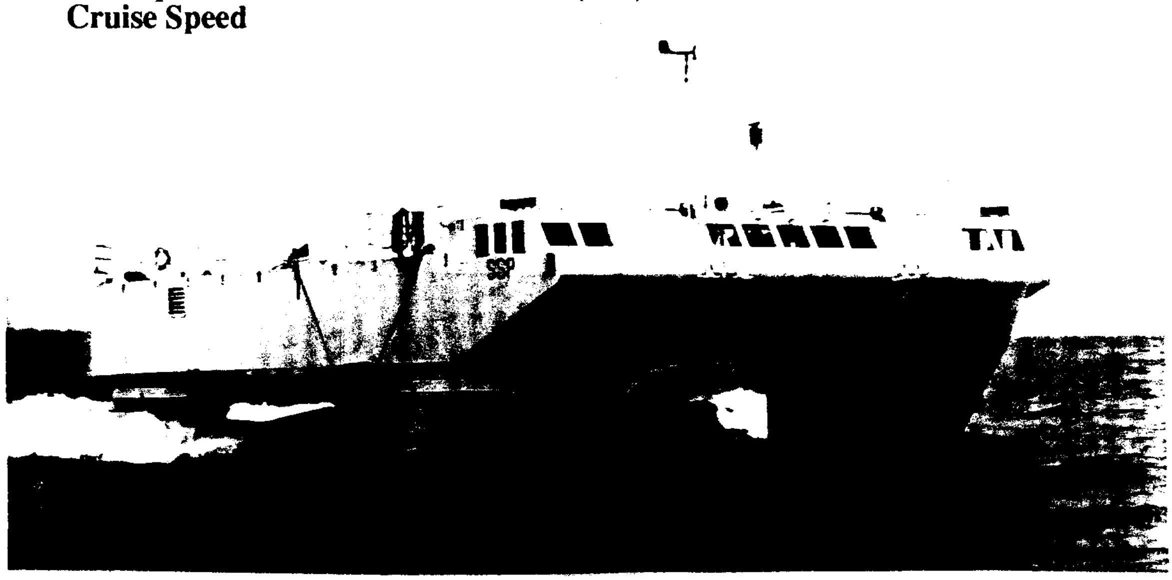


Vehicle	**SSP Kaimalino**

Description

Used as range support vessel
Aluminum cross section
High tensile steel struts & Hulls
Attributes : High operating speed / stable in rough seas
80 Helo (SH-2F Lamps) landings in SS4

Class	Small Waterplane Area Twin Hull (SWATH)
Manufacturer	US Coast Guard yard
Year	1973
Location	
Dimensions	
Length, Overall	89.0 ft
Beam	49.0 ft.
Weights	
Gross	190 tons
Empty	
Useful Load	30 tons
Powerplant	
Type	Gas turbines
Manufacturer	GE T64
No.	Two
SHP(ea)-max	2,100 hp ea.
SHP(ea)-cont.	
Propulsion	Chain Drive (100 rpm - 350 rpm) Propellers
Performance	
Max Speed	22-23 kn (SS4)
Cruise Speed	



PLAINVIEW (AGEH-1) REMEMBERED

By: Robert Alan May, CPL

Mr. May is a former PLAINVIEW crew member, having attained the rate of Boatswainmate Third Class while on board. He reported aboard just weeks after PLAINVIEW was delivered to the Navy, and holds the distinction of being one of the Plank Owners. Mr. May graduated with a Bachelor's Degree from the University of Hawaii in 1974 and has been involved in naval programs ever since. Currently, Mr. May is the Senior Logistician at Westinghouse Machinery Technology Division. Mr. May is member of the Internatinal Hydrofoil Society, a two time past Chairman of the Pittsburgh Section of the American Society of Naval Engineers, and was the Chairman of the 1994 ASNE Pittsburgh Section Technical Innovation Symposium. He is affiliated with the Society of Logistics Engineers as the Pittsburgh Section Chairman and serves on the SOLE Board of Directors as the Commercial Applications Division Chair.

ABSTRACT

In honor of the 25th anniversay of the International Hydrofoil Society, an historical dissertation of the largest hydrofoil in the world will be made. The author will present an accounting of the events leading up to the construction of PLAINVIEW, the early trial years, the late trial years, and the ignominious end of PLAINVIEW. For reference, technical specification will be presented as well as significant engineering advances. Personal recollections of life on board PLAINVIEW will be shared to include tense situations and comical anecdotes. The presentation will be highlighted by many pictures of PLAINVIEW.

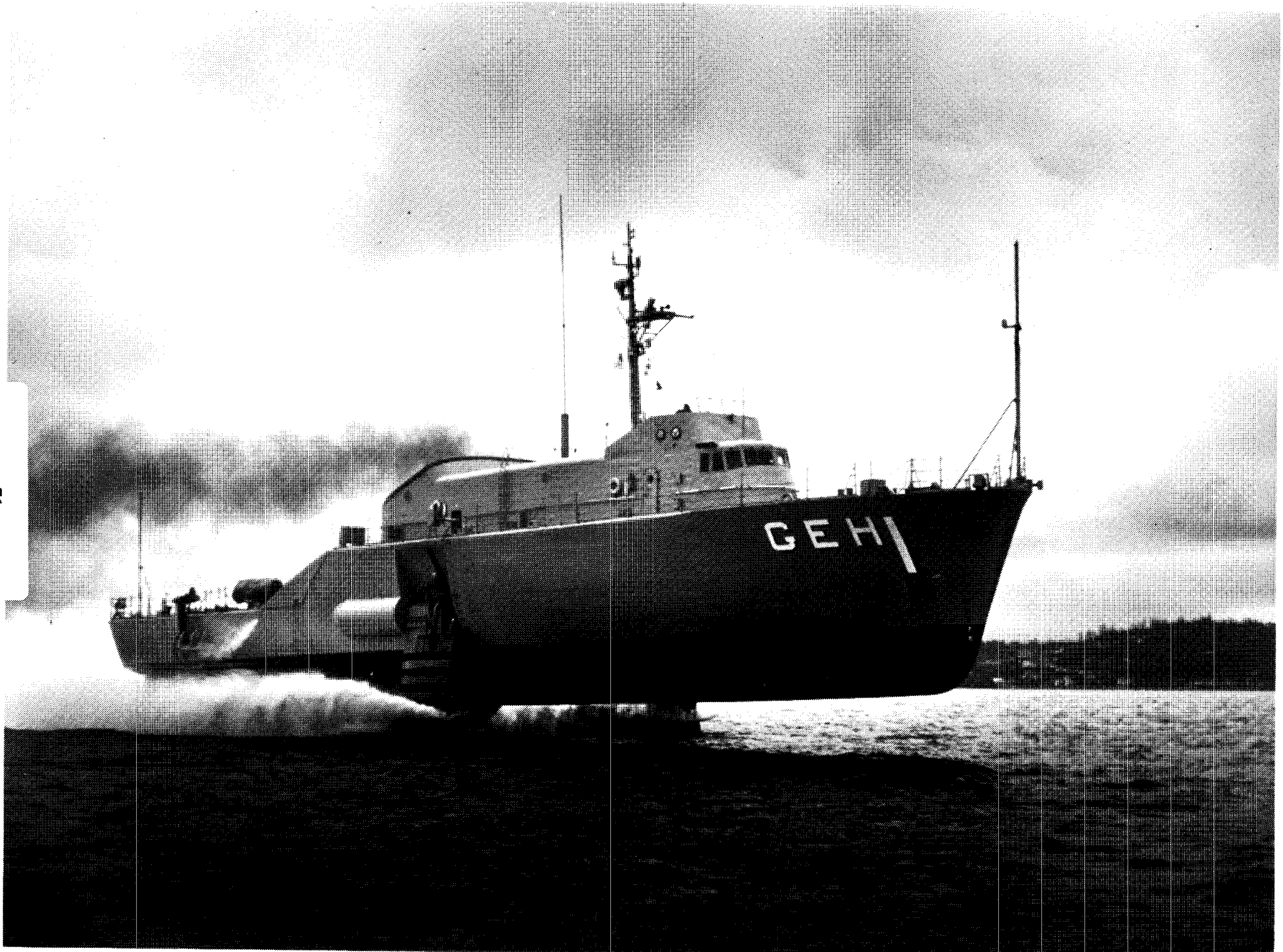
We are celebrating the 25th Anniversary of the founding of the International Hydrofoil Society. So if we go back 25 years from 1995 we end up at 1970, right in the middle of my tour of duty on PLAINVIEW (AGEH-1). And you know, no one asked me to join back then. We may have missed an equally important anniversary last year. As of this year, 101 years ago, the first recorded successful flight of a hydrofoil craft was recorded by the Meacham Brothers. It was in 1894 that they flew their 14 foot test craft near Chicago, Illinois. We can say then, that we flew 9 years before the Wright Brothers flew in 1903 at Kitty Hawk. In 1907 the Wright Brothers did some experimenting with a hydrofoil catamaran in the Ohio River. But these trials were halted by low water levels in the river and a greater interest in aviation development. In 1919, the 11,000 pound, 60 foot long HYDRODOMES (HD-4), a product of Alexander Graham Bell and Fredrick W. Baldwin set the world speed record of 70.85 miles per hour. Those events were the beginning. Much has transpired between then and now with the birth and death of courageous hydrofoils.

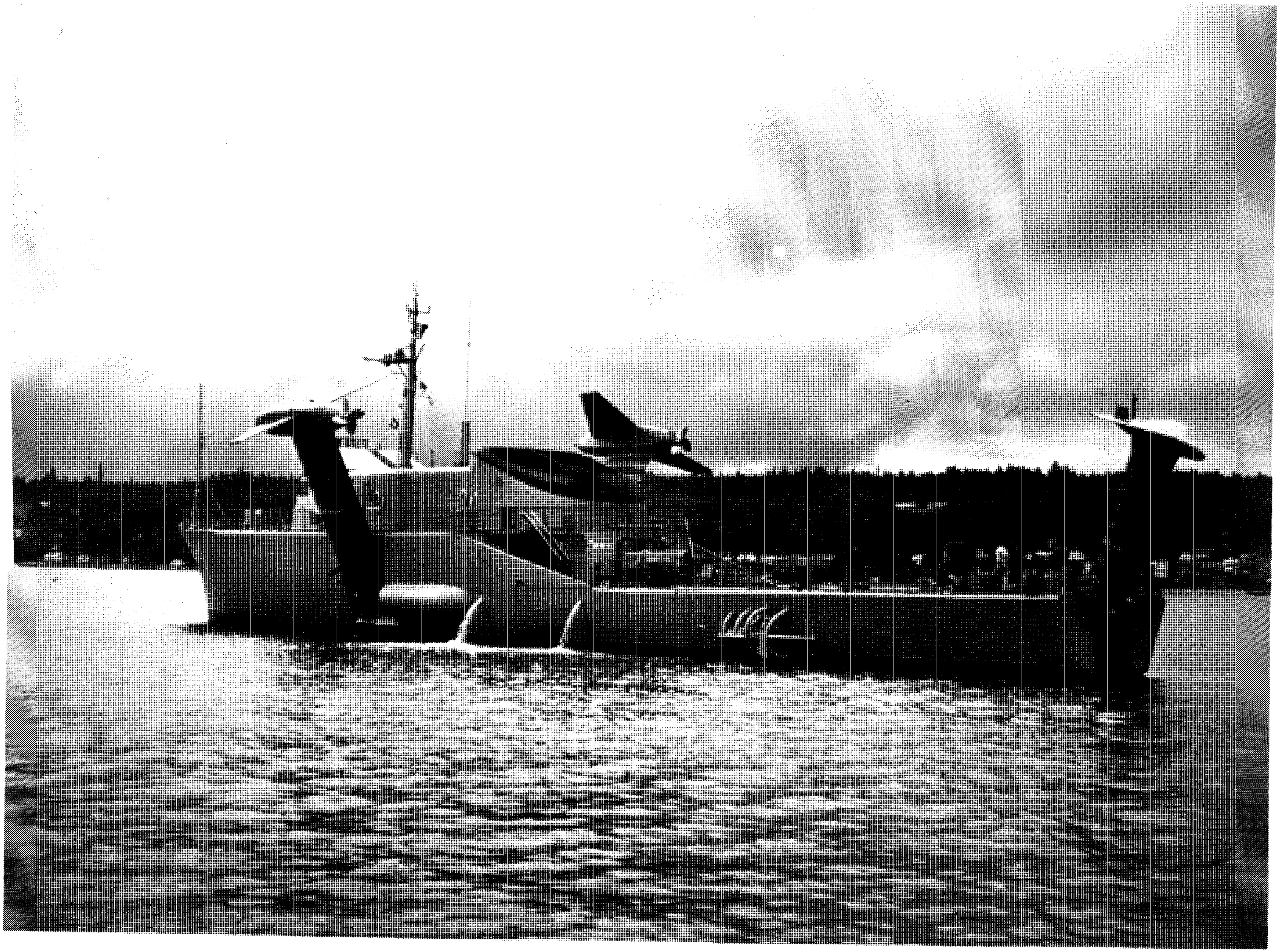
There's no telling where the future will lead us. Advance concepts have been on the drawing board and in the minds of forward thinking men such as John Meyer and Mark Rice, just to name my two favorite, since before I was employed at "the LAB" in 1983 and much earlier. There are those who think that the culmination of all hydrofoil technology was exhibited in the most worked Navy hydrofoil of all, the queen of hydrofoils, HIGHPOINT (PCH-1). Still others, true Navy hydrofoilers of the Eighties may think that the simultaneous flight of all six PHMs demonstrated that success was at hand. Certainly the flights of the other early hydrofoils all contributed to this unique success. But did you know that the early Hawaiians were the first to refine the technology? Kimo Kamaina contributed much to the early flying boats.

But from my vantage, the hydrofoil program achieved its greatest moment with the operations and flights of PLAINVIEW.

I was a reserve sailor temporarily assigned to the personnel office in Pearl Harbor. We reservists were allowed to request the duty we wanted; our wish list. Scuttlebutt had it that although they let us make a wish, they sent us were ever they wanted. Having always loved the sleek lines and daring missions of destroyers, I requested duty on a tin can out of Pearl; fully aware that we might be deployed to Southeast Asia. After reporting to active duty, I toiled away at meaningless personnel duties in the personnel office for about 2 months until one day my assignment arrived. The Senior Chief in the office had received my orders and was beaming from head to toe when he told me I was to report to AGEH-1. That was it, AGEH-1. It wasn't DE or DLG or CVA, ... AGEH-1. No one in the office knew what the AGEH-1 was. However, only months before, USS PUEBLO was seized by the North Koreans. Everyone in the personnel office was sure that a hull number with an A and a G in it meant spy ship. Just what I wanted to hear. Well, with a little research, we found out that the AGEH-1 was, in fact, an experimental hydrofoil vessel home-ported in the Seattle area. But what was a hydrofoil? Was the Navy into those fast racing boats with names like Miss Bardahl and Miss Budweiser? After all, wasn't it on Lake Washington where they held those races. As I was soon to discover, I wasn't the only one a little confused. I met up with PLAINVIEW in early April 1969 just after she had been reluctantly accepted by the Navy on the first of March.

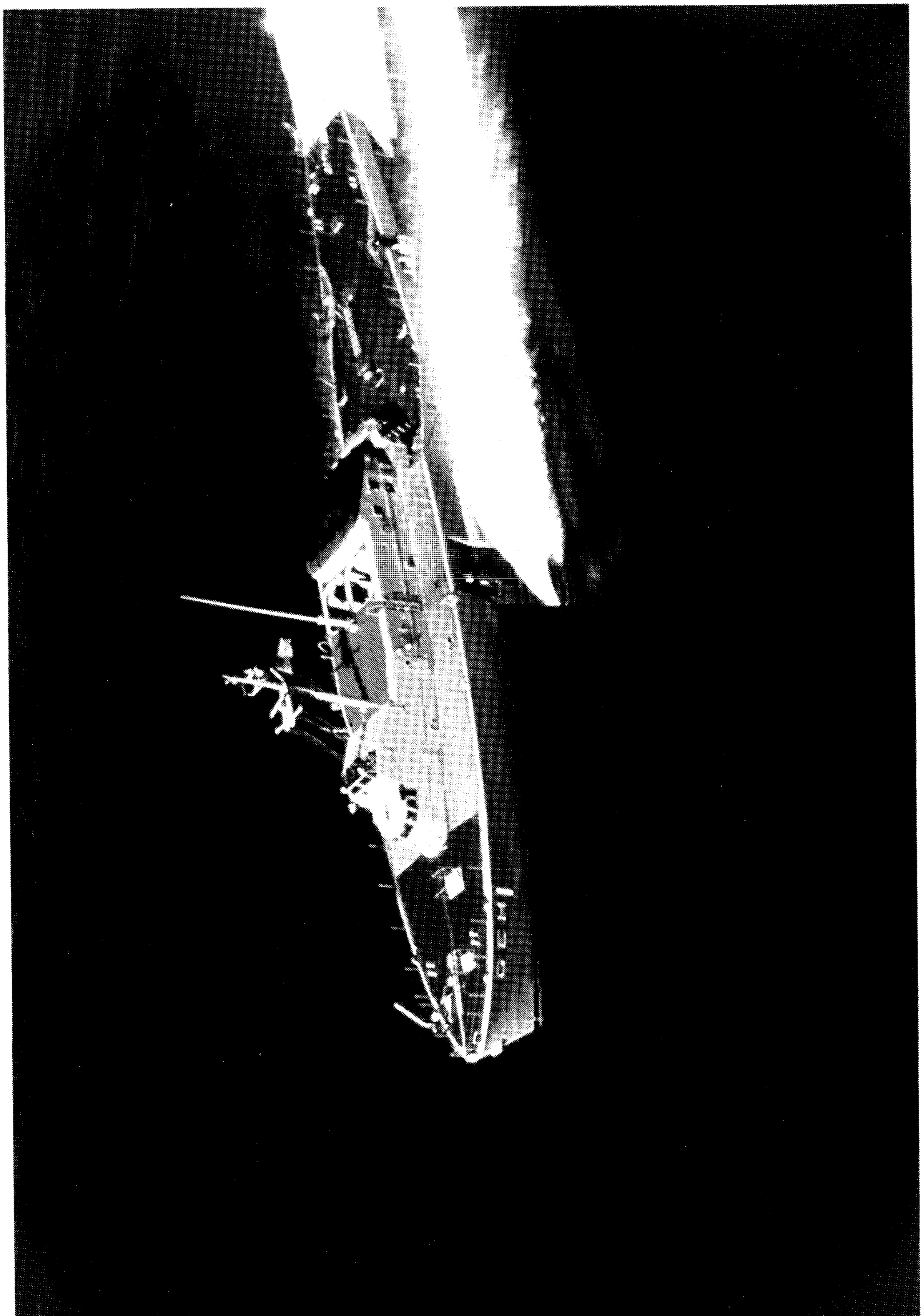
The idea for PLAINVIEW was spawned during a period of acute interest in hydrofoil craft. During the years of 1959 through 1961, the Maritime Administration built the 60-knot DENISON, the experimental high-speed test platform FRESH 1 was started by the Navy, and


GEH 1



a contract was awarded by the Navy to build HIGHPOINT. The Navy also realized a need for a high speed Anti-Submarine Warfare (ASW) platform. To answer this need, the Navy issued a Circular of Requirements defining the specifications to be met by a hydrofoil research ship. The requirements called for an ocean-going ship capable of attaining 50 knots and of maintaining this speed while foilborne is sea states that normally require displacement hulls to reduce speed. This experimental ship was to be capable of remaining at sea in the displacement mode. Emphasis was placed on the use of lightweight materials, lightweight rugged structure and lightweight and efficient machinery. Out of these basic requirements came PLAINVIEW (AGEH-1). As it turned out, the "A" stood for Auxiliary; the "G", general; the "E", experimental; and the "H", hydrofoil. PLAINVIEW was to be used to conduct experimental test and oceangoing trials to provide data for further hydrofoil development as well as to perform ASW exercises in support of high-speed ASW equipment development. The automatic control system requirements were stringent. The ship was to be capable of flying at all headings, in design sea state without manual assistance. The ship was to be capable of incorporating flat and coordinated (banked) turns. Fail safe and redundancy features were required for increased reliability. A vertical acceleration of no greater than 0.25 g was desired in all working and living spaces.

During foilborne operations, all personnel were to be at their assigned stations. These stations all had seats of some sort with safety belts; except for those few crew members assigned to the galley. These seats were ordinary galley chairs that were secured to the deck by a hooked lanyard. Usually only the cook and "Boats" were left to these seats as they were known to be extremely hardened seagoing sailors; or expendable. As a new member of the crew, I was told that if you were standing flat footed while the control system was activated, the potential existed for such great vertical accelerations that your vertebrae could become compressed, hence the requirements for everyone to be off their feet. I was assigned duty as the foilborne lookout. And, by design of my chair, in the enclosed area that was known as the flying bridge, I must have been thought of as a hardened seagoing sailor, too. Either that or expendable. You see, the top of the flying bridge was just about chest high, very convenient for resting your elbows while using the binoculars. The safety seat was a pull-down affair that was about two feet off the deck when in the pulled-down position. This position left the foilborne lookout with a beautiful view of the bulkhead in front of him (and the beautiful blue skies of Seattle if he looked up). While I'm on the subject of foilborne lookout station design, I'd like to share with you one other design flaw. Mounted to the front wall of the flying bridge was a windshield. This is a good idea for a very fast ship. At speeds in excess of 50 knots, it was important to keep the Puget Sound bugs out of the lookout's teeth. But there's another player. You've all heard about the Oregon mist. The Oregon mist is the incessant rain that falls year round on Seattle. It's called that because it missed Oregon. Well, the windshield was fitted with two windshield wipers. Good idea. Bad execution. The wipers were hand operated and only wiped the front of the glass. The Oregon mist was not particular as to what side of the windshield it fell. By the way, the windshields were manipulated by a hand operated lever on the opposite side of the wiper blade. This made it very difficult for the foilborne lookout to search for deadheads while wiping the outside of the windshield with the hand operated



crank with one hand while wiping the inside with a wet tissue, rag, or gloved hand while still keeping the binocs to the eyes, on his toes, which acted like springs to save his back in case of unusual vertical accelerations. Do you get the picture? Oh yes, add to this three cups of morning coffee, a cold and wet day, three layers of dungarees and foul weather gear and guess what? Just when they got out of the channel and wanted to start to fly, you had to go. We foilborne lookouts should have gotten medals.

Back to the design requirements, the ship was to have a displacement of around 320 tons, making it the world's largest hydrofoil. Fitted with two gas turbine engines, the craft was to achieve speeds in excess of 50 knots with the provisions for an additional two turbines and a supercavitating strut/foil system, elevating the speed to 90 knots. The perfect prototype for Admiral Zumwalt's 90 knot Navy. The following table lists the design characteristics.

DESIRED CHARACTERISTICS FOR PLAINVIEW AGEH-1	
Length	150 to 200 ft
Beam (hull)	30 to 45 ft
Displacement	250 to 300 long tons
Draft	26 ft
Range (foilborne)	500 NM @ 50 knots
Range (hullborne)	2500 NM @ 12 knots

The contract to build PLAINVIEW was only seven pages long. The events leading up to it are as follows. Several contractors submitted proposals based on the Circular of Requirements. On 26 December 1961, The Grumman Aerospace Corporation, then known as Grumman Aircraft Engineering Corporation, was awarded the initial guidance design contract. The Grumman proposal contained two designs, a fixed foil design whereby the foils could only be lifted pierside with a crane, and a fully self-retracting system. The fully self-retracting system was selected and phase one of the program began. Phase two called for the detailed design and construction and there was a provision in the contract that if the Navy did not like Grumman's cost estimate for phase two, they could open bids for new competition. Grumman teamed the effort with Newport News Shipbuilding Corporation and the General Electric Corporation. Phase one, the guidance design, took about one year. The preliminary design and weight estimates were submitted and approved in February, 1962 (over 33 years ago), and the contract drawings and final draft of the specification were signed off by Rear Admiral James, then the Chief of Bureau of Ships, on 9 October 1962.

The Navy had estimated and budgeted $12 million for detailed design and construction. Grumman's cost estimate was $17 million, so the Navy exercised their option to recompete the buy. Several bids were received in the neighborhood of $17 million, but Puget Sound Bridge and Drydock Company came in low at under $12 million. (They later became the Lockheed Shipbuilding and Construction Company). On 9 July 1963, the contract was awarded to the Seattle based company and construction was scheduled to begin at the beginning of the new year in 1964. It turns out, however, that the final cost, including later design changes, was close to $21 million. Again, the contract was only 7 pages long!!! Members of the Lockheed team were: W. C. Nickum & Sons for engineering and detail design, Ruker for hydraulic systems designs, General Electric for hullborne and foilborne transmissions, Hamilton Standard for the automatic control system, and Lockheed California for the strut/foil system.

During that year of the design phase, before the recompete, several significant changes were made as PLAINVIEW-ON-PAPER developed. Some of these were:

- The beam was increased by three feet to provide better transverse stability when hullborne with the struts retracted.

- In that the space requirements did not justify three full decks, and since the weight was increasing, the after portion of the main deck was eliminated. This change left the third deck as the second, the second as the main and the old main became the forecastle deck.

- The strut length was reduced by one foot which saved some weight and reduced takeoff drag.

- The foil span was increased by four feet to increase the foil area and the aspect ratio.

- Considerable redesign effort was made to simplify the transmission system. For example, the original design called for the forward struts to house four vertical shafts in order to use the same gears that were manufactured for DENISON. However, with the new availability of 25 inch spiral bevel gears, the four shaft design was reduced to two, thereby simplifying the transmission system design.

- The PLAINVIEW design was pioneering in several areas, particularly shining in the area of determining applied load conditions. Many computer models and physical models were used in these investigations. The shape of the bow was finally determined after extensive tests on eight different bow models, the final loads were based on crash conditions of 90 knots in 32 foot high waves. I believe that some of these model tests led to the following fable. Once upon a time... I recall being told that if the aft foil failed in the up position at speeds around 50 knots, the entire ship would flip stern-to-stem in 6 seconds. Being a former swimmer, I thought I was glad to be exposed to the water during foilborne operations; I'd be the only one to survive.

The keel was finally laid on 8 May 1964 and a little more than a year later, on 28 June 1965 she was launched. This was about two weeks after I graduated from high school. This vessel, the world's largest hydrofoil, was christened PLAINVIEW in honor of both Plainview, New York and Plainview, Texas. The assigned ship's motto was "Progress Through Research".

During the construction phase, Lockheed paid close attention to the technical problems that were encountered. The following bullets highlight some of the problems:

- Welding distortion needed to be controlled. Initial attempts to weld the original extruded aluminum panels, led to extensive distortion. The design was changed to panels with tee stiffeners rather than angle stiffeners. But, to achieve the weight limits, the panel could not be extruded, they had to be milled. With these new panels, the welding distortion was much easier to control.

- A great deal more engineering effort was required than planned to keep within the weight limits. Some systems turned out lighter than planned while others came in heavier. The end result, though, was a lighter than planned ship.

- It became difficult to control the longitudinal center of gravity. Weight was creeping far too forward, creating dangerous tailfoil loading. The fix seemed easy. The number one fuel tank was moved five frames aft of its original position.

- In the construction contract, the propeller was restricted to a diameter of 4.5 feet with only three blades. Tests conducted by Hydronautics, Inc. concluded that a propeller of this design could not produce adequate thrust within the power limitations of the engines. Subsequently, tests were conducted on seven propeller designs, all proposed by Hydronautics. The final propeller design, which stayed with the ship through her life was 5.2 feet in diameter, had four forged titanium blades that were bolted to the hub, and it was supercavitating. The propellers were built by Hamilton Standard.

Other construction dilemmas were met, addressed, solved and/or rejected. As noted in A Ship Whose Time Has Come and Gone PLAINVIEW (AGEH-1), the contract was restrictive in price. Lockheed was confronted with critical funding allocation decisions. Many of the engineering dilemmas could only be overcome by technical advances. There is no question that the sophisticated engineering that was required in so many cases was way beyond that called for from a shipyard engaged in conventional shipbuilding. So, some of PLAINVIEW's systems received excellent design attention and others did not.

To further complicate construction matters, the strut and foil systems had to be removed from the ship after the starboard assembly crashed into the pier. At this stage of the construction the strut/foil assemblies were held in the retracted position by wire rope. One of the ropes failed. The damaged assembly was completely disassembled and all the parts were extensively inspected for damage. Delays in completion plagued the delivery and had deleterious effects on the material condition of the ship. The major contributor to the delays were labor disputes and strikes at the shipyard and in the major vendor's plants. The originally intended delivery date was 9 November 1965. The ship was delivered, and reluctantly accepted, on 1 March, 1969... three and one-half years late!

After a ship is built, the builder's trials begin. Or with the PLAINVIEW, one could say that sometime after the builder's trials were initiated, the construction was finalized. It appears that very few records were kept of the early trials. Perhaps they were lost when the Nickum and Spaulding facility where they were stored caught fire. The Navy record shows that the first voyage was conducted on 4 August, 1967, a full two years after she was launched. The record shows that she got underway at 1132 hours, commenced underway maneuvering trials at 1145 hours, and ended the trials at 1315 hours when the hydraulic system failed leading to loss of steering. As I recall, many of our operating days ended this way. The hydraulic system, which operated the foils, steering, extension,retraction and locking of the struts, and the anchor windlass, operated at 3000 pound per square inch. In addition, the all welded, stainless steel pipe system was used to start the propulsion diesels. Since we didn't have to store many supplies, we had ample room for bales and bales of rags. I think that the rags were always our biggest bill at Servmart. The hydraulic fluid was great for removing paint and, as endorsed by EN3 Maple, whose primary station was in the hydraulic transmission room, it was good for softening callouses on his feet so he could scrape them off with his knife.

Records show that the first foilborne operation was conducted on 21 March 1968 and lasted for 11 1/2 minutes. As the story goes, the auto-pilot was left in the standby mode because of all the pre-first-flight excitement and nervousness. Upon take-off, PLAINVIEW literally flew the forward foils out of the water. On another early flight, an observer in a chase boat calculated the speed to be 57 knots over a measured course. This was before the onboard speed indicator had been calibrated. Following the first flight, until her last flight, the Seattle skies would be filled with smog-like gas turbine exhaust. If the environmentalists had been around in force then... ! There were 34 voyages recorded during the period of the builder's trials. During that time, the longest foilborne flight occurred on 14 November 1968, it was without incident (yet had plenty of incidence) for 46 minutes.

The Preliminary Acceptance Trials (PAT) were conducted in early February, 1969. The PAT requirements included:

- anchoring
- steering hullborne and foilborne
- steering with tail strut only down

- steering with all foils down (extended)
- sequencing hullborne to foilborne and reverse
- charging and training the torpedo tubes.

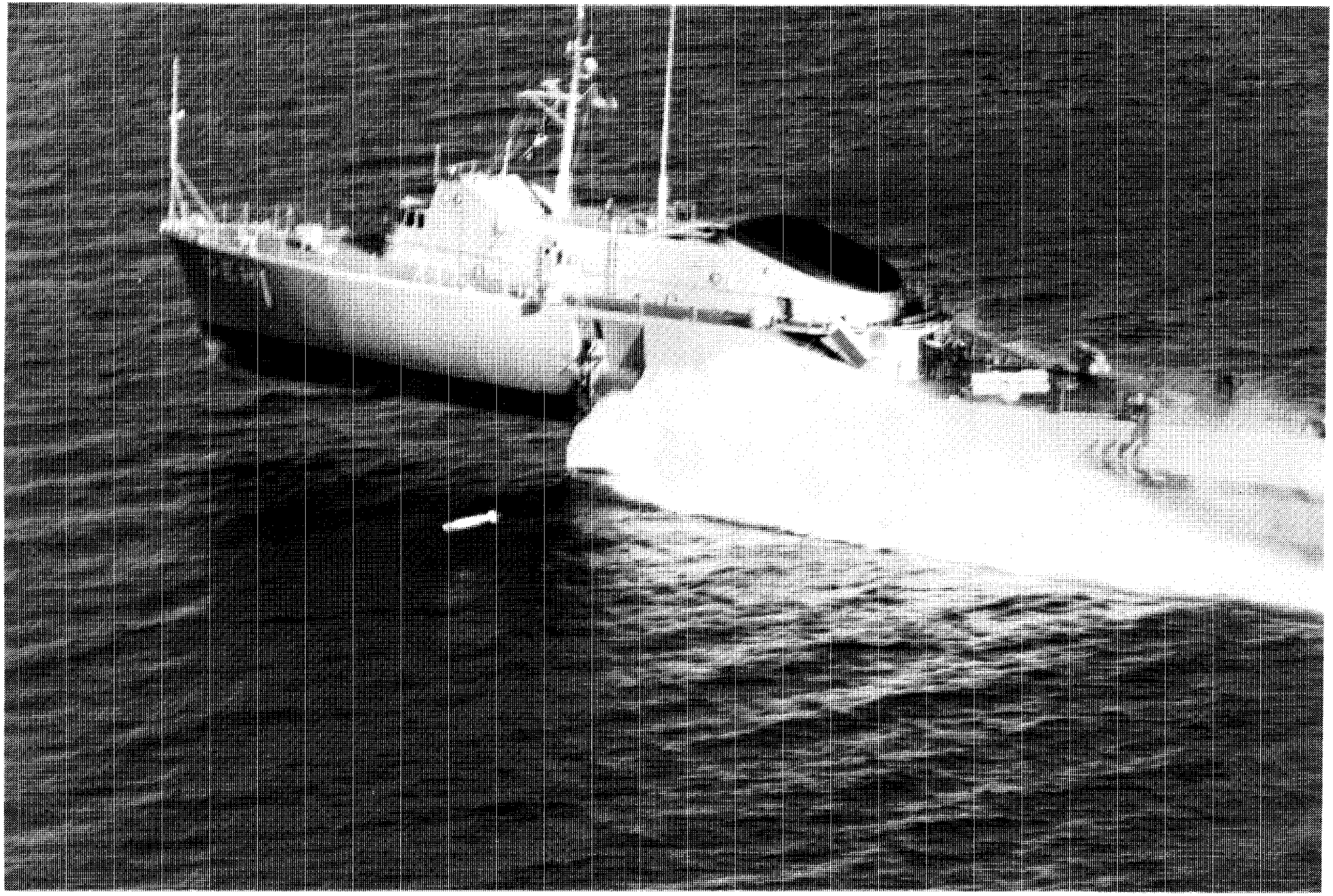
PLAINVIEW had two sets of three cluster torpedo tubes. They were mounted just aft of the transom on the main deck. I recall that they were trained outboard by a hand crank. Since there were no exterior guns on deck, the torpedo tubes made PLAINVIEW look like a fighting ship. On one of our VIP tours into Elliot Bay, we were allowed to display how the tubes worked. I was charged with the task of getting the high pressure air spheres charged with, as I remember, 3000 psi at one of the shops in the yard. I don't remember who actually got to "pull the trigger", but on this occasion, we actually fired something from a torpedo tube while foilborne. I'm not sure that the firing of this projectile was reported, because there wasn't supposed to be anything in the tubes. It seems as if I forgot to remove the desiccate bag. Fire one, a direct hit. We also had four or six M-1s, two 45 caliber Thompson submachine guns, and either two or four service 45s. While I was on board, I never saw any ammunition and the belts we wore while standing Quarter Deck watch always had an empty holster.

But back to the PAT ... The reluctance by the Navy to accept PLAINVIEW when they did is born in part by the results of the PAT. As described in the Johnson/O'Neill paper, "...the results were quite alarming and forecasted future difficulties with the ship." There were 360 items listed by the Trials Board. Eleven were two starred which meant they should have been corrected before delivery. Sixty-four items carried one star which meant they should have been corrected before going into service. At the time of delivery, a number of these items, including some two-starred ones had just not been resolved. These discrepancies obviously led to a greater work load during the early underway days thus a poor record of underway hours. So what was true then, is still true today in developmental projects. And that is, that it takes more than just a contractual agreement to conduct such a developmental undertaking. Dedicated people, committed to the success of the program make it a success, Those qualities are not and cannot be specified in a contractual agreement. With PLAINVIEW, there were plenty of these individuals but during the design, construction a trial period, there was not a continuity of these people. So on 1 March 1969 PLAINVIEW was delivered during ceremonies held pierside in the Lockheed yard. Steven Duich, then with a rank of Lieutenant, was the Officer-in-Charge and was my first skipper.

Since this is a talk of historical reference, I will not present any detailed material on PLAINVIEW's systems and technological achievements. However, let me list some of her unusual characteristics and some of the advanced activities in theoretical analysis and model testing associated with the PLAINVIEW program.

- At the time, PLAINVIEW was the largest hydrofoil in the world. This distinction was ultimately surpassed by the building of the Soviet BABOCHKA at 400 tons.

- PLAINVIEW sported the largest high-speed aluminum hull.



- At 1460 pounds per square inch, she had the highest subcavitating foil loading.
- PLAINVIEW had the largest vehicular hydraulic system with a pressure rating of 3,600 pound per square inch at 1,000 gallons per minute.
- The ZEE-drive transmission was the highest power unit with her two 15,000 horsepower power sources.
- Her high-speed supercavitating propellers were the largest; at 5.2 feet in diameter and a design rotational speed of 1,700 revolutions per minute.
- And, the highest design sea state capability at high speeds; design speeds through ten foot waves with little difficulty.

Other unique activities in the areas of theoretical analysis and model testing surrounding PLAINVIEW included:

- High speed hull impact pressures;
- Series 65 - hull form;
- Finite element program application to hull, strut, and foils;
- Plastic modeling of hull structure;
- Supercavitating strut-foils;
- Unsteady hydrodynamic loads;
- Hydroelasticity;
- Cavitation inception prediction programs;
- Effect of manufacturing tolerances on cavitation prediction;
- Large (40,000 horsepower) planetary gear development;
- Supercavitating and superventilated propellers;
- Nonlinear 6 degree-of-freedom hydrofoil ship simulation technique;
- Optimal control;
- Materials and construction;

- Corrosion control;
- Plastic piping systems;
- And, active and passive fire fighting systems.

Following is just a brief overview of PLAINVIEW the ship, with systems.

PLAINVIEW had a fully submerged foil system with two foils forward, amidships and the third, aft, acting as the rudder. Ninety percent of the lift was accomplished by the forward foils. The three foil systems, constructed from welded HY-80 and HY-100 steel alloys were 31 feet long. The foils, with swept-back leading edges, had a span of 26 feet. The swept-back leading edges helped to delay cavitation and facilitated the shredding of seaweed and other floating debris. You've all heard the stories of hydrofoils losing struts by hitting water logged logs. Besides looking out for small fishing boats, my foilborne lookout duty was to alert the pilot house (cockpit) (bridge) of pockets of floating debris. Elliot Bay was famous for its deadheads. Deadheads are essentially debranched trees that have become so water logged that they are barely buoyant and they float vertically. As they surface they can extend several feet out of the water, when they dive, they are invisible. Imagine a wet, rainy day, the sky is grey, the surface of the water is grey, the lookout is grey, wiping with one hand, wiping with the other, looking with the binoculars. Ahead, he sees what appears to be a telephone pole in the middle of the water. After adjusting the binoculars, he looks again and ... its gone. Immediately he alerts the bridge, "Bridge, Lookout... lookout, there's a deadhead, dead ahead, bearing 000 relative, 400 yards." Much to the lookout's concern, this sighting has occurred just when there is a serious technical problem with the control system or hydraulics. Only at the very last second is the impending danger acknowledged and sure disaster averted. On several occasions, PLAINVIEW was forced to fly right through clusters of debris with branches up to 10-12 inches in diameter. Often, broken branches and other debris would end up on the deck, having gotten there from the rooster tail plume generated by the forward struts. The struts were extended and retracted (and locked) by means of a hydraulically operated activating arm. Extension and retraction were supposed to be synchronized so that PLAINVIEW did not list to one side or the other during this evolution. It was also my duty to let the bridge know the percent travel of both struts. One day, while retracting the struts, the activating arm pivot pin sheared and the starboard strut came crashing down. From my position on the back coaming of the flying bridge, I couldn't tell exactly what had happened so I had to report, "Bridge, lookout, the starboard strut just fell off." Wasn't exactly true, but it did get some excited responses. As I recall, with one strut up and one strut down, there was quite a list on. I think it was to the starboard side. Needless to say, we had to lower the port strut and limp back home. It was slow going and as it grew dark, extra attention had to be given to the channel markers so we didn't run aground with these deep struts hanging down.

Since weight is of paramount importance in flying ships, PLAINVIEW hull and deck house were constructed entirely of 5456 aluminum; 125 tons of it. Many of the interior bulkheads were of aluminum-sheathed honeycomb construction similar to that used on aircraft. On quiet days, I was set to polishing the unpainted aluminum bulkheads in the crew's quarters. (Real productive work.)

All manned spaces, with the exception of certain engineering spaces, were air conditioned by a 15 ton capacity compressor system. The engine rooms, the galley, and the heads were all mechanically ventilated. In the pilot house, the pilot sat on the left, the co-pilot on the right, and an observer was seated between and slight behind these positions. Three Navy standard quick-acting water-tight doors provided access to the pilot house; one on the port side aft, one on the starboard side forward, and one inside from the main deck aft. The Captain had his own stateroom, the other Officers had theirs, and there was a crew's quarters. There were two heads. The officers had a wardroom and the crew had a mess decks with a galley. Food shopping was done at the commissary and there was always plenty of ice cream and hot coffee.

Foilborne propulsion was provided by two General Electric LM-1500 gas turbines, the marine version of the J-79. Remember that there were provisions for installing two more of these engines for a potential speed of in excess of 90 knots (bring on the hydroplanes). Each LM-1500 generated 14,500 horsepower. The power was transmitted through gear boxes, and the largest ZEE gear drive, to the titanium screws described earlier. Hullborne propulsion was provided by two General Motors V12-71 diesels, each rated at 500 horsepower. These diesels drove aft through shafting and a right angle gear box to externally mounted outdrives. The outdrives were fully retractable and could steer through 360 degrees. Outdrive propulsive force was provided by a four-foot five-inch diameter, five-bladed fixed pitch subcavitating propeller, fixed to each outdrive. Auxiliary power was provided by two General Motors V8-71 275 horsepower diesels driving two 100 kilowatt, 450 volt, 3 phase, 60 hertz generators.

The electronics system included: a Raytheon Pathfinder radar with an AN/SPA-25 repeater, an AN/WRC-18 Bendix radio, an AN/URC-58 radio from RF Comm Inc., and two AN/ARC-52X Collins radios.

Shortly after delivery, PLAINVIEW transited out of Elliot Bay, across Puget Sound to Rich Passage, around Point White into Sinclair Inlet to her new home at the Hydrofoil Special Trials Unit (HYSTU) at Puget Sound Naval Shipyard (9 years after conception). Nine years later, she would be stricken from the Naval Register. The Final Contract Trials were commenced on 21 January 1970 and on 2 March 1970, the Navy accepted the ship (1 year after delivery).

In between fix-ups, system design improvements, and drydocking overhauls, PLAINVIEW was used to explore the uses of hydrofoils ships in various mission roles and the compatibility of developed mission equipments, components, and systems in hydrofoil operations. These trials, without exception proved to be important learning experiences.

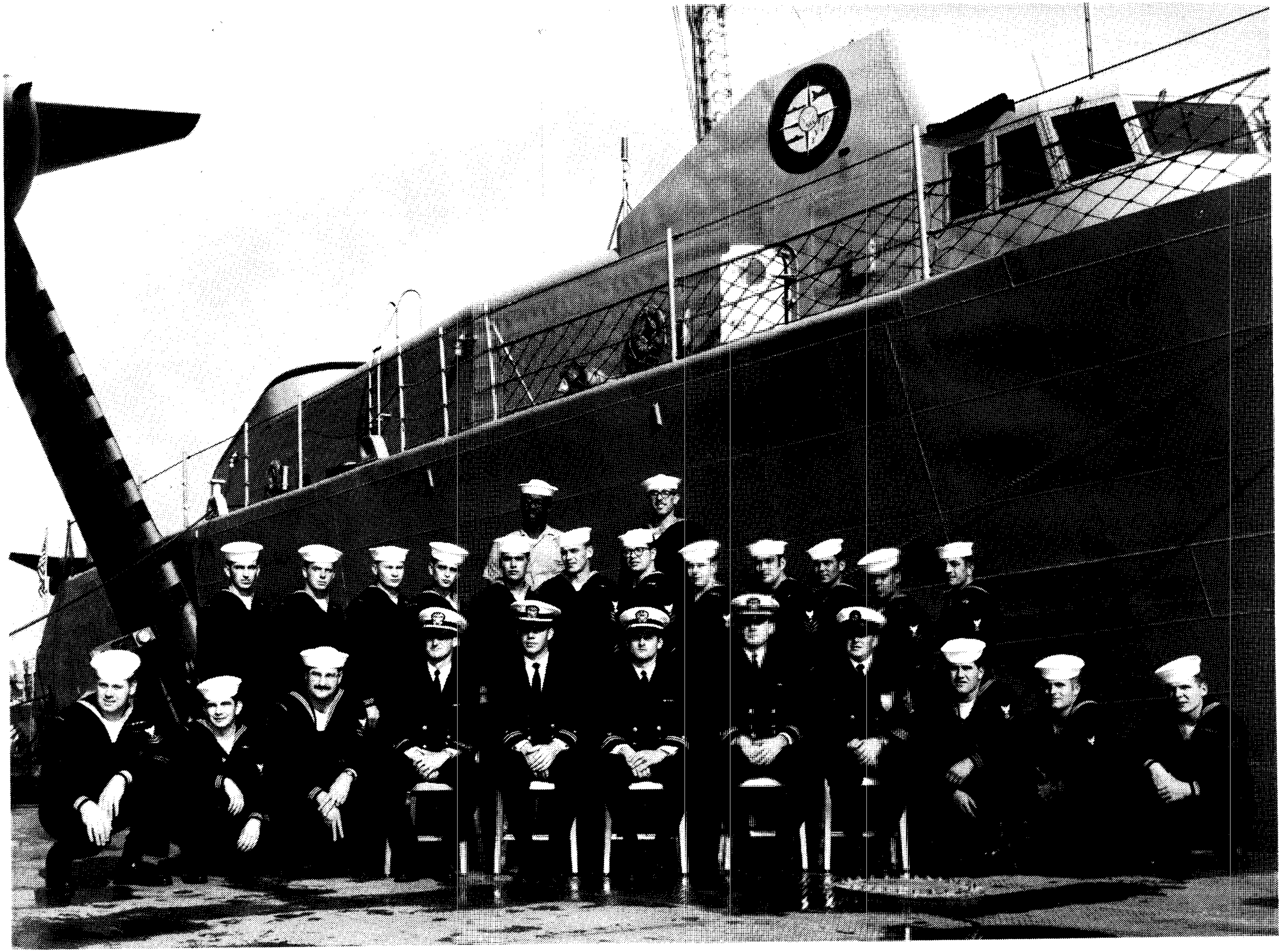
On 9 July 1970, Lieutenant William Erickson relieved Lieutenant Commander Duich as OIC. I have fond memories of the look on Boats' face as I explained that the Skipper had asked me to the "O"-Club with him for some tennis at lunch. We had a wide variety of personalities on the crew, but we all got along and all chipped in to get the ship functional for the next day's trials. I happen to have one of the very limited distribution copies of the crew picture taken while Steve Duich was still OIC. I was given my unconditional release from the Navy in October 1971 and I owe much of what I am engaged in now to that experience.

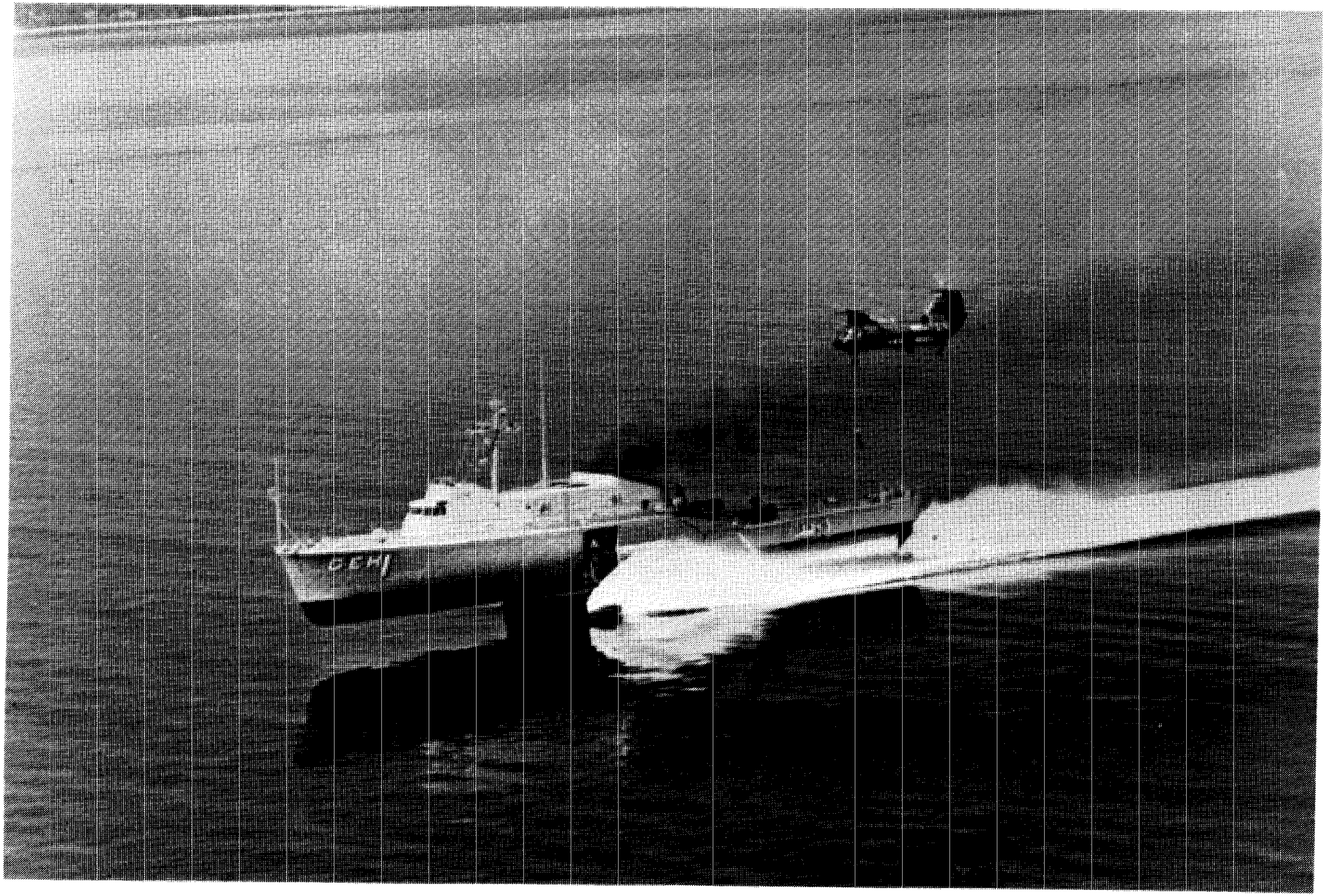
During 1971 and 1972, PLAINVIEW operated in the Puget Sound area where she spent many hours undergoing a variety of tests. These included: how tight a turn she could make foilborne, how fast she could stop while foilborne, and as I mentioned earlier, how fast she could foul up the Seattle sky line. In August 1972, PLAINVIEW participated in Seattle's annual Seafair activities where she was available for guided tours at Seattle's Pier 91. On 6 June 1972, she passed her 100th foilborne hour.

In September 1972, PLAINVIEW was underway continuously for three days and two nights in the Puget Sound and Hood Canal areas. She was foilborne most of the time during the day hours of this mission and hullborne at night. The tests were conducted to see if there were particular restrictions encountered if she were to be deployed at sea for long periods of time. Prior to my departure, PLAINVIEW made one extended voyage up Puget Sound into the Straights of Juan De Fuca. We flew most of the way up there, maneuvered hullborne near Port Angeles and spent the night at anchor off the coast. The next day we transited back to our berth at the shipyard. Back to September 1972, PLAINVIEW conducted the first foilborne hydrofoil-to-helicopter personnel transfer. During this exercise, Stewardsman Bobby Billings (another expendable type) was hoisted from the fantail to a CH-46 helicopter. The exercise verified that the turbine exhaust would not present a problem for foilborne transfers. The helicopter pilot reported that the increased stability in a seaway while foilborne made this method of personnel and material transfer preferable over conditions encountered on other, mere mortal, surface ships.

In November of that busy 1972, PLAINVIEW transited to the Canadian Forces naval base near Victoria, British Columbia. For the next month, she would transit almost daily to the open Pacific Ocean to conduct technical trials in eight to ten foot seas. The data collected during these trials included: control parameters, speed, power, and structural loads. Also during this time, the Sea Sparrow missile was evaluated through a series of at sea tests. A special single canister delivery system was designed and installed on the fantail. Three missiles were fired, one while hullborne and two while foilborne at 42 knots. There was no interference to or damage to the ship and the missiles performed properly throughout their flight. This test provided valuable information for the future development of hydrofoil/missile operations for the PHM program.

Sadly, the end began in December 1972 following the very successful operations in the Pacific. While returning from the test area in the open ocean to the base in British





Columbia, the marine gear linkage in the starboard strut snapped, causing PLAINVIEW to roll hard to starboard, crashing into the water. Although there were no personnel injuries, this casualty led to an extended downtime that exempted PLAINVIEW from conducting other concept proving trials that could have or would have glorified her in the eyes of those who controlled budgets [of course this is only my opinion (though not my only opinion)].

In January 1973, PLAINVIEW began an overhaul at Puget. However, due to an over committed schedule at the yard she was sent to Lockheed for minor repairs. Bill Erickson was relieved on 12 July 1973, replaced by Lieutenant Edmund Woolen. Finally, on 16 May 1974, what was to be a two year overhaul and modernization program was began at Todd Shipyard in Seattle. The work package included:

- a new hydraulic system with all welded piping;
- disassembly and refurbishment of the main struts and foils;
- a new incidence control system;
- a new tail strut of HY-130 steel;
- the Hydrofoil Universal Digital Autopilot;
- and, a radar height sensor instead of the sonic one.

During the overhaul period, Lt. Woollen was relieved by Lt. Hudson.

Soon after returning to the trials arena, the Carter Administration, the Congress thereof, exhibited typical shortsightedness (my opinion) in leveling the budget axe on this extremely worthy R&D effort (the path to naval ships of the 21st century). Even while the fleece of this sacrificial lamb was being sheared, PLAINVIEW was underway again, this time in the company of her sister, HIGH POINT, back up to Canada to help celebrate Queen Elizabeth's birthday. In July and August of 1977 PLAINVIEW participated in pressure ranging tests and in December, PLAINVIEW launched and recovered remotely piloted vehicles (RPV) from the fantail. At the time, RPVs were of interest for over-the-horizon targeting and communications. The hydrofoil proved to have one feature that made RPV operations intriguing. Since the foilborne speed is actually faster than the RPV stall speed, the hydrofoil could maneuver under a flying RPV and retrieve it at the same speed (officially referred to as "zero-relative-speed recovery").

And now for the end. The House of Representatives' Conference Report No. 95-451 of 21 June 1977 recommended that both hydrofoil research ships, PLAINVIEW and HIGH POINT, be deactivated and mothballed in fiscal year 1978. In answer to this report, the Secretary of the Navy, W. Graham Claytor, Jr., in a letter dated 1 December 1977, acknowledged the reduction in Hydrofoil Craft (Advanced) line funding from $2,132,000 to $500,000 and

requested, in light of further development of PHM missions, that HIGH POINT be retained through fiscal year 1978 and that PLAINVIEW be retained through fiscal year 1983. On 15 December 1997, House Appropriation Chairman, George Mahon, responded to this request with the following:

> "The committee considered Secretary Claytor's letter of 1 December 1977, which proposes to retain HIGH POINT (PCH-1) and PLAINVIEW (AGEH-1) in service beyond the end of FY 1978 and to initiate an RDT&E effort to develop additional missions for the NATO PHM class of ships. As pointed out in the letter, $500,000 was appropriated in FY 1978 for the purpose of deactivating/mothballing the PCH-1 and AGEH-1. The Committee directs that the funds appropriated be used for the purpose identified in House Report 95-451. The funds estimated to be used for the development of additional missions for the PHM are considered to be far in excess of the funds required for a reasonable and prudent effort at this time."

Even by this letter we can see that the PHMs, as well, were doomed. On 3 March 1978, the Secretary of the Navy directed that PLAINVIEW be stricken from the naval vessel register on 30 September 1978 and disposed of accordingly. On 24 March 1978 Lt. Victor Ackley relieved LCDR Hudson as PLAINVIEW's last OIC. During early summer of 1978, PLAINVIEW conducted joint ship exercises with HIGH POINT and recorded her final foilborne voyage on 17 July 1978. Total foilborne hours, 268. PLAINVIEW was never tested to the limits of her rough water capability.

In May of 1979, PLAINVIEW was sold to the Levin Metal Corporation, of San Jose, California, for the grand sum of $128,000. A far cry from the $21 million purchase price and in no way indicative of her total value and worth to the Navy and the hydrofoil research community. It was proposed by her buyers that she would become a fishing vessel. On 20 July 1979, PLAINVIEW, stripped of her struts and foils, her gas turbines, her instrumentation, and other equipment, was towed out of the Inactive Ship Facility. The proud and beautiful PLAINVIEW never made it to California but ended up, ignominiously, abandoned on a mud flat near Astoria, Oregon.

DIMENSIONS (EXTERNAL)	
LENGTH OVERALL, HULL	212 FEET
LENGTH WATERLINE, HULL	205 FEET, 1.75 INCHES
LENGTH OVERALL, FOILS RETRACTED	223 FEET, 8 INCHES
LENGTH OVERALL, FOILS EXTENDED	219 FEET, 1/2 INCH
HULL BEAM	40 FEET, 5 INCHES
BEAM OVERALL, FOILS RETRACTED	82 FEET, 8 INCHES
BEAM OVERALL, FOILS EXTENDED	70 FEET
DRAFT, FOILS RETRACTED	6 FEET, 3 INCHES
FREEBOARD, FORWARD	15 FEET, 6 INCHES
FREEBOARD, AFT	7 FEET, 6.5 INCHES
HEIGHT TO TOP OF MAST	54 FEET, 9.5 INCHES
WEIGHTS	
LIGHT DISPLACEMENT	265 TONS
NORMAL TAKE-OFF	290 TONS
MAXIMUM TAKE-OFF	328 TONS
PERFORMANCE	
MAXIMUM SPEED FOILBORNE	50+ KNOTS
CRUISING SPEED FOILBORNE	42 KNOTS
MAXIMUM SPEED HULLBORNE	13.5 KNOTS
CRUISING SPEED HULLBORNE	12 KNOTS
MAXIMUM PERMISSIBLE SEA STATE AND WAVE HEIGHT IN FOILBORNE MODE (DESIGN SEA STATE	BEAUFORT 6, SEA STATE 6
CALM WATER TAKE-OFF SPEED	33 KNOTS

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OVERVIEW OF THE HYDROFOIL TECHNICAL AND RESEARCH BULLETIN

James H. King

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ABSTRACT

The International Hydrofoil Society, together with the Society of Naval Architects and Marine Engineers, is preparing a Technical and Research Bulletin to characterize hydrofoil design principles. This paper describes the purpose behind the T&R Bulletin, and the approach to its preparation. The paper includes summaries of the various sections of the T&R Bulletin and describes the progress made.

INTRODUCTION

Many in the hydrofoil community have recognized the need for a standard reference on hydrofoil design. In this paper, we discuss the ongoing effort to write such a reference. We also illustrate many of the highlights of the document.

First, we will present the genesis of the current effort and describe its objectives and general approach. Then, we will provide a representative summary for each section of the T&R Bulletin. Finally, we will discuss the progress toward its completion and ask for help from the community.

GENESIS

In 1981, the International Hydrofoil Society (IHS) embarked on an ambitious effort to prepare a Principles of Hydrofoil Technology. This was to be a standard textbook on hydrofoil design, similar to the Principles of Naval Architecture, published by the Society of Naval Architects and Marine Engineers (SNAME). An outline for Principles was developed and authors were selected for each section. Many of the authors contributed their sections, though not all did. In the end, Principles was never completed.

In 1993, the IHS Board of Directors decided to examine the outstanding issues of Principles. Should we complete it? Should we abandon it? How would it be published and how would we pay for its publication? We did a feasibility study to support a decision. After reviewing the "Draft" of Principles, we arrived at several conclusions:

- There was a lot of excellent material in the document, which needed to be published,
- Several sections were completely missing, including the very important sections on control systems, foil/strut structures, and machinery,
- Other sections were incomplete,
- The section on foil/strut hydrodynamics was actually two sections, one on surface-piercing foils, the other on fully-submerged foils,
- Many authors emphasized issues that were topically significant at the time that their sections were written, rather than general technical principles,
- Much of the text is "dated", discussing technology which is now old, not incorporating much new technology,
- There was too much emphasis on naval applications and design in many sections, and
- The document was in terrible shape, not nearly ready for publication.

At about the same time, SNAME Panel SD-5 embarked on an effort to prepare Technical and Research Bulletins on each type of advanced ship. It became clear that, for the present time, the best approach might be for IHS and SNAME to join forces to prepare a hydrofoil T&R Bulletin, based on Principles. We could adapt material from Principles, shorten it, and have it published under SNAME auspices, at affordable costs. We prepared an outline and approach and submitted them to both the IHS Board and SNAME SD-5. They both approved, and work began.

OBJECTIVES

In beginning to prepare the T&R Bulletin, we proposed several objectives, as described below:

- Make the document much shorter than the present draft of Principles,
- Design the report for the practicing naval architect. Emphasize those elements which are unique to hydrofoil design and differ from standard naval architecture,
- Treat fully-submerged, surface-piercing, and hybrid concepts in a unified manner
- De-emphasize technology and emphasize principles, and
- Address design from a general standpoint rather than from a naval application.

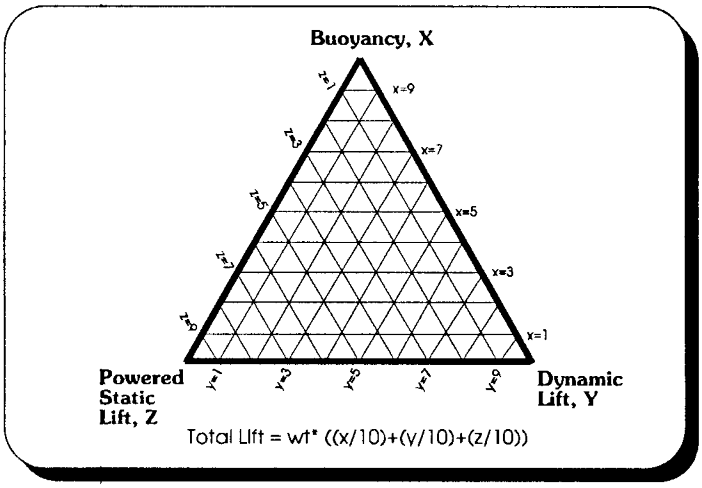
The T&R Bulletin is designed to be complete and brief, but not thorough. It will provide a naval architect with the information that he needs to get started in a design project. It provides only feasibility-level information which will augment his basic naval architecture education and experience. He will need to consult more complete references in order to complete each element of the design.

SUMMARY OF THE T&R BULLETIN

The T&R Bulletin begins by describing the sustention triangle, an important concept in hydrofoil design.

THE SUSTENTION TRIANGLE

In 1976, Dr. David A. Jewell introduced the concept of a sustention triangle, (See Jewell, 1976). The sustention triangle is used to identify the distribution of the forces which support the ship during its normal operations. Buoyant forces are those which support most ships. Powered static forces are used in air cushion and surface effect craft. Dynamic lift is provided by hydrofoils and planing craft.



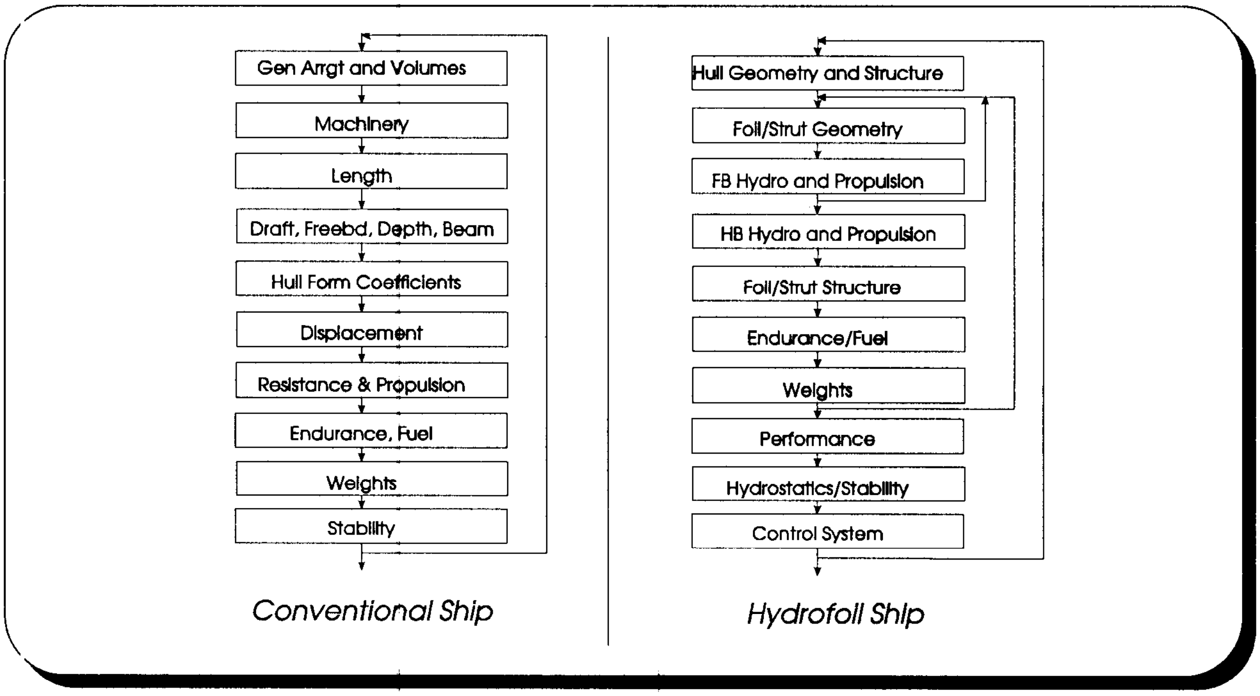
It is possible to conceive of a vessel which is supported simultaneously by all three kinds of forces. Although we are interested in hydrofoils, we recognize that there is no such thing as a pure hydrofoil. Even high performance hydrofoil craft derive 5% to 10% of their support from buoyancy provided by struts and foils, and we must include the application of hydrofoil technology to hybrid vessels in which a major portion of their lift is derived from other sources.

The Bulletin provides the reader with a broad understanding of the various types of hydrofoil systems, their characteristics, and their history. It also introduces the concept of hybrid hydrofoils.

DESIGN PROCESS

In order to initiate the naval architect to hydrofoil design, the T&R Bulletin includes a section on the hydrofoil design process. It shows how the elements of this process differ from those of standard ship design. The figure below, adapted from King and Devine, 1991, shows the hydrofoil design process, compared to a standard design process. As with most advanced ships, the hydrofoil designer cannot rely on rules of thumb. Much of the design work must be done from "first principles".

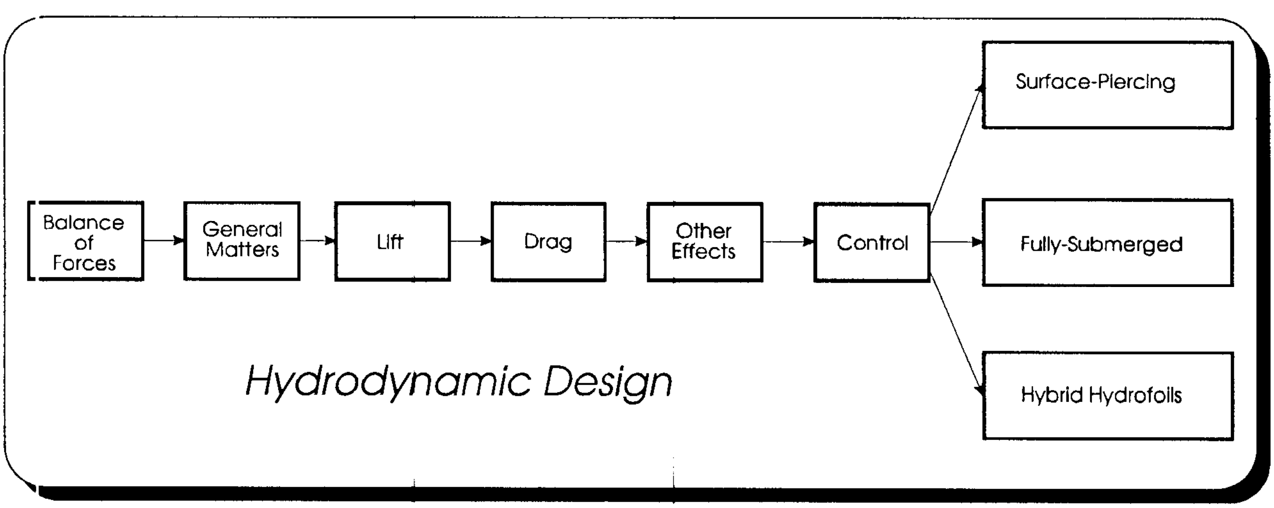
The naval architect must pay closer attention to weights, due to the weight sensitivity of hydrofoils. The location of the weights is as important as their total because they impact on lift distribution and variation through both the voyage and the life cycle.



FOIL/STRUT SYSTEM DESIGN

Obviously, the design of the foil system is critical. Hydrodynamic design must account for operation through the normal range of weights and speeds and for takeoff. Sufficient stability and control authority must be provided. The structural design of the foils is relatively unique.

As mentioned earlier, the section of foil system design in Principles was really two sections: one on surface-piercing design, the second on fully-submerged design. There was essentially no commonalty among these two sections; they reflected as much the authors' approaches as much as they did design principles. These differences were not necessary because many of the principles and approaches to the design of the two types can be common. The unique aspects, though important, are relatively few. Because it was designed around the separate approaches, the hydrodynamic sections of Principles provided no guidance to the designer of hybrid hydrofoils. We attempted to correct these deficiencies in the T&R Bulletin.



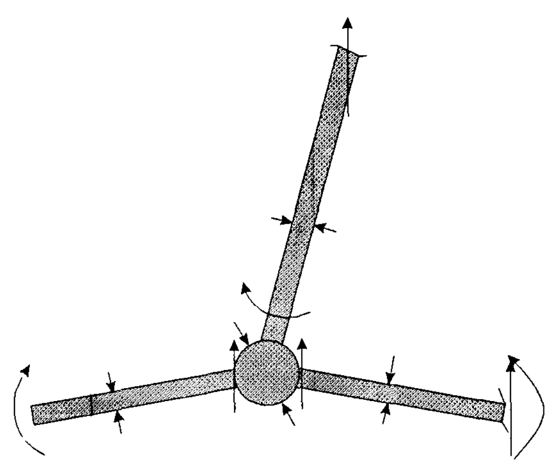
Foil/Strut Hydrodynamics

The naval architect must consider many elements of foil hydrodynamic design. These follow:

- Balance of Forces
- Foil Loading
- Aspect Ratio
- Foil Section
- Lift
  1. Lift Coefficient
  2. Limited Span -- modifies lift curve slope based on aspect ratio
  3. Finite Depth -- modifies lift coefficient and lift curve slope
  4. Sweepback -- modifies lift curve slope
  5. Dihedral -- modifies angle of attack and lift vector
  6. Flap Angle -- produces an incremental amount of lift due to flap deflection angle
- Drag
  1. Foil Drag -- including induced drag and parasite drag
  2. Strut Drag -- including profile, wave, and spray drag
- Tandem Interference Effects
- Cavitation and Ventilation
- Control Authority and Directional Stability
- Surface-Piercing Considerations
  1. Spray Drag on Foils
  2. Variation in Aspect Ratio and Depth of Submergence
- Fully-Submerged Considerations
  1. Pod Drag -- Depending on type of pod
- Hybrid Design

Foil/Strut Structure

The structural design of a foil system is relatively unique in ship design. Foil system weight is crucial. Of course, structural reliability is very important. Both point and distributed loads are imposed. The foil design will include joints and load concentrations. The figure illustrates some of the considerations that the designer must consider in the design of his foil system.



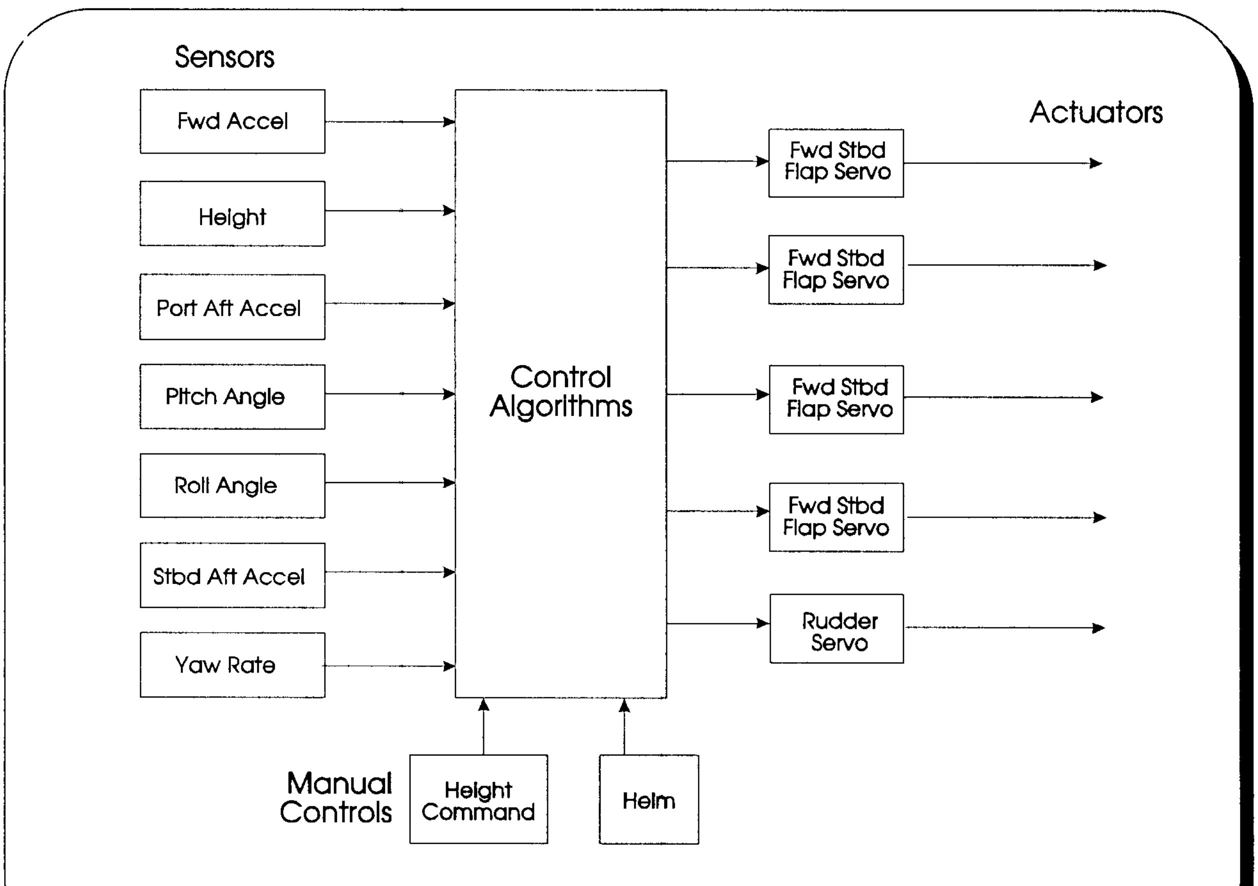
Some Foil System Loads

Control Systems

Technology may have affected control systems more than any other aspect of hydrofoil design. When Principles was drafted, analog control systems were preeminent in hydrofoils and other ship control problems. Digital control systems were proposed and development efforts were underway, but such systems were not common. Now, digital control systems are widely used. As time progresses, engineers will develop new, more efficient approaches, perhaps based on fuzzy logic or neural nets. It may have been the understanding of the advances in technology that prevented the authors of Principles from completing the control section. For purposes of the T&R Bulletin, we are attempting to prepare a description which:

- Describes the control problem,
- Shows broad approaches toward its solution, and
- Does not recommend a specific approach, but
- Leads the designer toward a fundamental design sufficiently robust that a sound control design will work.

A broadly defined schematic for a control system is illustrated below.



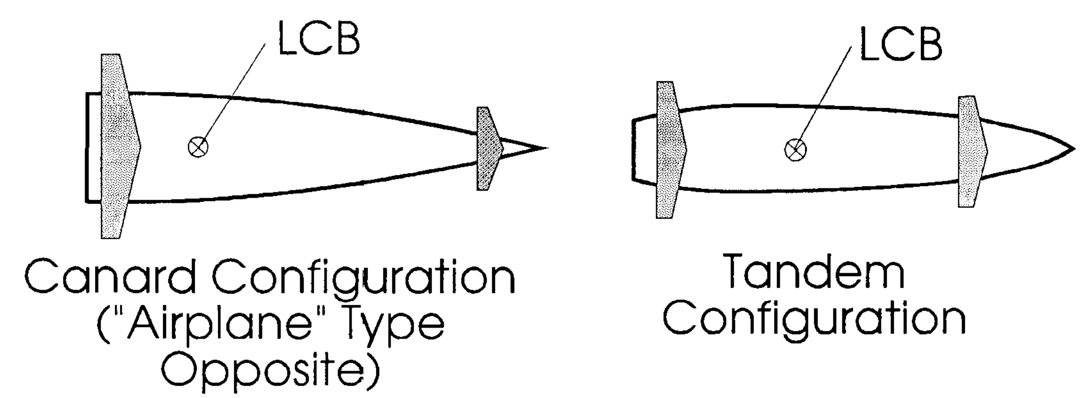
HYDROFOIL CONTROL SYSTEM SCHEMATIC

HULL DESIGN

Hull Lines

When designing a hull for a hydrofoil ship, the designer must consider the balance of foilborne versus hullborne operation. If the ship is to operate primarily in the hullborne mode, using the foils only for a boost situation, then the hull should be optimized for the hullborne mode. However, the designer must consider the resistance of the hull as speed increases during a takeoff run. The hull resistance is added to that of the foils as foil lift is increased to result in a total drag which can be quite high and must be overcome. This takeoff drag can result in the controlling power requirement for the ship. This could lead a hull designer to compromise hullborne efficiency to reduce resistance during takeoff. If the ship is to operate primarily in the foilborne mode, the designer might select parameters to minimize the takeoff resistance.

Because the ship operates in two modes, the designer must design the hull to match the force distribution produced by the foils. As we all know, the ship will trim so that the longitudinal center of buoyancy matches the longitudinal center of gravity. The figure below shows how foil lift distribution can influence hull form.



Foil Distribution Influences Hull Form

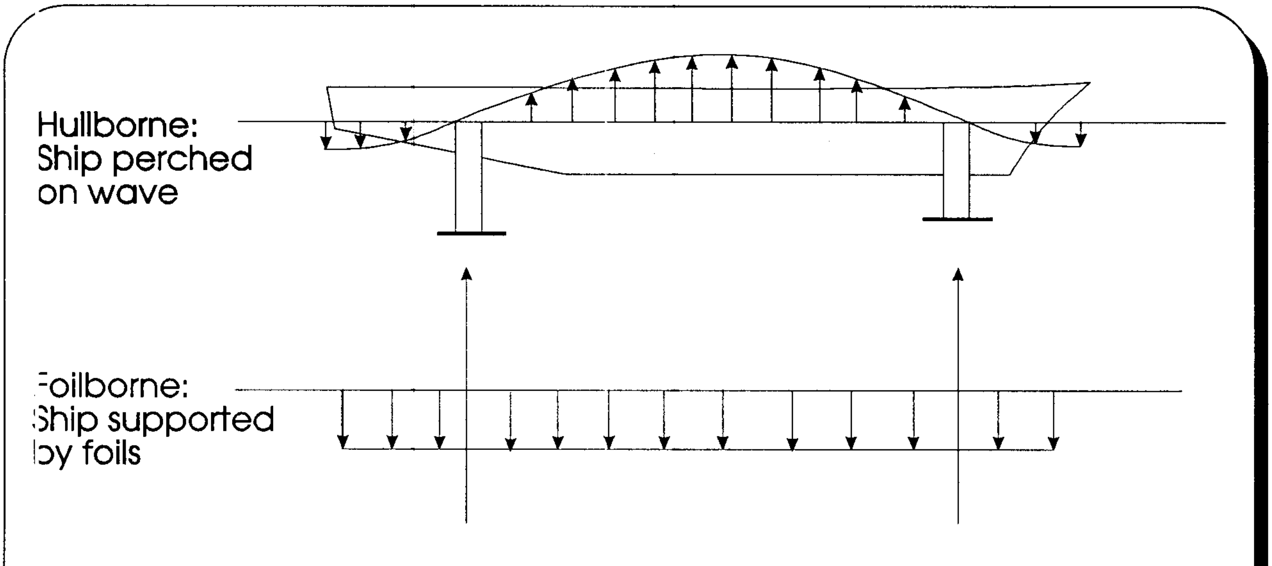
The designer must also consider seaborne loads in his hull design. Because foilborne speeds are higher than usual ship speeds, the wave impact loads can be quite high. Loads due to "crash landings" can also be high. Either the wave impact or crash landing loads will usually be the controlling loads for hull plating. Careful control over the bottom slopes can mitigate the loads imposed on the hull.

It may sound simple, but the hull has to connect to the foils. This simple geometrical constraint can distort the hull lines away from those which might otherwise be selected.

The foil system can have a major impact on hullborne stability. This must be considered in the design. The foil system is a large weight, with little buoyancy, very low. This contributes to making the ship "stiff". However, if the foils are retracted, then that weight moves to a higher location. This reduces the stiffness and makes the ship less stable.

Hull Structure

Loads imposed by the foil system influence the hull design very significantly. Essentially, two complete structural conditions must be considered for primary structure. These are shown in the figure below.



Hull Structural Loads

In most cases, however, secondary loads control the structural design. As described above, sea impact loads can be quite high. Plate pressures are a function of many factors including ship speed, wave height, vertical motion, etc. Plate size has been demonstrated to have a major influence on impact pressures. Design pressures as high as 50 psi have been used on some small hydrofoils.

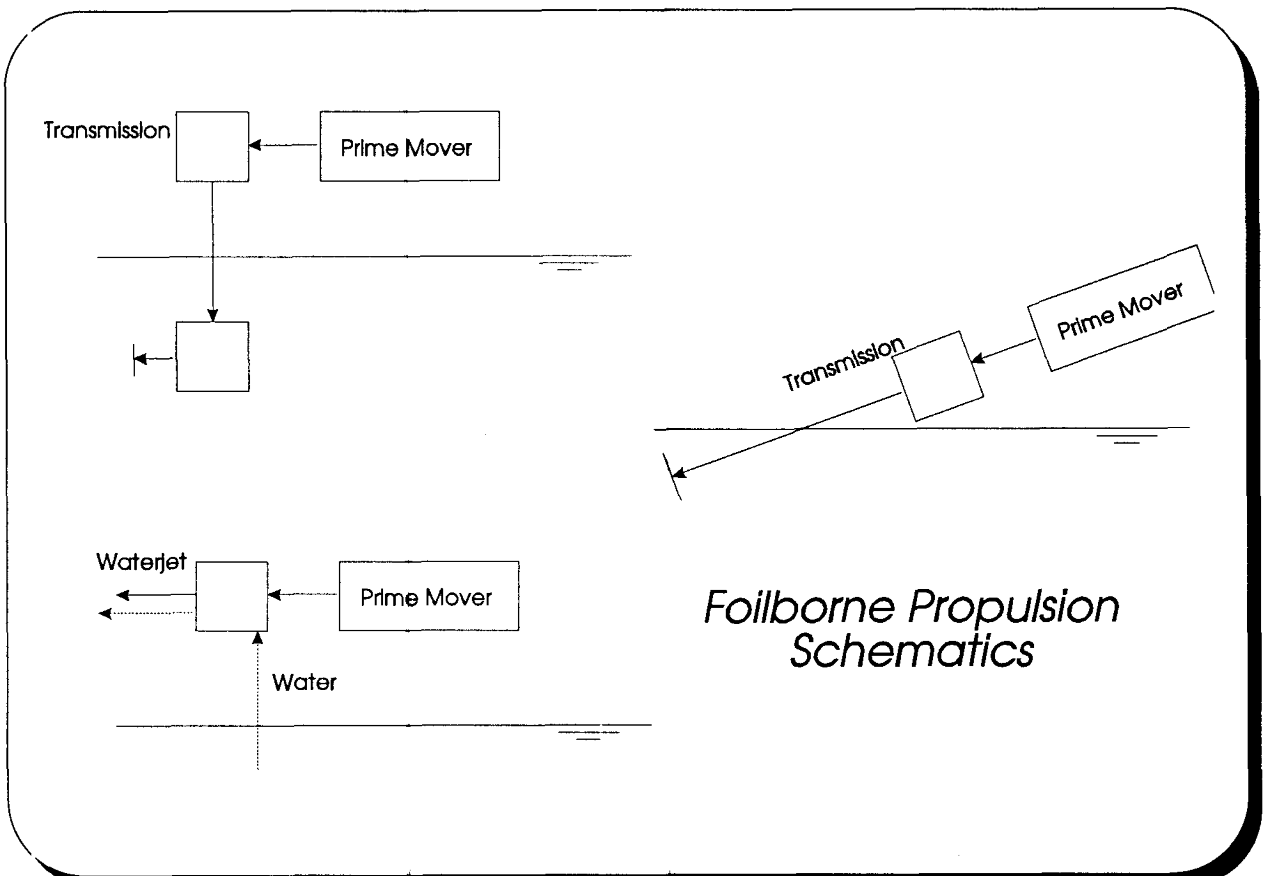
As in other systems, weight control is important. Hull structure weight is usually the largest single component in the ship's total. Therefore, it has a large leverage. Frequently, tight frame spacings are used to minimize skin thickness. This results in structures that are not stiff. Sometimes, this can be uncomfortable. The designer must be careful to ensure that elements that require stiffness for alignment and such are sufficiently stiff.

MACHINERY

This section of the Bulletin will discuss foilborne and hullborne propulsion, the propulsor, and auxiliary and electrical systems sections.

Foilborne Propulsion System

The figure below schematically demonstrates the primary problem with propulsion machinery for hydrofoils.



Foilborne Propulsion Schematics

The design of a propulsion system is one of the great challenges for a hydrofoil designer. Some of the challenges are described below:

- The prime mover is usually located in the hull, yet some connection must usually be made to the water. This dislocation leads to an inefficient propulsion system arrangement. Complex arrangements must be made for the connection. This could be a long propulsion shaft through a Vee-box, sets of bevel gears and a vertical shaft, or waterjet ducts. These systems can threaten reliability and cost weight.

- Propulsion systems for hydrofoils should be light. They contribute to the total weight of a weight-sensitive design. This can lead to high power-density components that can have reliability problems.
- Customers want high fuel efficiency. This influences range and operating cost. Yet, the most efficient prime movers may not meet the weight requirements. These must be traded off in a systems context. The designer should consider the impact of lost payload weight or increased ship size due to poor efficiency versus that due to system weight, and the influence of acquisition cost and fuel cost on life cycle cost.
- The usual considerations of reliability, safety, and environmental impact apply.

Prime Mover

The prime mover can be either a gas turbine or high-speed diesel. Gasoline engines are generally precluded due to safety considerations. The fuel efficiency/weight/cost tradeoff described above applies most strongly here. In addition, the operating experience and training practices of the ship's owner must be considered.

Transmission System

The transmission system has the usual function of matching prime mover speed to propulsor speed and transferring the energy from the prime mover to the propulsor. The first of these functions is most similar to that for other high-speed ship applications. However, the latter function is unique.

The most simple approach is the straight shaft, most often used on a surface-piercing hydrofoil. Depending on machinery layout and foil depth, shaft angles can be quite severe.

If the propulsor is located on a pod, the set of bevel gears and vertical shaft will be used to transfer the power to the pod. The designer must decide where to take the speed reduction. From a weight standpoint, it is very attractive to take the reduction in the pod. High-speed bevel gears and shafts transmit the power; and these are relatively light. On the other hand, the pod must be large enough to include the reduction gear and supporting equipments, and there is the ensuing maintenance risk of having the reduction gear in the water. Usually, this is the best approach.

A waterjet system reverses the problem by bringing the water to the prime mover. Water enters a pod and travels up a strut. A waterjet accelerates the water and it exits through the transom. This dramatically simplifies the mechanical problem, though lightweight waterjet ducts have experienced structural fatigue and erosion failure and the weight of the entrained water can be considerable.

Other transmission systems, such as electric drive and hydraulic drive have been studied. Right now, these are not viable candidates.

Propulsor

The choice of a propulsor is similar to the tradeoffs that apply to hull design. The designer must consider hullborne versus foilborne performance and the thrust demands imposed during takeoff versus those at high speed. This decision is also intimately related to the transmission issue, described above.

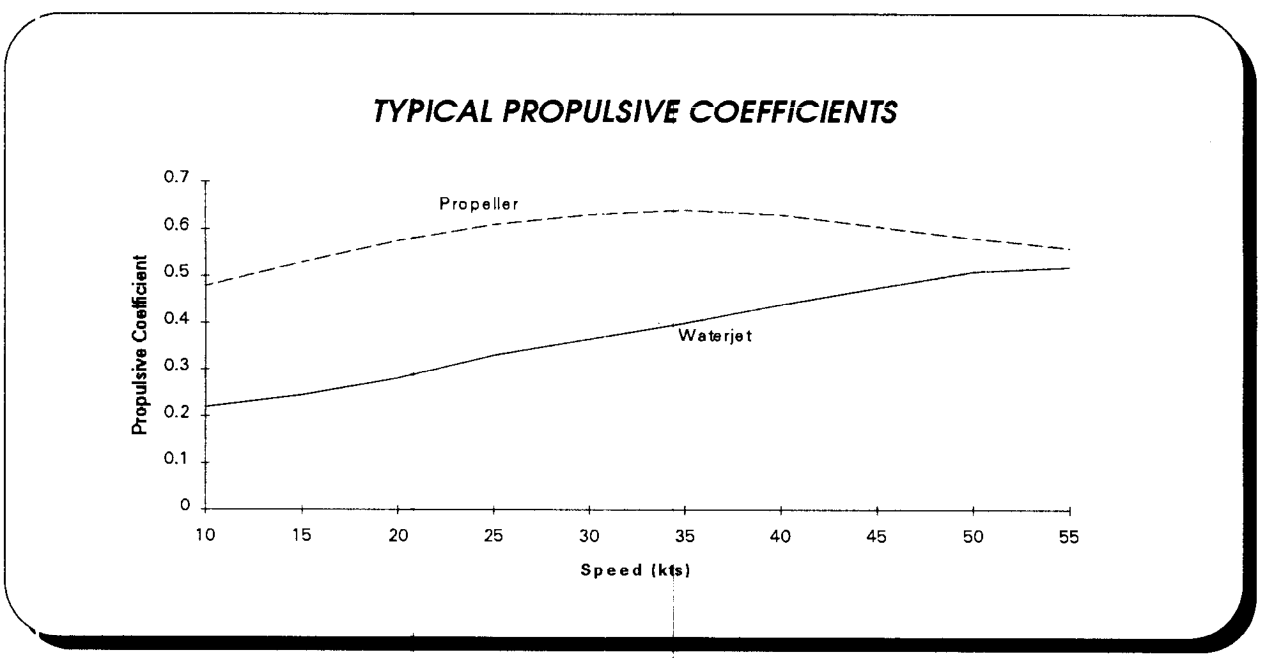
The T&R Bulletin goes into some considerable detail to describe the special considerations regarding propeller design. These include:

- Hullborne Efficiency
- Takeoff Thrust requirements
- High Speed Thrust Requirements
- Cavitation
- Supercavitating Propellers

Waterjet propulsion is discussed by considering the following factors:

- Ideal waterjet efficiency
- Limits on waterjet efficiency
- Cavitation
- Takeoff versus High-Speed Operation

The accompanying figure shows typical propeller and waterjet propulsive coefficients.



Hullborne Propulsion Machinery

The hydrofoil design may include a hullborne propulsion system due to either to retraction of the foil system or to a desire for improved efficiency or maneuverability while hullborne. Efficiency, weight, and reliability considerations will dictate the choices that the designer makes. The transmission complexities that apply to the foilborne system do not generally apply to the hullborne system.

Electrical and Auxiliary Systems

These systems can be designed using normal marine practice. However, typically, measures are taken to reduce weight. In some cases, 400 Hz electrical systems have been used for this purpose. In some cases, high pressure hydraulics have been used.

The system loads due to actuation of the control surfaces must be considered. Typically, hydraulic systems have been used for this purpose.

PERFORMANCE

This section of the Bulletin provides guidance to the hydrofoil designer in three critical performance areas: weight, propulsion, and seakeeping.

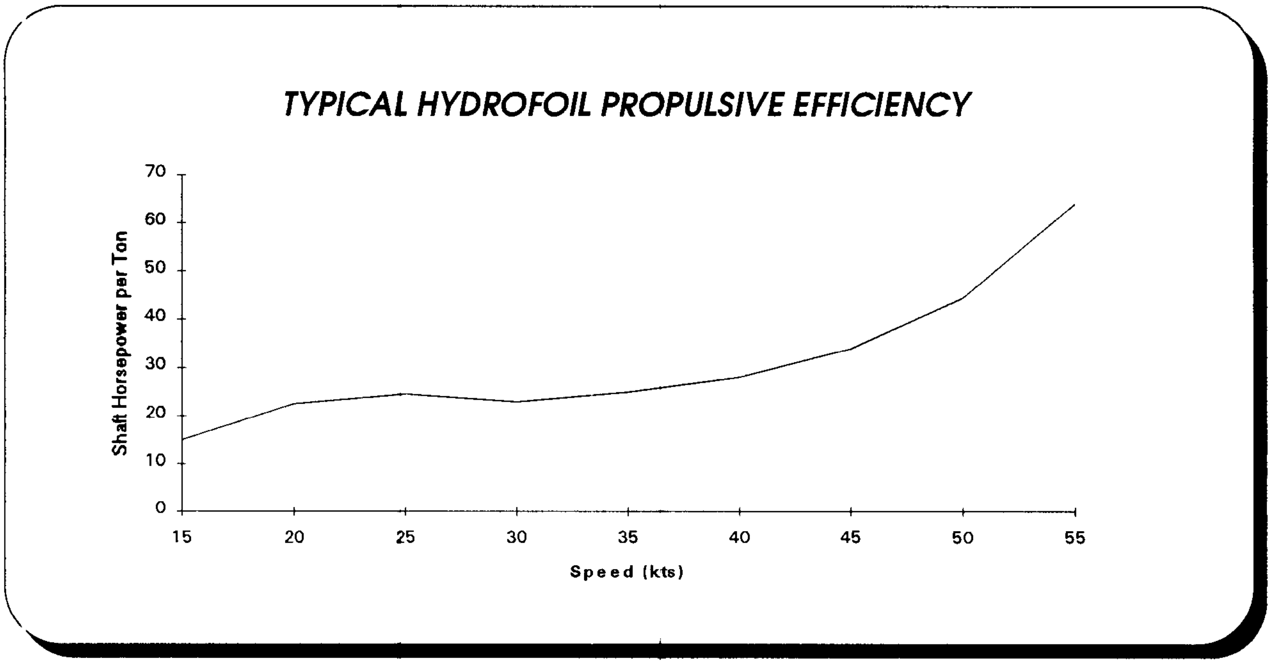
Weight

The T&R Bulletin provides typical weight breakdowns and guidance for estimation for hydrofoil ships, as shown in the table below. They are not precise because the weights of the ships are very dependent on the specifics of the designs, but they provide a starting point.

SYSTEM	WEIGHT ESTIMATION	GUIDANCE
Hull Structure	2.58+/- .44 lbs/ft^3 hull vol	Based on aluminum hull
FB Propulsion	12% - 15% of displ	If waterjet, include weight of entrained water.
HB Propulsion		
Electrical System	2% - 6% of displ	Very dependent on specific ship reqts.
Auxiliary Systems	2% - 7% of displ	Very dependent on specific ship reqts.
Foil/Strut Structure	0.16 +/- .04 lb/lb dyn lift	
Outfitting Systems	1% to 7% of displ	Very dependent on specific ship reqts.
Margins		Large margin because of ship weight sensitivity and foil sensitivity to LCG shifts

Propulsion

A rather extensive discussion of hydrofoil propulsive performance estimation is planned. This will emphasize foilborne performance, but will include off-design performance. The chart of typical hydrofoil propulsive efficiency as shown below represents the figures which will be in the Bulletin. This figure is adapted from Meyer, 1992.



Seakeeping

This section will describe the key factors associated with hydrofoil seakeeping performance. These apply whether the ship has fully-submerged or surface-piercing foil systems or is a hybrid. Ways of estimating seakeeping performance will also be provided.

BIBLIOGRAPHY

The Bulletin will include a bibliography. This will be keyed to the Bulletin's outline. It will include the most up-to-date references which would provide design guidance to the designer of a hydrofoil ship. They should be design-oriented rather than technology-oriented.

PROGRESS

Early in the Bulletin development, we prepared an annotated outline and page budget. The IHS Board and SD-5 panel reviewed and approved this outline and it has guided the Bulletin's progress.

To date, we have:

- Secured most of the material necessary to fill gaps in the Principles draft.
- Prepared the Introductory section and the section on hydrofoil design types
- Prepared the foil system design section. We rewrote this section to do a better job of unifying fully-submerged, surface-piercing, and hybrid considerations
- Completed the section on design process.

In some cases, it has been very hard to winnow down the information provided in the Principles draft. Each section's authors described the relevant technical issues in complete detail. We could not describe the issues nearly so completely within the page budget for the Bulletin.

The preparation of the Bulletin has been more slow than we had hoped. Because no funding has been provided, it is being written completely "after hours". These hours are limited. In addition, the disk containing much of the early manuscript was stolen in early 1994. We had to rewrite these sections from notes.

HELP NEEDED

How can IHS members help with the Bulletin? First, after reading this paper, they can furnish any comments on the direction that the Bulletin is taking. If we need to change emphasis or include some other items, we would like to know soon. Second, readers can volunteer to review the draft as it is completed. The more eyes that review it, the better that it will be. Third, readers can recommend references to be included in the bibliography. These references should be readily available to a reader who is in the process of designing a hydrofoil ship.

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Meyer, John R., Technical Aspects of Hydrofoils, Hydrofoil Technology, Inc., 1992.

HYDROFOIL SHIP LOAD CRITERIA DEVELOPMENT: A RETROSPECTION

by
William H. Buckley

THE AUTHOR

Recently retired from the David Taylor Research Center. He received bachelor degrees in Aeronautical Engineering ('48) and Business Administration ('49) from the Massachusetts Institute of Technology and a Master of Science Degree in Ocean and Marine Engineering ('82) from the George Washington University. He was employed for 20 years by the Bell Aerospace Company where he was responsible for structural design criteria and loads for the X-22A aircraft, SKMR-1 air cushion vehicle and SES-100B surface effect ship. He joined the U.S. Navy's David Taylor Research Center in 1971 where he conducted hydrofoil ship loads research. In 1978 he initiated a loads research program for displacement ships with emphasis on casualty analysis, statistical analyses of non-linear random processes, extreme wave characteristics and most recently the development of world wide seaway criteria and its use in a first principles design methodology.

ABSTRACT

The paper reviews foil system load criteria developments from an R&D perspective for the period 1972 to 1992. It summarizes the results of developmental trials and fleet operating experience as they influenced structural load criteria development. In particular, it reviews the results of calm and rough water trials of the PCH-1 Mod 1 and resulting modifications of early foil system load criteria. In-service foil system cracking due to cumulative loading effects is examined to identify critical structural components and the extensive measures later taken to assure adequate service life for PHM-3 Series ships. Lastly, foil system damage incidents are reviewed together with measures recommended for minimizing such damage.

INTRODUCTION

This paper presents a brief summary of the limit load criteria which was employed for the most part in the design of the U.S. Navy's hydrofoil ships. It then considers the results of trials utilizing PCH-1 Mod 1 in calm and rough water as they revealed the need for revision or expansion of these criteria. Service experience is described for the hydrofoil ships PCH-1 Mod 0, AGEH-1, PGH-1, PGH-2, PCH-1 Mod 1 and the PHM-1 class which have played an important role in load and other design criteria developments. Utilizing this experience, the paper also deals with fatigue load criteria and impact damage resistance . In conclusion, the last section suggests briefly how the state-of-the-art of limit load and service load criteria might be developed further.

BACKGROUND

The initial involvement of aircraft companies in the design of hydrofoil ships was logical in part because of their familiarity with structural design for minimum weight. Achievement of specified foilborne range, payload and speed requirements is critically dependent upon meeting structural weight targets in the case of hull and foil system components. Their lack of experience regarding critical foilborne loading conditions, however, was a significant handicap. This situation began to change with the Boeing Company's successful bid to do detail design and construct PCH-1 Mod 0, the Navy's first hydrofoil ship. The BuShips requirement to have loads measured during sea trials placed Boeing in a unique position to subsequently influence foil system load criteria development.

It is believed appropriate to digress briefly here to outline the approach to aircraft structural load criteria development which has been employed for many years past. In this case a variety of potentially critical *limit* loading conditions are specified which in turn led to limit loads which are then factored to *yield* loads to be sustained without appreciable permanent deformation and to *ultimate* loads to be sustained without collapse (Note: Over time, contractually required static tests led to expertise in designing minimum weight aircraft structures). The associated approach to structural design criteria can be characterized as a first principle methodology (FPM) involving Operational Requirements, Atmospheric Criteria (gust enviroments,air density, Mach number, etc. vs altitude), Critical Condition Criteria for specified maneuvers and gust attacks, Analytical Methods for proceeding from critical design conditions to limit loads and finally Response Criteria which specify acceptable behavior under yield and ultimate loads.

As applied to the design of hydrofoil ships the elements of FPM can be paraphrased as follows:
<u>Operational Requirements</u> which identify anticipated ocean, gulf, or bay areas and routes of operation, speeds in calm and rough water, design displacements, required operational life, etc.
<u>Seaway Criteria</u> which define for the operating areas climatic (long-term average) wave conditions as well as short term storm wave conditions. These criteria generally involve frequency domain wave spectra for linear response analyses and time domain wave height characteristics for nonlinear analyses.
<u>Critical Design Condition Criteria</u> which identify those particular wave and operating conditions that a designer should consider in satisfying Response Criteria. When identifying critical wave conditions the entire range of the Seaway Criteria should be considered. Critical Design Conditions should also account for broaching, slamming, ditching, wave impact loads, etc.
<u>Analytical Methods</u> which permit determination of design loadings from Critical Design Condition Criteria. These methods must lead ultimately to deterministic results for design purposes. They must be available for both preliminary and final design phases and in the case of the latter for analyzing linear and nonlinear responses as required.
<u>Response Criteria</u> which define acceptable or unacceptable structural behavior under Critical Design Conditions (i. e. freedom from yielding under Yield loads and collapse under Ultimate loads).

Referring now to the 1958-59 time frame in which the preliminary design of the PCH-1 Mod 0 was undertaken such a rational design philosophy was unworkable for lack of appropriate seaway criteria and a lack of knowledge of critical foilborne design conditions. What then was done and where has it led?

FOILBORNE LOADING CRITERIA

The preliminary design of the PCH-1 Mod 0 foil system was based upon the following load criteria. (Taken from ref. 1; see also ref. 2, pp. 27-33.)

<u>Forward Foil and Strut:</u> 1.7 x 0.30 x the Design Gross Weight applied to one side of the foil combined with a strut side load (from a 40 knot, 7 ship length turn) x 1.30.

Aft Struts and Foil: Same as forward foil system but with loading factor increased from 0.3 to 0.7.
Flaps: 2600 psf at 11 degree deflection
Rudder: 2600 psf at 20 degree deflection
(Note. The associated yield factor of safety of 1.0 was increased to 1.25 at time of contract design.)

Deflection limits were also established:
Forward Foil: 3/4 degree slope change from root to tip.
Forward Strut: 1 degree slope change from hull to foil.
Aft Foil: 3/8 degree slope change from nacelle to tip.
Aft Struts: 2 inch deflection from hull to foil (as a frame bent)
Flaps and Rudder: 2 degrees twist under design loading.
Note: The influence of these deflection criteria on foil system scantlings is not known except that it is understood that the aft struts were designed to deflection limits required by the transmission shafting which they contained.

Strain gage installations on the foil system and subsequent load calibrations were required by BuShips in the Detail Specifications. Despite the loss of some strain gage outputs due to sea water immersion it was apparent that the foil system load criteria originally employed in design adequately covered yield and ultimate load magnitudes in most cases, although these criteria were not well related to the operating conditions that produced the loads. For example, the original limit load criteria for forward strut lateral and aft foil tip bending loads, however, could be exceeded in rough water. In addition to these findings, it became evident that the foil system was subject to foilborne encounters with logs drifting in the Puget Sound area. These generally floated horizontally on the surface of the water. However, as they aged and became more water logged they often floated vertically at the surface making these "deadheads" especially difficult to avoid. Log and other impact experience of PCH-1 and other Navy hydrofoil ships operating in the Puget Sound area is reviewed under Impact Loadings.

Foil system limit load criteria subsequently developed by Boeing Marine Systems (BMS) is presented in Appendix 1. These criteria were used in the design of the PGH-2 and PHM-1 foil systems. As noted, in the case of the latter two additional limit load criteria were added for design of the PHM-3 series foil systems.

Calm Water Trials of PCH-1 Mod 1. See Figure 1. (Oct. 10, 1975)

Reference 3 summarizes results of the calm water trials program in which foil system loads were measured during debris avoidance maneuvers and induced broaches in turns. The former was expected to result in maximum helmsman-induced loadings on the foil system. It corresponded to an operational situation in which the helmsman, while in a tight turn, reversed the helm abruptly to avoid debris or other objects in the path of the ship. It normally can be expected to produce large loads on directional control surfaces. The broaches-in-turns on the other hand were expected to reveal the source of rough water broach recovery loadings on foil system components.

Hull-mounted cameras were operated during all test maneuvers and broaches to record the hydrodynamic flow over the forward foil port and starboard semispans and over the aft foil port tip. Forward foil broaches-in-turns were expected to (1) produce asymmetric lift loads associated with ventilated hydrodynamic flow on one semispan and unventilated flow on the other and (2) allow local flow conditions to be compared with concurrent foil system load measurements. The procedure employed and the test agenda are given in reference 3. Before the broaches were performed the ship was trimmed bow-up approximately 1.5 deg. so as to avoid broaching the aft foil system. A number of still pictures from the camera recordings are presented in reference 3 which help to correlate foil loadings and local flow conditions. Surprising mixes of ventilated flow, sheet cavitation and cavity shedding are revealed.

The following conclusions were drawn from these tests:

1. Debris avoidance maneuvers resulted in relatively high forward strut loadings at the time of helm reversal. Vapor cavity shedding on the strut during the maximum helm displacement maneuver suggested that the peak loading approached the maximum attainable steady state value. This loading was estimated from calibrated strain gage responses to be approximately 1200 psf at both 36 and 45 knots, which is consistent with maximum strut loading obtained from model test data for similar strut hydrodynamic sections. See reference 4.

2. Flap cavitation and buffet boundaries were defined as a function of ship speed and forward flap deflection angle. Both boundaries were found to be strong functions of ship speed. At 45 knots the spread between onset of cavitation and the onset of flap buffeting was approximately 2.5 deg. of flap displacement.

3. Calm water broaches-in-turns successfully reproduced the forward foil asymmetric lift conditions which were believed to cause the large forward strut bending moments measured during broaches in rough water. The maximum lower strut bending strain measured in these trials attained 85% of the maximum value measured in rough water trials. Photographic data revealed that the maximum asymmetric lift condition resulted from vented flow over one foil semispan and wetted flow over the other with the flap full down. Because of the loss of lift at the time of emergence of the uphill semispan, the subsequent sink speed at the forward foil resulted in a positive angle of attack acting in combination with a full flap down displacement.

4. Broaches were performed at roll angles of 0, 3, 6 and 9 deg. Substantially different flow conditions were produced on the downhill semispan for the two highest roll angles. At 0 deg. roll venting occurred simultaneously on each semispan, with the vent developing first near the tips of the foil. At 3 deg. of roll the downhill as well as the uphill semispan vented with the latter occurring slightly sooner. At 6 deg. of roll, the downhill semispan experienced a mixture of vented and cavitated flow, whereas at 9 deg. of roll it vented momentarily only over the flap. In the latter case, cavitation along the leading edge of the downhill semispan reached the point of vapor cavity shedding. In general, the maximum value of lower strut bending moment was a direct function of the roll angle at which the broach was performed, the highest bending moment being associated with the broach at 9 deg. of roll.

5. Following emergence of the forward foil during broaches at 0 deg. of roll, constant sink speed at essentially constant ship pitch attitude was observed. From this it was concluded that foil lift in the fully vented flow condition with the flap full down was approximately equal to the nominal 1 g foil loading of 1370 psf. Venting of the foil following emergence was found to persist to submergence levels at which spray due to hull impact obscured the foil.

6. Relatively large, unsteady lift loads acted on the aft foil center section during all broaches. These appeared to result from the development of vented flow on the forward foil during the broach.

7. Tiller arm torques exceeded full actuator output during the recovery phase of the broach performed at 9 deg. of roll. Strut venting may have been a contributing factor to the large torque encountered at this time but this could not be established conclusively with the available data.

Rough Water Trials of PCH-1 Mod 1: Sea State 5 (Nov. 4-6, 1975)

No formal report of rough water trials has been prepared. A DTNSRDC in-house memorandum report was prepared, however, of which the following is a digest. Table 1 provides a summary of peak foil system component strain gage readings together with"redline" (i.e. do not exceed) strains for trials monitoring purposes and 1g calm water strain levels for both forward and aft foils. Strain ratios are determined for each peak value of component strain divided by redline strain, as well as for maximum component strain from calm water trials divided by the maximum value from rough water. In addition, maximum rough water foil strain is divided by its 1g level flight strain so as to identify the associated "factors of lift". In the discussion which follows "broaching" refers to the partial or complete emergence of a foil from the water. "Wave cresting" refers to the penetration of a wave by the hull while the ship is foilborne.

With respect to forward foil maximum bending strains (Items a and b), the peak semispan strain due to upward lift was comfortably lower than the redline strain value. It is noteworthy that the peak strain attained during the 90 deg. helm displacement broach-in-turn was 98% of that reached during rough water trails. Each corresponded to slightly less than a 2 factor lift load. (Note. The Maximum Foilborne Lift criterion of Table 1 is treated in design as two times the steady 1g lift load (i.e. 1 + 0.5 x 2g lift). The peak strain due negative lift resulted from a "neck stretcher" type loading following a forward foil broach in rough water. In this case a head seas, hull-level wave impact produced an upward acceleration which caused the automatic control system (ACS) to introduce a downward foil loading in opposition. This symmetrical downward lift increment corresponded to slightly more than a one factor negative loading. In this case the calm water trials produced a bending strain only 49 percent of the rough water value. Based upon a nominal 1g forward foil loading of 1370 psf during rough water trials and the factors of lift which were experienced, the respective foil loadings were 2690 psf and -1521 psf.

The peak bending moment at the lower end of the forward strut in rough water (Item d) revealed that the redline strain value had been attained. Eighty five percent of this value was attained in calm water trials during a 90 deg. helm displacement broach-in-turn. The peak bending moment at the upper end of the strut (Item c) reached 119 percent of redline strain during a broach recovery in rough water and 100% of redline strain during the 90 deg. helm displacement broach-in-turn. Since the original load criteria did not cover this broach recovery load condition it was added to the criteria for the PHM-3 series ships as shown in Appendix 1.

The peak side load on the forward strut (Item f) occurred during beam seas operation when the hull was apparently loaded by a breaking wave during a cresting impact. (Redline strain was not available for comparison with this loading.) Calm water trials during a 180 deg. (maximum) helm displacement debris avoidance maneuver produced 62 percent of this rough water side loading. In terms of unit loadings on the submerged portion of the strut, each lateral loading corresponded closely to the maximum predicted loading for a strut at the test condition submergence, i.e. 1200 psf for partial and 1465 psf for full submergence.

In port bow seas, a heavy cresting-impact produced 82 percent of redline strain at the upper end of the starboard aft strut and 107 percent of redline strain at the root of the starboard foil tip (Item g). Calm water trials by comparison produced 31 and 72 percent respectively of the redline strain values. In term of factors of lift, the foil tip experienced a 2.74 factor loading or 2907 psf based upon a nominal 1g trials loading of 1060 psf. Item g of the table shows that a peak negative strain of -540 micro-in./in.. was reached at the aft foil tip during a hull cresting impact at what was believed to be a head seas heading. Redline strain was not available for comparison but the factor of lift -0.77

corresponded to a negative loading of - 816 psf. A strain level of 56% of the rough water value was measured in the calm water 90 deg. helm displacement broach-in-turn.

Strain gages located on the aft center foil panel near the starboard strut experienced a peak loading during a wave cresting hull impact. Again a redline strain was not available for comparison but the apparent factor of lift of 2.78 corresponded to a lift loading of 2947 psf. A 60 deg. helm displacement during a broach-in-turn produced a calm water trials peak strain of 83 percent of the rough water maximum.

In order to indicate the significance of the forward and aft foil loadings cited above, model data from hydrodynamic tests of the PHM-1 aft foil system have been plotted vs speed in Figure 2 for 0 deg. and full flap down deflections. The peak loadings on the aft foil segments of 2907 and 2947 psf are close to the maximum model test value of about 3100 psf for the entire foil. Because of the lower aspect ratio of the forward foil the lower maximum value of 2640 psf in trials is not unreasonable. These findings together with the agreement of forward strut peak loadings from trials with model test data suggest that the maximum foilborne lift load criteria of Appendix 1 be revised to reflect hydrodynamically attainable loadings from model tests rather than to base them on 1g loadings which are arbitrarily chosen by the ship designer. If this were done it would seem reasonable for the associated yield factor of safety to be reduced from 1.50 to 1.20.

The rough water trials results also illustrate that wave impact loadings on the hull due to forward foil broaching and wave cresting play a significant role in determining maximum loadings on the forward foil and especially on the aft foil system. Motions induced by wave impacts cause intervention by the ACS in response to the output of three accelerometers, one height sensor, pitch and roll angle sensors and a yaw rate gyro. This matter will be discussed further under service load criteria. Suffice to say that some revisions of the limit load criteria of Appendix 1 to reflect the results of rough water trials is believed to be appropriate.

SERVICE LOAD CRITERIA

Prior to the time of the PHM-1 Operational and Technical Evaluation (1976) fatigue and flaw growth problems in foil systems were not regarded as serious. Foil system cracks which appeared at that time, however, were sufficiently numerous that the PHM-1 foil system had to be given an extensive refurbishment. Of more lasting significance was the fact that when authorization for completion of four follow-on ships (PHM-3 thru 6) was given, a complete structural redesign of the foil system was undertaken which required compliance with fatigue, flaw growth and fracture strength requirements in addition to the customary static strength requirements. As a consequence of the redesign effort many foil system scantlings were determined by these new requirements. The following is a brief summary of foil system in-service cracking and of the structural components most susceptible to this problem. Measures taken in the design of the PHM-3 series foil system are then outlined with emphasis on cumulative service loads. Lastly recommendations are given for the establishment of cumulative loads in the design of other fully submerged foil systems.

With hindsight, the 17-4 PH foil system of the PGH-2 gave indications of impending problems in the PHM-1 foil system which was fabricated of the same material. One of these indications was literally accidental. During a dry docking which followed extensive foilborne operations, the forward strut was accidentally released from its retracted position so that the strut/foil assembly rotated freely about the trunnion supports until it impacted at the down lock support foundation. This caused the king post to break at its attachment to the upper end of the strut. Examination of the fracture surface revealed a fatigue crack, due to drag type bending moments, as the origin of the fracture. Several years later PGH-2 had the misfortune of running on to a reef while foilborne. It was subsequently decommissioned so that the foil system became available for detailed inspections. These revealed a number of cracks in welds in struts, flaps, foil attachments lugs and strut foundation structure. It was concluded that cyclic loads associated with the mechanical elements of the foilborne flight control system were an important source of fatigue loads. This finding was somewhat paradoxical since one of the important features of the ACS is its ability to maintain a steady 1g lift load on the foils when operating in a seaway. Obviously, significant cyclic loads arise from the flap control deflections needed to maintain 1g lift and a level attitude. Broaching and hull cresting loads were, of course, regarded as an important additional source of high stress, low cycle loadings.

Following Operational and Technical Evaluation of the PHM-1, its foil system showed cracking in components similar in nature to those of PGH-2 with one major exception. Whereas the solid, machined foils of the latter were free of cracking, the welded foils of the former contained a number of sizable cracks. Removal of some of these for metallurgical examination revealed incomplete welds which were believed to have contributed to the cracking problem. Subsequent dismantling of the foil system for inspection and repair revealed additional fatigue cracks and welding difficulties.

When the construction of the PHM-3 series ships was authorized, Boeing Marine Systems initiated a complete structural redesign of the foil system. This effort was uncompromising in its approach and it is fair to say that the extensive technical resources of Boeing were drawn upon as required. Of particular importance was the active participation of fatigue, flaw growth and fracture experts from Boeing's aircraft division. In addition, as a result of a joint Navy/Boeing effort a Service Life Assurance Requirements (SLAR) specification was drafted and later incorporated in the Ship System Specification. The outline of the SLAR is presented in Table 2 to indicate its scope.

From a structural design point of view major changes were incorporated, e.g. :

(1) Welding was minimized. For example, ribs were removed because thicker foil plating could now carry chordwise shear and bending loads. Spanwise stiffeners and associated plating were milled from large billets of 17-4 PH. The resulting large subassemblies also minimized welding. As an additional measure, blind closure welds were located in areas of compression under 1g flight loads wherever possible.

(2) Multiple highly torqued bolts were used to connect struts and foils so that clamping friction carried much of the shear transfer between mating attachment lugs thereby avoiding the high stress concentrations which would exist if shear transfer occurred thru the bolts themselves.

(3) Small flaws in welds were considered in determining the service life of the foil system as required the SLAR. During the ship's service life flaws were not permitted to grow to a size which would degrade static strength below the limit load level. (Many more examples could be cited but they are beyond the scope of this paper).

The ability of Boeing to employ proprietary fatigue, flaw growth and fracture toughness analysis methods from their aircraft structural design procedures was of considerable importance in satisfying SLAR requirements. In particular, stress analysts were able to check structural details for compliance with static, fatigue, flaw growth and fracture strength requirements without delay.(To put this achievement in perspective, reference 5 in referring to fatigue analyses of tanker hull structure which had cracked in service states: "Finding a viable solution is a long and tedious operation, usually requiring 1 year or more to develop a solution.")

For purposes of complying with requirements of the SLAR, the determination of cumulative service loads for foil system components was of particular importance. The limit load criteria of Appendix 1 was of no help since service loads are directly related to the characteristics of the ACS in response to operation in various seaways and further to the occasional effects of forward foil broaching and hull impacts in waves. The establishment of cumulative service loads for the PHM-3 series foil system was necessarily pragmatic as stated in the abstract of reference 6: "Production PHM foil system loads have been derived principally from sea trials information using data recorded on PCH-1 Mod 1 and Jetfoil hydrofoil ships. Loads were extrapolated to PHM by evaluation of geometry, hydrodynamic and ACS differences. Final load descriptions reflect operation of the PHM in the prescribed sea model with time spent equally at all headings."

The trials data referred to here are not in the public domain which leaves a serious void for anyone now undertaking the design of a foil system to service life requirements. Under these circumstances an alternative approach is suggested which is based upon two recent developments. First it is common practice when designing a new hydrofoil ship to establish a computer based seakeeping simulation for use in designing the ACS. Second, realistic three parameter closed-form wave spectrum formulations are now available from a variety of measured extreme and climatic (long-term) seaway conditions for use in exercising the simulation, see references 7 and 8. Conceptually therefore service loads can be obtained from this combined capability. There are however some limitations:

a) The usual ACS simulation functions with only gross loads and moments on the foil system being determined. There is a need here for information regarding distributed loads on individual foil system components so that local shears, bending moments and torques can be determined. Provision must also be made for accumulating cyclic loads which are generally of a broad band character as opposed to a commonly assumed narrow band Gaussian character (and its Rayleigh distribution of loading events).

b) Nonlinear loadings associated with broaches and hull/wave impacts must generally be considered separately in time domain analyses. With respect to the former, foil system hydrodynamic lift forces can be estimated based upon PCH-1 Mod 1 load measurements obtained during broaches in turns. See reference 3.

c) The seaway spectra of reference 8 do not identify the nonlinear characteristics of the associated seaways, especially Seaways of Limiting Steepness. (See Figure 11 of reference 7.) Tank wave making experiments reported in reference 9 nevertheless show that much of the nonlinearity in a steep (hurricane driven) seaway is recaptured if the associated wave spectrum is accurately replicated at model scale. This result suggests that time domain hull loads during wave cresting events can be approximated in model tests during which the hull alone encounters steep, breaking waves at a fixed heading, speed and "depth setting".

The approach to determining foil system service loads which is suggested here is clearly developmental so that measurement of foil system component loads during prototype sea trials is highly recommended. Consideration might also be given to load measurements during broaches-in-turns and debris avoidance maneuvers in calm water in order to provide an indication of foil system loadings to be encountered during rough water trials.

IMPACT LOADINGS

The combination of high speed and occasional poor visibility can lead to navigation problems which make foilborne hydrofoil vessels vulnerable to impact damage from various sources. Table 3 briefly summarizes the U.S. Navy's hydrofoil ship foilborne operating experience with respect to damaging impacts. From an operational point of view it should be noted that the operating area, i.e. Puget Sound and the Strait of Juan de Fuca, is the site of a major logging industry.

The incidents of Table 3 involve a range of impact loading conditions, i.e. from log impacts to collision with a grey whale (PGH- 1) and finally to grounding on a submerged reef (PGH-2). With regard to minimizing damage, what should be done? Since no two impacts appear to be the same clearly no single answer can be given. However, guidelines can be suggested based upon what has been learned from the incidents of Table 3.

With respect to the grounding of PGH-2 on a reef it is notable that:

(a) The forward strut and foil assembly suffered major damage which was due primarily to its rotation around the retraction trunnions with the result that the trailing edge of the flaps sliced rearward thru the water tight bulkhead on which the down lock fitting was mounted. The lesson here is that when a retractable foil system is involved, involuntary rearward rotation should be considered and loss of water tight integrity minimized. Penetration of a fuel tank or other hazardous storage compartment should also be avoided. The Boeing Marine Systems Division when redesigning the JETFOIL foil system incorporated energy absorbing linkages in the forward strut support structure which would be effective in minimizing damage as a result of this type of loading situation.

The PGH-1 which struck a grey whale off San Diego incorporated design features in its aft mounted steerable strut which localized damage because the rearward retracting strut/foil assembly contained a shear pin in the down lock mechanism.

The log strike incidents of Table 3 with two exceptions did not result in significant danger to the crew or the vessel. The exceptions involved PGH-2 and PCH-1 Mod 1 which both employed steerable forward struts. In each case a log strike near the tip of the forward foil caused the steering actuator to rupture and the forward strut to rotate so that an uncontrolled turn and outboard roll followed. The outboard roll resulted in part from the helmsman's immediate attempt to arrest the turn with opposite helm input. This caused the ACS to introduce a roll motion which increased the outward roll angle. In the case of the PCH-1 Mod-1, its instrumentation suite recorded a momentary lateral acceleration of 1.0g , an outward roll angle of 19 degrees and a total turn of about 180 deg. Strain gages on the forward strut revealed a strut side loading of approximately 3500 psf which is well above the slowly applied maximum of 1200 psf. The separate dead head log strikes on each of the fixed forward strut assemblies of the AGEH-1 were analyzed based upon calibrated strain gage outputs. The magnitude of the 8/24/71 impact was the greater of the two. As shown in Figure 3 this impact lasted for 0.032 sec. during which time the vessel moved forward just over 2 ft. A small dent at the leading edge of the foil identified the spanwise location of the impact while Measurand 4116 suggested a peak loading of about 75,000 lbs. as having caused the measured chordwise bending moment.

Concern for high strut side loads and uncontrolled motions of the PCH-1 Mod 1 stimulated the conceptual design of an energy absorbing tiller arm which could help prevent rupture of the steering actuator. Based upon the experimental results of reference 10 which showed good energy absorption characteristics for shear bolts installed in chamfered holes, a multi-bolt, slotted design was evolved which came close to absorbing the necessary torsional energy. (Additional hydrodynamic damping due to rapid strut rotation was not included in the analysis).

This device was never installed on PCH-1 Mod 1. However, as a result of a technical audit of the PHM-1 prior to the redesign of the foil system for the PHM-3 series ships, the energy absorbing tiller arm conceptual design was adopted and U.S. Patent No. 4,086,012 issued to Messrs. Buckley and Ryland of DTNSRDC. The detail design by Boeing Marine System included additional energy absorbing bolts which became engaged by a stub arm attached to the king post in the event all of the tiller arm bolts had been sheared thru. To the writer's knowledge no log strikes or equivalent have been experienced by the PHM-1 class ships equipped with this tiller arm. However, as noted in Figure 4 the "fuse pin" of the tiller arm assembly, which carries all torsional loads associated with normal steering, failed during an unusually rough transit to avoid hurricane Kate in November of 1985. The fuse pin failure was reported to be due to torque loads associated with forward foil broaching in heavy seas. A clue to this unexpected failure is given in Figure 31 of reference 3 where full hydraulic system pressure of the PCH-1 Mod 1 steering actuator was exceeded during a calm water broach-in-turn. It is appears that the fuse pin which protects the steering actuator is under strength for torques associated with asymmetric broaches in heavy seas. An upward revision of the Foil Emergence limit load criterion of Table 1 is apparently needed.

EPILOGUE

The time frame of the foregoing developments suggests that hydrofoil ship load criteria is presently in a state of arrested development. How might we move on if the need arose ? First of all we should consider revising the limit load criteria of Appendix 1 to reflect the findings of Table 1 as much as possible. This might be a difficult task and one could well ask: why brother revising the criteria of the appendix since it is not well related to the critical seaway loading conditions to begin with? The answer is that with some modifications it is valuable for use in the initial phases of structural design because it requires so little knowledge of seaway conditions, hull configuration and automatic control system (ACS) characteristics. Would a suitably revised criteria then be sufficient for final design? The answer is" no" because fatigue and flaw growth analyses can not be conducted with limit load criteria alone. We now require both maximum and in-service loadings.

How should we proceed to facilitate this ned? This question deserves an in depth answer which exceeds the scope of the paper. Briefly, the major elements of a suitable approach have already been touched upon:

(1) A Service Life Assurance Requirements (SLAR) design criteria document is essential given the many facets of the service life problem (see Table 2). The SLAR developed for the PHM-3 series of hydrofoil ships is an excellent model for this purpose although its contents should be reviewed by qualified individuals so as to review what was known or unknown at the time it was prepared and thus to determine what changes should now be incorporated.

(2) Cumulative service loads which are substantially linear in nature can be derived from the ACS simulation using appropriate three parameter wave spectra (i.e. frequency domain) approximations for the design seaways and operating times specified in the SLAR. The extraction of structural component cyclic loads from an ACS simulation is a development problem which should be addressed early on. Nonlinear loadings associated with broaching and wave cresting must be approached using critical time domain wave characteristics and ACS responses. This area of seaway criteria is not fully developed unfortunately. Tank wave generation as suggested above is a viable method for situations where wave steepness and size are critical.

(3) Methods of fatigue, flaw growth and fracture analysis need to be made available which are equivalent to those employed by Boeing Marine Systems in the design of the PHM-3 series foil system are essential for purposes of meeting component design schedules.

(4) Impact loading design criteria are needed and should be included in the SLAR under foil system component strengths in the presence of specified flaws or fatigue cracks.

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APPENDIX 1: PHM -1 FOIL SYSTEM LIMIT LOAD CRITERIA

MAXIMUM FOILBORNE LIFT

The foils and struts shall withstand vertical loads equivalent to the foil one-factor load plus an incremental vertical acceleration of 0.5g applied with a dynamic magnification factor of 2.0, the whole assumed to have a 60-40 percent distribution about the foil centerline.

MAXIMUM FOIL DOWNLOAD

A foil-strut system shall withstand the symmetrical one-factor load on that foil, applied in a downward direction.

FOIL EMERGENCE

The foil-strut-system shall withstand loads associated with partial emergence of a foil. For the forward foil, 85 percent of the entire foil one-factor load shall be applied to a single semispan with zero load on the other semispan. For the after foil, zero load shall be applied to one tip outboard of the strut centerline, with the remaining part of the foil being subjected to the entire foil one-factor load. The immersed part of the foil in either case shall be assumed to be ventilated, with a correspondingly lower lift drag ratio.

MANEUVERING SIDE LOAD

The foils shall withstand the steady loads on the ship associated with 0.2g side load combined with the loads from an incremental vertical acceleration of 0.25g applied with a dynamic magnification factor of 2.0. The struts shall be designed to support these loads, and, in addition, simultaneously withstand the loads derived by considering the one-factor load and the vertical increment redistributed 60-40 percent about the foil centerline and the steady 0.2g strut side loads further increased by sudden immersion of the struts to the keel line. The initial foilborne waterline for this condition shall be midway between the keel and the foil chord plane. For the after foil system., both struts shall be loaded simultaneously. The assumed strut side load distribution shall be such that its centroid lies at 60 percent of the immersed strut depth.

BEAM WAVE

Struts and foils shall withstand side loads that result from wave orbital motion and strut immersion to the baseline. For this condition, the assumed wave shall have a length-to-height ratio of 15 and a height equal to the distance between the baseline and the foil chord plane less a distance equal to the foil mean hydrodynamic chord. For the after foil system, both struts shall be considered to be loaded simultaneously. Foil loading for this condition shall be one-factor load increased by a vertical increment of 0.25g applied with a dynamic magnification factor of 2.0, the total distributed 60-40 percent about the foil centerline.

MANEUVERING SIDE LOAD WITH MAXIMUM DOWNLOAD (<u>PHM- 3 SERIES</u>)

This condition is the same as that [above] except that the download of [MAXIMUM FOIL DOWNLOAD] is used in lieu of the nominal one-factor load plus an incremental 0.25g load with dynamic factor of 2.0.

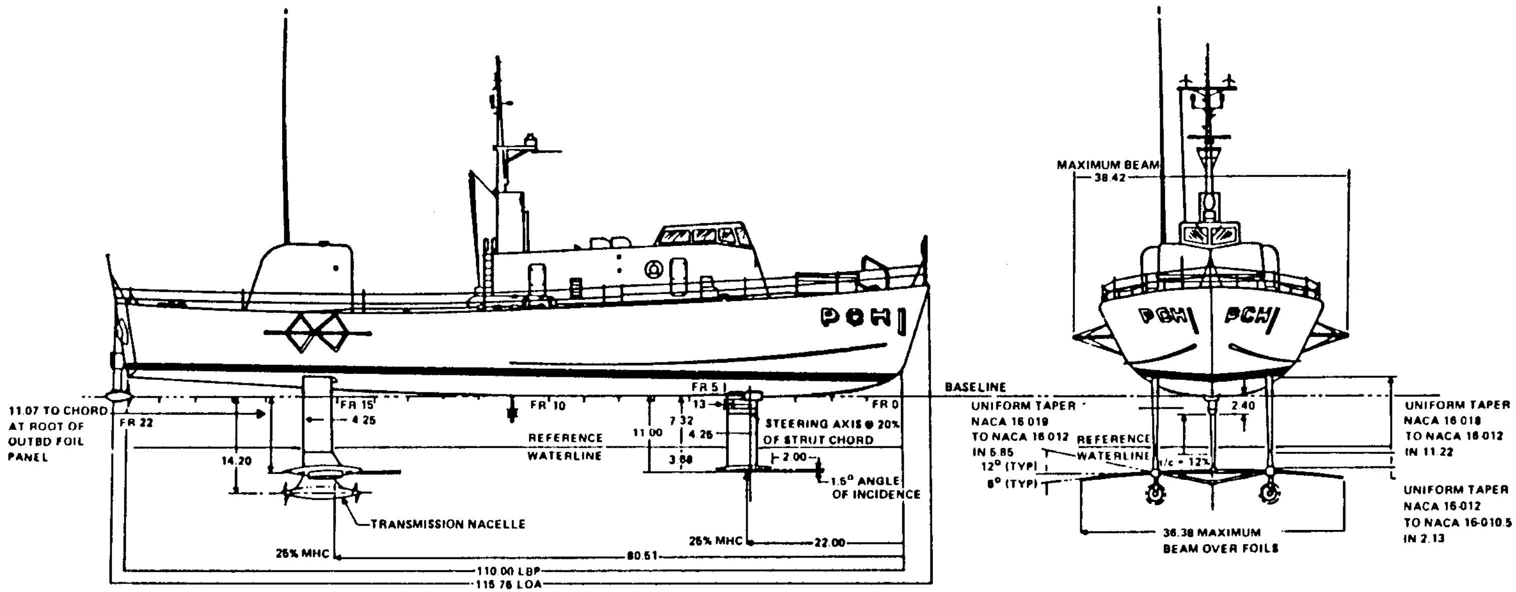
BROACH RECOVERY (<u>PHM- 3 SERIES</u>)

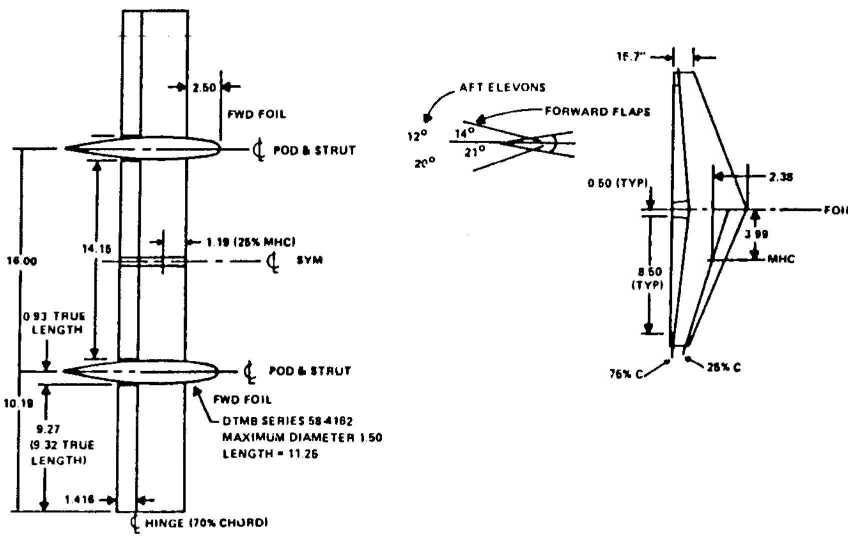
The forward foil system shall be capable of withstanding loads associated with the following condition. For this condition the yield factor of safety shall be 1.20 and the ultimate factor of safety 1.50. Under yield loads the structure shall not deform elastically or plastically so as to interfere with the intended function of the foil system. The structure shall not fail under ultimate loads. The Broach Recovery condition shall include combined effects of the following:

a) Maximum ship speed for rough water operation.
b) Forward flap at maximum down position.
c) Lift on one foil semispan at fully ventilated flow (assumed to average 47.9 kpa, 1000 psf) and on the other semispan at unventilated flow (assumed to average 153.2 kpa, 3200 psf).
d) Foil drag shall be one-sixth of total foil lift, acting off the center line on the unvented side so as to produce a rudder torque equal to maximum steady-state steering actuator output.
e) Foil pitching moment shall correspond to the lift forces acting at 50 percent of the MHC on the vented semispan and 25 percent of the MHC (mean hydrodynamic chord) on the unvented semispan.
f) Strut at maximum submergence and rotated to maximum deflection such that strut side force acts to increase strut bending moment from asymmetric foil lift.
g) Strut side load shall correspond to an average lateral load of 76.6 kpa 1600 psf applied at the 25 percent chord line, acting normal to the strut chord plane.
h) Strut drag loads shall correspond to the side load attained at full rudder deflection.

As used herein, the term "foilborne-one-factor load" shall refer to the lift imposed on the foil in normal steady-state foilborne operation in the calm sea, including loads due to thrust-drag couples and foil pitching moments.

Foil system structure shall be designed for ultimate loads which include a factor of safety of 1.5 times the limit load. "Limit load" as used herein is defined as the calculated maximum load expected in authorized service, including the effects of acceleration and dynamic magnification. Ultimate loads shall not exceed the yield strength of the material nor cause failure by elastic instability.





AFT FOIL

W/S	1060 lbs/ft^2
S	172.85 ft^2
A	7.65
b	36.38 ft
C_R	4.75 ft
C_T	4.75 ft
λ	0.00
MHC	4.75 ft
t/c	0.09
SWEEP c/4	0°
DIHEDRAL ANGLE	6° OUTBOARD · 12° INBOARD
% TOTAL FOIL AREA	72.48
TOTAL FLAP AREA	46.29 ft^2
FLAP CHORD / FOIL CHORD	0.3
SECTION	NACA 16-309

FORWARD FOIL

W/S	1370 lb/ft^2
S	65.63 ft^2
A	6.1
b	20.0 ft
C_R	5.25 ft
C_T	1.31 ft
λ	0.25
MHC	3.68 ft
t/c	0.09
SWEEP c/4	15°
DIHEDRAL ANGLE	0°
% TOTAL FOIL AREA	27.52
TOTAL FLAP AREA	6.416 ft^2
FLAP CHORD / FOIL CHORD	0.25
SECTION	NACA 16-309

NOTE:

ALL DIMENSIONS ARE IN FEET (EXCEPT AS NOTED)

FWD STRUT ROTATES ± 10°

Figure 1 - PCH 1 MOD 1 Principal Dimensions and Foil System Arrangement

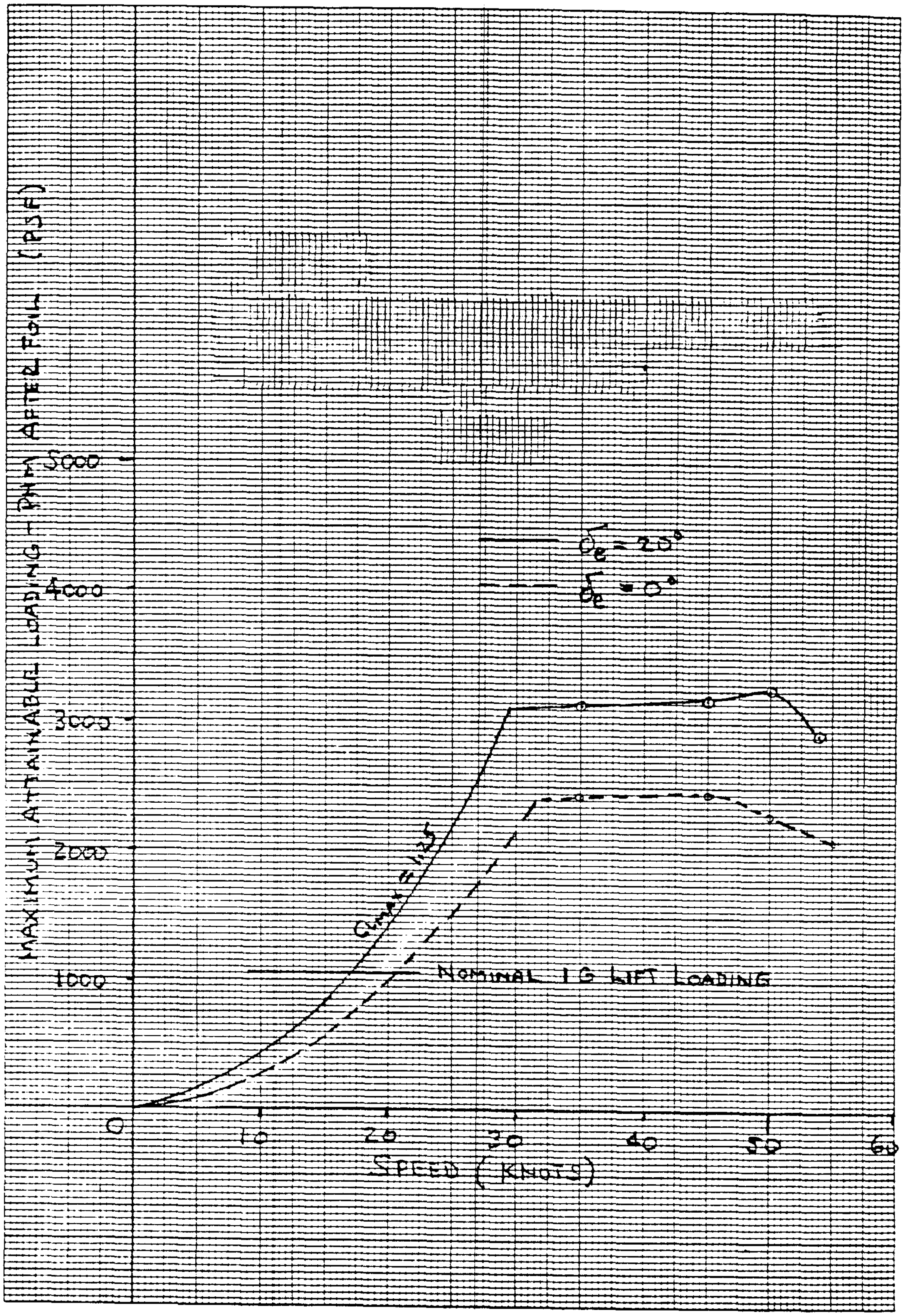


Figure 2 Maximum Attainable Loading on PHM-1 Aft Foil vs Speed

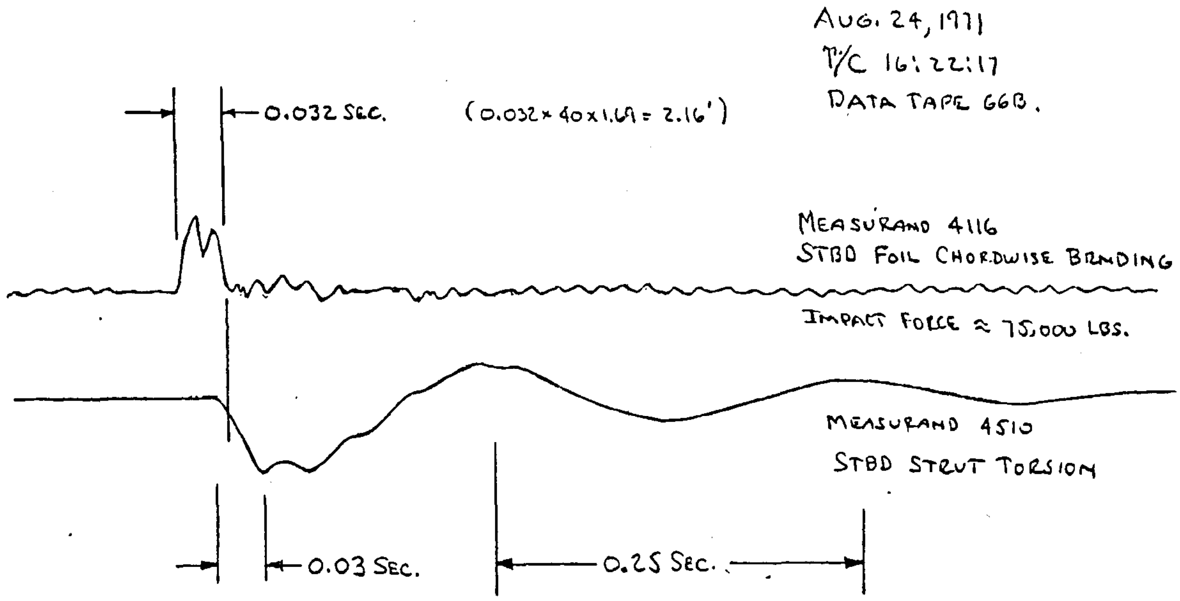


Figure 3 Log Strike at 85% of AGEH-1 Main Foil Semi-Span

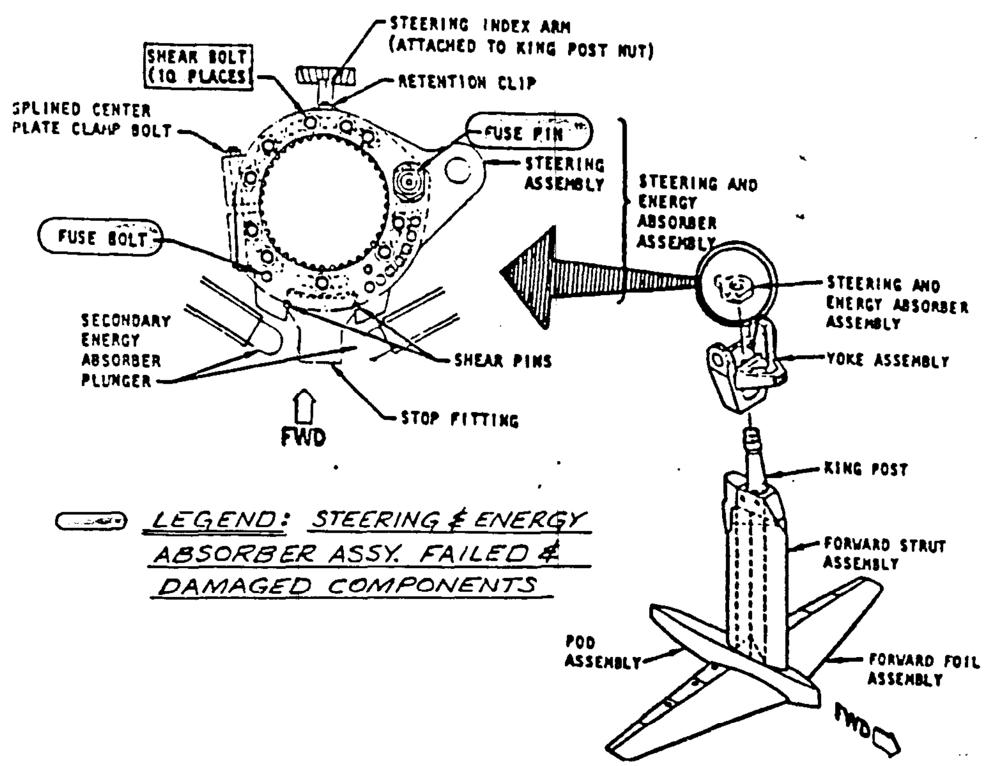


Figure 4 PHM-3 Energy Absorbing Tiller Arm Following Rough Water Transit

TABLE 1: SUMMARY OF MAXIMUM LOADING CASES FROM PCH-1 Mod 1 ROUGH WATER TRIALS

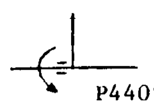
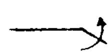
Item	Component Loading	Circumstances of Loading	Peak Strain From Calm Water Trials	Strain Ratios	Comments
(a)	 P4405 (STBD Semi-Span) Tape: PT 1245 S Time: 12:07:11.3 (1) Peak Strain = 1330 με (2) Red Line Strain = 1900με (4) 1g STRAIN = 690 με	° Port Bow Seas Heading ° Forward Foil Asymmetric Broach	(3) P4405 = 1300 During 90° Helm Displacement Broach-In-Turn	(1)/(2) = 0.69 (3)/(2) = 0.98 (1)/(4) = 1.93	° Calm Water Trials produced 91% of rough water bending strain ° 1.93×1370 = 2640 psf. ° May not reflect most critical loading situation because starboard semi-span was at shallow submergence.
(b)	 P4405 Tape: PT 1245 Time: 12:24:45.9 (1) Peak Strain = −759 με (2) Red Line Strain Not Available. ( ) 1g STRAIN = 690 με	° Heading Unknown ⟨1⟩ ° Followed from a hull level impact with a wave crest. ("Neck stretcher" Loading).	(3) P4405 = 0 During 60° Helm Displacement Broach-In-Turn	- (1)/(4) = −1.11	° Calm Water Trials Produced $\left(\frac{690}{690+759}\right)$ x 100 = 49 % of rough water bending strain. ° Loading on Foil was Symmetric ⟨1⟩ Low level pitch and roll motions suggest head seas operation. ° −1.11×1370 = −1521 psf.
(c)	 P4413 (STBD FWD) Tape: PT 1245 S Time: 12:06:57.6 (1) Peak Strain = 220 με (2) 3000 PSI Actuator Pressure ~ 385 με	° Port Bow Heading ° Full Flap Down During Recovery from an Asymmetric Forward Foil Broach.	(3) P4413 = 200 με During 90° Helm Broach-In-Turn	(1)/(2) = 0.57 (3)/(2) = 0.91	° Calm Water Trials produced 91% of rough water hinge moment ° Hinge moments approaching 220 με level were common during rough water trials.

TABLE 1 (continued)

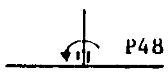
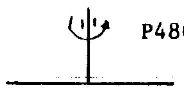
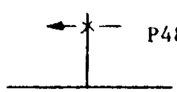
Item	Component Loading	Circumstances of Loading	Peak Strain From Calm Water Trials	Strain Ratios	Comments
(d)	 P4810 Tape: PT 1245S Time: 11:03:38.8 (1) Peak Strain = 1650 $\mu\epsilon$ (2) Red Line Strain = 1650 $\mu\epsilon$	° Head Sea Heading ° Forward Foil Asymmetric Broach	(3) P4810 = 1400 $\mu\epsilon$ During 90° Helm Displacement Broach-In-Turn	(1)/(2) = 1.0 (3)/(2) = 0.85	° Calm Water Trials Produced 85% of Rough Water Strain
(e)	 P4803 Tape: PT 1251S Time: 12:21:13.6 (1) Peak Strain = 1135 $\mu\epsilon$ (2) Red Line Strain = 950 $\mu\epsilon$	°Rough Water Turn, Heading Unknown ° Forward Foil Asymmetric Broach Followed by Large Strut Rotation During Wave Entry	(3) P4803 = 950 $\mu\epsilon$ During 90° Helm Displacement During Broach-In-Turn	(1)/(2) = 1.19 (3)/(2) = 1.0	° Calm Water Trials Produced 84% of Rough Water Strain
(f)	 P4801 Tape: PT 1245S Time: 12:02:40.5 (1) Peak Strain = 324 $\mu\epsilon$ (2) Red Line Strain Not Available	° Starboard Beam Seas ° Hull Apparently Loaded by Breaking Wave During Cresting Impact	(3) P4801 = 200 $\mu\epsilon$ During 180° Helm Displacement Debris Avoidance Maneuver	-	° Calm Water Trials Produced 62% of Rough Water Strain

TABLE 1 (continued)

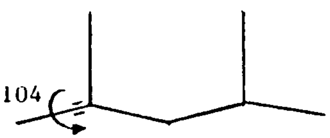
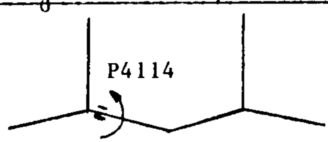
Item	Component Loading	Circumstances of Loading	Peak Strain From Calm Water Trials	Strain Ratios	Comments
(g)	P4501 P4104  Tape: 1245S Time: 12:05:19.7 ① Peak Strains: = 1310 $\mu\epsilon$ (P4501) = 1920 $\mu\epsilon$ (P4104) ② Red Line Strains: = 1600 $\mu\epsilon$ (P4501) = 1800 $\mu\epsilon$ (P4104) ④ 1g STRAIN = 700 $\mu\epsilon$ (P4104)	° Port Bow Seas ° Heavy Cresting Impact	Strut: ③ P4501 = 500 $\mu\epsilon$ During Straight-away Broaches and 180° Helm Displacement Debris Avoidance Maneuver	①/② = 0.82 ③/② = 0.31	° Calm Water Trials Produced 31% of Rough Water Strain
			Foil: ③ P4104 = 1300 $\mu\epsilon$ During 0° and 60° Helm Displacement Broach-In-Turns	①/② = 1.07 ③/② = 0.72 ①/④ = 2.74	° Calm Water Trials Produced 68% of Rough Water Strain o 2.74×1060 = 2907 psf.
(h)	P4104  Tape: PT 1245S Time: 12:23:04.2 ① Peak Strain = −540 $\mu\epsilon$ ② Red Line Strain Not Available ④ 1g STRAIN = 700 $\mu\epsilon$	° Heading Unknown ▷1 ° Cresting Impact (Neck Stretcher Loading) ▷1 Low Level Roll Motions Suggest Head Seas Operation	③ P4104 = 0 $\mu\epsilon$ During 90° Helm Displacement Broach-In-Turn	- ①/④ = −0.77	° Calm Water Trials Produced a Strain Increment of about 0−690 = −690 $\mu\epsilon$ Compared to −690 −540 = −1230 $\mu\epsilon$ or 56% of the Rough Water Value o −0.77×1060 = −816 psf.
(i)	P4114  Tape: PT 1251S Time: 11:18:20.5 ① Peak Strain = 1390 $\mu\epsilon$ ② Red Line Strain Not Available ④ 1g STRAIN = 500 $\mu\epsilon$	° Port Bow Heading ° Hull Apparently Loaded by Breaking Wave During Cresting Impact	③ P1150 = 1150 $\mu\epsilon$ During 60° Helm Displacement Broach-In-Turn	- ①/④ = 2.78	° Calm Water Trials Produced 83% of Rough Water Strain o 2.78×1060 = 2947 psf

TABLE 2 PHM-3 SERIES SERVICE LIFE ASSURANCE REQUIREMENTS:

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TABLE 3 SUMMARY OF SIGNIFICANT FOILBORNE IMPACTS*

HYDROFOIL VESSEL	IMPACT LOADING	REMARKS
AGEH-1	Two "deadhead" log strikes (8/24/71), (5/31/72)	See Figure 3 and associated text.
PCH-1 Mod 0 (Fixed forward strut)	Apparent log strike (2/26/68)	Propeller damaged and replaced.
	Floating log 3-5 ft. in diameter (4/30/68)	Forward strut and stbd. aft strut foundations damaged. Dry docking required for repair.
	Deadhead log strike (1/15/69)	Forward foil struck - no damage. Stbd. forward propeller damaged and replaced.
PCH-1 Mod 1 (Steerable forward strut)	Deadhead log strike (6/25/74)	Impact on forward foil. Steering actuator ruptured. Strut loading of approximately 3500 psf reached at about 15-18 deg. of rotation.
PGH-1	Whale strike (1/21/75)	Aft steerable strut impacted whale resulting in failure of aft down lock fitting and propeller damage.
PGH-2	Log strike (12/12/67)	Forward strut/ hull foundation damaged.
	Log strike (11/22/68)	Extensive fairing damage.
	Underwater object impact (1/5/68)	Steering actuator ruptured. Stbd. aft water jet inlet damaged.
	Struck reef near Puerto Rico	Extensive damage to forward strut and foil and associated hull structure.

* Note: Foilborne operations terminated.

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THE PHM, CONCEPTION TO REALITY, A DIFFICULT BIRTH
International Cooperation-Lessons for the Future

AUTHOR: Captain Robert K. Ripley, USN (Ret) An early player on the NATO PHM "Team". 1970-1978. Pentagon Warrior 1970-74, and 1976-78. Office of Chief of Naval Operations (CNO).

INTRODUCTION

This article is a personal account of the author's involvement many years ago in conceiving, and then achieving, the Patrol Combatant Missile (Hydrofoil), the PHM. This first ship designed to meet NATO specifications, and designed to metric standards, is a credit to the U.S. Navy. There will be many who read this article, or hear an abbreviated presentation at the twenty-fifth anniversary of the IHS, who know much of what is related, and those who know a great many more details of various elements of this story. The author also shares the honor with Bill Ellsworth, and other friends and colleagues, to be a charter member of the North American Chapter of the International Hydrofoil Society (IHS). We Americans joined those in England, and elsewhere around the world who founded the IHS, and are proud to be part of it.

Over the past twenty-five years, many nationalities in the International Hydrofoil Society (IHS) have shared the excitement of world-wide hydrofoil growth, and now look to the future. Many have already read and heard from others about the hydrofoils of the world, including the PHM; and such veteran stalwarts as the United States' Ellsworth, King, Jenkins and Wilkins in their writings and speaking captured for this organization the sense of history and struggle in bringing the PHM from concept to construction, and the deployment and use of the U.S. PHM Squadron.

Today, advanced ship design advocates envision improved hydrofoils, and more of them in a variety of roles. Advanced ship design panels, such as the one led until recently by Ken Spaulding, Ship Design Panel Five (SD-5) of the Society of Naval Architects and Marine Engineers (SNAME), have been chronicling the experiences of international hydrofoil pioneers in design and manufacturing. Other institutions, like the IHS, have regularly reported on developments in the military and commercial world. As new pioneers plan for the future, nations should be buoyed by past international hydrofoil cooperation.

So it is, that as the new pioneers draw on PHM experience for future development, it is highly appropriate to salute those long devoted to other high speed, advanced design disciplines, be they ships on a bubble of air, or with a variety of underwater shapes, or hybrid designs that have evolved from the trials and tribulations of several technologies.

We pause to remember those naval and civilian advocates in each nation that were, and remain, dedicated to other advanced concept ships and weapon systems. They bring to the shipbuilding world an equally enthusiastic and creative pioneer spirit in advancing their own candidates. In the United States Navy the Surface Effect and Air-Cushion advocates competed for limited funds for research and development budgets. However, it was their shared enthusiasm for high speed on the water that helped fuel Congressional enthusiasm for the PHM in the face of fierce opposition within the Navy, the Department of Defense and several administrations.

In an early 1970's discussion of this need for mutual support, in the midst of NATO negotiations, and the rapid emergence of hydrofoils, Surface Effect Ships (SES), and Air-cushioned Vehicles (ACV's), Captain Randy King, Commanding Officer of the R&D Center at Carderock, Maryland, Captain John King and the author laid out some rules about one set of advocates supporting the others, and restraining parochialism and internecine warfare among advanced ship design communities. The very embodiment of this spirit was that shown by two Surface Effect Ship (SES) pioneers, Captain Carl Boyd and top Navy R&D civilian, Nat Kobitz, recently retired. These two gentlemen "led the charge" for SES high-speed ships; but, even while competing hard for limited funds, they also supported hydrofoil development.

Those at the R&D Center at Carderock, Maryland, deserve a special and historical place, in first nurturing the new hydrofoil technology, and then seeing it through many years of early prototypes' development and vigorous test and evaluation, that led to the future PHM. The Ellsworths, Johnstons, the Meyers, O'Neill's and Clarks, along with the Navy Ships Engineering Center's (NAVSEC's) Jeff Benson, were core in-fighters. They brought the Navy forward in hydrofoil technology along with brilliant advocates from the Naval Ship Systems Command (NAVSHIPSYSCOM) like Jim Schuler, and Captains and Project Managers, Earl Fowler, Jim Wilkins and Ed Molzan. There efforts were augmented by premier strategist, Jim Hamil, from the Office of the Chief of Operations (OPNAV), and later Naval Material Command (NAVMAT), in carrying the technical and institutional hydrofoil fight to the forefront. All worked tirelessly with officers in the Office of the Chief of Naval Operations (OPNAV) to bring the technology through its growing pains. The combined "team" spent endless hours in NATO working and project groups, Office of the Secretary of Defense Decision and Review Centers (OSD DSARC's), and Navy Office of Program Analysis (OPA), as well as nearly continuous Congressional decision-making forums, in order to create the PHM Squadron. Rear Admiral Ron Hayes, and senior civilian staffer, Bruce Ensley, were key players in gaining mutual support decisions by the Secretary of the Navy (SECNAV) and CNO, as the follow-on PHM's became a Squadron.

Navy Captain Bill Erickson is unique in hydrofoil development, participating as an engineer, an OPNAV Action Officer, and as a PHM skipper. Another naval officer, LT Chuck Rabel added enthusiastic support to Bill Ellsworth at Carderock. Great credit goes to Captain Karl Duff, who in a variety of roles for many years, contributed immeasurably to hydrofoil and PHM prominence, and has eloquently written of his adventures in the hydrofoil world.

We pay tribute also to follow-on PHM skippers and squadron Commodores, who with OPNAV warriors, and SYSCOM and Carderock engineers, kept the faith, made possible PHM operations, and suffered the "tortures-of-the-damned" in operating and maintaining a one-of-a-kind ship.

There is another group of officers and enlisted men who deserve to share our anniversary of hydrofoil enthusiasts. Frequently maligned, and usually forgotten for praise, are U.S. Navy, Fleet maintenance staffs. They deserve hydrofoilers' profound gratitude, because they planned and executed the day-to-day PHM logistic support so vital to this new, and unique fleet addition. They had a tough job, because they primarily served conventional ship masters. They tried very hard to support the new weapons system in a drug interdiction role that is to this day not recognized as a military mission by Defense officials, including the Navy. Boeing's logistic support is patently worthy of mention; and is prominent in post-operations' reports such as RIMPAC 78, and drug interdiction mission reports by the PHM's. Boeing, and Tony Maier, who was first with Boeing, and then on his own in Florida, were always there, able to solve some really tough problems. Shipboard enlisted crewmen, rose to every occasion superbly.

INTERNATIONAL HYDROFOIL DEVELOPMENT

In reviewing PHM history, we rightfully pay homage to the earliest U.S., Canadian, Swiss and Italian efforts to first invent, and then enhance surface-piercing and fully-submerged foil craft. We salute the pioneering efforts of NATO countries, notably Canada and Italy, who built and sailed early operational hydrofoils. It is with great respect that we remember the critical advocacy efforts in NATO of the British, Germans, Dutch, French, Norwegians and Danes, who joined Italian advocates in the Mediterranean, as they pressed for speed on the turbulent North Atlantic and Baltic high seas for small ships they knew and historically operated so superbly.

We should never forget that basic hydrofoil technology existed elsewhere during the NATO hydrofoil development period, and most certainly does today, in Asia, notably in Japan, Hong Kong, and China. It has taken the innovative thinking, the commercial impetus, and the technical successes and failures of worldwide hydrofoil advocates to bring this species into being. Most maritime nations, including Russia, and continue to contribute to the knowledge needed to combine hydrofoil technology with other new ship design concepts.

Israel and arab countries such as Saudi Arabia are part of recent hydrofoil and Air Cushion Vehicle (ACV) history too. Let members from all nations pause on the twenty-fifth, IHS birthday to remember an important lesson: H*uman ingenuity and curiosity abound everywhere. Creative ideas are not limited to one place, one people, by a nation's power and wealth, or a single common interest.* Still, while many nations are part of hydrofoil history in one way or another, it is in NATO, led by the United States, that the PHM design was born; and this personal story honors the author's own compatriots and those of our allies.

THE RIPLEY INVOLVEMENT WITH THE PHM

The author's association with the PHM, a concept then not yet envisioned in any detail, or yet named for its weapons and role, came from a new assignment in 1970, the third time around in the Pentagon since 1960. This assignment to the Ship's Characteristics Board in the Surface Warfare Division of the Office of the Chief of Naval Operations, followed two ship commands in Vietnam, with familiarity on those wartime tours with both "brown water" and "blue water" navies as that war first started in earnest, stalled and changed to winning Vietnamese "hearts and minds" through in-country operations in Vietnam.

This author may have been assigned to that Shipbuilding Board because in the course of three amphibious commands since 1957, his ships suffered about every conceivable operational casualty that could require investigation and repair. Command at sea led to close contact with the Engineering Duty Officers (EDO's) and civilian scientists and managers of the Navy and their shipbuilding cohorts in industry. It was experience, good and bad, in how to keep ships afloat that put the author in the Pentagon. As an amphibious "desk officer", one first assignment in (OPNAV) was to serve in 1970 as an intermediary to three admirals, two of which became CNO's over the years, as they began to lay ground-work for a modest, long-range program to develop small, high-speed ships and craft, since the U.S. Navy limited inventory was largely handed over to the South Vietnamese, scrapped, or sold to third countries. Understanding and appreciation of the role played by Swift Boats and other Fast Patrol Boats (FPB's) in Vietnam later led to most needed high-level Navy support, sometimes when least expected.

Recall, if you will, that the U.S. Navy faced in 1970 vast shipbuilding expense to renew the fleet, while decommissioning nearly a thousand WW II ships, as the Vietnam War was "winding-down". The resultant program of modernization, and increased Navy inventory of new and more capable fighting ships, became known as the "high-low" mix. This was a combination of conventional and/or readily re-producible ships on the one hand, and on the other, those ships that required full concept development that contained the most sophisticated hull design and expensive weaponry possible for the "New Navy". It was the "low" end of the cost and risk spectrum that the hydrofoils represented, at a relatively well proved state of development when this strategy began.

Part of the job of the Characteristics Board in the office of the Deputy Chief of Naval Operations for Surface Warfare (OP 03) was that of translating the "soft-money" of Research and Development (R&D) to the Ship Building and Conversion (SCN), "hard" money of ship improvement and new construction for both high and low mix ships. A small cadre of officers, representing varied ship types, became named the Ship Acquisition and Improvement Division to reflect these dual roles. Our leader, VADM Jerry King, was elevated to the Surface Warfare head (OP-03), and our new leader became RADM, later VADM, Frank Price, with a special designator, Director of the Ships' Acquisition and Improvement Division (OP 97, then OP 097). OPNAV advanced ship desk officers worked for Admiral Price, his brilliant Deputy, RADM George Halvorson, and at one time directly for Admiral King, and his Deputy, RADM Jim Morrison. All these flag officers were hard working, hands-on leaders that had great experience in operations and technical programs. All were enthusiasts for the "new Navy", and converts to the Zumwalt way of getting difficult things done differently.

After a brief hiatus in 1974-76, where the author went to Greece to undergo their revolution and U.S. Navy home-porting expulsion, as the Navy Chief of the Joint Military Aid Group to Greece (JUSMAGG), he returned to become Deputy for RADM Bill Read, who had relieved VADM Price as the Director of the Ship's Acquisition and Improvement Division, now (OP-37). VADM Price became OP 03, and was soon relieved by VADM Jim Doyle. This was the era dedicated to the time-consuming fight for full PHM Squadron construction and hydrofoil survival.

At the beginning of the PHM journey, it was a long-time shipmate and friend, John King, who brought the author into the hydrofoil world, along with another Surface Warfare Requirements Division leader for clandestine warfare (now called Special Operations), Captain Larry Kelly.

There is a prized picture of the conceptual PHM, given to the author by Captain John King on the wall as this article is written, with a hand-written endorsement on it --"To Bob Ripley, one of three who had the dream!". The other two believers in that dream instilled enthusiasm for the PHM that has never faded. Thus it was that Admiral Zumwalt, now Chief of Naval Operations (CNO), had an embattled team of contentious warriors, King, Kelly and Ripley, that are still around to tell the story of the birth of the PHM. John the heart of it all, Larry who knew what it took to get a mission for a NATO high speed ship, and how to use hydrofoils, and this author-Captain that joined them.

NATO 1970-1974

In considering the early '70's as the NATO European period, as a "cowboy from Montana", the author prefers to refer to the PHM perambulations in the United States, as, "meanwhile, back at the ranch." This is because the NATO impetus for its first shipbuilding experiment had a virtual life of its own, while interested government "ranches" reacted in different ways to this new concept in warfare, developed on the NATO "range."

There are many players remembered with affection that for nearly four years were deeply involved in hydrofoil development. Many of these NATO delegates are known to you, some are not; but PHM could not have been designed had they not bombarded their respective governments with their ideas and enthusiasms for hydrofoils, first in exploratory, then in a dedicated hydrofoil project working groups. During this period, U.S. Navy delegates had the close personal attention of ADM Zumwalt, and instant decision-making communication through Admirals King and Price. This direct access and immediate decision-making response were key factors in moving the PHM design program along successfully in NATO. Equally effective in providing strong and responsive, technical decision-making support were two Commanders of the NAVSHIPSYSCOM, RADM's Sonenshein and Gooding.

Working in several NATO working groups, which became more sharply focused on the PHM final design agreements between Italy, Germany and the United States as time went on, each country's delegation struggled to get started. Italian VADM Cioppa, our NATO senior, proved invaluable in planning the strategy, and setting the scene within NATO. At the start, each delegation had to convince the NATO high command and mother governments that high speed ships were needed; and it was then necessary to prove that the hydrofoil was the best Fast Patrol Boat (FPB) candidate, and the only one that fully met NATO requirements.

To accomplish this task, the U.S. Delegation worked with the staff of the Commander in Chief of NATO Southern Forces (CINCSOUTH) in Naples in 1969 to develop a mission statement for that area requiring very high speed small craft. This concept of attacks by many small boats against larger ships had its Mediterranean origins in very early Italian history, and was first called the "sea-dust principle", as hundreds of small boats grappled with "biremes and triremes", and won! The basic military requirement, which was predicated on countering the Soviet OSA KOMAR class ship, was firmly established, and soon extended to the Baltic areas, and thus to NATO everywhere. Careful negotiations, and strong support from the other hydrofoil delegates from Canada, U.K. France, and especially the Netherlands, along with Italy, Germany, Denmark and Norway convinced their NATO governments that high speed craft needed joint development.

The mutually-agreed, NATO speed and sea state requirements were set sufficiently high that conventional hull ships fell short on meeting operational requirements for speed over thirty-five knots. The requirement all spelled out fast patrol boats (FPB's) with excellent sea-keeping characteristics in small size, which are prized characteristics of hydrofoils. Thus it was that the stage was set for a new, high-speed hydrofoil ship of advanced design to meet NATO specifications. The requirement for the hydrofoil was soon validated, and approved, by higher NATO command. The individual governments (back at their respective "ranches") approved the requirement developed by the International Exploratory Group. The next task was to develop NATO design specifications in the newly formed, PHM Project Group.

Once the need for speed on the water was identified, and the hydrofoil became a NATO requirement, part of that generated solution called for proof that there were military or commercial hydrofoil prototypes available in the world that could be turned into small warships. The U.S. Navy arranged during this critical decision period to have the Boeing prototype hydrofoil, TUCUMCARI, brought to Europe with a converted "mothership," (LST WOOD COUNTY) to support its operations and ship visits. TUCUMCARI, and its subsequent captain, LT ED Bond, did much for the hydrofoil program. Ed continues to view us hydrofoilers with affection as a high official in Boeing.

In the course of NATO negotiations, a memorable "sail-off" demonstration took place off southern England with TUCUMCARI, conventional patrol craft and air-cushioned British vehicles, in which the "Tuke" performed admirably under its Captain, Lt. Dick Stedd. Other visits were made at various times to NATO countries. One visit to Italy included an Italian Navy in a fleet exercise, where there was an opportunity to observe the sea-keeping of the hydrofoil in sufficiently high seas to support our assertions about usefulness. The Chief of Naval Material, Admiral Ike Kidd, accompanied by Captain Jack Lowentrout, John's, Larry's and the author's immediate boss at the time, observed these particular trials.

A personal sidelight occurred as the time to commit to a common PHM design program approached. Jeff Benson, then a feisty LCDR, and the author, made a ten day trip to five NATO capitols to argue the need for hydrofoil support versus conventional small craft. Our cohorts in the NATO working group had laid the groundwork for a warm welcome, and identified the degree of support we could expect in NATO. Benson's ability to translate the technical jargon to understandable language for laymen later served him well as he followed Jim Schuler, and brought to fleet prominence the air-cushioned landing craft, the LCAC's we have today.

After long, and often frustrating negotiations, hard commitment came finally from Germany and Italy for the Design Phase of the PHM Project. Detailed planning followed, orchestrated by the U.S. side, led by John King, who became the International Chairman of the NATO PHM Working Group, whose U.S. Delegation Representative was the author of this article. Even before negotiations with our NATO partners came to fruition, the U.S. Navy, led by Admiral Zumwalt, had already started an information and advocacy campaign in the Navy Secretariat and the Office of the Secretary of Defense (OS). Players were varied, ranging from R&D approval "chain" desk officers, to Secretary and Under-Secretary level in both OSD and the Navy. This Secretarial, rather than the Joint Chiefs of Staff (JCS) "route" on many Research and Development (R&D) initiatives was important in the total shipbuilding era.

There were greater possibilities for shipbuilding programs in this course of action than those that might result in simply splitting the defense funding "pie" among all Services four ways in the JCS arena. Everyone is aware of the tremendous amount of money over many years that was necessary to build the "new Navy". Advanced design ships increased the Navy's R&D budget by a needed percentage, and advanced the state of the art at the same time. It will be greatly interesting to hear Admiral Zumwalt recall his own thoughts during the PHM program; but, suffice to say, that hydrofoilers could not have had a better advocate.

Both hull and integrated weapons system design were an integral part of PHM planning, once the idea of a fast patrol hydrofoil was accepted. The Project Group had to consider weapons systems to meet new problems that were generated by the hydrofoil's size and high-speed design implications, and find ways to adapt and procure them. In this endeavor, Admiral Price, who was the Program Coordinator for the development of the Patrol Frigate, and anxious to promote "downstream" sales in other countries, took the lead in finding NATO weaponry that could be adapted to both ship types. Thus it was that the Italian OTO MELARA 76MM fully automatic gun, and the Dutch, SIGNALL MARK 94 fire control system, adapted for PHM and Frigate use by the Republic of Germany, and later by the U.S. Navy, and now called the U.S. MARK 96, became part of the PHM weapons system.

After much debate about these installed weapons, and the introduction of the missile weaponry in the form of the newly developed U.S. "HARPOON" (thus the designation Patrol Combatant Missile (Hydrofoil) [PHM]) as the candidate chosen over those of several other countries, a common, integrated ship weapon system was approved for detailed PHM design that met the needs of the U.S. Navy Patrol Frigate Program, and at the same time advanced the PHM Program. Weapons testing and demonstration on small high speed ships is an interesting part of PHM history, and deserves separate treatment at another time.

In designing to NATO specifications, the PHM Project Group had to consider international balance of payments, individual country weapons and propulsion contributions and trade-offs, which in both hull and weapons systems would have to be designed in metric dimensions. This very important "first" required a major decision, and concession, by the U.S. Navy technical community, and was made by VADM Bob Gooding. Of course, mutual design, stressing commonality, involved many different government and industrial players in each committed nation; and it is a credit to the three design-stage participants, and their respective CNO's, that agreement could be reached.

The author had the great fortune on the Ripley-Benson trip to Italy to gain three OTO MELARA guns for our eventual testing, modification and PHM installation from the Italian CNO, and full credit is due to the Italian PHM Project Group members, and Admiral Cioppa, for setting the stage for the offer. Back at the U.S. "ranch" we had to convince the Department of Defense (OASD-ISA) to support the trade-offs necessary to procure the Italian weapon system.

The internal PHM Project Group design considerations, and decisions that needed resolution, first in NATO and then in respective national chains of command, soon began to boil and bubble "back at the U.S. ranch". News of intense debates related to both requirements and technical commonality choices reached our Administration and Congress, as well as the government hierarchies of Germany and Italy.

No time was wasted by NATO "in-fighters" to decide what it would take to convince respective governments that we should and could build a PHM. That fighting ship could not merely be a research "toy", but had to be a viable fighting ship that could compete fully with other war ships in NATO threat scenarios, or national threats outside of NATO. A key requirement was that such a PHM had to be easy to construct by member nations. *These considerations drove the "commonality" argument so that more than one nation could convince its government to participate in both design and construction.* The Group settled on a basic hydrofoil concept, the Boeing-built "TUCUMCARI" in a close competition with the Grumman "FLAGSTAFF." This was a critical technical decision, as the NATO mixed group of technically and mission-oriented members, spelled out the compelling need for speed; reviewed prototype candidates available; and made the design decisions necessary to reach final 95 % commonality. This was a formidable task, considering national military-industrial complexes' "not-invented here" tendencies and parochial weapon system and propulsion equipment choices. Jim Wilkins, the PHM Project Manager, and Karl Duff, then his Deputy, were key figures in these choices. They, and the U.S. Navy civilian hydrofoil "gurus", Ellsworth and Schuler, and LCDR Benson, were the heart and soul of diplomacy in the war of "technical smarts".

In this intense period of trade-off decisions, You would be pleased to know that the author participated in design of various coffee pots, but in this single, and most traditional, area failed to achieve full commonality. If memory serves, we selected some 17 different wire sizes, all needing conversion to metric descriptions, and different electric power requirements for European and U.S. versions of the PHM.

The spirited competition between Program Managers Gene Myers of Boeing, and those of their Italian subsidiary, ALINAVI, and Bob Johnston of Grumman, was highly professional, and for the author, eye-opening and inspirational. Such was their expertise and so effective their candid testimony about design features and prototype operational performance of both hydrofoils, that all NATO delegates were convinced that the fledgling U.S. hydrofoil industry was fully committed without reservations to produce the PHM to NATO specifications.

It was obvious to the three nations committed to design of the PHM that we had to insert this new element in naval warfare, the high-speed, missile-firing small ship, into the very much more complicated international naval warfare scene, even while deciding the PHM mission and design.

In short, we had to foresee what world and area roles countries that possessed a nominal PHM might play; and how to retain the NATO control over design and construction necessary to prevent misuse of the PHM design between warring factions outside of NATO, who were affiliated with member NATO nations. Israel and the arab states come to mind. When this subject came up, some of the most delicate negotiations of all took place, including with U.S. State-Defense working groups faced with the realities of the Middle East conflict. Middle East considerations were immediately added to those concerned with the Soviet bloc that we normally considered in NATO.

The Soviets were equally interested in hydrofoils, and remained so. They vigorously began to build the latest technically advanced hydrofoils in significant numbers that they needed for their rivers, coastlines and inland seas. The Asian theater nations were beginning to show interest in our progress; and, even at an early date, information was requested by other governments outside of NATO, including Japan. It became evident also that the PHM, with possible "down-stream" sales to other countries throughout the world, would be suitable in both major oceans by our Navy, and those of our allies. Thus, our NATO PHM begin to burst the confines of NATO, even before PHM cooperative design commenced in earnest.

It seems highly ironic to the author that this unique PHM evinced such great interest as a newly emerging weapon system, and appeared to pose such a threat to stability in the region, when at the same time we faced, and to a degree, still face, a variety of national critics that denigrate PHM importance and capability.

It was always fundamental, and a paramount concern, that the U.S. government (Navy) stand solidly behind the PHM, and that it must be clear that the U.S. intended to build them. Thanks to Admiral Zumwalt this happened, despite bitter opposition in and out of the Navy. Stories of generating essential and critical support have been told by others who were, like the author, privy to incessant in-fighting by anti-hydrofoil, then anti-PHM, never-ending critics.

It is more than fair to say that our PHM USN team had its arguments at every level; and when finally we agreed on anything technical or mission-oriented in NATO, we didn't have to go far in Washington to find opposition. Special tribute is due the work of the US-NATO international development team, whose OPNAV Research and Development Officers of (OP 98-098), RADM Tag Livingston, Bill Montgomery, and John King in succession as NATO Exploratory and PHM Project Group leaders, worked closely with (OP 03) officers during PHM development. The OPNAV team's work, coupled with the budgetary and mission work provided by the Material Command, and the analytic help provided by the System Analysis Division (OP 96), and the Navy Comptroller chain of command, ensured that critical opposition was defeated, and PEGASUS, the PHM lead ship PEGASUS (PHM-1) was approved. Italy and the FRG then agreed that the first PHM would be a U.S. version.

THE PHM SQUADRON

We determined at one critical part of negotiations within NATO that the United States would build as many as thirty six ships (six squadrons), which were later drastically reduced throughout several years of U.S. decision making, largely dictated by cost, to one squadron of eight ships, which cost considerations again reduced to six, with two lead prototypes, of which PEGASUS would be the first PHM built. We announced this to the NATO PHM Working Group. It was about this time, the author left OPNAV for Greece, but was kept current by RADM Bill Read and Captain John King.

In the fall of 1976, the arguments so well described by George Jenkins were going on "full throttle". These decisions about the future of the PHM, U.S. Version, and the plans by the Italians and Germans to move into the construction phase were being formulated. In discussion were lead ship numbers (two versus one), PHM-2 construction and weapons systems, support ship versus aircraft van maintenance, and fleet assignment of Pegasus and the rest of the follow-on ships. Homeporting, deployment plans and manning and organizational considerations, were an on-going part of the often contentious dialogue.

During this period, RADM Bill Read was a pillar of strength, having been long convinced that this ship squadron must be part of the Navy inventory of fighting ships, and that the hydrofoil had uses not yet envisioned that we would discover once the PHM Squadron was built, properly maintained and deployed. He was often alone in his enthusiasm within the Pentagon, although VADM Doyle and Admiral Zumwalt gave him every chance to carry the battle up the chain-of-command to the President. He also was warmly supported in the Ship System Command by RADM Bob Walters. Several other key players in the Office of Program Appraisal (OPA), OP 96, Systems Analysis, and in OSD, the Office of International Security Affairs (ISA), played vital roles in withstanding a massive budgetary and technical attack by almost everyone else in Washington that played a role in Navy shipbuilding programs. Admiral Kidd, Chief of Navy Material (CHNAVMAT), supported the PHM program that Admiral Zumwalt proposed during several key decisions to proceed, and COMNAVSHIPSYSCOM provided strong and convincing technical argument. We later had strong post-construction support within the Navy and in Congress by a famed-WW II PT boat hero, RADM John D.Buckley, who was then President of the Board of Inspection and Survey.

RADM Monroe, who became the Commander of The Navy's Operational Test and Evaluation Force (OPTEVFOR), the Navy arm of the OSD Assistant Secretary for Development, Research Test and Evaluation (ASD-DRT&E), after previously serving as the head of Navy System Analysis (OP-96), performed the key technical and operational evaluation of PEGASUS (PHM 1) that sustained PHM advocates' arguments with the Secretary of Defense and the Congress at one key juncture.

ADM Monroe's first preliminary draft report on Operational Evaluation (OPEVAL) of the PHM lead ship could have, but did not, scuttle the PHM program with the Secretary of the Navy and Congress, because it was prematurely far more negative than it should have been, as was later proved as the testing progressed and the final, completely supportive formal report was submitted. A rumor by the "grapevine" to GAO about this unfortunate OPTEVFOR preliminary draft test report, that Bill Read refused to believe, eventually was dragged forward, and was of some embarrassment to SECNAV, a year or so later. Bill Read was criticized for not submitting the first raw data, when, in his Deputy's view, he should have been congratulated for moral courage in resisting the trumpeting of that erroneous preliminary data.

This incident, and other problems with senior Defense, Congressional Committee and administration officials can be attributed in large measure to the general negative attitude of some staff in both the offices of the Assistant Secretary of the Navy for Research and Development (ASN R&D) and in OSD, namely in (ASD-RDT&E). As most Pentagon experts know, key players for their own reasons, some not related at all to this program, but who advocated other programs competing for the limited funds available, were consistently opposed to the PHM, and it took the Assistant Secretary for International Security Affairs (ISA) to break the construction logjam.

To illustrate the depth of Administration skepticism, President Carter rescinded the PHM squadron construction program; and it took the resolute support of the PHM by Senate and House Armed Services and Appropriations Committees to keep the program going. Even then, the in-fighting delays during the mid-1970's caused fiscal year budget snafu's and delays that resulted in under-funding of the PHM's and deferral of funding for Squadron PHM combat systems. In retrospect, this author considers the budget arguments over several years that resulted in the loss of the very important PHM support ship in the Navy shipbuilding budget, also to be short-sighted.

PHM OPERATIONAL HISTORY AND RETIREMENT

The remainder of PHM history (1978-1992) is capsuled because the author was not an on-scene player, although in civilian consultant work in 1988, there was occasion to study the high-tech inventories of the world, particularly the Soviet Union. The U.S. PHM was placed against the world competitor hydrofoils and was of the highest capability. The author has carefully studied general operational PHM history, gained in part because the author belatedly came to Washington to join a great many others more prominent senior officers and civilians, including the Chairman of the Senate Armed Services Committee, as they tried to save the PHM Squadron from early retirement. Further information has kindly been provided in editing this article by John King and George Jenkins. From this background, the author's conclusion is that the eventual retirement decision was a premature one; and in the Navy's rush for PHM retirement, the ships' final disposition was clumsily handled, including the planning for research and development, and in dealing with foreign military sales opportunities.

Because of sea-going experience and PHM involvement, this author has found time over the years to draw some strong conclusions. First among them is that hydrofoil advocates have been far more objective, and fair-minded than have hydrofoil adversaries, and in their desire for fairness they appear overly self-critical. It must be remembered, that in creating the PHM Squadron, the program benefitted from those with no particular "axe to grind", and primarily because they understood the value of the PHM, the value of hydrofoil sea-keeping in small size, and economic benefits of small PHM crews which could make equal contributions with ships that were large and personnel-intensive.

It seems obvious that the hydrofoil "product", when properly understood by laymen and technically informed people alike, "sold", and continues to "sell", itself. One ride above the waves at high speed, as the PHM banked and turned like an aircraft, with the passenger in relative comfort, hull-borne in heavy weather, served to turn many of the most skeptical critics into "believers". The future of hybrid high-speed ships should be as bright, and the hydrofoil contribution to that hybrid concept, is a major one.

SUMMARY AND LESSONS-LEARNED

Now to thoughts of how we could have done better in all phases of PHM development, and the lessons-learned from failure, as well as success. Let's review the PHM story together for these pearls of hind-sight wisdom!

The first question is that of operational research prototype vehicles versus operational ships. If someone could have told us at the beginning of NATO negotiations that the problems of designing, constructing, then redesigning, maintaining and repairing a sea-going operational PHM for the first time would be as intensely frustrating and costly as was the case throughout PHM history, the NATO Exploratory Group probably would have been forced to abandon the project. There are those today that believe that the timing of the shift from R&D to Shipbuilding and Conversion (SCN) budgetary funding was a mistake.

This "doomed" the fiscal support for follow-on progression to larger hydrofoils and hybrids, and led to premature decommissioning of the PHM Squadron. There is credence to these arguments because of the many problems of transition to PHM warships from research platforms. It was the competition within the Navy for hard-to-come-by shipbuilding funding that generated such intense opposition when these ships became part of the Navy's active inventory.

Obviously, during inflationary and "down-sizing" periods the PHM's remained a contentious issue. The reader may not consider a PHM a "one-on-one" trade-off with a destroyer, but when non-sympathetic "bean counters" wanted to "dump" the program, they found ways to use the few operational PHM's in such comparisons with other ships of the line in order to justify putting them out of commission.

The R&D community is acutely aware that high visibility problems, and competition for limited funds, are often the downfall of solid research projects that need more time and money for successful development. The PHM had highly over-stated and over-publicized problems in the Navy and at Boeing that plagued construction, along with repair and routine maintenance problems that contributed to premature end of the PHM Squadron's operational life. Notwithstanding, as one who helped make those decisions of transition from "research craft" to operational weapon system, the author is thoroughly convinced that a much stronger case can be made that the total PHM experience added far more to advancing the state of the art than it detracted from it.

The lessons learned in designing and building this part-ship, part-aircraft, enhanced understanding of high-speed ships much more quickly than would otherwise be the case. Said another way, by virtue of the PHM competing as a fighting ship on the high seas, hydrofoils' utility for the future has been demonstrated; and those improvements and increases in size and capability that make them more valuable were clearly identified and readily translatable to the commercial use of this high-speed platform as well. There is nothing like "kicking the tires" of an operational ship or weapons system to advance progress. It remains for new advocates to make those advances, and no apologies are in order to "arm-chair quarterbacks" for decisions along the way to build and use the PHM's, and put them "on-the-line" for all to see.

A NEW IDEA IN A BUSY WORLD

Organizational and government institutional problems are part of the lessons-learned department where PHM's are concerned. Again, let us review the background considerations during the last quarter century of hydrofoil development. As we know, a major world power, such as the United States, has different considerations than a lesser power. Decisions made from that perspective dominate the form and substance of military inventory. During development of the PHM, two major world powers existed; and the political and economic stakes were high for both of them. Military inventory included nuclear weapons and launching systems, substantial conventional forces, and intensive and extensive research and development of weapons and counter-weapons. "Star Wars" expense comes to mind.

Furthermore, what represents a major system to a minor power, is a minor system to a major one. Thus, the PHM, a major system to some of our allies, was still too expensive for them, no matter how much they wanted the inherent capability that PHM's provided.

Conversely, PHM looked too insignificant to the U.S. "blue-water" Navy, relative to the cost to fully utilize the PHM in single-mission scenarios. In our three-branch Navy, every single weapons system clamors for each dollar, particularly in highly inflationary times.

Budget estimates were very poor, and over-runs were commonplace in the ship-building world in the late 1970's and early 1980's, and continued to be difficult in subsequent periods of Soviet Union decline and collapse, and U.S. forces' subsequent down-sizing. All these factors played a part in PHM's turbulent history.

After sharing design costs, three NATO partners considered respective construction plans after PEGASUS was launched. A case can be made that the Germans probably would have built some form of the PHM design, as the Italians later did (in smaller size), had it not been for two factors. The FRG government was kept informed in detail on every PHM test and evaluation, and early operational, PEGASUS casualty report, no matter how minor. At this same time, the U.S. Navy PHM advocates were fighting to have the remaining five ships of the PHM Squadron constructed. As the U.S. wavered on acceptance of the PHM Squadron progress, this indecisive attitude contributed negatively; and when our hesitancy was combined with this steady "water drip" of maintenance complaints, the two situations may have influenced the FRG decision not to build at that critical time. On the positive side, the Italian Government went ahead with smaller versions of the PHM, and their commercial hydrofoils added much to technical knowledge needed to build better hydrofoils and hybrids.

THE FRUSTRATION OF OPERATIONS, REPAIRS AND MAINTENANCE

Let us review the problems of repair and maintenance of the PHM's from early construction through Key West operations. Clearly, despite highly placed claims to the contrary, the PHM's performed very reliably in spite of operational casualties, with repair and maintenance usually complicated by being one-of-a-kind in the fleet. It is a fact that for several years the PHM logistic support program was nominated for top Defense Department logistic support awards.

The author will always believe that if there had been a greater will to do so by senior Navy officers, we would have used these ships in more than the drug interdiction role, a role in which they really did extremely well, by the way. Despite some unfortunate and highly-publicized operational casualties throughout PHM Squadron history, and the natural loss of confidence by the non-initiated that accidents and casualties engender, particularly in new weapons systems, there appears little doubt that PHM's would have proved useful in the Persian Gulf during several crises in both the Carter and Reagan administrations.

During the Bush administration, they could have played a part in the Gulf War. They might have been of use in Panama, and, finally, done much more in Grenada, where they were used, but not to any extent, due to late arrival.

The reasons given that PHM's were never considered an operational "plus" during this period, was because, since their commissioning, at crises times, the entire squadron was not ready for deployment; or, if deployed, they would have required unusual efforts for transport to the Mid-East theater, and to maintain them while there; and lastly, and perhaps more importantly, that they were single mission ships without any anti-submarine warfare (ASW), and no effective anti-air warfare (AAW) capability against missile attack.

From a hydrofoil advocate perspective, these are the arguments of those who never wanted to use PHM's, or to risk their popular appeal to the detriment of other U.S. Navy fleet assets. While not wanting to second-guess too much from a safe perch in Montana, it is obvious to this author, that in NATO PHM scenarios that were used during PHM development, there were several that would have applied to Mideast operations. Such scenarios utilized the unique qualities of hydrofoil attack craft, including foil-borne imperviousness to mines and submarine torpedoes, and maneuvering agility to avoid aircraft attack.

It is significant that unique PHM qualities were demonstrated by prototype research and development prototypes, as well as during the extensive hydrofoil evaluation and post-construction testing of PHM-1, PEGASUS. One clear-cut attribute of the PHM, due to its inherent high speed and agility, is hit-and-run capability intended to keep the enemy off-balance against enemy capital ships, and emplaced weapons systems. The PHM has superior ability to keep slower small craft at bay. In a key scenario during PHM development, often called the "dark and stormy night" scenario, postulated in narrow seas or straits, the small crew and relative cost of PHM loss in an exchange with enemy capital ships, weighed heavily in favor of the PHM in mission-effectiveness analyses.

It is not hard to visualize, that a PHM, high-speed, on-foil, run at an oil rig in the Gulf would have "terrorized the natives", and could have been attacked with smaller risk than possible with any other surface ships in theater. Some experts tartly observe that finding old mines by large ships hitting them is a poor substitute for potential mine area search by small hydrofoils, whose imperviousness to mine fields was demonstrated by TUCUMCARI in Denmark mine-field operations even before PHM's were built. Parenthetically, Air Cushion Vehicles are even more impervious to mines.

Of interest in regarding the tactical maneuvering possible for a PHM, the agility of those PHM's was proved during the Operational evaluation of PEGASUS, when her agility was such that the PEGASUS could maintain a probe light, which was mounted in the barrel of the 76MM cannon, constantly in the cockpit of the "attacking" fighter plane as it maneuvered to attack, and the PHM could very often turn successfully inside the airplane's attack parameters. Given that the range of AAW capability of the PHM is extremely limited in a highly sophisticated setting of multiple missile air attacks, there still was mission-effective utility for PHM's during the times at the places in question.

As for readiness for Gulf or other European and Mid-East theater operations, most insiders know of the "one-hoss-shay" variety of engineering problems that hit the PHM Squadron at just the wrong time; the reluctance to go far from overly-elaborate van maintenance support by some PHM commanders, whose caution was natural considering OPNAV and operational seniors' own inherent fears, which in hind-sight appear largely unsubstantiated. While some do not agree with this thesis, this author believes there was a critical short-fall in failure to have a mobile, forward-based in-theater, PHM support ship (that was lost in budgetary cuts that, even if made, need not have been charged against this program), a concept that had been proved in TUCUMCARI deployment years before. Having operated for long periods at sea with limited support in Vietnam, as well as in-country, and aware of the ingenuity of our Navy when they need to employ it; it is hard for an amphibious naval officer, or a destroyerman, to believe that all obstacles could not have been overcome, with results justifying that effort, had PHM's been allowed to prove themselves overseas as fighting ships.

Critics of the author's thesis should refer to several fleet operational reports of exercises with early hydrofoil prototypes, and PHM's, that show that this high-speed attack ship can more than justify its cost; and that such attacks can completely disorient a conventional task force defenses, particularly at night; and post-exercise conclusions dramatically demonstrate that the PHM would be a valuable fleet asset today.

WHAT IT WILL TAKE TO GO FROM HERE

What should be emphasized in this personal PHM experience is the thrill and challenge of the up-hill struggle to produce the PHM's, and the pride in hydrofoil performance. It is easy to translate the past excitement to the struggles ahead to produce new and better hydrofoils; or other advanced design ships that also go extremely fast on the water, or show superior sea-keeping qualities in various sizes. The author knows from keeping reasonably current on world developments, and from the work of the SD-5 Design panel, of which he is a member, that pioneers are already hard at work on plans for future development that are very promising, particularly in the world of commerce on the high seas. For military applications, threat analyses support new technology, as do cost considerations in this post-Soviet, politically turbulent era. New hydrofoil improvements of evolutionary nature have already been identified. They include: longer sea legs, perhaps up to 2,000 miles; huskier and higher hull-borne diesel power, at least to 15 knots; increased redundancy in foil-borne mode of operation; replacement of faulty power units with more reliable ship service generators; and increased multi-capable weapon systems, and addition of more versatile systems. The U.S. must fight many distractions as we strive to stay abreast of the technologies available, and continue to advocate the need for speed and stability in high seas in our small craft and large ships.

Many PHM program participants believe the United States Navy itself would not initiate another hydrofoil program; and that it would take the Congress, or outside warfare analyses "think tanks" that include hydrofoil proponents, to force the Navy in this direction. Having played fair with what is recognized as a lack of enthusiasm by our Navy, this author suggests that you summarize in your own mind what qualities in men of all nations it will take to bring into being truly new and controversial design ideas and translate them to greater capabilities for sea commerce.

Looking though the PHM experience, perhaps they can be summarized in a "Pact for the Future". In writing this article, there appeared to be a convenient way to remember the qualities required, described by using the acronym P.A.C.T. in the following way:

"P" stands for prescience, patience, and perseverance. Those traits will give you a vision of the future, the ability to press on, or retreat, at the proper moment, and the courage to move forward despite man-made obstacles to achieving your vision.

"A" stands for accuracy, adaptability and accountability. Whether it be in matters of technology or program progress, you will need to be accurate about what you say; be able to adapt to new solutions for problems and situations, usually unforseen; and accountable in all you say, so that people, including adversaries, believe you. A program "oversold" is a program eventually lost.

"C" stands for creativity, competence and character. These traits will bring you new ideas and strategies, if they are based upon your technical and tactical competence, and the inherent character to be true to yourself, and to unselfishly, without personal aggrandizement, pursue your vision.

"T" stands for talent, trust and temperament. You will succeed in reaching a bright and productive future only if you have the ability to invent, invest and convince, and the belief in your fellow advocates and strugglers against the tide of indifference and ignorant opposition. If you then possess the level temperament to forgive your enemies, forget past mistakes or slights, and look always forward, you will succeed!

This "Pact for the Future" is held in large measure by past hydrofoilers, and by its successors in all countries; and that young and ambitious thinkers and innovators in our shipbuilding and aerospace industries will bring us into the twenty-first century with far more than "old-timer-hydrofoilers" were given.

"The Departure of PEGASUS"
by
John Monk

BIOGRAPHIC: John Monk ended his thirty some years in the hydrofoil community on the first of January 1994 when he completed his part of the PHM base closing in Key West. He returned to Virginia where he took up the duties of a security guard lieutenant at UNISYS. Throughout those thirty years he was involved in one way or another with the development and operation of all U.S. Navy hydrofoils.

ABSTRACT: This is an account of the last four months of the PHM base at Key West and how its closing affected the people still working on the program. During the months of July 1993 through January 1994 Boeing, Navy and AEPCO personnel packed and shipped the remaining spares to Virginia for storage.

One

Peggy, the affectionate name given to the USS PEGASUS by the officers and men of the PHM squadron, came to Key West in May of 1980. She was the first of her class to arrive there and like her sister ships was named for constellations located in the northern hemisphere of the night sky. Originally the little lady with the green eye shade (before the days of computers) named her for the constellation of the dolphin, DELPHINUS. Noting that this name might cause the crew to be considered cream puffs, a young Lieutenant Commander, insisted that the admiral change the name! The admiral, allowing it would probably save some black eyes and broken heads, gave his permission, and the name was changed to the flying horse, PEGASUS. Undoubtedly, if she had remained the Dolphin, the politically correct (dolphin lovers) activists would have come forward to save the ships from annihilation.

But that was not to be and she and her sisters, GEMINI, AQUILA, TAURUS, HERCULES and ARIES came north to Little Creek, Virginia. Where they were ceremoniously sent to the scrap heap on the thirtieth of July 1993. After the ships left Trumbo Point Annex, all that remained of COMPHMRON TWO was an empty pier, the supply area in the seaplane hanger, and the Boeing office in the headquarters building. The few remaining Mobile Support Logistic Group vans, that once covered the pier, now set in front of the hanger waiting for eighteen wheelers to haul them away. Inside the old seaplane hanger, the store room and all the ship's spare parts, waited to be packed and shipped to the north.

It was an exceptionally hot day when I arrived at Key West for my last official business trip. When I reported to the NAVSEA representative at the Boeing office I was told to go to the old seaplane hanger where I would find the team working. The seaplane hanger at Trumbo Point Annex is a large gray building. It sits in the middle of a large apron that reaches to the shore where several ramps go into the water. On the west side of the hanger is a huge door that reaches almost to the top of the building and is almost fifty feet across. The door is jammed in an open position and can not be shut. Therefore, one always feels that he is outside, even though he's in the hanger. As I had been away from the squadron and Key West for over a year I'd forgotten how just how hot it could get inside.

The inventory of the parts in the stores was well under way when I arrived. (If there had been a need for lessons learned, it would have been this, for what we should have done was to inventoriy the parts at the same time we packaged them). The large spares and small mechanical parts stores were located in a large fenced area inside the old hanger. For all practical reasons the storage area was exposed to the weather because the hanger door could not be closed. Thus the area was dirty, hot and filled with nasty little mosquitoes Outside, on the runway, the temperature was in the upper nineties, while inside the hanger it was usually over a hundred degrees. Of course it had to be an exceptionally hot Key West summer, that lingered way into September, making working conditions miserable until the rains came late in the month. After that, except for the mosquitoes, it was rather pleasant working inside the old hanger.

The crew consisted of four Boeing people, two personnel from the squadron, two people representing NAVSEA and me. We all worked in shorts, T shirts and grungy shoes. You came away from there each day dirty, sweaty and covered with bites. (Fortunately mosquitoes dislike me, and to the other's chagrin, I did not require the daily dusting with OFF). Inside the hanger it was very dark and the air was still with the heat of the day. To overcome these two disadvantages, we used portable light stands between the narrow rows of parts, and also located large fans at each end of the row. The fans made it possible for us to believe we were being cooled. You could only work about forty-five minutes before you had to stop and get something to drink and go outside and cool off in the ninety-degree air. A feeling of depression and gloom existed about the job especially for the team members who would be out of work when the job is over. For me, however, it was the depression of seeing the old dream coming to an end. We had worked so many years to put the hydrofoils into the Navy and now after having proved their worth, were out the door. Now and then news would come from up north that somebody or some county wanted them. Yet you knew it was just another rumor, and the work continued. By early October the inventory was complete and the Boeing packing and handling engineers from Seattle had arrived. Paul Sharp came from the Boeing Oklahoma office, to head the effort. He had never seen a hydrofoil! If fact, none of the people from Seattle knew anything about the hydrofoils. So I alone, carried the weight of the dying program, and maybe sometimes I talked too much about the good old days when they were still operating.

After taking one look at how much equipment was in the stores Paul knew he couldn't get the job done by the end of January. It took him several days to convince NAVSEA that he needed more people and money to accomplish the job. NAVSEA, shocked at this turn of events cried foul, and asked Boeing why their first proposal was too low. Paul decided it was too low because it did not comply with the Navy's requirements. Eventually the Navy and Boeing came to terms and NAVSEA quickly came up with the additional money. Paul hired the additional people he needed through the local Florida unemployment office, and we started the dead end job of closing the base.

Two

For the next several weeks I sat at the computer preparing the necessary paperwork to salvage the "Navy-common" parts. While I was burning my eyes and brain out on a software deprived notebook that NAVSEA provided, I had time to observe how the departure of the squadron affected the people and business in Key West.

Take the Paradise Cafe for example, a sandwich place on the corner of Elisabeth and Eton Streets, which lost over 50% of its business. The ships' crews and the squadron staff had kept them busy all day long making sandwiches to go. The owner told me that he not only missed the business and money, but, they also missed the friends they had made over the years the ships were there. A big loser I discovered, was the Little League. Every year since Peggy had arrived, the squadron had sponsored teams in the league. Also gone were the children from the squadron families, that played in the league. Another organization that suffered because the squadron left was the Boy Scouts. Over the years that Peggy was in Key West the Boy Scouts were able to honor their ranks with eagle scouts. Something they had not done since the days when the Naval Base was still active back in the sixties and probably won't do again for a while.

There's always strangeness associated with closing a base like this. And in this case it was baseball! One must first understand there has always been some contention between the Navy and the City. (As any officer or sailor that served there in the fifties and sixties will confirm.) In general the existence of the squadron in Key West was rather cordial and as I pointed out before, very oriented to community support. As the drug interdiction forces grew in Key West, the Navy ran out of housing for its dependents There had always been a waiting period for personnel to get housing for their family. It was not uncommon for an officer's family to have to live in the BOQ for several weeks and occasionally for a month or so. This not only upset the family, but it also drove the bachelor officers crazy. The Navy decided to solve the problem by building new housing in the park across the street from the BOQ. This park, and the associated baseball field belonged to the Navy. In fact, the ballpark was originally constructed by the naval base as part of the seamen's sports activities. Therefore, when the naval base was closed the city leagues more or less just took over ball park. Now they figure they've played there so long they have "squatters rights." The furious fight that resulted between the city folk and the Navy took several months to resolve. The Navy won, allowing them to go ahead with their plans to build new family housing, and the city leagues had to move down town to the kids field.

However, before the Navy could actually start construction the decision was made to close down the squadron, and the city leagues rejoiced! They just knew the would get their old field back. However, that was not to be. The Navy, even though they no longer needed the housing, started construction. (They completed the construction in the fall of 1994.)

Three

October and daylight-saving time had passed and by Thanksgiving we had assembled (laid out on the hanger floor) eight semi-trailers worth of crates. The spare, hullborne diesel engines were packed and ready for shipment. The crew Boeing hired from the unemployment office was very diversified and from everywhere, but they were good! They learned the cleaning and packing procedures quickly and worked well together as a team. By this time the store was shrinking, and several sections of fencing had been removed. When the first trucks had departed, there was a great emptiness to the place.

Each week another one of us would leave and we would all gather at some Key West restaurant or bar to say farewell. The team grew smaller and the store continued to shrink. By December, all of the salvage parts had been shipped to Navy stores at the air base. My work was about done and I was scheduled to leave on the 31 of December. Sometimes on the way home I would stop at the empty pier and watch the sun set. I remembered once, back in 1984 after all the ships had arrived how the sun used to go down behind ships moored to the pier, its orange glow reflecting off the retracted foils. How the vans of the MLSG, tightly connected on the pier, sat with the sun's last rays reflecting in white walls, waiting to come alive in the morning with the scramble of sailors bringing life to the ships once again.

My work done, I left Key West on the first day of 1994. Boeing continued to pack the few remaining parts and ship them out. By January 28 the work was done right on time. An icy wind blew in from the north that day and it was rather cold in Key West, one of those days when all of the locals put on heavy sweaters and long pants. It was also overcast and rather gloomy.

Paul Sharp arrived at the hanger around noon. That day he wore a jacket, just like the locals. Getting out of his car he walked into the empty hanger. The wind was blowing in through the open hanger door causing him to pull his collar up around his neck. The floor was bare except for a single telephone, its connecting wire hanging down from the overhead structure.

He goes to the phone reaches into his back pocket and pulling out a pair of wire cutters, reaches up as far as he can. With one snap, that echoes across the empty hanger, he severs the wire ending the PHM program. Turning slowly he takes one last look around the empty hanger, then walks outside. Soon you hear his car start and then pull away. The dangling phone wire slowly swings back and forth in the cold wind blowing in through the open hanger doorway.

The end.

Decavitator Human-Powered Hydrofoil

Mark Drela * Marc Schafer † Matt Wall ‡

Abstract

The *Decavitator* is a human-powered hydrofoil water vehicle designed for the fastest-possible speed over short distances. Since 1988, numerous versions of the underwater hydrofoil system, control and stability system, and pontoons were built and tested. In its present configuration, the vehicle consists of two kayak-type pontoons, with a central frame supporting the rider and the large air propeller. Two underwater hydrofoil wings are positioned directly under the rider. The vehicle has three operating modes: on the hulls, on two wings, or on one wing. In the fastest one-wing mode, the *Decavitator* in October 1991 set an official speed record (pending ratification) of 18.50 knots / 9.53 m/s over a 100-meter course, with an unofficial 19.59 knots / 10.08 m/s being the fastest measured speed to date. This article will outline the technical features and design philosophy of the latest version of the vehicle.

Introduction

The recent surge of activity in the development of human-powered watercraft has been sparked largely by the sanctioning of the relatively unrestricted watercraft category by the IHPVA. The novel *Flying Fish* [1] and the *Hydroped* [2] hydrofoil vehicles have substantially exceeded the performance of traditional rowed racing shells, whose development has largely reached a plateau. The race to develop the fastest water vehicle has further intensified since the announcement of the $ 25 000 DuPont Watercraft Speed Prize [3], which will be awarded to the first vehicle to exceed 20 knots / 10.29 m/s, or, to the record holder if the prize remains unclaimed after 1992.

The *Decavitator* human-powered water vehicle, shown in Figures 1 and 2, was designed expressly for the fastest-possible speed over short distances. It consists of two lightweight 17-ft / 5.2-m kayak-type hulls between which a frame supporting the recumbent rider and the large air propeller are placed. Two underwater wings (hydrofoils) are positioned under the rider via thin vertical struts. The smaller of the two wings is positioned beneath the larger wing. In addition, a small "canard" trim surface and small rudder arranged in an inverted-T are mounted at the front tip of each pontoon, similar to the systems employed by the *Hydroped* and *Flying Fish* vehicles. A surface-following skimmer controls the angle of attack of each trim surface, passively controlling the depth of each pontoon bow and thus giving roll stability. The rider controls the front rudders via a right sidestick, providing directional control. The sidestick also actuates larger rear rudders which work only when on the pontoons. The rider controls the wing submergence depth via a left lever.

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Operation

The *Decavitator* has three basic modes of operation.

Low speed. Initially, the vehicle floats on the pontoons like a normal displacement boat. The propeller is relatively inefficient at these low speeds, and the maximum speed attainable in this mode is about 8 knots (4 m/s).

High speed. The initial foil-borne mode is entered by setting the two wings at their maximum lift angle and increasing the speed to about 7–8 knots / 3.5–4 m/s (with a 140-lb / 64-kg rider). As the wings gradually lift the pontoons out of the water, the drag drops and the speed further increases, eventually allowing the pontoons to be lifted entirely clear. The low-drag pontoons and the high aspect ratios of the wings give a very shallow "power hump", so that the transition requires only a modest anaerobic effort for a few seconds. Once flying on the hydrofoils, the vehicle can be sustained by a fit cyclist at 9–10 knots / 4.5–5 m/s with aerobic power levels. A maximum effort produces about 15 knots (7.5 m/s).

Very High Speed. After unlocking a safety latch, the rider has the option to pivot the large wing up and out of the water, much like on one of the more recent *Hydroped* variants. The wing pivoting is accomplished by accelerating the vehicle to at least 14 knots / 7 m/s (a fairly hard effort), and then suddenly increasing the angle of attack of the entire wing system via the left lever, which drives the vehicle upwards. When the upper large wing breaks the water surface, rubber cords pivot it together with its mounting struts forward and up into a streamlined receptacle. The sequence is shown in Figure 3. If the high power is sustained, the vehicle then rapidly accelerates on the remaining small wing to its maximum speed. The air propeller becomes very efficient in this operating mode.

Pontoons

Each 17-foot / 5.2-m pontoon hull is shaped like a modern open-water women's racing kayak, with the deck lowered by about 2 inches / 50 mm. A similar design is employed for the monohull *Hydroped* vehicle. Molded composite construction with a hard gelcoat finish gives very nearly the lowest drag attainable. Although such exotic pontoons might seem frivolous on a hydrofoil boat, their low drag is in fact crucial to the top-speed capability of the vehicle. Reducing pontoon drag permits higher takeoff speeds, which in turn permit smaller wings and higher maximum speeds.

Higher takeoff speeds also have the important effect of reducing wave drag associated with the two-dimensional wave train set up behind a lifting airfoil. This is quite independent of the "inverse ground effect" mechanism of the free surface which increases the induced drag of a 3-D lifting wing. As described in Hoerner [4], the 2-D wave drag scales inversely with the square of the chord-based Froude number and exponentially with the square of the depth-based Froude number: $C_{D_{wave}}/C_L^2 \simeq 0.5\,gc/V^2 \exp(-2gh/V^2)$. This drag can dominate the overall vehicle drag if large-chord wings are used at low takeoff speeds. An earlier version of the *Decavitator* had a rather large takeoff wing of 5 in / 125 mm average chord, and required excessive takeoff power due to the 2-D wave drag mechanism — as clearly evidenced by the dramatic wave train set up behind the wing. Reducing the wing area by nearly half gave a larger Froude number, and produced a large power reduction despite the larger takeoff speed.

A further advantage of higher takeoff speeds is that it permits optimizing the propeller for higher maximum speeds. One useful feature of a racing-kayak hull shape is that it retains its low-drag characteristics when partially raised out of the water. This permits a very gradual and low-power transition to the foil-borne mode, where the wings gradually lift the pontoons as the speed is increased. The use of a rider-adjustable angle of attack of the wings is also important, as it permits the pontoons to remain at a nearly-level, low-drag orientation at all speeds.

Drive System

The rider is seated in a semi-recumbent position on an adjustable seat with Kevlar cloth webbing. The pedals are linked to the two-bladed 10-ft / 3-m diameter air prop via a 1/4-in / 6-mm pitch stainless-steel chain-drive with a 2:1 gear ratio. The propeller is of a minimum-induced-loss type, and has been designed with algorithms similar to those of Larrabee [5]. The propeller is designed to rotate at 250 rpm (125 rpm at the pedals) with maximum power at 20 knots / 10 m/s. Its pitch can be dock-adjusted to optimize its performance at lower speeds and power levels, and to compensate for wind direction.

If the air/water density ratio is accounted for, the 10-ft / 3-m air propeller is equivalent to a 4-in / 100-mm diameter water prop in terms of the non-dimensional thrust coefficient $T_c = 2T/\rho V^2 \pi R^2$, which determines the induced or "slip" losses. At low takeoff speeds, the 10-ft air prop gives high disk loadings (large T_c) and poor efficiency relative to what could be obtained with an effectively larger 8-in / 200-mm water prop, say. At speeds close to 20 knots, however, T_c becomes sufficiently small to give efficiencies close to 90% even at maximum power. This high efficiency is also due to the prop blade lift coefficients being reasonably high at $C_L \simeq 0.6$ (the Daedalus prop airfoil is used), so that the blade-profile lift-to-drag ratios are fairly good. Ordinarily, a substantial blade C_L at high speeds result in a very large blade C_L at lower speeds, stalling the blades and making transition to the hydrofoils difficult. However, because of the high disk loading, the prop has a very substantial self-induction, or "slip", at low speeds (i.e. it draws air into itself). Together with the modest takeoff-power requirements of the low-drag pontoons, this self-induction is sufficient to prevent the blades from stalling above speeds of 5–8 knots / 2.5–4 m/s, depending on the geometric pitch setting.

Another very large advantage offered by the air propeller is that the wing struts do not need to enclose any drive system, and can be sized as small as material-stress and buckling limitations permit. Where it attaches to the small wing, each strut has only a 1-in / 25-mm chord and a 0.15-in / 4-mm thickness. A strut enclosing a chain or shaft transmitting 1 hp / 750 W would need to be far larger. In addition, the exposed hardware associated with an air propeller has negligible air drag, while a housing for an underwater propeller mount typically has a substantial drag penalty.

Hydrofoil/Strut System

The hydrofoil system consists of two fully-submerged high-aspect-ratio wings under the rider, and two skimmer-actuated trim surfaces on the pontoon bows. The larger 60×2.35-in / 1520×60-mm (span × mean chord) wing is placed about 6 in / 150 mm below the pontoon bottoms, and the smaller 30×1.75-in / 760×45-mm wing is placed another 6 in / 150 mm lower. Each wing is supported by two slender struts placed 26 in / 660 mm apart. The advantage of using two struts is that they do not need to carry significant bending moment, and hence can be made much smaller and have a lower overall drag than an equivalent single strut. Using two struts also greatly relieves bending moments on the wings, and permits much smaller wings to be used for a given material-stress limit.

The wings employ a custom 14%-thick airfoil which has been tailored for the operating Reynolds-number range of 150 000 – 400 000, using the design principles and numerical simulation methods employed for the Daedalus wing airfoils [6, 7]. The structural merit of the relatively thick airfoil allows smaller wing areas and less overall drag than the 10-12%-thick airfoils more commonly employed at these low Reynolds numbers. The thick airfoil also gives the rather wide usable lift-coefficient range $0.2 < C_L < 1.1$, which translates to low wing drag over a wide range of speeds. The ability of the large wing to perform well from 7 to 15 knots is particularly important for the *Decavitator* as it is brought to its maximum-speed mode.

Each of the two 9×0.85-in / 230×22-mm front trim surfaces is mounted at the bottom of a slender rudder in an inverted-T configuration. Each rudder pivots on two axes in a gimbal mounted on the pontoon bow. The pitch axis is controlled by a surface skimmer cantilevered forward from the gimbal, while the steering axis is controlled by the rider via cables linked to a right side-stick. The geometry of the skimmer/trim-surface mechanism is set up to lift the pontoon bow a few inches off the water surface at speeds over 6 knots / 3 m/s. This height is firmly maintained at all higher speeds, so that the vehicle is stabilized in depth and roll, and can pivot only in pitch about the pontoon bows. This pitching alters the wing's angle of attack relative to the water surface, so that for any given speed the boat rapidly seeks the one unique pitch attitude where the wing lift equals the vehicle weight. By altering wing angle of attack relative to the boat via the left lever, the rider can therefore precisely control the pitch attitude and hence the wing submergence depth. At low speeds, a large submergence depth is best to keep the large profile- and induced-drag contributions of the free surface in check. At high speeds, the viscous profile drag of the support struts becomes more dominant, and a very small submergence depth is optimal. The minimum workable depth is set by the need to avoid ventilating the wing by an errant wave trough. Loss of lift due to ventilation immediately drops the vehicle onto the pontoons.

The pivoting of the large wing out of the water is an essential feature of the *Decavitator's* hydrofoil system. Removal of the large wing reduces the total underwater wetted area by a factor of three, giving a roughly proportional reduction in profile drag. This is partially offset, however, by a substantial increase in the induced drag due to the loss in total loaded span. Overall, a speed increase of about three knots is realized for the same power level.

Construction

The *Decavitator* makes extensive use of structural and manufacturing technology developed at MIT in the course of numerous human-powered-aircraft projects. All underwater surfaces are made via wet lay-up of solid carbon/epoxy vacuum-bagged in female molds. The use of carbon fiber is essential since the small wing dimensions push material stresses to the limit. The small wing, for example, experiences 100 000 psi / 690 MPa material stress with a 140-lb / 64-kg rider at 2 g, and hence could not be safely built even out of aircraft-grade solid aluminum. The struts connecting the pontoons are oven-baked tubes made of pre-preg carbon fiber formed around aluminum mandrels. These are also highly stressed, and the use of carbon fiber gives greater stiffness as well as weight reductions of many pounds over equivalent aluminum tubes.

Each pontoon shell is a pre-preg glass/carbon/Nomex/glass sandwich, and was baked inside a mold for an open-water women's kayak owned by Composite Engineering of West

Concord, MA. The top of each pontoon is permanently sealed off with a glass/Nomex/glass deck. Internal plywood bulkheads hold the strut-attachment bolts.

The fuselage frame supporting the rider and drive system is constructed of thin-walled large-diameter aluminum tubes joined with Kevlar/epoxy lashings in lieu of welds. Carbon-fiber tubes were rejected for the frame from durability considerations. In retrospect, a carbon-tube frame clearly would not have survived the numerous modifications and general abuse seen by the frame over the vehicle's three-year lifetime. The seat is likewise constructed of lashed thinwall aluminum tubing with a Kevlar cloth webbing, and employs adjustable mounts for different-sized riders. The drive system employs standard bicycle cranks and pedals, lightened somewhat by drilling. The chainwheels and sprockets for the 1/4-in / 6-mm pitch chain were custom-made from high-strength 2024-T4 aluminum plate by numerically-controlled machining.

Each propeller blade is a hollow shell with a hard Rohacell-foam shear web, bonded to an aluminum-tube root stub. The shell surface is a Kevlar/Rohacell/Kevlar sandwich, laid-up wet and vacuum-bagged in a female mold. Carbon-fiber rovings are incorporated into the shell sandwich for bending strength. The propeller shaft is a thin-walled large-diameter aluminum tube.

Further Developments

Possibilities for further increasing the *Decavitator's* performance include the following.

Smaller Takeoff Wing. Since the effort required to lift the pontoons off the water is quite modest, the area of the large wing could be decreased somewhat. The areas of the front trim surfaces could be decreased proportionately as well. The reduction in wetted area would reduce the considerable effort needed to achieve sufficient speed for the transition to the single-wing mode. The rider would then have more energy available at maximum speed.

Aero Fairing. Although all major exposed tubes and struts have already been carefully faired, the aerodynamic drag near 20 knots / 10.3 m/s still consumes between 25% to 35% of the propulsive power, most of this being drag on the rider. Enclosing the rider in a high-quality aerodynamic shell would theoretically push the maximum speed past 20 knots. Naturally, for record-setting runs it is desirable to operate the vehicle with the fastest legal tailwind (3.22 knots / 1.67 m/s) to reduce the air drag to an absolute minimum.

Larger Rider. The benefits of increasing rider size on a hydrofoil vehicle are significantly smaller than on a bicycle. The actual benefits depend on the relative fractions between profile and induced drags. With the maximum legal tailwind, the *Decavitator's* induced drag is about 27% of the total at 18 knots / 9 m/s, and 20% at 20 knots / 10 m/s, so a larger rider would have some advantage. However, the vehicle's hydrofoil system is already very highly stressed with the 140-lb / 64-kg design rider weight, and a significantly heavier rider would require larger underwater surfaces to provide greater structural strength. Also, the heavier rider would need to expend disproportionately more power to lift the pontoons and when preparing for the single-wing operating mode, unless the wing areas are increased. In either case, much of the larger rider's advantage disappears.

Larger Propeller. As mentioned earlier, the air propeller is relatively inefficient at lower speeds due to excessive disk loading. Increasing the diameter would therefore give more thrust at low speeds for the same power input, giving faster transition and acceleration. This may significantly conserve the rider's energy and hence permit a higher power level to be sustained over the 100-meter course, although this is difficult to quantify. Offsetting this potential benefit is the increase in size and weight of the supporting frame, and an increase in the nose-down moment of the high thrust line. The latter must be overcome primarily by the small front trim surfaces, and these would need to be larger to avoid stalling at low speeds, which would in turn carry a drag penalty at higher speeds. Likewise, the larger prop would be more prone to blade stall at low speeds. This would require reducing the design blade lift coefficients, which in turn would reduce the blade-profile lift-to-drag ratios and lower the efficiency at maximum speeds. It appears that the tradeoffs inherent in the larger air propeller are complex enough to defy a reliable analytic optimization, and trial-and-error may be the right recourse.

Cleaner Large-Wing Configuration for Recreation. The current hydrofoil system has two separate struts on each side for the large and small wings, in order to permit the large wing to pivot out of the water. The two struts on each side are arranged one behind the other with a small gap. This produces a significant drag penalty when the vehicle is operated on both wings. For a recreational vehicle, the power levels in this mode could be significantly reduced by removing the small wing and the double-strut system, and relying only on the large wing supported by two slender non-pivoting struts.

Conclusions

The key design features employed on the *Decavitator* have resulted in a substantial maximum-speed increase over alternative human-powered vehicle concepts. In particular, the air propeller, pivoting large takeoff wing, solid-carbon-fiber hydrofoil construction, and low-drag pontoons combine to allow a very small underwater drag area and high propeller efficiency at top speed. Additional gains can be realized primarily with improved above-water streamlining.

References

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Figure 2. The *Decavitator* flying on the small wing in a practice run.

Photo by Steve Finberg

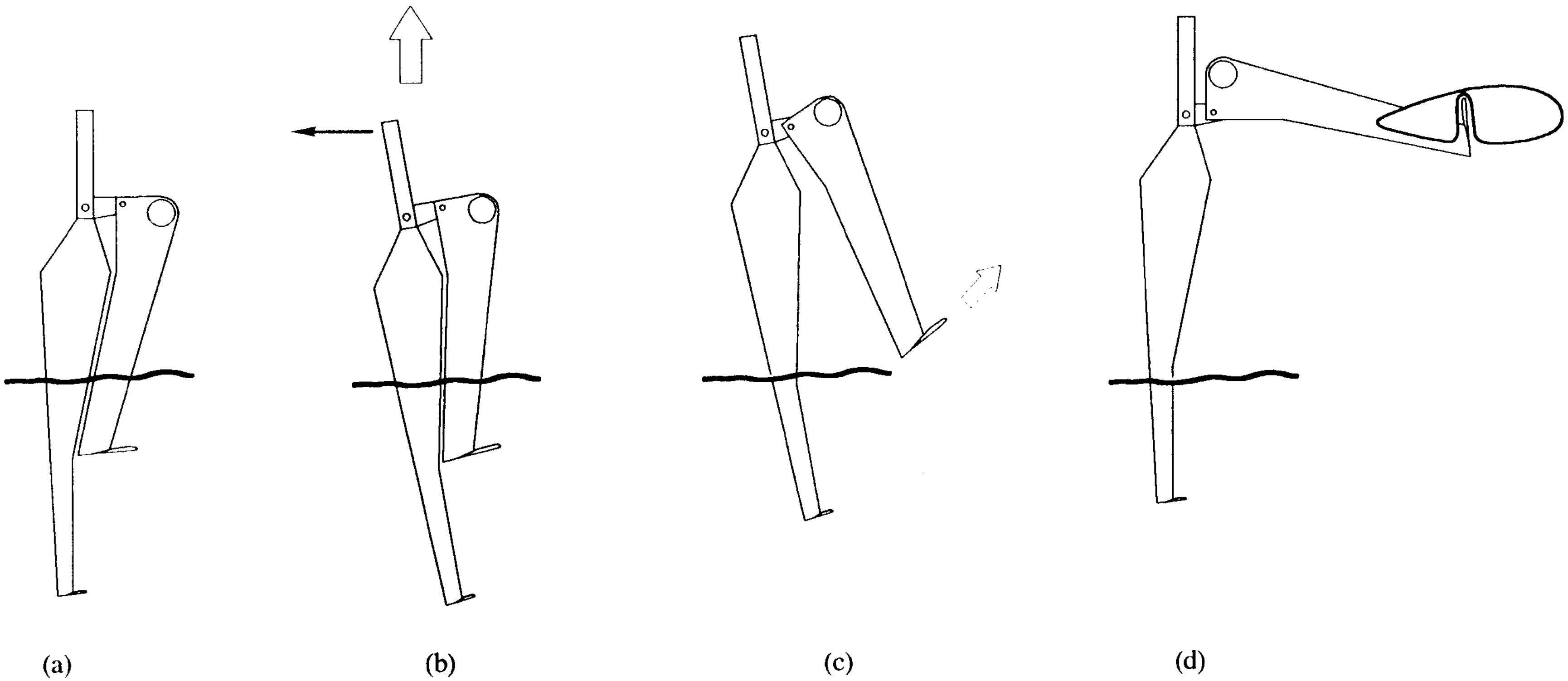

Figure 3. Transition sequence from two- to single-wing mode. Large wing pivots out of the water into streamlined receptacle.

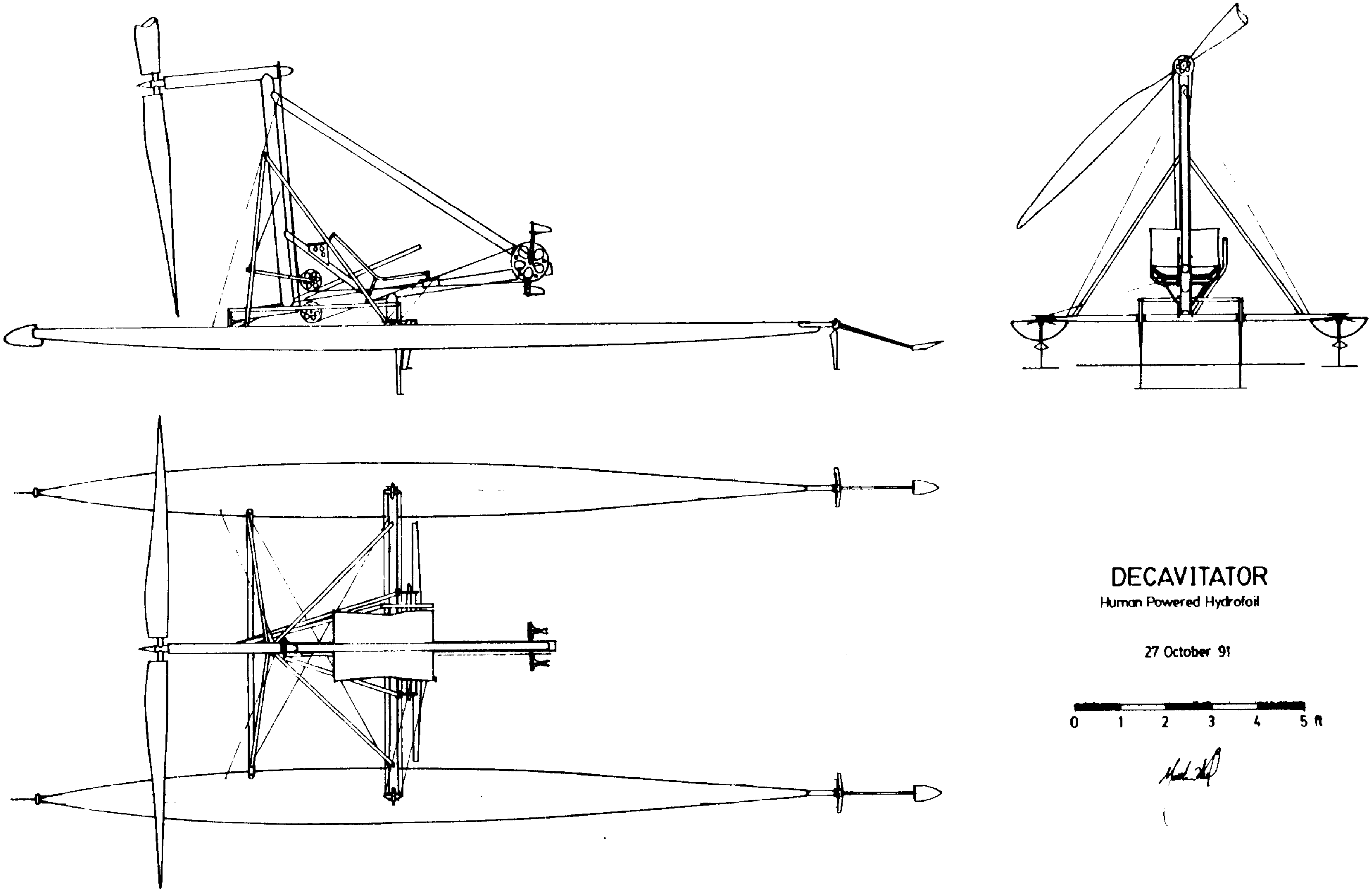

Figure 1. *Decavitator* 3-view. Aerodynamic fairings not shown.

Decavitator Specifications

Vehicle weight	48 lb	22 kg	
Rider weight	140 lb	64 kg	design
	160 lb	73 kg	max
Rider position	semi-recumbent		
Overall length	20 ft	6.1 m	
Overall width	8 ft	2.4 m	
Air prop diameter	10 ft	3.0 m	
Drive	1/4" pitch stainless steel chain		
Gear ratio	2:1 prop to pedal speedup		
Large wing area, span	140 in^2, 60 in	0.09 m^2, 1520 mm	
Small wing area, span	52 in^2, 30 in	0.034 m^2, 760 mm	
Trim surface area, span	7.5 in^2, 9 in	0.0048 m^2, 230 mm	each (2 used)
Vertical strut area	10–30 in^2	0.006–0.02 m^2	(depending on operating mode)

RECENT HYDROFOIL DEVELOPMENTS IN EAST ASIA

By

Frank Peterson

Dr. Frank Peterson is a graduate of the University of California, Berkeley in Mechanical Engineering. He later obtained his Doctorate in Mechanical Engineering at Northwestern University. At the David Taylor Model Basin, which is what the Carderock Division, Naval Surface Warfare Center was called in the mid 1960s, he has involved in research on Fluids. This led to becoming the Program Manager for submarine drag reduction and later technical director for Submarine propulsors at NAVSEA. During the last 10 years he has been Head of Propulsor Technology at the Center.

ABSTRACT:

Recent East Asia developments in hydrofoil and hydrofoil assisted vessels are summarized. The vessels considered are from China, Japan, and Korea with an emphasis on those now in service. Selected references that give a detailed description of the vessels design and performance characteristics are included.

1.0 INTRODUCTION:

Vessels that rely on the dynamic lift from hydrofoils for drag reduction have been in use in East Asia for almost thirty five years. Hitachi Zosen introduced the Supramar surface piercing hydrofoil in 1960 and manufactured 52 until production stopped in 1983. The first hydrofoil vessel in China became operational in 1961 and was replaced in 1993. In 1964 the Far East Hydrofoil Company in Hong Kong began hydrofoil service on the Hong Kong/Macao route with the Rodriquez PT-50. These were eventually replaced with used Boeing Jetfoils. Now they have 17 Boeing Jetfoils that leave very 15 minutes during the day and every 30 minutes at night. This Hong Kong/Macao route is the most intensive use of hydrofoil vessels in Asia.

Kawasaki Heavy Industries continues to build the Jetfoil in Japan, with 14 built to date, for numerous routes in Japan. One international route between the southern Japanese island of Kyushu and Pusan, Korea uses a Kawasaki Jetfoil for the 3 hour trip which can experience a relatively high sea state during the passage. Speed and passenger comfort are the primary reasons for the use of the Jetfoil. Most operators indicate the initial cost and high fuel consumption of gas turbines have held back more extensive use of this type of propulsion. .

Economic development and transportation systems are mutually dependent. As economic development increases, more frequent service and improved comfort are required. Slow speed vessels are replaced with higher speed vessels or the route is abandoned for alternate transportation. Higher speed allows longer routes without increasing transit time or allows more frequent service without adding vessels. Onboard passenger accommodations are also dependent on the duration of travel. If a low speed vessel for an overnight passage was replaced with a high speed vessel, which allowed space allocation primarily to aircraft style seating, then the vessel size could be reduced considerably. Today high speed passenger vessels compete with air and land transportation. Routes of several hours or less are attractive alternatives to air travel if the passage is reliable and comfortable. Japan, with its high level of economic development, many islands, rugged terrain, and numerous heavily populated areas, has long had a need for high speed and comfortable vessels. Now the economic development of other countries in East Asia is creating the need for higher speed and comfort. Hydrofoil vessels can provide this required comfort and speed, however, their cost appears to have suppressed their wide application.

The Techno Super Liner (TSL) project has now demonstrated the technology to move 1000 tons of cargo 500 nautical miles at 50 knots. This service speed was selected such that one vessel could have a daily round trip between Tokyo and Kyushu Island in the south or Hokkaido Island in the north. This speed also allows favorable competition with truck transport. To maintain a 98% operational capability the TSL will need to be able to operate in sea state 6 conditions. The Japanese government has been promoting this modal shift from the highways to the sea since the mid 1980's and the TSL vessels have been in development since 1989.

The future commercial success of this modal shift in Japan is dependent on two factors: a new method to collect and load cargo in ports and a cost competitive vessel. The cost for TSL transport is currently projected to be 1.7 to 2.1 times the cost for truck transport (reference 1). It has also been projected that the upper limit for the acceptable cost to operate the TSL is about 1.2 to 1.3 times the cost of the currently operating ferries (reference 2). Of the two types of TSL, surface effect ship TSL-A and hydrofoil TSL-F, the TSL-F is estimated to use almost twice the horsepower of the TSL-A. Which concept is to be put in service will depend on the tradeoff between performance and economics.

Hybrid vessels, most notably catamarans, are providing a compromise between comfort and cost for current high speed passenger vessels. A hybrid vessel also allows the size to increase beyond that sustainable with hydrofoils alone. The concept of hybrid vessels was articulated by Jewell (reference 3). The hybrid vessel utilizes more than one source of lift. The sources consist of hydrostatic lift, dynamic lift, and static air pressure. Hydrostatic lift relies on the buoyancy of the hull. Dynamic lift can be developed either aerodynamically or hydrodynamically. The hybrid concept that is now receiving considerable attention is the catamaran with foils spanning the demihulls as was first discussed in detail by Calkins in 1981(reference 4) In Japan, Miyata at the University of Tokyo (references 5,6,7) and Hitachi Zosen together designed a similar hybrid that became the Superjet 30 of which 7 have been delivered to date. Similarly, a catamaran with foil lift assist has been developed by Daewoo Shipbuilding and recently was put into service in Korea

These hybrids are today the subject of considerable research and development in Japan and Korea. The foil assisted hybrid has size and speed regimes where the use of the foil has a payoff in drag reduction. These regimes were clearly presented and discussed by Tasaki and Sato (reference 8). In general, the demihulls are designed such that their beam at waterline decreases as the foil lifts the hull up in the water. As the length to beam ratio increases, the wave drag is reduced. At low speeds the hydrofoil drag can increase the overall vessel resistance and again at high speeds the hydrofoil drag limits the speed that can be attained. Thus, for specific foil lift to drag ratios the hybrid catamaran can be designed to reduce drag within a speed and displacement operating envelope. If the speed is sufficiently high, cavitation on the hydrofoil provides the practical speed limit. 50 knots currently appears to be the speed limited by cavitation for deeply submerged hydrofoils while the shallow hydrofoils will cavitate at lower speeds. If the lift to drag ratio is changed, this operating envelope will change. These foils also contribute to improved seakeeping and reduced accelerations for improved passenger comfort. Flaps added to the foils are also used for further reductions in vessel motion.

In a hybrid vessel the hydrofoil is used primarily for drag reduction with seakeeping and ride control as added benefits when implemented. In some vessels the hydrofoil is used primarily for ride control and the vessel speed is typically reduced due to the hydrofoil drag. These ride control hydrofoils are also used to change the vessel trim and some shipyards claim a small speed increase. Applications of hydrofoils primarily for ride control will not be reviewed in this paper.

2.0 HYDROFOIL VESSELS:

2.1 CHINA:

The first Chinese hydrofoil was put into service in 1960 (references 9, 10) for use on the Yangtze river. It was of the self stabilizing surface piercing foil design and is shown in figure 1 and its characteristics given in Table 1. R&D continued with various manned models built and in 1988 the self stabilizing shallow submerged hydrofoil "Flying Fish" (FF-30) was completed. Figure 2 depicts the overall configuration of the FF-40 which is a scaled up version of the FF-30. No other hydrofoil vessels were operating in China at that time and a ferry company interested in using the vessel could not be found. Shortly thereafter the catamarans based in Guangdong province had to start paying an embankment maintenance fee and the value of the FF-30's low wake was more fully appreciated. It then began service in 1992 north of the city of Guangzhou. Numerous local shipping companies then wanted to put into service hydrofoil vessels but a suitable size was not available in China. As of the summer of 1994 16 Russian VOSKHOD -2 shallow submergence, self stabilizing hydrofoils had been imported and put into service. These are outfitted for 60 passengers. All of these are propeller driven and at least some of them use surface piercing propellers. An 80 passenger version of the Flying Fish, FF-80, is now being designed for inland river service and its principal characteristics are shown in Table 2. Surface piercing foils are included to assist in motion control. An overview of the Chinese hydrofoil development is given in reference 11.

During this author's ride in the upper part of the Pearl river on the "POLICY", a VOSKHOD -2 class vessel, the transition to foilborne operation was imperceptable and no vibration was apparent from the surface piercing propeller. The river was very crowded with many small and large craft and vessels so the excellent maneuverability and low wake were very positive attributes.

The need for additional hydrofoil vessels on the Far East Hydrofoil Company's Hong Kong /Macao route and the limited number of used Boeing Jetfoils on the market promoted the effort to develop an alternative source. The PS 30 built in the SIMNO shipyard in Shanghai, China is the result and its characteristics are given in Table 3. The first of these was launched in the summer of 1994 and is now in service on the Hong Kong/Macao route. The China State Ship Research Center(CSSRC) performed numerous studies and tests to improve the Jetfoil, details of which can be found in reference 11, and these were incorporated in the PS 30. Areas that were hydrodynamically improved include the underwater hull lines, the aft foil, and the waterjet inlet/duct. The hard chine area at the stern was revised to reduce the takeoff hump drag with the resistance to displacement ratio reduced from 0.12 to 0.09. A new aft foil was designed using the Eppler-Shen method(reference 12) to increase the lift to drag ratio and improve the cavitation performance. The waterjet inlet pod was redesigned to have an inlet for each pump and side vents were added which automatically open when the dynamic head is low.

2.2 JAPAN:

In mid 1993 the Mitsubishi Heavy Industries Super Shuttle 400 design called the "Rainbow" was put into service on routes between the main Japanese island of Honshu and the Oki Islands in the Sea of Japan. The Rainbow carries 341 passengers at a 40 knot service speed with shorter transit time and greater comfort than the monohull it replaced. The ability to operate in higher sea states with a high level of passenger comfort has increased schedule reliability and increased the number of passengers using the ferry service (reference 13). Table 4 provides the vessel characteristics. Details of the Rainbow design can be found in references 14, 15, 16, and 17. There are several significant design differences between the Jetfoil and the Rainbow. The Rainbow is a diesel powered catamaran and has non retractable struts and foils while the Jetfoil is a gas turbine powered monohull and has retractable struts and foils. The Jetfoil uses strut flaps for maneuvering and the Rainbow can use either separately or together forward strut flaps and waterjet deflection for maneuvering. On the Rainbow significant dynamic lift starts at 18 knots and 100% dynamic lift occurs around 27 knots with only 75% of full power required to achieve maximum lift. Thus reserve power is available to maneuver with jet deflection during vessel acceleration or to get foil borne during heavy seas. The hydrofoils were designed using the methods of Eppler and Shen (reference 12) to improve the cavitation performance beyond that possible with standard blade sections.

3.0 HYBRID VESSELS:

3.1 JAPAN:

Hybrid concepts in Japan have progressed in two directions, the hydrofoil assisted catamaran and the hydrofoil with submerged buoyant body. Hitachi Zosen and the University of Tokyo together developed the Superjet 30 design where the foils provide between 80% and 90% of the lift for both drag reduction and ride control references 18, 19, and 20 review the design issues and summarizes the design approach taken with the Superjet 30 and reference 21 outlines the Mitsui Engineering and Shipbuilding design approach to a similar Hydrofoil assisted catamaran. Seven Superjet 30 vessels have been delivered as of September 1994 and the principal characteristics can be found in Table 5. The demi hulls have a decreasing beam at the waterline as the hulls are lifted up in the water. Versions with and without flapped foils for ride control have been put in service. The Superjet 30 has both forward and aft foils spanning between the demi hulls and suspended nominally 0.9 meters below the bottom of the hull.

The second hybrid design is part of the national Techno Super Liner(TSL) project.

Five major shipyards lead by Kawasaki Heavy Industries are developing the TSL-F which has a monohull supported by a submerged buoyant body for 50% of the lift and hydrofoils attached to the submerged body for the other 50%. Details can be found in references 22, 23, and 24 and its configuration shown in Figure 3. A 1/6 scale model of the TSL-F, called the Hayate, has been in sea trials since April 1994 and its principal dimensions are given in Table 6. The Hayate has apparently achieved a speed of 41 knots and demonstrated its anticipated good seakeeping. Based on the sea trial results further efforts are required to reduce cavitation and to improve the water jet inlet.(reference 1) It is now being suggested that the TSL-F may be appropriate for super high speed passenger service when a size considerably larger than the Jetfoil is required(reference 25) This concept is essentially that referred to in the U.S. as the HYSWAS (reference 26).

3.2 KOREA:

The hybrid hydrofoil catamaran of Daewoo Shipbuilding & Heavy Machinery, F-Cat 40, was put into Korean coastal service in the summer of 1994. This vessel uses one passive hydrofoil just aft of the center of gravity and it develops a lift equal to 25% of the displacement. The foil has a NACA 66 section and is located one half meter below the hull for a resistance reduction at the service speed and for hydrodynamic damping to improve seakeeping. The version put into service carries up to 8 cars and 250 passengers. Details of the vessel can be found in references 27, 28, and 29 and summarized in Table 7, noting that the hull lines actually used on the F-Cat 40 are the type II described in reference 30. Reference 31 indicates that the foil with the type II hull reduces the resistance by 15% and increases the speed over a standard catamaran by 2.5 knots. Based on the sea trials, Daewoo claims it is the fastest 40 meter catamaran available that uses only 2 of the 2000 kW diesels. As a point of reference conventional catamarans with the same diesels and water jets and comparable dead weight capacity have speeds of 34 to 36 knots. Trial speeds of 41.5 knots at one third dead weight and 39 knots in two meter waves are claimed by Daewoo. Accelerations measured during trials can be found in reference 32. The F-Cat 80 is a factor of two scale up of the F-Cat 40 and is now under consideration. General characteristics are summarized in Table 8.

4.0 ADDITIONAL R&D:

Many other efforts are ongoing for hydrofoil catamarans and monohulls. One major effort is the Korean hydrofoil assisted catamaran at Hyundai Heavy Industries designed originally for 35 knot passenger service between the Russian Far East and Korea. This 45 meter catamaran has fore and aft foils spanning the demihulls with flaps for ride control. The foils were intended to provide 40% of the lift for both drag reduction and improved seakeeping. Although the vessel has provided Hyundai with valuable feedback for future designs, it needs additional foil refinement before it can be put into service.

Li, at the South China University of Technology(reference 33), described a catamaran with fore and aft foils developing 80% to 90% of the required lift. A 12.6 meter 50 passenger version of this hybrid catamaran vessel was reported to be under construction for use on inland rivers. At Harbin Engineering University in China (reference 34), a series of deep vee-monohulls were tested with a center line channel. The channel is spanned with two foils that are reported to increase the speed of a 5 meter test boat by 8%. Another application was recently reported by Kruglov (reference 35) for a displacement hull catamaran with three foils spanning the demihulls. The motivation for the work was to improve the seakeeping of catamarans and at the same time improve the powering performance.

5.0 CONCLUSIONS:

Renewed interest in shallow submergence hydrofoil vessels has recently occurred in China because of their low wake effects on river embankments. High speed vessels with deeply submerged hydrofoils are used only on routes where passenger comfort in a seaway is the primary consideration. Most efforts are focused on the hybrid vessels that use hydrofoils for vessel drag reduction and some improvement in passenger comfort. These hybrid vessels can be scaled to displacements beyond that possible for vessels relying solely on hydrofoils for lift. The introduction of a variety of hybrid vessels into service is now just beginning and their breadth of application for high speed with good seakeeping is still to be determined.

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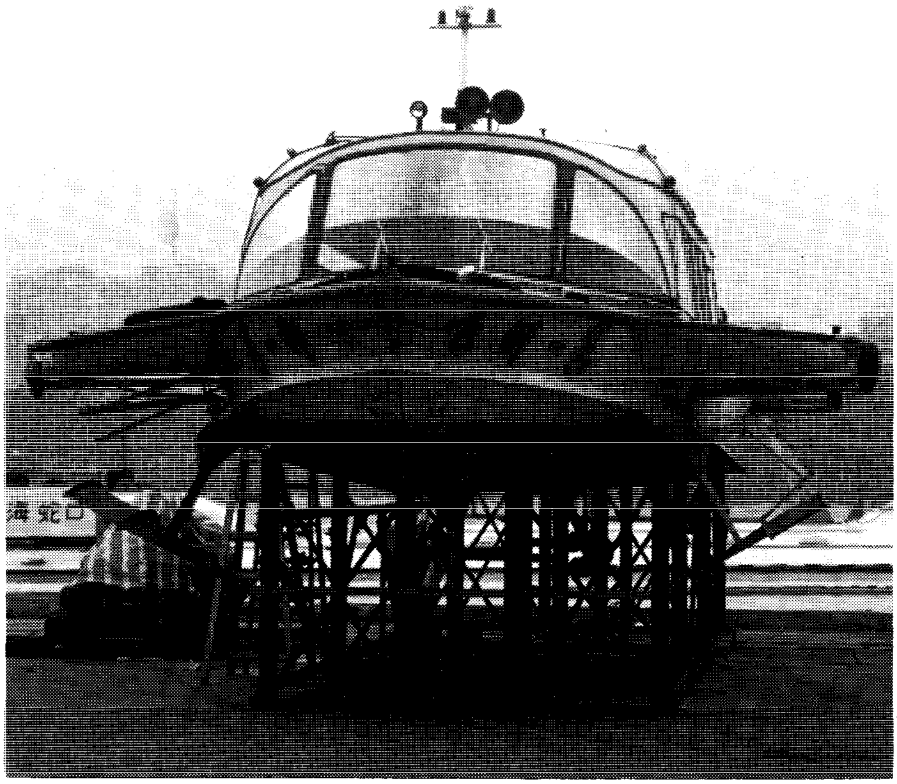

Figure 1. Chinese "Hydrofoil No. 1."

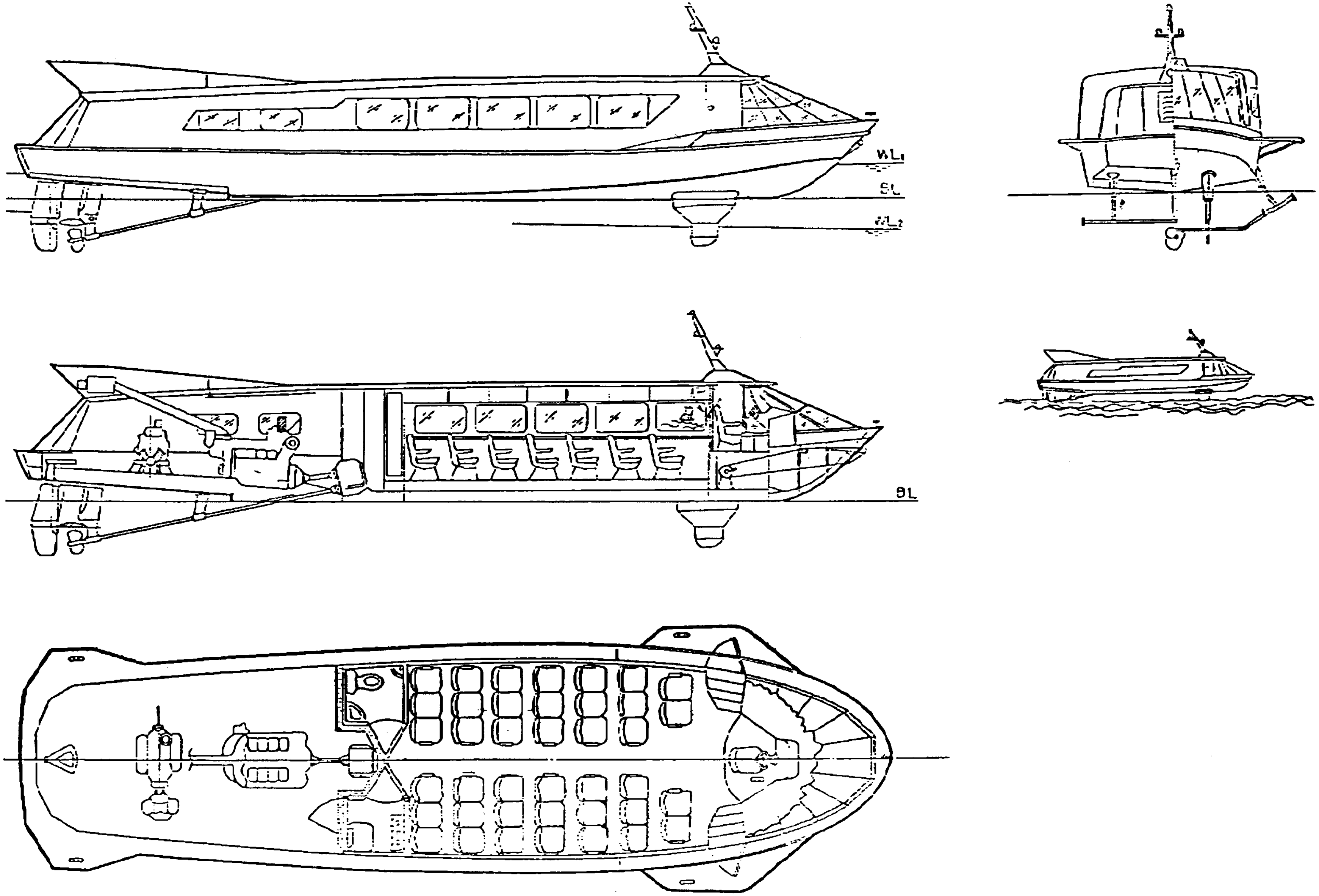

Figure 2. Chinese FF-40.

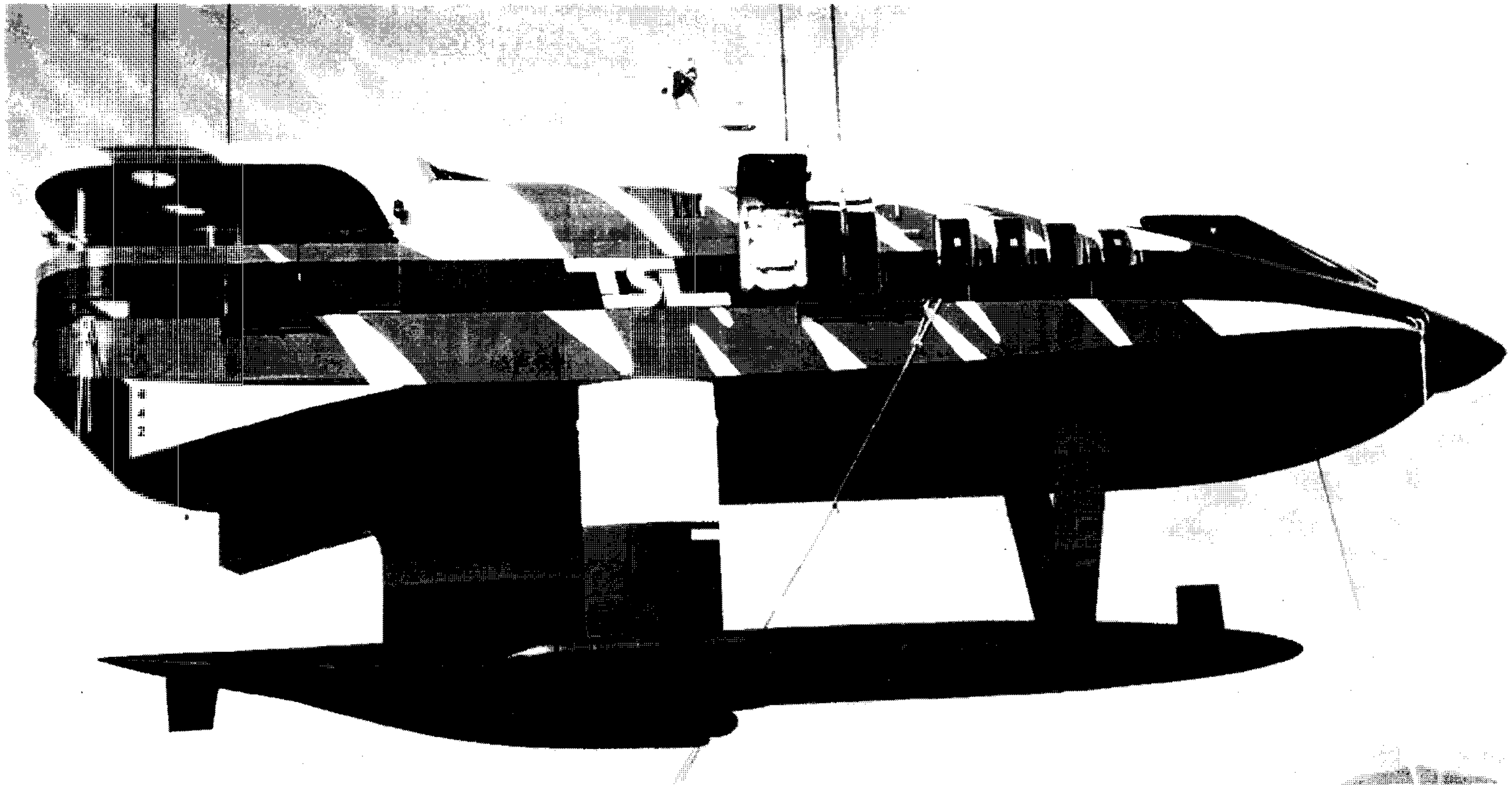

Figure 3a. TSL-F Configuration.

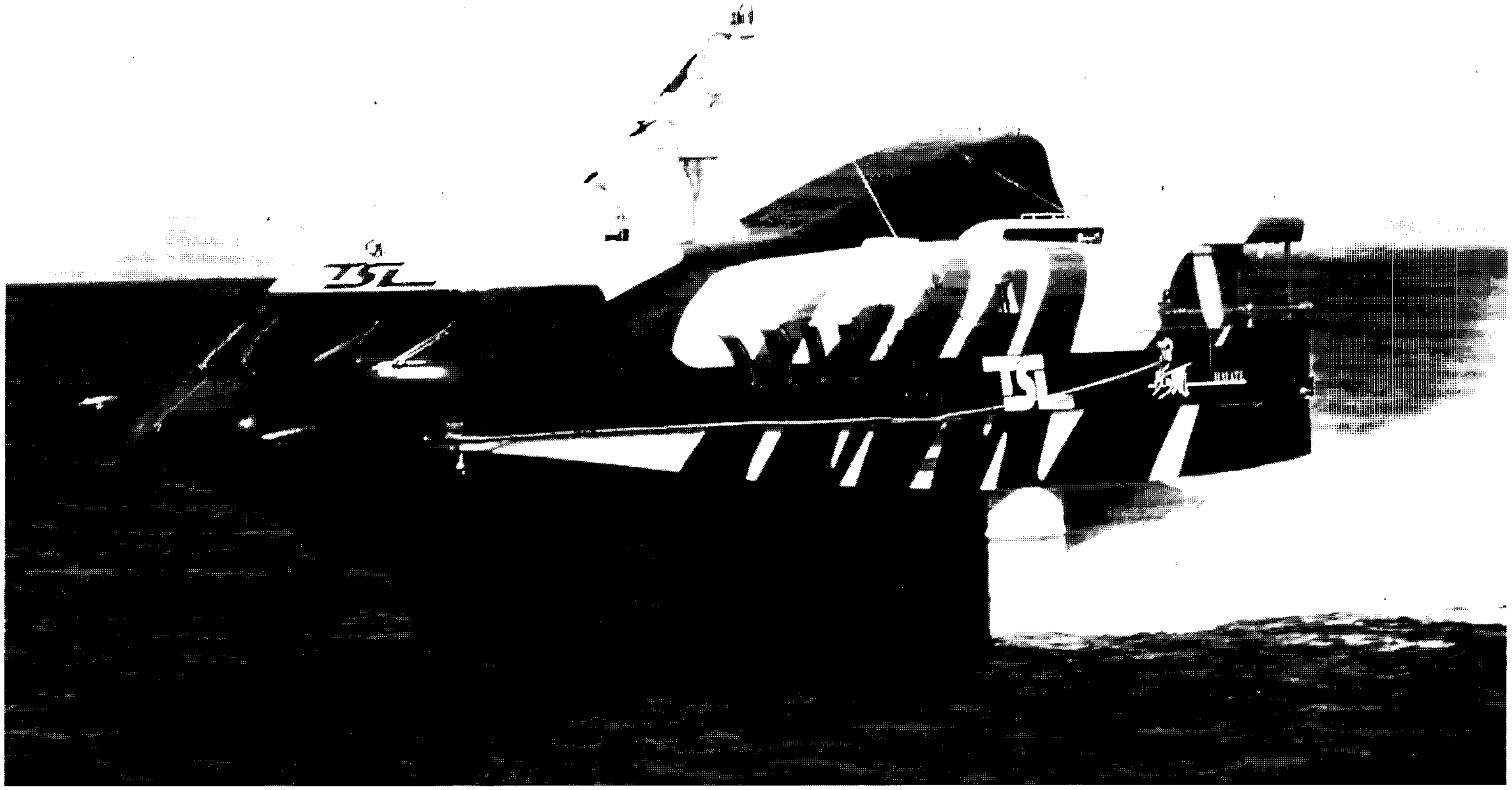

Figure 3b. TSL-F Configuration.

Table 1. First Chinese Hydrofoil Craft "Hydrofoil No. 1."

Length Overall	24.95 m
Hull Width	4.6 m
Full Load Displacement	27.5 t
Passengers	40
Crew	5
Maximum Rating	895 kW/1850 rpm
Cruising Rating	672 kW/1650 rpm 60 km/h
Cruising Speed	60 km/h

Table 2. River Hydrofoil Craft FF-80.

Specifications			
Length Overall	24.20 m	Power	2 x 461 kW
Width Overall	7.12 m	Speed	68 km/h
Hull Width	4.80 m	Passengers	80
Hull Height	4.00 m	Crew	4 –5
Maximum Floating Draft	2.00 m	Range	350 km
Foil-borne Draft	1.3 m	Foil-borne Wave Height	1.3 m
Displacement	32 t		

Table 3. PS30 (full submerged auto-control hydrofoil craft).

Length Overall	28.5 m	Crew	9
Hull Width	9.2 m	Displacement	118 t
Hull Draft	1.5 m	Cruising Speed	42 kn
Hull-borne Draft	5.0 m	Cruising Range	100 miles
Foil-borne Draft	1.8 m	Normal Power (Gas Turbine)	2 < 2800 kW
Passengers	274		

Table 4. Principal Particulars of the "Rainbow."

Length Overall	33.24 m
Breadth Extreme	13.20 m
Depth Molded	4.20 m
Design Hull-borne Draft	4.50 m
Design Foil-borne Draft	2.10 m
Gross Tonnage (Japanese)	302 tons
Passengers	341 People
Dead Weight	About 35 tons
Propulsion - Diesel	2,100 kW x 4

Table 5. Superjet-30 Principal Characteristics.

Length Overall	31.5 m
Breadth Molded	9.8 m
Depth Molded	3.50 m
Draft Excluding Foils	About 1.90 m
Gross Tonnage	About 190 gt
Speed Max.	About 38 kn
Passengers	200
Main Engine	High Speed Diesel Engine x 2 2,500 PS
Propulsion	Water Jet x 2

Table 6. Principal dimension of TSL-F test ship.

Total Length	17.10 m
Length (Approx. 90% of upper deck)	14.94 m
Width	6.17 m
Depth (upper deck)	1.50 m
Submerged Length	14.17 m
Submerged Diameter	0.93 m
Draft at Time of Sailing	3.13 m
Draft at Time of Planning (from submerged undersurface)	1.60 m
Main Engines: Gas Turbine x 1	3800 PS
Water-Jet Propulsor (axial flow type) x 1	
Speed	Max. about 40.6 kn
Gross Tonnage	About 30 tons

Table 7. F-CAT 40.

F-CAT40

Main Characteristics

Length Over All	41.8 m
Breadth	9.3 m
Draft	1.5 m
Hull	Al Alloy
– Passengers	250
– Cars	8
Speed max	40 Kts
Range	400 N.M
Fuel Consumption	950 L/H
Propulsion	
– Diesel Engine	2000 KWx2
– Water Jet	2

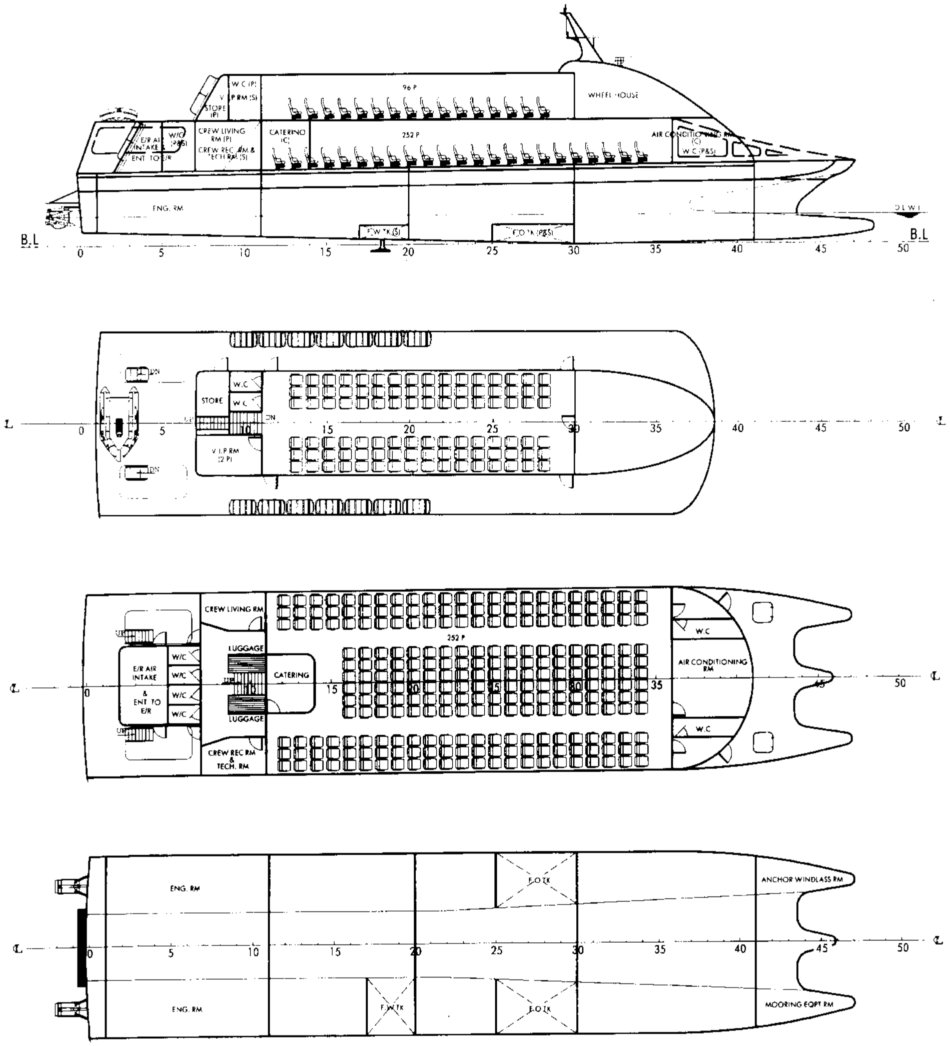

Table 8. F-CAT80.

Main Characteristics	
Length Overall	85.0 m
Breadth	18.5 m
Draft	2.2 m
Hull	Al Alloy
Passengers and Cars	
-- Passengers	600
-- Cars	70
Speed Max.	42 knots
Range	500 N.M
Fuel Consumption	3200 L/H
Propulsion	
-- Diesel Engine	4000 kWx4
-- Water Jet	2

SUMMARY OF THE TECHNO-SUPERLINER PROJECT TSL-F
BY
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John R. Meyer holds Bachelors and Masters degrees in Aeronautical Engineering from Rensselaer Polytechnic Institute, and has done additional graduate work at the Massachusetts Institute of Technology in the same field. Since joining the David Taylor Naval Ship R&D Center in 1971, he has been associated with Advanced Naval Vehicles, particularly hydrofoils and hybrid ship forms. In 1991, DTRC became part of the Carderock Division, Naval Surface Warfare Center (CDNSWC). He has authored a number of DTRC reports, AIAA, and ASNE papers on the subject of hydrofoils and hybrid marine vehicles. Prior to his current employment at DTRC he held several research and development, long range planning, and engineering management positions with Boeing-Vertol, Trans-Sonics Inc., Air Force Cambridge Research Center, and the Aero-Elastic Laboratory at M.I.T. He has served on the AIAA Marine Systems and Technologies Committee, and for the past four years as President of the International Hydrofoil Society. He is also a member of American Society of Naval Engineers, American Institute of Aeronautics and Astronautics, and the Society of Sigma Xi.

Abstract

The paper summarizes material from the available literature describing the Techno-Superliner project in Japan related to the TSL-F (foil supported) concept. About six years ago the Japanese Ministry of Transportation and the Technological Research Association of Techno-Superliner established a goal to develop ships to carry 1,000 tons of cargo, 500 nautical miles at 50 knots in Sea State 6. The Association completed the TSL-F type and TSL-A type prototypes in March and June 1994, respectively, for trials at sea. The former is a hybrid-type ship using hydrofoils, submerged lower hull, and struts; the latter is a hybrid-type hullform using both air cushion and a relatively high amount of buoyancy in the cushion-borne mode. The TSL-F R&D has been promoted by the joint efforts of Kawasaki Heavy Industries, Ltd. (KHI), Ishikawajima-Harima Heavy Industries Co., Ltd., NKK Corp., Hitachi Zosen Corp. and Sumitomo Heavy Industries, Ltd.

Introduction

Conventional merchant vessels such as those represented by tankers, bulk carriers and container ships still play a significant role in mass transportation at a comparatively low speed. Meanwhile, small-lot, but high value, products require much faster marine transport. Civil aviation, the general choice for fast transportation, is rapidly expanding, centered on the transport of manufactured goods and fresh foodstuffs resulting from development of the world economy and expansion of trade. Conventional air and marine cargo carriers differ widely in speed and capacity. An intermediate mode of transportation with a speed and capacity midway between those of aircraft and slow ships has long been sought. In Japan, trucking has served as such an intermediate transportation mode, but road hauling has suffered from traffic congestion, a shortage of drivers and pollution by exhaust gas.

As a possible solution to these problems, the proposed modal shift from motor freight to marine transportation has drawn nationwide attention in Japan. Although slower than other modes of transport, ships offer large cargo capacities. If the problems of speed and punctuality could be overcome, the modal shift to marine transportation would become practicable. The Japanese Ministry of Transportation (JMT) contended that evolution of such a transportation system will be necessary as the mainstay of development planned for the world of the 21st century. They believe it is highly desirable to plan to speed up the flow of goods to shorten transportation times and contribute to the activation of the Japanese shipbuilding industry by developing new types of high speed ships.

A target performance goal of 1,000 tons of cargo, 500 nautical miles at 50 knots in Sea State 6 was established. The five years from 1989 to 1994 was considered as the research period during which time the essential technology of new types of high speed ships to satisfy the target performance would be pursued. Subsequently, the transition from research to practical construction of actual ships was planned.

When the new type of high speed ship is realized, the connection time between Kanto and Hokkaido, or between Kanto and Kyushu, could be about 10 hours, for example. Once in service, the Techno-Superliner will be able to provide approximately half-day cargo service between metropolitan Tokyo and Hokkaido, Japan's northernmost region, and Kyushu, the southernmost region (see Figure 1). The Japanese foresaw that both the producer and consumer will benefit from this high-speed cargo service, and local communities will enjoy greater prosperity. The TSL will provide, subsequent to the Year 2000, one-or two-day service connecting Japan and neighboring countries in Asia; see Figure 2.

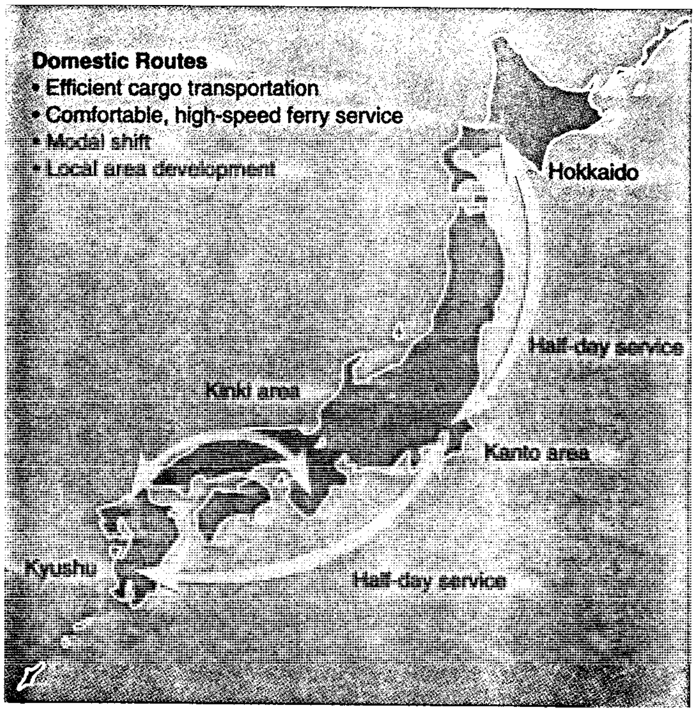

Figure 1 - Map of Anticipated TSL Routes in Japan (Ref 1)

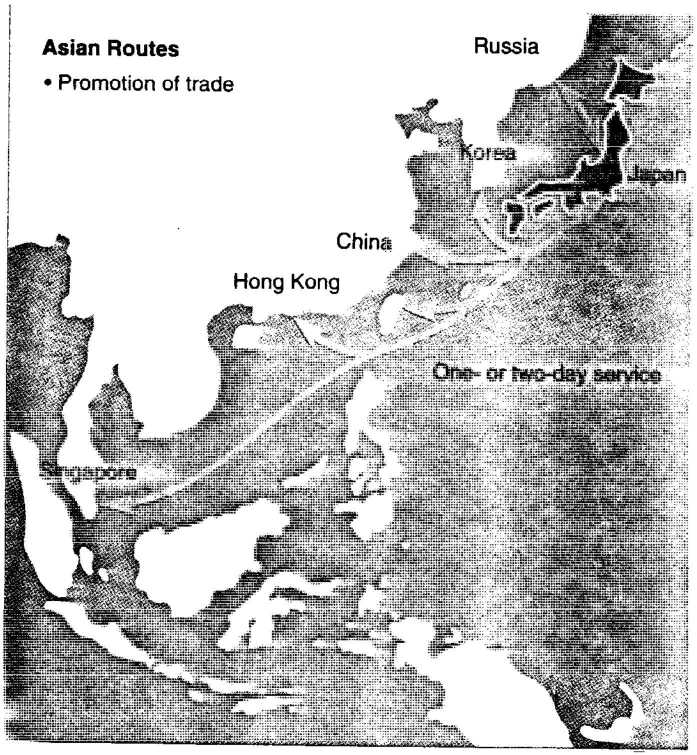

Figure 2 - Map of TSL Routes in the Year 2000 (Ref 1)

Early Planning

The Techno-Superliner Research and Development Program in Japan was inaugurated as a national project in 1989 under the supervision of the Ministry of Transport. The formulation of this program has been reported by several sources; see References 1 - 4. The following seven leading shipbuilders in Japan (in alphabetical order) have assumed major roles in the overall program:

Hitachi Zosen Corporation
Ishikawajima-Harima Heavy Industries Co. Ltd.
Kawasaki Heavy Industries, Ltd.
Mitsubishi Heavy Industries, Ltd.
Mitsui Engineering & Shipbuilding Co. Ltd.
NKK Corporation
Sumitomo Heavy Industries, Ltd.

The Ministry of Transport decided that what is required for this new kind of high speed ship is: (1) speed of 50 knots (about 93 Km per hour), (2) a payload of 1,000 tons, (3) a cruising range of 500 nautical miles (about 930 Km), and moreover, in order to preserve fixed schedules, have the ability to operate even in very rough seas (Sea State 6). Since this requirement far exceeds known displacement-type ship technology, research and development were needed to explore basic technology and reconsider methods of supporting the hull.

There are three types of hull support: buoyancy, dynamic lift, and air cushion pressure support. Because they have their respective advantages and disadvantages, the JMT considered that in order to realize these new types of "super high speed ships", it was necessary to optimally combine these three support methods as a "composite support method".

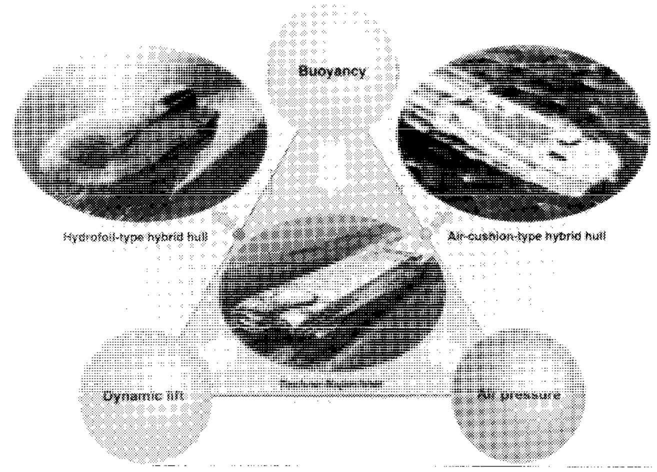

Figure 3 - Sustension Triangle (Ref 1)

The approach taken by the Techno-Superliner Research and Development Program was to select dynamic lift and cushion lift, each of which was combined with buoyancy as illustrated in Figure 3. Research programs were then developed around these two hullforms.

The TSL-F hybrid hullform, employing a long slender, fully submerged lower hull, augmented by dynamic lift from a foil system, with single or multiple struts and upper hull had been previously been described, studied and experiments performed by the U.S. Navy, and Mohr and Bertram in Germany. The Japanese team responsible for the TSL-F part of the program conducted their own experimental research in a number of essential areas. This team consisted of: Kawasaki Heavy Industries, Ltd. (KHI), Ishikawajima-Harima Heavy Industries Co., Ltd., NKK Corp., Hitachi Zosen Corp. and Sumitomo Heavy Industries, Ltd.

In addition to many theoretical studies, a series of model tests were performed to "prove out" the TSL-F concept to their satisfaction. However, before describing this work, it is appropriate to mention an early version of the full scale TSL-F which employed two lower hulls as shown in Figure 4. Note that there were several foils spanning the space between the hulls. Later, single lower hull versions of the TSL-F were shown; see Figure 5.

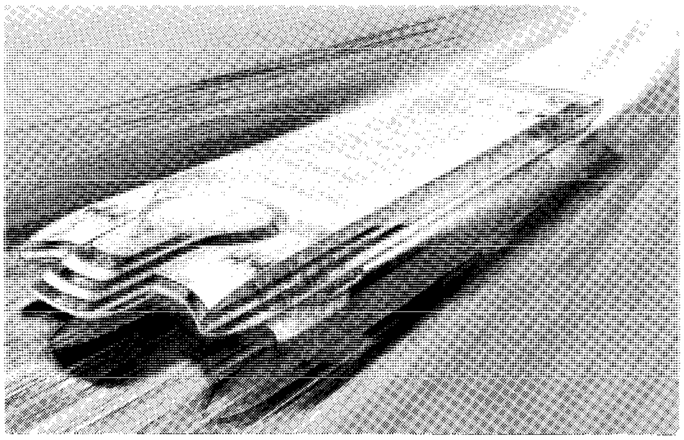

Figure 4 - Early TSL-F Rendering With Two Lower Hulls

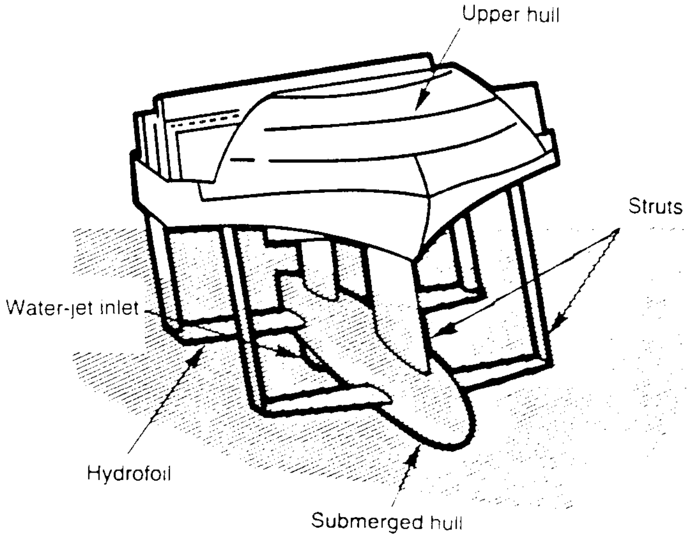

Figure 5 - TSL-F With Single Lower Hull

Modes of operation are similar to those of a conventional hydrofoil. The hullborne, takeoff, and foilborne sequence for the ship is illustrated in Figure 6.

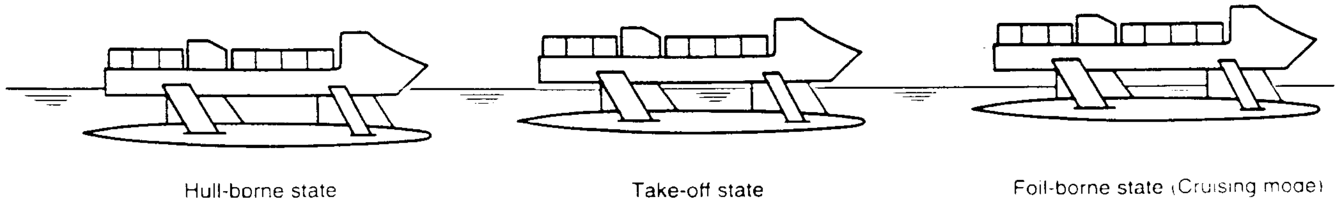

Figure 6 - TSL-F Takeoff Sequence

Tank Model Testing

Tank model tests were performed at the Ship Research Institute of Japan in about the 1990 time frame and reported at FAST '91 (Ref. 5). The purpose of these tests was to determine resistance of the hullform and understand the flow around the lower hull, foils and strut combination. Also of importance was the hydrodynamic interactions between components. Main hydrodynamic interactions studied were: a) Hydrodynamic interaction between forward and aft submerged foils b) Hydrodynamic interaction between side struts and submerged foils c) Hydrodynamic interaction between submerged lower hull and submerged foil.

The authors considered the interaction between the submerged lower hull and submerged foils a unique phenomenon to TSL-F. It was essential to recognize the hydrodynamic mechanism and the interaction phenomenon in relation to the TSL-F configuration.

A 1/21.5-scaled model was tested to measure resistance, lift and trim moments of the whole model. Also resistance, lift and moments acting on the forward and aft foils were measured by strain gauge type load cells. Flaps on the submerged foils were driven by a mechanism installed inside the submerged lower hull, and hinge-moments acting on the flaps were measured by a strain gauge type torsion sensors incorporated in the drive mechanism. Apparently this was a rather sophisticated model. A photo of it under test in the foilborne condition is shown in Figure 7.

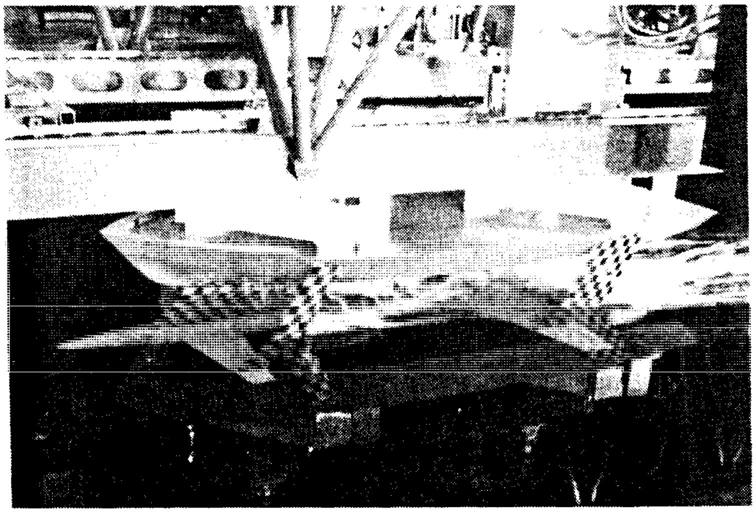

Figure 7 - TSL-F Model in FB Mode (Ref 5)

Influence of the submerged lower hull on flow around the aft foil was studied by flow field measurements. Figure 8, taken from Reference 5, shows some interesting plots of wave height at various locations relative to the submerged body. The abscissa shows the longitudinal coordinate along the model and the origin coincides with the forward end of the submerged lower hull. The vertical axis shows the wave elevation. Results of the tank tests are shown as the the solid line. Several analytical calculations were made and plotted for comparison purposes. The remainder of the paper goes on to describe the reduction in lift from the aft foils relative to the expected lift in uniform flow. As one might expect, the angle of attack of the aft foil on the model is reduce by the wave generated by lower hull and wave/downwash generated by forward foil.

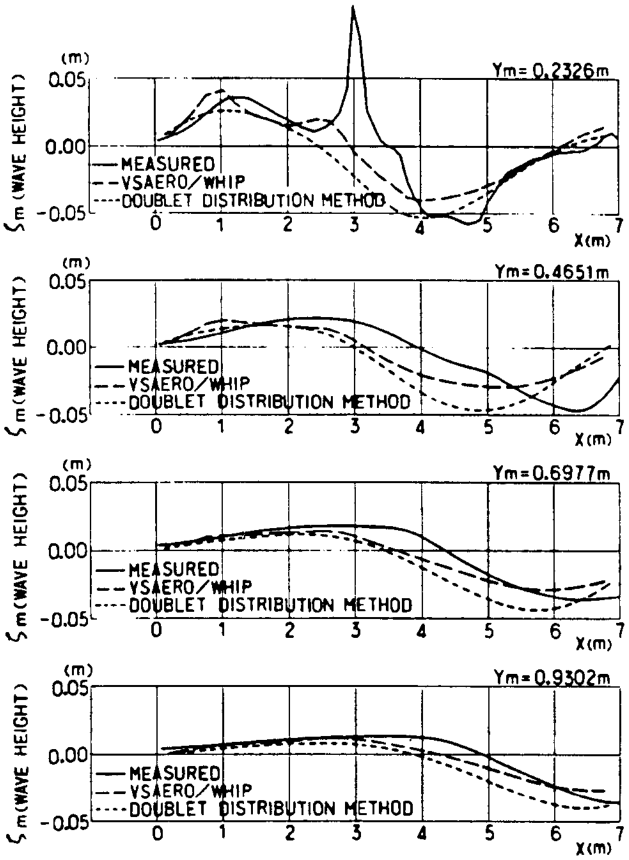

Figure 8 - Measured Wave Pattern in Vicinity of Lower Hull (Ref 5)

Self-Propelled Basic TSL-F Model

A 1/20 scale self-propelled "basic" model ship was built for conducting open water experiments. Figure 9 shows a one-man, gasoline-engine driven waterjet propelled craft, manipulated by a joy stick lever. "Control in the foilborne mode depended on human senses to prove the soundness of the concept. It was a simple experimental vehicle, but the TSL-F concept showed generally that this type of hullform was excellent in seaworthiness" (Ref 12).

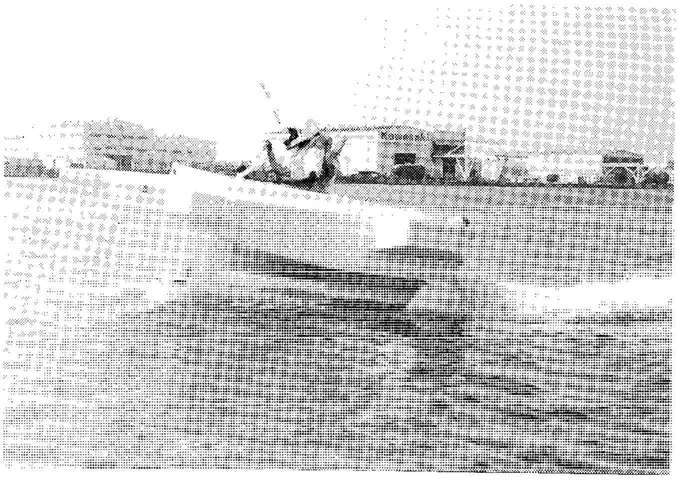

Figure 9 - Self-Propelled Basic TSL-F Model

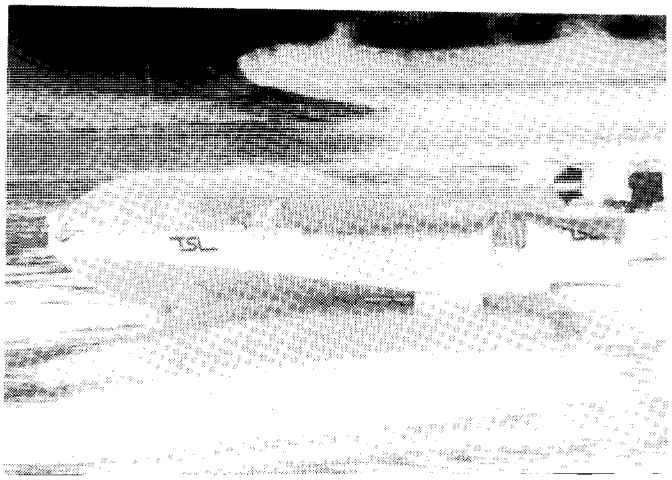

Figure 10 - Self-Propelled TSL-F Model

Self-Propelled TSL-F Model

Next, a 1/20 scale self-propelled model was built (see Figure 10). This was to test an automatic attitude control system that was developed and to confirm the quality of controls in extreme conditions which could not be conclusively confirmed by simulators. The attitude control system that was developed to make it possible for the craft to operate in open water. "Through these tests, the ability of the TSL-F to take off smoothly even in high waves, landing on water, and operate stably when foilborne, was confirmed"; (Ref 12).

Design and Construction of TSL-F Large Test Model

Based on the results obtained from these model tests and theoretical studies, sufficient technology was available to design a practical vehicle of greater size. However, there was a need to confirm the effects of scaling and the overall design. But from the beginning of the project, it was planned to construct a practical ship with 1/4 to 1/6 the size of the full scale TSL-F for testing at sea. This would then complete the research phase of the program and allow examination of the results of research and the completion of TSL-F full scale design.

Accordingly, in 1992, the design of a TSL-F large test model was begun in parallel with research in essential technical areas by the five companies previously mentioned. Construction of a TSL-F test model was begun at KHI Kobe Yard in early 1993 and was near completion in March, 1994; see Figure 11. In April, trial runs were begun on Osaka Bay. According to Reference 12, successful take off, and foilborne operation at 40.6 knots was confirmed on April 18; see Figure 12. The principal characteristics of the large test model are shown in Table I. Although an engine that would produce a ship speed of about 20 knots on the basis of Froude Number would have been theoretically satisfactory, the main engine horsepower was increased to provide a speed of approximately 40 knots. Propulsion is accomplished by a gas-turbine driven a waterjet pump.

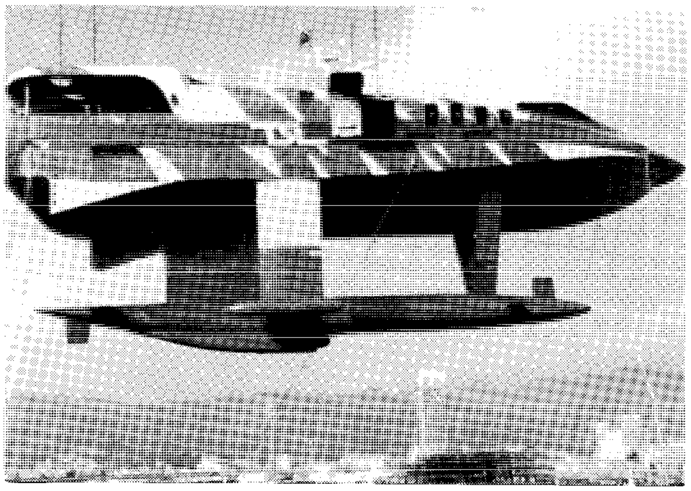

Figure 11 - Pre-Launch View of HYATE

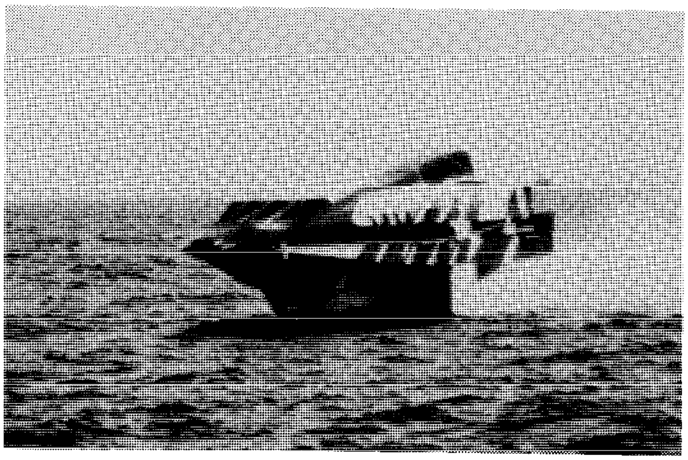

Figure 12 - HYATE Foilborne at 40 Knots

It was concluded at this juncture that the R&D had been progressing extremely well, and all of the initial performance objectives were expected to be attained. Since the TSL was required to operate in the open seas, and capable of maintaining schedule reliability at high operational rates, the TSL-F has met these requirements; Ref 13.

Table I - Characteristics of TECHNO-SUPERLINER LARGE TEST MODELS

ITEM	TSL-F (HYATE)	TSL-A (HISHO)
DISPLACEMENT	38 L TONS (Est.)	?
LENGTH		
UPPER HULL	17.1 M	70.0 M
LOWER HULL	~20.2 M (Est.)	---
BEAM		
UPPER HULL	6.2 M	18.6 M
LOWER HULL	~1.3 M (Est.)	---
DRAFT	HB: 3.6 M	OFF CUSHION: 3.5 M
	FB: 2.1 M	ON CUSHION: 1.1 M
POWER		
PROPULSION	3800 ps	2 @ 16,000 ps
LIFT FANS	---	4 @ 2,000 ps
PROPULSOR	1 WATERJET	2 WATERJETS
SPEED (CALM WATER)	40 KTS	50 KTS

For comparison purposes, the TSL-A SES hybrid is also shown here.

During the High Performance Marine Vehicle Conference in 1992, Yoshio Yamagami presented a paper entitled: "An Estimation Method of the Motions In Waves For A Submerged Hull and Foil Hybrid High-Speed Ship" (Ref 7). He and his co-authors presented an estimation method for the evaluation of seakeeping quality of submerged hull and foil hybrid high-speed ships, such as a the TSL-F.

The equations of motion essential for the motion estimation were described focusing on the characteristics of the hydrodynamic forces acting on the ship. Since the equations of motion are nonlinear, the memory part of the hydrodynamic forces on the hydrofoils and struts needed to be expressed in the time domain. A practical approximation formula was proposed for the treatment of the hydrodynamic forces. With respect to the validity of the proposed approximation formula, it was pointed out that the approximated values of the unsteady lift of hydrofoils agreed well with the theoretical values supported by experiments. Using the present method, a time domain simulation for TSL-F was carried out. The result indicated good seakeeping of the TSL-F concept.

The authors pointed out that an advantage of this type of ship is that the influence of sea waves on the ship is very small since the lower hull is removed from wave excitation. Furthermore, the ship motions in waves can be controlled to desired values with hydrofoils utilized as control surfaces. In other words, it has good controllability and excellent seakeeping qualities. They have employed a simulation method of obtaining the motions in irregular waves in the time domain to evaluate the seakeeping quality of the TSL-F (see Figure 13). The time domain simulation using equations of motion was carried out under various sea conditions and the time histories analyzed by a statistical method to obtain quantities such as RMS response values.

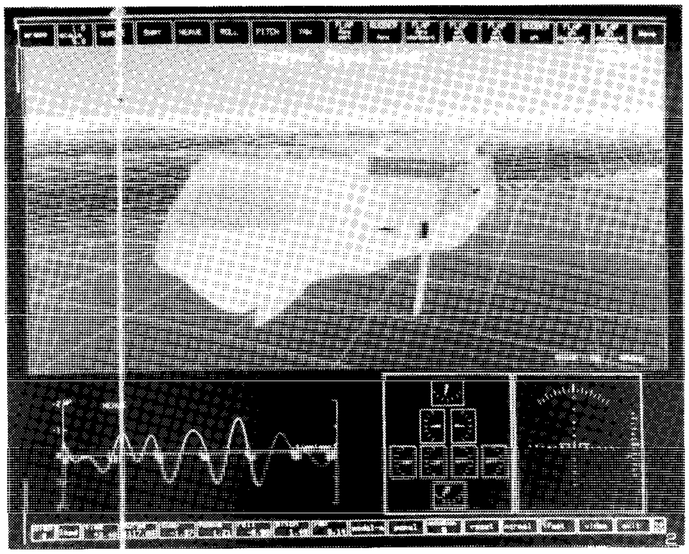

Figure 13 - Illustration of Simulator for Control Design

The simulation was not carried out in frequency domain because the equations include nonlinearity. The hydrodynamic forces on the ship have nonlinear properties such as cavitation which can not be neglected when the waves are high. And the control actions has a nonlinear property which comes from the characteristics of the flap restricted in movable angle and angular velocity due to high speed manipulation. They described the hydrodynamic characteristics and the equations of motion. A videotape of the simulation was shown at the HPMV-92 Conference and made a good impression on the audience.

During FAST '93 there were a total of 20 papers related to hydrofoils. Six of these were related to "conventional" hydrofoils, six to foil-assisted catamarans, five to "Foilcats", and three specifically related to the Techno-Superliner Foil (TSL-F) Hybrid. The latter three papers are briefly summarized here.

"A Submerged Hull and Foil Hybrid Super-High Speed Liner" by Ryotaro Ogiwara, et al (Ref 8). This paper described the "novel super-high speed ocean liner", the TSL-F. The authors stated that the latest results of the hydrodynamically oriented research and development on the TSL-F project have proved its "fitness" as a solution in pursuit of a high speed and seaworthy ocean liner. The TSL-F exhibits extremely good seaworthiness, with almost no speed reduction or undue motion in high sea state operation; (see Figures

14 and 15). The seaworthiness of the TSL-F has been analyzed and examined with various model experiments to measure the hydrodynamic characteristics, in particular, added wave resistance and motion in waves, using a captured model and/or free model installed with an automatic motion control system.

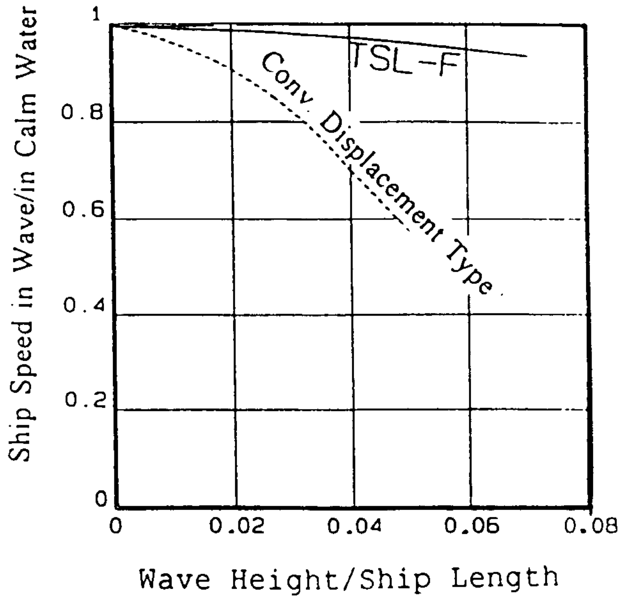

Figure 14 - TSL-F Speed Loss in Waves (Ref 8)

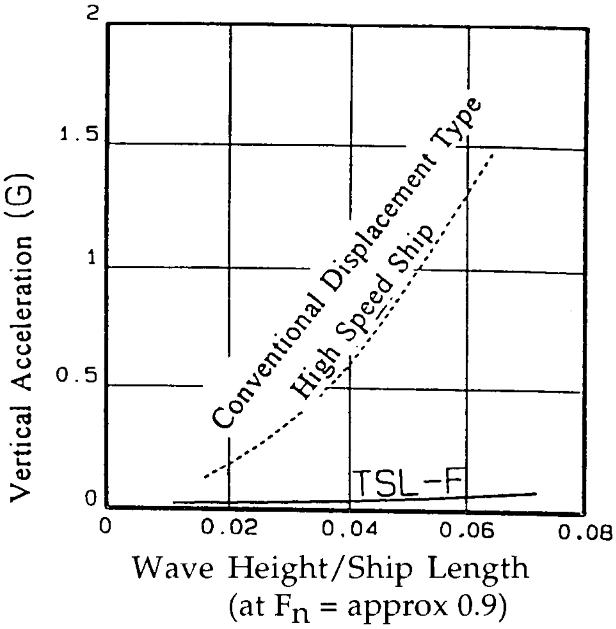

Figure 15 - TSL-F Motions (Ref 8)

Another paper from FAST '93 is a follow-on to the HPMV-92 paper on the same subject. "The Real-Time Simulation to Verify the Automatic Control System for a Submerged Hull and Foil Hybrid Super-High-Speed Liner", by Toshiyuki Itoko, et al (Ref 9). The authors stated that they have been studying an automatic control system for a submerged hull and foil hybrid super high-speed liner as part of the R&D program for the Techno-Superliner (TSL). For reliability of the automatic control system, they have developed a highly redundant control system. To verify the various functions of the duplex computer system developed and to evaluate the performance of the vessel investigated with the practical redundant automatic control system, a real-time simulator was developed. Various tests were carried out to validate the automatic control system under many conditions. The results obtained have verified the validity of the control system.

To maintain a high-speed vessel's safety, the automatic control system developed employs a configuration composed of a duplex computer and an automatic emergency landing system, which allows safe landings when the altitude control does not function, for example, in case both computers fail. Even though the vessel is equipped with an automatic emergency landing system, hard emergency landings are to be avoided because of the unfavorable effect on the ship's hull and payload. Accordingly, they have adopted a highly redundant system which has redundant sensors, a duplex digital computer system, redundant control surfaces, and twin-actuator systems. The paper introduces the real-time simulator developed and proceeds to describe some simulation results obtained.

Structures was the theme of the third paper during FAST '93 on the TSL-F design. It was entitled: "Structural Analysis of a Submerged Hull and Foil Hybrid Super-High Speed Liner" by Isao Neki, et al (Ref 10). A submerged-hull and foil hybrid high-speed liner (TSL-F), has a unique structural configuration. The authors pointed out that to obtain structural response characteristics of such a hybrid hull form in waves, it is unsuitable to analyze the longitudinal and transverse strengths individually and to subject it to "decided" design loads like a conventional ship. To obtain structural response characteristics, a whole-ship, three-dimensional finite element method (3-D FEM) analysis in various wave conditions was carried out.

The paper outlined the results of research on structural response analyses and reliability analyses in wave conditions, extracted from structural strength studies for TSL-F. Regarding materials for the hull construction, high-tensile stainless steel, which has excellent corrosion resistance in sea water, is used for the submerged parts which require high strength and corrosion-resistance, while aluminum alloy is used for the upper hull to minimize hull weight. The authors described a procedure for the structural response analysis and the reliability analysis in the development of TSL-F. First, the dynamic pressures and dynamic forces acting on the ship were calculated in regular waves with various wave lengths and headings. Second, using the structural response analysis system, the structural response characteristics in regular waves (stress response amplitude operators) for the target structural members were obtained. A whole-ship 3-D FEM model for this analysis was subjected to hydrodynamic loads.

Next, long-term prediction for the stress response of target structural members in irregular waves was calculated from the sea conditions of the "design route", the operating conditions, and stress response amplitude operators, using the structural reliability-analysis system. Finally, the probability of failure and the safety index of each structural member corresponding to the failure mode, such as fatigue, yield, and buckling were calculated using the structural reliability analysis system. As a result of this strength evaluation, scantlings of insufficient strength and over-strength members were adjusted to optimize hull weight and safety of the structure.

Hydrodynamic forces in waves, the characteristic of structural response in waves and reliability-based strength evaluation were obtained using the three systems -- the analysis system of hydro-dynamic forces, the structural response analysis system, and the structural reliability analysis system, developed during the R&D of TSL-F. According to the results, hull weight and safety of the structure were optimized and a hull construction design for the TSL-F was completed.

Full Scale TSL Cargo Ships

Characteristics of the full scale TSL ships taken from Ref 13 are shown in Table II.

TABLE II - FULL-SCALE TECHNO-SUPERLINER CHARACTERISTICS

ITEM	TSL-F	TSL-A
DISPLACEMENT	?	?
LENGTH		
UPPER HULL	72.0 M	127.0 M
LOWER HULL	85.0 M	---
BEAM		
UPPER HULL	37.0 M	27.2 M
LOWER HULL	5.6	---
DRAFT	HB: 12.0 M	OFF CUSHION: 5.0 M
	FB: 9.6 M	ON CUSHION: 1.4 M
POWER		
PROPULSION	?	4 @ 25,000 ps
LIFT FANS	---	4 @ 4,300 ps
PROPULSOR	? WATERJETS	4 WATERJETS

Some of the parameters have not, at this writing, been published. It is suspected that the full load displacements are both in the range of 3,000 to 4,000 tons. Note that the TSL-F is much shorter in length, but has a greater beam than the TSL-A. Also of interest is the TSL-F lower hull length which is 13 meters greater than the upper hull. Both of these dimensions are the equivalent of dimensions scaled up from the large test model (shown in Table I) by a factor of approximately 4.2. This is interesting since in several literature sources the TSL-F model is quoted as a 1/6 scale model. Note that the TSL-A large test model is a much larger "scale model" than the TSL-F since it has a scale factor of only 1.7. A sketch of the full scale TSL-F shown in Reference 13 indicates it carries 168 containers, each of which measure 8'x8'x20' (see Figure 16).

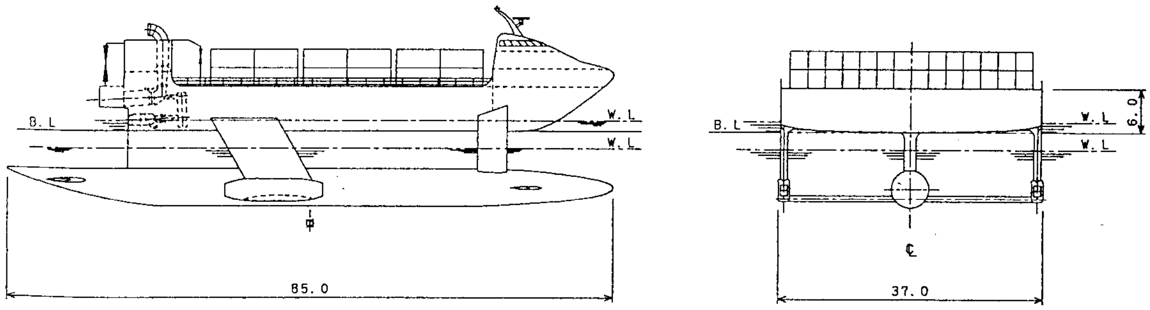

Figure 16 - Sketch of Full Scale TSL-F (Ref. 13)

Intermodal System

Japan is planning for incorporation of the Techno-Superliner into its Intermodal Transportation System. Illustrated here in Figures 17 and 18 are sketches (taken from Reference 1) of two versions of how the TSL would be integrated with a port facility.

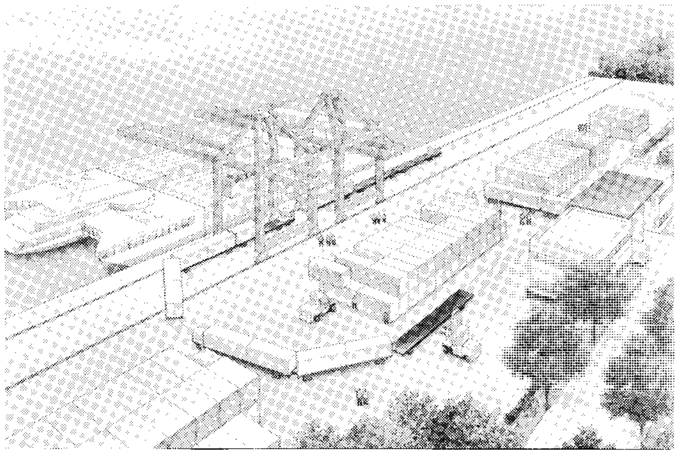

Figure 17 - Pierside Loading Concept by Ministry of Transport

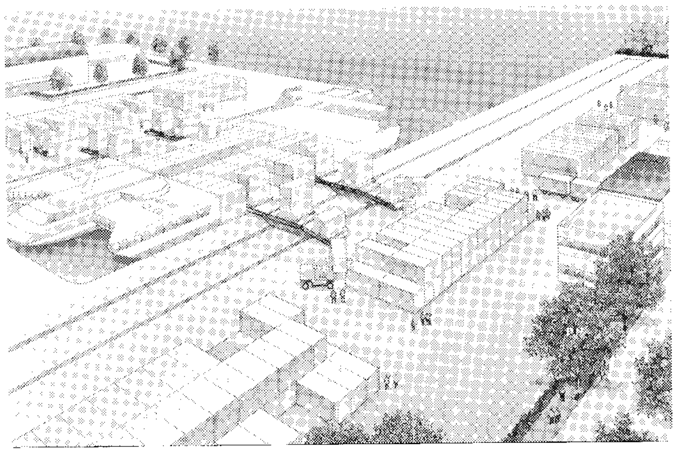

Figure 18 - U-Shaped Pier Arrangement by Ministry of Transport

According to Reference 11, the R&D Techno-Superliner program has progressed successfully and as planned. After the sea tests are completed, the companies involved in the program will be ready to accept full scale building orders, and it may be possible for these ships to make their debut by the end of this century. However, some problems still remain for utilization of the TSL in the "Modal Shift of Cargo Transportation" in Japan. Improvement of the infra-structure such as interconnecting transportation systems, port and harbor facilities, and safety rules and regulations are considered the most urgent problems. According to Reference 1, interested parties have already begun feasibility studies of such systems.

Conclusions

The shipbuilding companies involved in the TSL program have shown the will and ability to explore advanced and innovative new hull form concepts cooperatively and to overcome fundamental breakthrough technologies necessary for developing and realizing those concepts. They apparently have the required expertise for designing the TSL-F including the basic design technology, various computational fluid dynamic analyses, structural analysis, analyses of propulsor characteristics, and a simulator for the development of attitude control.

It can be concluded from the literature available that the overall TSL program has been well planned and funded. The TSL-F approach has seen a logical and well thought out combination of analytical and experimental studies generously intermingled with simulation work to bring the project to what we believe is a successful large test model of this hybrid form.

It will be of interest to many of us to learn more of the details of both the design and test results from this extremely interesting program.

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DEVELOPMENT OF FULLY SUBMERGED HYDROFOIL CATAMARAN

by Kazuyuki Kihara, Naoji Toki and Tohru Kitamura

Kazuyuki Kihara holds Doctor of Engineering degree in Naval Architecture from the university of Kyusyu. He entered Mitsubishi Heavy Industries, LTD.(MHI) in 1965 and has been engaged in designing and development of several types of advanced marine vehicles, such as SES, "Hi-Stable Cabin Craft(HSCC)" and hydrofoil. In 1992, he was commended by Japanese Minister of Transport because of his achievement for development of several types of advanced marine vehicles. He has taken part in the Techno-Superliner(TSL) project as a chief designer from 1990, and he accomplished a 70m large experimental SES in 1995. He is now a technical manager of Marine New Product Department Headquarters of MHI.

Naoji Toki holds Bachelors and Masters degrees in Naval Architecture from the university of Tokyo. After joining Nagasaki Research and Development Center of MHI in 1973, he has been engaged in seakeeping studies of conventional ships. He was sent by his company to the department of Naval Architecture and Marine Engineering at the university of Michigan, and spent a year as a visiting scholar. Recent years, his task is expanded to include the development of advanced marine vehicles, such as SWATH, SES and hydrofoil.

Tohru Kitamura holds Bachelors and Masters degrees in Naval Architecture from the university of Hiroshima. After joining Shimonoseki Shipyard and Machinery Works of MHI in 1985, he has been engaged in development of several types of advanced marine vehicles with Dr. K.Kihara. In the development of fully submerged hydrofoil catamaran, he has been in charge of motion control part. He belongs to Initial Designing and Estimate Section, Ship and Ocean Department of Shimonoseki Shipyard and Machinery Works of MHI.

Abstract

A diesel driven fully submerged hydrofoil catamaran has completed. She is a newly developed passenger ferry with the speed of 40 knots and passenger capacity of 341 and now in commercial service on the Oki Island route in Shimane Prefecture. Her technical features are as follows :

(1) Catamaran hull brings hydrofoils with bigger span and small hull resistance in take-off condition and relatively soft wave impact in rough seas because of greater dead rise of the bottom than the mono-hull type.

(2) Tandem foil configuration where fore and aft hydrofoils are exactly same shape brings higher aspect ratio with high lift to drag ratio in comparison with the canard foil configuration on existing craft.

(3) Automatic ride control system keeps foil-borne condition stable.

(4) Her propulsion system consists of 4 sets of light weight high-speed diesel engines and 2 sets of newly-developed light weight water-jet propulsors.

1. Introduction

Recently, there has been increasing demands for high-speed passenger craft that are well adapted to sea conditions so as to provide a smooth and comfortable ride in waves. While there are various kinds of high-speed craft operating in Japan, it is not easy to obtain a comfortable ride while keeping high speed performance in waves. After surveying various concepts of high-speed craft, the authors concluded that a fully submerged hydrofoil is a promising answer to such demands when the requirement of comfortable ride is crucial.

For existing fully submerged hydrofoils, there are other demands from the side of operators including improvement of economic performance and increase of passenger capacity. Existing craft of this type have passenger capacities of up to 280 people and are powered by gas turbine engines for which initial and maintenance costs are very high, while high-speed diesel engines which are most popular as propulsion units of high-speed craft have never been adopted to this type of craft because of their heavy weight.

Considering such backgrounds, the authors decided to develop a diesel driven fully submerged large hydrofoil catamaran, the "Mitsubishi Super-Shuttle 400". In order to increase passenger capacity, a catamaran hull configuration is adopted, and economic performance is improved by saving construction and maintenance costs, while newly developed high-speed diesel engines are installed as her main source of propulsion instead of the gas turbine engines usually used for this type of craft. A water-jet propulsion system was also newly developed to match the engine.

The construction of the first Super-Shuttle 400, named the "Rainbow", began in February 1992 and sea trials started in October of the same year. After a series of sea trials and operational training carried out for about six months, she was delivered to her owner, Oki Shinko Inc. in March, 1993. Then, the craft began daily services as a passenger ferry running between Oki Islands and Honshu island (Japanese mainland) on April 1 under the operation of Oki Steam Ship Inc. Fig. 1 shows a rough location of Oki route where the "Rainbow" is operating.

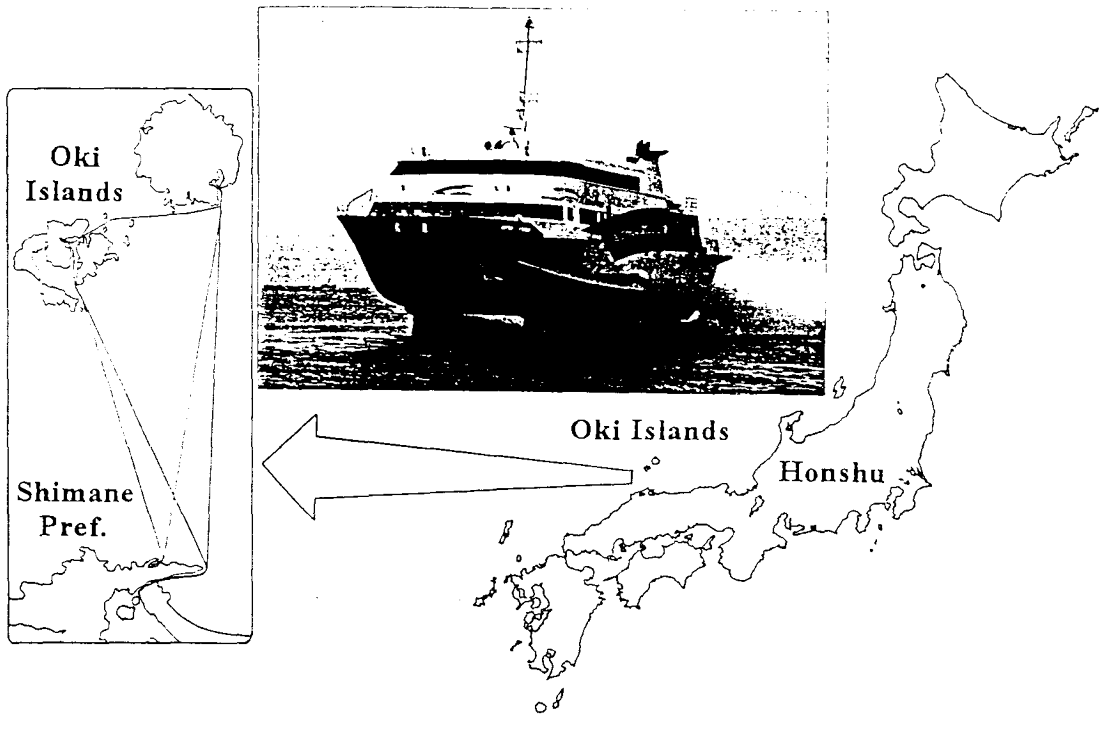

Fig. 1 A rough location of Oki route

2. Design concept[1][2]

In the design and construction of a hydrofoil craft, the apparent and most urgent task is saving weight. For that, not only the total power plant including diesel engines but also the hull structure, foil system, water-jet propulsor and every component of the craft are designed to be as light-weighted as possible. The design highlights of the craft are summarized below.

(1) Although the newly-developed engines have low weight to power output ratio, they are inherently and significantly heavier than gas turbine engines having the same power output. To compensate for the weight penalty imposed by the adoption of diesel engines, hydrofoils with a greater aspect ratio and consequently higher lift to drag ratio are used. It is one merit of adopting a catamaran hull which allows the use of hydrofoils with bigger spans than mono-hulls.

(2) Other merits that can be realized through use of a catamaran hull include the following. Because the demi-hull of a catamaran can be thinner than a mono-hull, wave-making resistance of the hull during the take-off process is smaller than that of a mono-hull. Wave impact on the bottom which is likely to occur in rough weather is relatively soft, because the greater dead rise of the bottom can be adopted for catamaran demi-hulls compared with mono-hulls.

(3) Existing fully submerged hydrofoils usually adopt a canard foil configuration, which is a combination of a small forward foil and a full span large aft foil, because gas-turbine engines and water-jet pumps are installed close to the aft end of the craft, and therefore the center of gravity is in the aft. In the case of this craft, two aligned diesel engines are installed along the centerline of each demi-hull to obtain the required propulsive power. As a result, the center of gravity moves forward close to midship, and a tandem foil configuration is adopted where fore and aft hydrofoils are exactly the same shape.

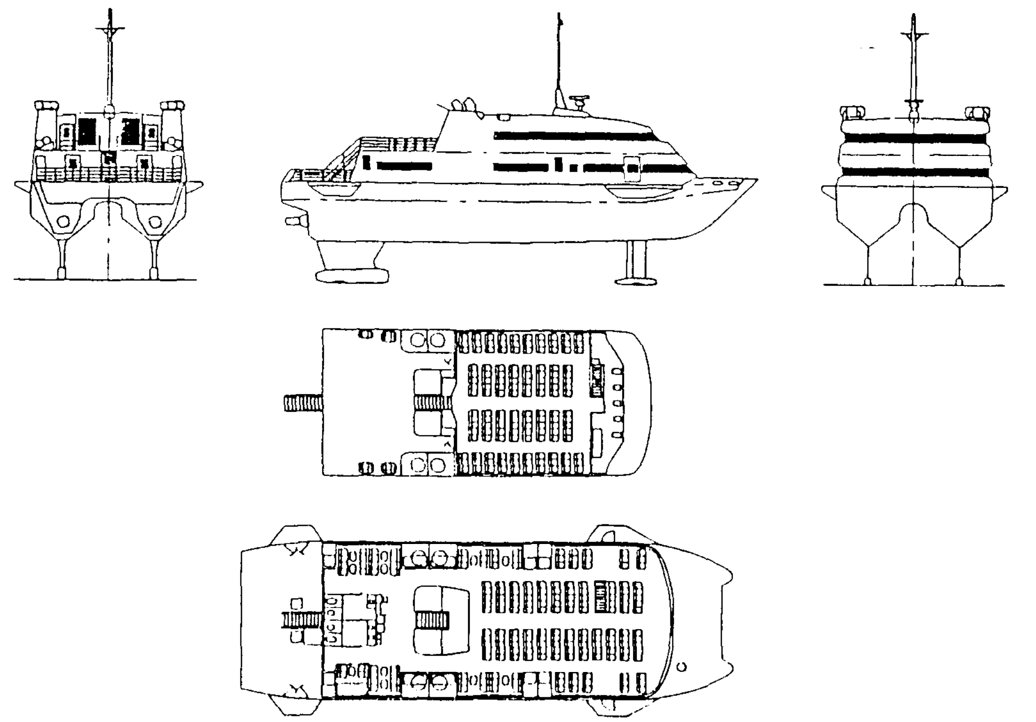

Fig. 2 General arrangement of the "Rainbow"

The general arrangement of the vessel is shown in Fig. 2. Principal particulars of the craft are listed in Table 1.

Table 1 Principal particulars of the Mitsubishi Super-Shuttle 400

Length overall	33.24 m	Gross tonnage (Japanese)	302 tons
Beam overall	13.20 m	Service speed	40 kn
Depth molded	4.20 m	Passengers	341 people
Design hull-borne draft	4.50 m	Crews	4 people
Design foil-borne draft	2.10 m	Dead weight	App. 35 tons

3. Hull structure and foil system[3]

Safe and reliable structure and weight saving are the main goals being sought in the structural design. These two aims are contradictory in a sense, and careful design studies were carried out for hull structures as well as foil systems in order to find an appropriate compromise between them.

3.1 Hull structures

Extensive stress analyses were conducted using three-dimensional finite element method in order to design the structure with minimum weight and sufficient strength. Careful design by such analysis was performed for the connecting structures between the hull and forward struts in particular so as to distribute the concentrated supporting force on the struts into elements of the hull structure. Because the fore and aft propulsion engines and generator engine are set inside of each demi-hull, significant areas of the upper deck must be covered by removable plates for the purpose of taking the engines out of the hull during maintenance. Special attention was paid to maintain the required bending strength of the hull by the remaining part of the deck. Aluminum honey-comb plates are used for these removable plates so as to minimize their weight.

3.2 Measures against noise and vibration

As the noise level of diesel engines is higher than that of gas turbine engines, it is an important task to proof the passenger cabins against noise and vibration from the engine rooms as much as possible. A series of numerical calculations were carried out to estimate the relation between the noise level in the passenger cabins and necessary weight of the soundproof system. The following measures were taken on the basis of these results.

(1) Thick sheets of rock wool were placed between the upper deck plate and the overlay flooring.

(2) All ceilings and walls were finished with newly developed aluminum honey-comb panels.

(3) Upper deck cabin windows were finished with double plates of glass.

As a result, a maximum noise level of 76dB(A) was attained in the cabins.

3.3 Foil System

The foil system of this craft consists of fore and aft foils (12.8m in span) and two pairs of supporting struts. Fore and aft foils have exactly the same shape. Motion control flaps and rudder flaps are fitted to the trailing edges of the foils and fore struts, respectively. The fore and aft foils and fore struts are made of precipitation-hardening corrosion resistant stainless steel of 15-5PH, and they are designed to have considerable amount of hollow space inside in order to minimize weight. The motion control flaps are made of solid titanium alloy.

In the structural design of the foils and struts, extensive stress analyses were conducted using a three-dimensional finite element method. A finite element model of the fore foil and strut is shown in Fig. 3.

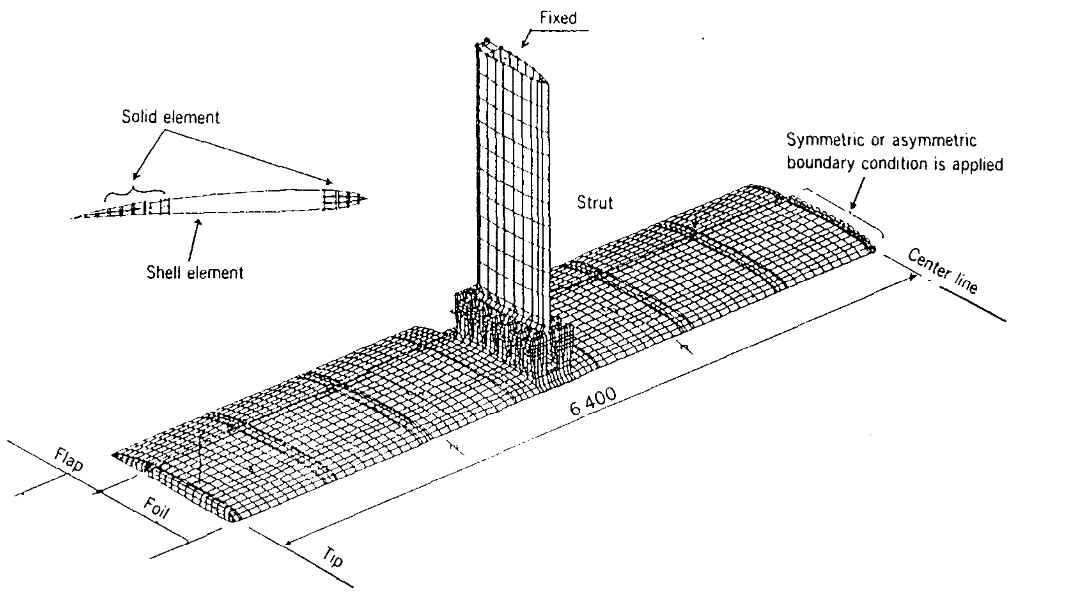

Fig. 3 Finite element model of fore foil and strut

The manufacturing process of the foil structure consists of rough shaping of solid billets, assembly of the parts by welding, heat treatment and final machining. To retain high strength, toughness and corrosion resistance in sea water for 15-5PH welded joints, a new process of heat treatment was used as described below through an extensive test program using a 1/2 scale model.

Solution heat treatment : 790℃ 3hr

Aging(Precipitation hardening) : 570℃ 4hr

In the heat treatment process, the foil was placed in a stainless steel muffle and many thermocouples were attached to control the temperature constant over the span length of the foil. The mechanical properties of 15-5PH before and after welding and heat treatment are listed in Table 2.

Table 2 Effect of the heat treatment on strength of 15-5PH

	0.2% yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Reduction of area (%)	Position of failure	Absorbed energy (J)
Base plate	1 014	1 054	20.0	61.8	—	62.71
After welding and heat treatment						
Base metal	832	903	24.0	75.3	—	252
Welded part	825	902	24.0	76.6	Welded metal	281

As can be seen in the Table 2, the base metal and welded parts have higher absorbed energy after welding and heat treatment than the base plate while retaining sufficient yield strength.

After the heat treatment, the foil was machined to the outer molded line, and further all external surfaces were polished to improve hydrodynamic performance.

The aft struts, which are fabricated of aluminum alloy, have built-in structures of water-jet inlets and ducts.

4. Propulsion system

The propulsion system consists of four high-speed diesel engines and two water-jet propulsors which are divided into two groups. Two diesel engines are installed in each demi-hull of the catamaran to power each water-jet propulsor set on the respective transoms of the hull.

4.1 High-speed diesel Engine

A high-speed S16R-MTK-S diesel engine was newly developed based on MHI's widely used SR-series of diesel engines.

Table 3 Particulars of S16R-MTK-S

Type of engine	V type, 4-Cycle, Direct injection, Turbo-charged, Inter-cooled
Number of cylinders	16
Bore	170 mm
Stroke	180 mm
Displacement	65.4 *l*
Output (MCR)	2 100 kW
Speed (MCR)	2 000 rpm
Weight (Dry)	5 500 kg

An extensive test program was formulated and various refinements in design were made in order to increase power output and reduce total weight. As a result, the engine has achieved the lowest level of weight to power output ratio as a marine use diesel engine at 2.6kg/kW. The particulars of the engine are listed in Table 3.

The aft engine is set above the propeller shaft with a forward rake and is connected to the shaft through a conical type reduction gear, while the fore engine is set aligned with the shaft and connected by a regular parallel type reduction gear.

4.2 Water-jet propulsor[4]

A MWJ-5000A water-jet propulsor was also newly developed to match the propulsion engine. The specifications of the MWJ-5000A water-jet propulsion unit are listed in Table 4.

Table 4 Specification of water-jet propulsion unit

Pump type	Special axial flow (double cascade)
Input power (max.)	5 500 PS
Input speed	1 022 rpm
Direction of rotation	Counterclockwise view from the stern
Diameter of impeller	814 mm
Reversing & steering system	Fixed louver type
Weight	2.2 t

In order to accelerate the craft during the take-off process at relatively low speed, high suction performance is required at the low suction head, while high efficiency is required during high speed corresponding to service conditions at foil-borne. These two requirements usually contradict each other, and a double cascade axial flow type impeller was specially designed to resolve them. Six forward blades keep high suction performance at lower speed, while twelve rear blades assure high efficiency during high speed. A photo of the double cascade type impeller is shown in Fig. 4.

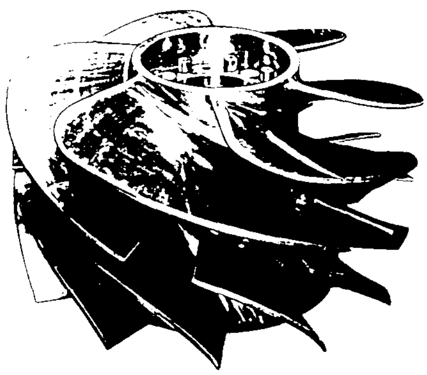

Fig. 4 Double cascade type impeller
Six forward blades and twelve rear blades are shaped by machining of a block of 15-5PH.

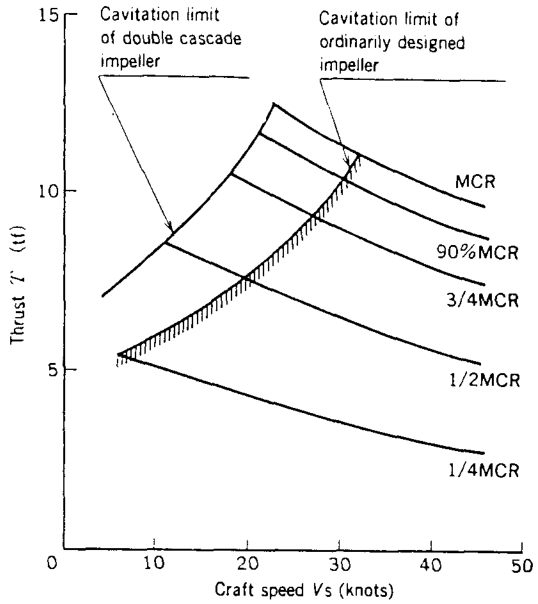

Fig.5 Thrust characteristics of the water-jet system
Thrust limits due to cavitation becomes higher with use of this double cascade impeller. As a result, a sufficient thrust margin during the take-off process is obtained.

Detailed structural design of the impeller was made using a finite element method, and the external forces on the blades of impeller were estimated on the basis of the results of performance tests using a model of the impeller. The impeller is manufactured of 15-5PH stainless steel in order to realize savings in weight.

The inlet duct is an important part of a water-jet propulsion system, and special attention was paid to optimize the total performance of the water-jet system. Performance of the inlet duct was verified by model tests in a wind tunnel and cavitation tunnel.

Thrust characteristics of the water-jet system composed of the propulsor and the inlet duct are shown in Fig. 5, and are compared with those when an ordinarily designed impeller is used. As shown in Fig. 5, thrust limit due to cavitation becomes higher by use of this double cascade impeller. This means that a sufficient thrust margin during the take-off process is obtained.

5. Automatic ride control system[5]

As this craft is categorized in fully submerged hydrofoil which is unstable during her foil-borne condition without an automatic motion control system, the development of a suitable control system is a major task. Arrangement of the motion control system known as the APF (Auto Pilot on Foils) system is shown in Fig. 6.

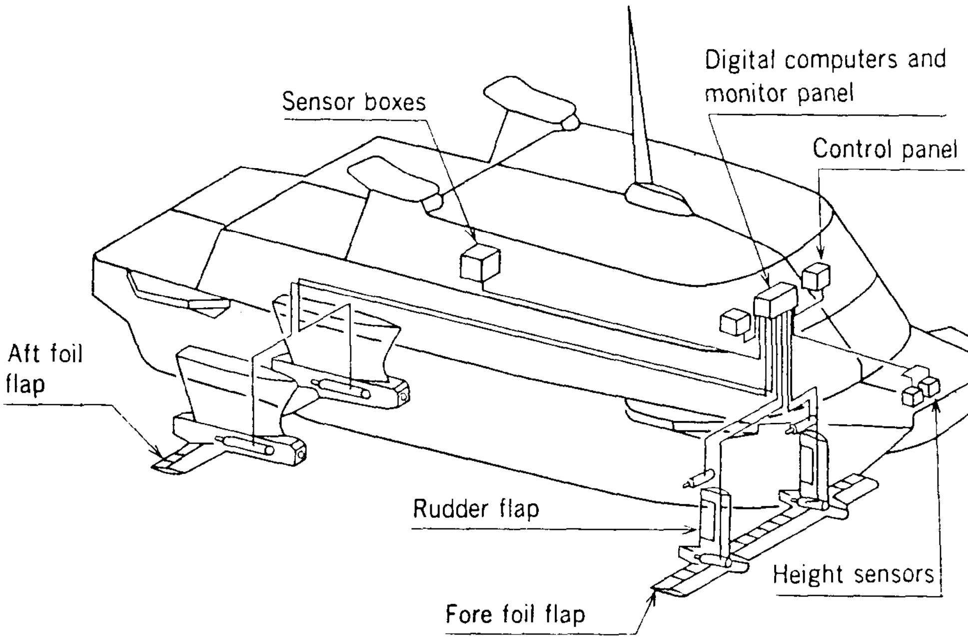

Fig. 6 Arrangement of APF system
Sensor signals are sent to the digital computers which calculate the command signals for the motion control flaps.

The APF system consists of feed-back sensors, electronic components, hydraulic components and flap mechanisms.

5.1 Design process

The concept design of the system was mainly carried out on the basis of studies of published references, and was developed through a series of calculations by a newly-developed calculation program designed to estimate hydrodynamic coefficients and simulate non-linear ship motions. Model tests are considered indispensable to confirm the concept design and verify the simulation program as well as the designed control system. The two series of model tests were planned and conducted. They are ;

(1) Free running tests using a small radio-controlled model with a simplified motion control system, in order to investigate the basic requirements of the control system for the craft and to check over-all behavior of the model.

(2) Take-off and landing simulations by controlling a larger scaled model in the towing tank, in order to verify the simulation program and the designed control system.

The results of these model tests were reflected to the design of the control system and improvements of the simulation program.

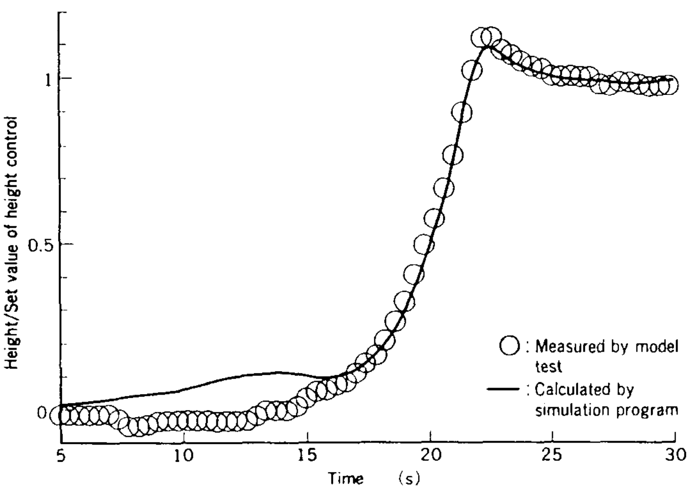

Fig. 7 Comparison between simulation results and model test results (Variation of relative bow height during take-off process)
The results of simulation agree with model test results fairly well

Fig. 7 shows the variation of relative bow height during the take-off process obtained by the time-domain simulation program which is compared with model test results obtained by a take-off simulation in the towing tank. Simulation results agree with the measured ones fairly well, thereby the reliability of the simulation program is confirmed.

Physical simulations using a towing tank model and numerical simulation by the program were carried out for several settings of the control system. The obtained results were analyzed, and the design of the control system was modified and improved accordingly. The development of the control system was completed prior to the commencement of sea trials where final adjustments to the system were performed.

5.2 Feed-back sensors

In order to maintain necessary redundancy of the automatic ride control system for safety, two sets of feed-back sensors are mounted. The utilized sensors are listed in Table 5.

Table 5 List of sensors

Motion component	Type of sensor	Number
Pitch	Vertical gyro	2
Roll	Vertical gyro	2
Pitch rate	Rate gyro	2
Roll rate	Rate gyro	2
Yaw rate	Rate gyro	2
Heave velocity	Heave sensor	2
Relative height	Ultra-sonic type	2
Heave acceleration	Accelerometer	4
Advance speed	Electro-magnetic log	2

Each of the two sensor boxes installed on the upper deck at midship contains a vertical gyro, roll-pitch-yaw rate gyros and a heave velocity sensor. Four heave accelerometers are installed on the upper deck above four struts. Two ultra-sonic type height sensors are fixed at the fore end of the inner hull bottom, while electro-magnetic logs are installed on the forward bottom of starboard and port side pods on the forward foil.

Two sets of sensors usually run concurrently, and the average values of the signals from the two sensors are used as feed-back signals. When a sensor has failed, it is automatically cut-off from the control system and the signal from the other sensor is used. Information of the failure is displayed on the APF's monitor panel.

5.3 Electronic components

Electronic components consist of two digital computers, control and monitor panels and a sequencer. They are powered by 24 volt DC batteries to assure that steady control can be continued even in the case of a black-out in the electric power supply. Usually the two computers carry out the same calculations receiving the same feed-back signals, but the calculated commands regarding flap angles by only one computer are transmitted to the hydraulic servo system. When the computer on duty happens to fail, the output lines are automatically switched by the sequencer to the other computer, and information of the failure is displayed on the monitor panel.

5.4 Hydraulic components and flap mechanisms

After conducting a comparative study of various types of flap control mechanisms, a type was selected in which hydraulic servo actuators are installed in water, just next to flaps. Minimum mechanism to transmit the movement of actuator to the flap and hydraulic system for the cylinder were designed. Long-term endurance tests were then performed for various type of seals in order to select a seal system for the actuator which can assure sufficient reliability in sea water.

Four hydraulic actuators are installed, one each in four pods located at the intersections of the foils and struts; fore & aft and starboard & port sides. Each fore and aft foil has twelve component flaps. Each hydraulic actuator activates six component flaps located on the starboard and port side of the actuator.

6. Sea trials

The construction of the "Rainbow" was completed at the beginning of October 1992, and sea trials began on October 15 starting with the adjustment of the main engines and automatic control system. Soon after the normal operation of the various systems on board were confirmed towards the end of October, the craft succeeded to take off with an engine output of only 75% MCR, and a stable foil-borne condition was obtained. With this success, various tests and adjustments of the system during high-speed could be started ahead of schedule. In November, the "Rainbow" recorded her maximum speed of 45.4 knots during overload output of the main engines.

Adjustments to banked turn control were repeated, and very smooth turning was finally obtained. Because the "Rainbow" can continue foil-borne running at relatively low thrust, she can use a water-jet steering system as well as vertical flap rudders for maneuvering at foil- borne condition, and the effects of rudder ventilation can be minimized. The results of hard-over turning tests in foil-borne condition are shown in Fig. 8. The diameter of the turning circle is less than 400m.

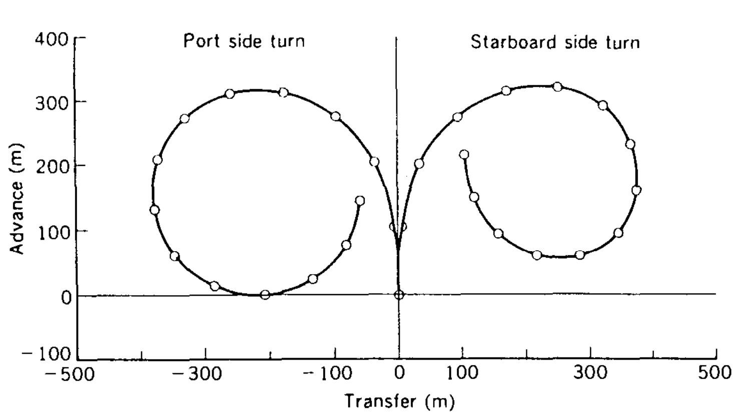

Fig. 8 Results of turning tests during foil-borne state (Initial speed : about 41 knots)

From December, trials were repeated in waves with prepared sets of control gains, and the motion characteristics of the craft were measured. From the results analyzed, a few sets of control gains were selected for practical use. In total, 36 sea trials were carried out for about five months until the end of February 1993, and the validity of the design was confirmed through various measurements, such as stresses on the hull structure and foil system, as well as noise and vibration in the cabins and engine rooms.

On March 5, the "Rainbow" was transferred from the Shimonoseki shipyard to the area of Oki Islands, and more than 20 operations practice were carried out until the beginning of her commercial services. Final adjustments to the automatic control system were made at the site of real operation.

7. Conclusions and acknowledgment

This paper summarizes the outline of a fully submerged hydrofoil catamaran called "Mitsubishi Super-Shuttle 400".

The first Super-Shuttle 400, the "Rainbow" started her regular service on April 1, 1993. The number of passengers in 1993 increased to about twice as many as that of the previous year when the conventional mono-hull vessel was in operation, as she has large passenger capacity of 341 people and can reach high speeds of around 40 knots while maintaining comfort in waves. Although the "Rainbow" has been operating successfully so far, she is the first prototype of the "Mitsubishi Super-Shuttle 400", and her operation record is only for about two and half years including sea trials. The authors would like to watch her operation and take every possible means to improve the performance of the craft.

At the end of this paper, the authors wish to express their sincere gratitude to Mr. Masahira Okada, the president of Oki Shinko, Inc., and Mr. Teruo Taguro, the chairman of the board of Oki Steam Ship, Inc., as well as the Messrs of Shimane Prefecture and seven towns and villages of the Oki Islands; Saigo, Fuse, Goka, Tsuma, Ama, Nishinoshima and Chibu. They also wish to express their deep appreciation to Professor Takeo Koyama of Tokyo University, Professor Emeritus Michio Nakato and Professor Kazuhiro Mori of Hirosima University, and Professor Takeshi Takahashi of Kurume National College of Technology for their kind guidance during the development of the "Mitsubishi Super-Shuttle 400".

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HYSWAS Design Activities in Germany

Volker Bertram, Julius Schmidt

Biographies

Volker Bertram teaches at the Institut für Schiffbau, University of Hamburg. He is active in the fields of ship hydromechanics and ship design and has published among other topics on SWATH and HYSWAS. He holds degrees as Dipl.-Ing., Dr.-Ing. (Univ. Hamburg) and M.S.E. (Univ. of Michigan). After graduation he joined a management consulting company and the Hamburg Ship Model Basin, before returning to his current position.

Hans-Julius Schmidt graduated as Dipl.-Ing. (M.S.E. equivalent) in Aeronautical and Astronautical Engineering from the University of Stuttgart in 1983. He worked as development engineer designing missiles in the German defence industry until the end of 1988. In 1989 he immigrated to Australia and worked as research assistant in the Civil/Mechanical Engineering department of the University of Tasmania. In December 1990 he joined Advanced Multi-Hull Designs in Sydney as research engineer working on motion sickness estimations, ride control design and assessment/calculation/simulation of catamarans' motions in seaways. Since November 1993 he has been employed with EMIT (Vulkan Verbund) in Bremerhaven, Germany, where he develops new concepts for fast ships as SES and HYSWAS.

Abstract

HYSWAS design activities in Germany focus currently in a joined effort on the conceptual design of a 500t passenger car ferry. Design considerations, layout and some underlying design formulas are explained. The HYSWAS design is compared to other fast ferry designs (catamarans, SES, etc) in terms of transport efficiency. Results indicate that HYSWAS becomes an interesting alternative in areas with rough seas like the North Sea.

Introduction

Hydrofoil-supported monohulls are a still relatively unknown hybrid ship combining buoyancy and dynamic lift. They are usually referred to as HYSWAS (Hydrofoil Small Waterplane Area Ship). The HYSWAS combines elements of conventional hydrofoils and (demi-)SWATH ships. The design process is therefore generally based on experience for these two ship types. In Germany, Ernst Mohr developed since the mid-80es HYSWAS designs being unaware of related work in the USA and France. The potential of the concept was not realized by industry and academia at that time. This was partly due to a focus on large naval vessels – which were too complex and expensive to be considered as a demonstrator for a new technology –, partly due to an inappropriate presentation of the concept. Subsequent refinement of the design backed up by theoretical and experimental studies lead to a growing acceptance within the German shipbuilding community. Studies involved computer flow simulations to improve the hull, Bertram and Mohr (1992), wind tunnel experiments, Blendermann (1993), and resistance tests in the small HSVA towing tank. In 1994, EMIT, the development center for maritime and industrial technology of Germany's largest shipbuilding corporation Bremer Vulkan Verbund, decided that the concept was mature enough to deserve a closer investigation. A feasibility study for a 500t HYSWAS ferry named MARK was initiated in September 1994. Intermediate results of the work in progress are reported here.

Design of a 500t HYSWAS Passenger Car Ferry

The general hydrodynamic characteristics of a HYSWAS have been previously described by e.g. Meyer (1992). Recent sea trials of the first HYSWAS built, the Japanese TSL-F small-scale prototype, are expected to confirm the excellent sea keeping properties predicted by model tests. This feature makes the HYSWAS an ideal passenger ferry for long exposed routes like the North Sea or the English Channel. Except for SWATH and hydrofoils, all common high-speed light crafts as catamarans, hovercrafts, and SES are not suited for exposed routes on many days in the year.

The main technical data to be achieved by MARK are a full-load displacement of 500t, cruising speed of 39 knots in a sea state of H1/3 = 3m, maximum operational sea state of H1/3 = 4m, carrying capacity of 80 cars and 350 passengers, and range of 500 nm. The INCAT 74m Wavepiercing Catamaran has a similar combination of payload and speed. However, it was reported that seakeeping characteristics (prior to installation of a motion control system) and operational experience that passengers tend to get bored on routes longer than 2 hours, caused INCAT 74m WPC to be withdrawn from long exposed routes such as Bass Strait (Australia) and Portmouth to Cherbourg (Channel). MARK shall be equipped with a spicy, comfortable passenger area, a restaurant and have excellent board-service to keep passengers in good spirits on long "flights". Typical routes could be Bremerhaven-Newcastle (373nm, 10h) or Vlissingen-London City (134nm, 4h).

Two versions of MARK are currently under further investigation, the diesel-powered MARK4, Fig.1., and the turbine-powered MARK6. The two versions differ in some engine-related aspects described below.

MARK4 is designed to fit two MTU 20V 1163 TB73L diesel engines. Therefore the geometry at the "foot" of the strut is modified to fit the head of the engine. Also the thickness of the strut shall make it possible to remove the engines through the machinery pit which has an inner breadth of a least 1.7m over 10m length. The rated shaft power of this engine package is almost 13000kW. At 90% MCR the available shaft power after the rear gearbox is about 11400kW and fuel consumption 206g/kWh. The price of the complete package consisting of two engines, two gear boxes, controllable pitch propeller (CPP), bearings, and shafting is estimated at 8 Mill. DM. The mass of the complete package is estimated to be about 80t. In contrast to gas turbines, diesel engines can be operated economically at low ratings for cruising at low speeds off-foil. Therefore the auxiliary propellers in the side floaters need only some propulsion power for manoeuvring. The strut supplies enough righting y-moment and z-force to make the vessel dynamically stable in pitch and heave when cruising with design draft.

MARK6 is designed to fit comfortably two Allison 571-K liquid fuel gas turbines mounted side by side. The thickness of the rear strut shall make it possible to remove the engines through the machinery pit which has an inner breadth of at least 0.9m and a useful cross section area of more than $4m^2$ for the gas turbines' fresh air and exhaust fume ducts. The front strut gives structural support and has the rudder fitted like most vessels with fully submerged hydrofoils. A skeg gives directional stability and holds the stabilizer. The rated shaft power of the two engines together is 11400kW. At a realistic service rating, the available shaft power after the rear gearbox is about 9300kW, fuel consumption 251g/kWh. The price of the complete package consisting of two engines, one gear box, CPP, bearings, and shafting is estimated at 8.5 Mill. DM. The mass of the complete turbine propulsion package is estimated to be about 47t. As gas turbines cannot operate economically at low ratings, an additional propulsion system is required to supply the propulsion system power for up to 20kn speeds. Also, according to preliminary resistance calculations, 9300kW is not sufficient shaft power to achieve 39kn. Therefore MTU 8V 396 TE 74L diesels rated at 1000kW shall be installed on each side near the strut to drive a traction propeller via z-drive through the side strut. The traction propellers are mounted where wing tip and side strut join and supply excellent manoeuvrability.

Due to the submergence and the even wake, an unusually high propulsive efficiency for the propeller can be achieved. Waterjets could not have given the same propulsive efficiency at the intended 39kn. The choice of the Japanese TSL-F waterjets might be a better option due to its higher design speed of 50kn. Good manoeuvrability is a must for high-speed ferries to achieve short berthing times matching short crossing times. Therefore MARK is equipped with additional outward positioned propellers and bow thrusters. The auxiliary thrusters allow a propulsion mode for cruising at speeds of ca. 15kn to 20kn in restricted waterways, e.g. on the Thames between Shields and the City of London or in shallow-water regions of the North Sea.

MARK shall be able to pierce regular waves up to 4m height. Piercing means that heave, pitch, and roll motions can be kept minimum if not zero. When MARK encounters regular waves higher than 4m, the ride control system shall switch from piercing to contouring mode. Contouring waves of 5m height seems to be the limit of passenger acceptance. Therefore the maximal operational seaway for MARK was defined by a significant wave height $H_{1/3} = 4$m, when the probability for occurence of waves higher than 5m is less than 5%. Draft on foils (design waterline CWL) was selected such that the propeller will not emerge for a 4m high wave. This avoids significant increase in residual drag and loss of propulsive efficiency. Also submergence of retracted side floaters and slamming of the wet deck shall be avoided in 4m waves. Seakeeping investigations are scheduled as next steps.

An "airplane" foil configuration was deemed best because:

1. An internal investigation at the Hamburg Ship Model Basin came to the conclusion that investigated canard configurations perform worse than airplane configurations due to down-wash and other effects.
2. Yamanaka et al. (1991) deal with the hydrodynamic effects at the aft foil of a tandem foil configuraton. Large changes in flow direction at a foil positioned abaft of a forward foil are described. The magnitude of the effect causes lift of the aft foil to decrease by 60% at design speed and to even less at lower speeds.
3. Conventional airplanes are optimized for long range performance and avoid downwash of wings or stabilizers positioned afront. The main wing then operates in "clean flow". Canard configurations are found in fighter airplanes and missiles for maximal manoeuvrability.
4. The roll/heel stabilization of HYSWAS can be best performed by a main foil of as much span as possible or practical. Therefore the span of the main foil shall be maximized.

MARK4 has a main or forward foil. MARK6 has a main foil with struts at its tips to reduce drag and to maximize roll stabilisation by larger profile chord and higher lift slope near the tips.

A stabilizer foil positioned abaft of the main foil shall provide moments to trim the vessel and to dampen pitch oscillations. To ensure dynamic pitch stability, the longitudinal position of the main foil's resultant lift force must be located near the center of gravity, which is identical with the longitudinal position of the center of buoyancy. Then to keep trim, the stabilizer's contribution to the hydrodynamic lift becomes neglegible. The planform area of the stabilizer can be kept small to save frictional drag. The stabilizer is mounted behind the propeller (MARK4) or below the propeller axis (MARK6) to avoid disturbance of the propeller inflow due to stabilizer downwash.

Both MARK4 and MARK6 can be built with or without adjustable side floaters. Major European ferry terminals allow a draft of T=7.5m. Therefore the full-load draft off-foils is limited to 7.5m. MARK4 at lightship displacement of less than 400t (unloaded in the harbour) with retracted side floaters has a draft of less than 6m. Then the retracted side floater supplies stability only at an unacceptably high heel angle. For this configuration about 100t of ballast water in the aft compartments of hull and strut would be needed to stabilize and trim the vessel. Operation out of small ports to meet special market demands can be profitable. Small ports require a minimum draft off-foils. Therefore (electrically powered) adjustable side floaters with ca. 300t displacement are meant to reduce the draft off-foils to T=3.5m.

MARK has only two decks to minimize structure weight and frontal area because aerodynamic drag can become a considerable resistance component in strong head winds. The *car deck* provides parking space for about 83 middle class cars requiring each $10m^2$. The useful height is 2m over the outer 3 lanes and 3.2m over the center lanes. At the center, 2 lanes of vans, caravans etc. up to 3m height and 2.2m width can be parked instead of 3 lanes of cars. Double lane ramps to the car deck are fitted at bow and stern. Pillars reinforce the structure on each side of the machinery pit, yet leave enough width for vans to drive through. The *passenger deck* is staggered due to different heights of the car deck. The floor is 1.2m higher over the center width of 8.4m than over the outer 5.8m. Ca. 270 second-class passengers can be seated in the lower deck area. In the higher deck area ca. 80 first-class passengers can be seated abaft. A 50-pax restaurant is located afront. A passenger lift in front of the machinery pit goes from the car deck to the center part of the passenger deck. Staircases from the car to the passenger deck are located at each of the four "corners" of the deck.

Weight estimation followed SWATH experience for structure, outfitting and furnishing, auxiliary machines, crew, and margin. Weights for machinery and fuel were estimated in cooperation with suppliers. The payload was estimated to 110t.

Design Formulas for Power Prognosis

We predict the wave resistance separately for hull and strut neglecting the interaction and the wave resistance influence of the foils. Computations were based on Michell's thin ship theory. Michell's theory gives good results for high Froude numbers and can be implemented on a personal computer. For design purposes, it is thus an ideal tool as long as the ship geometry is thin and the speed is high which is the case for a HYSWAS.

The frictional resistance is $R_F = C_F \frac{\rho}{2} V^2 S$. $C_F = 0.075(\log_{10}(R_n) - 2.0)^{-2}$ is the friction coefficient according to ITTC, ρ the density of water, V the ship speed and S the wetted surface. The submerged part of the ship at design speed consists of torpedo-like hull, strut and hydrofoils. These parts are considered separately where a local Reynolds number R_n is taken in each case.

The pressure resistance of viscous origin is estimated for a torpedo-like hull by $(R_{PV})_H = 0.17(R_F)_H$ and for the strut by $(R_{PV})_S = (2\frac{B_S}{L_S} + 60(\frac{B_S}{L_S})^4)(R_F)_S$ where B_S is the width of the strut and L_S its length.

Spray drag is associated with the thin sheet of water that covers the strut above the static waterline increasing the wetted surface area. It is assumed to occur only for strut Froude numbers F_n larger than 0.5. Then we estimate it by $R_{SP} = 0.12\lambda B_S^2 \frac{\rho}{2} V^2$ with

$$\lambda = \begin{cases} 1.0 & \text{for} \quad 2.3 < F_n \\ 0.694F_n - 0.597 & \text{for} \quad 0.86 < F_n < 2.3 \\ 0.0 & \text{for} \quad F_n < 0.86 \end{cases}$$

The induced foil resistance is estimated by $R_I = 1.1L^2/(\pi \frac{\rho}{2} V^2 B_{HF}^2)$ where L is the lift of the foils and B_{HF} the span. The factor 1.1 accounts for the deviation from the ideal elliptic lift distribution.

The wind resistance is estimated by $R_{WI} = 0.5\left(\rho_a \frac{1}{2} V^2 A_F\right)$ where $\rho_a = 1.2\text{kg/m}^2$ is the density of air and A_F the frontal area above water.

The required installed power is determined from the total resistance – the sum of the above resistance components – by

$$P_B = \frac{R_T \cdot V}{\eta_0 \eta_H \eta_R \eta_S \eta_G}(SM + 1)$$

The open-water efficiency $\eta_0 = 0.718$ was determined from a propeller optimization, the other efficiencies are set based on SWATH and torpedo experience: hull efficiency $\eta_H = 1.03$, relative rotative efficiency $\eta_R = 0.95$, shaft efficiency η_S=0.98, and gear efficiency $\eta_G = 0.97$. The sea margin is set to 15%. The total required power was thus estimated to 10960kW.

Transport Efficiency

Economical aspects of the HYSWAS in comparison to competitors can not be evaluated in detail at present due to lack of data concerning prices, operating cost, and live span of a HYSWAS as well as its competitors. However, simpler parameter can serve to describe the transport efficiency to estimate at least at an early stage if the design is hopelessly inferior to existing competing products.

Karman and Gabrielli (1950) use total mass M, speed V, and power P to form a parameter for the transport efficiency. They used this parameter to compare very different vehicles such as airplanes, cars, ships, and trains:

$$\text{TE}_{K-G} = \frac{M \cdot V}{P}$$

Karman and Gabrielli plotted the inverse of the efficiency over the speed. The Karman-Gabrielli diagram allowed – despite its simple approach – valuable insight into the transport efficiency of various vehicles:

- There is seemingly a limit curve for the transport efficiency which vehicles can not overcome. "Good" vehicles lie close to this curve.
- Increased speed lowers the maximum possible transport efficiency.
- Sea transport is the most efficient form of transport at low speed, ground transport at medium speed, and air transport at high speed.

The original limit curve of Karman and Gabrielli has been shifted by technological improvements over the last four decades. Akagi (1991) gives the current state of the Karman-Gabrielli diagram with special respect to fast ships. Akagi points out that the Karman-Gabrielli diagram despite its popularity is unsuited to evaluate the transport efficiency of a vehicle. If you lower a vehicle's payload N, and thus its total mass, the transport efficiency in the Karman-Gabrielli diagram is increased. It is therefore better to use the payload, instead of the total mass, to evaluate the transport efficiency:

$$\mathrm{TE} = \frac{N \cdot V}{P}$$

This parameter is simple and still allows a comparison with other ships because it contains only data which are usually published. A reasonable comparison should still be limited to a narrow speed range, because lower speeds generally allow better transport efficiencies. For (designed or built) modern, fast car ferries of approximately 500t displacement, the following table gives the transport efficiency TE:

	type	V [kn]	P [kW]	N [t]	TE [t·kn/kW]
INCAT 78WPC	Cat	37	17280	250	0.53
Jumbocat	Cat	36	17280	230	0.48
Cirr 215 P	SES	43	11892	128	0.46
Corsair 600	SES	46	12400	114	0.42
SSW 320A	SWATH	36	22960	250	0.39
MARK	HYSWAS	39	11400	110	0.38
Aquastrada	Mono	40	29930	190	0.25
Mestral	Mono	35	20000	120	0.21
TSL-A	SES	50	87500	1000	0.57
TSL-F	HYSWAS	50	149000	1000	0.34

The 500t HYSWAS appears to be quite inefficient in this comparison. Especially, catamarans and SES ferries feature high efficiencies. The two full-scale versions of the Japanese Techno-Superliner TSL are listed separately because they differ significantly from the others in the table in payload and speed which restricts their comparability. However, again the SES is clearly superior to the TSL-F (HYSWAS) in this comparison.

The parameter for the transport efficiency still uses V, the speed in smooth water. For transport in real sea conditions however, the actually obtainable speed in sea waves is relevant. Especially for fast ships, consideration of the speed loss in sea waves can lead to a different ranking in the transport efficiency. The different types of fast ships differ largely in their seakeeping performance, Fig.2.

For some of the previously mentioned ships, the following published data are available:

	TE	V_1/V	TE_1	V_2/V	TE_2	V_3/V	TE_3
	[t·kn/kW]		[t·kn/kW]		[t·kn/kW]		[t·kn/kW]
Corsair 600	0.42	93%	0.39	87%	0.37	78%	0.33
SSW 320A	0.39	100%	0.39	99%	0.39	98%*	0.38
MARK	0.38	100%	0.38	100%	0.38	100%	0.38
Aquastrada	0.25	96%*	0.24	90%*	0.23	85%*	0.21

The index in the transport efficiency and speed gives the significant wave height in meter, i.e. TE_2 is the transport efficiency in seas with 2m significant wave height. The asterisk means that for this ship the speed loss in sea waves was estimated based on comparable ships (same type, similar size). For rough seas, SWATH and HYSWAS improve their relative position compared to other fast ships.

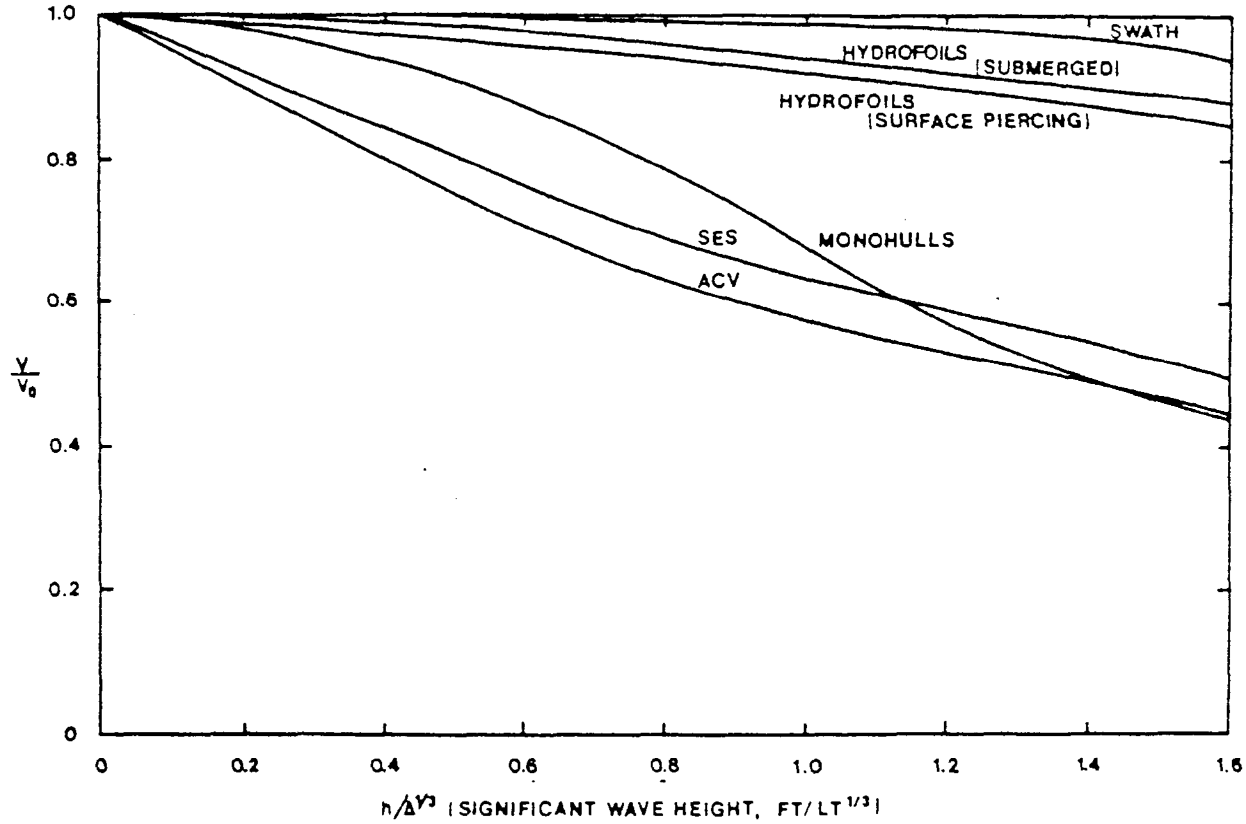

Fig.2: Speed loss in seaway for various fast ships, Long and Slogett (1985)

Conclusion: In calm water, catamarans and SES are recommended as fast ships. The HYSWAS gains in attractiveness in rough seas. For sea states from 1.5 to 2m significant wave heights, the HYSWAS becomes an attractive alternative provided its calm-water transport efficiency is close to or superior to a SWATH ship. Sea states with 1.6m significant wave height or more (SS4 and higher) are found e.g. in the North Atlantic for 72% of the year.

Next Steps

The following aspects need to be studied in more detail:

- the main foils' hydrodynamic and structural layout
- the hydrodynamic interaction between hull and foil system over the whole speed range
- the layout of the ride control system, sensors, electronics and actuators for the foil flaps
- detailed weight estimation
- cost estimation
- seakeeping calculations

The hydrodynamic aspects are currently investigated in cooperation with various universities, sometimes in form of thesis' work. Weight and cost estimations are performed in cooperation with ship yards of the Bremer Vulkan shipbuilding group. Bertram et al. (1995) will report on further progress of the design work.

Conclusion

A feasibility study investigates a 500t passenger car ferry named MARK. A diesel-powered and a turbine-powered version are currently further pursued. The transport efficiency of the HYSWAS designs appear attractive when speed loss in sea waves is taken into account. The promising intermediate results merit further investigations.

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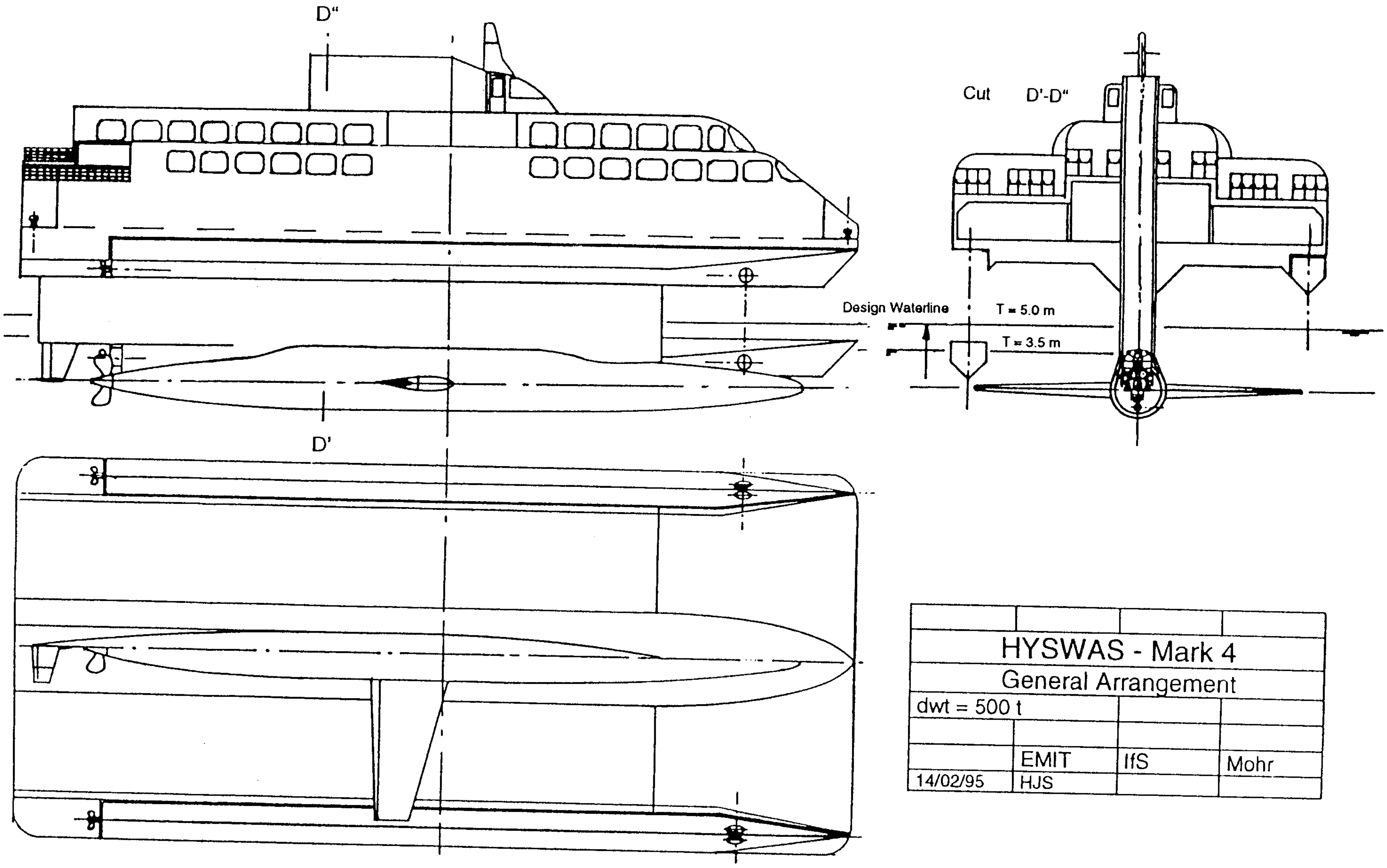

Fig.1: General arrangement plan of MARK4

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HYSWAS CONCEPT DEMONSTRATOR

By
John R. Meyer, Jay A. DeVeny, P. Daniel Jordan

John R. Meyer holds Bachelors and Masters degrees in Aeronautical Engineering from Rensselaer Polytechnic Institute, and has done additional graduate work at the Massachusetts Institute of Technology in the same field. Since joining the David Taylor Naval Ship R&D Center in 1971, he has been associated with Advanced Naval Vehicles, particularly hydrofoils and hybrid ship forms, in the Advanced Concepts Office and more recently in the Programs Department of the Ship Systems and Programs Directorate. In 1991, DTRC became part of the Carderock Division, Naval Surface Warfare Center (CDNSWC). He has authored a number of DTRC reports, AIAA, and ASNE papers on the subject of hydrofoils and hybrid marine vehicles. He holds several patents in this technical area. Prior to his current employment at DTRC he held several research and development, long range planning, and engineering management positions with Boeing-Vertol, Trans-Sonics Inc., Air Force Cambridge Research Center, and the Aero-Elastic Laboratory at M.I.T. He has served on the AIAA Marine Systems and Technologies Committee, the High Speed Vehicle Committee of the American Towing Tank Conference, and now as President of the International Hydrofoil Society. He is also a member of American Society of Naval Engineers, American Institute of Aeronautics and Astronautics, and the Society of Sigma Xi.

Jay A. DeVeny is a graduate of the University of Maryland with a Bachelors degree in Mechanical Engineering. Since joining Maritime Applied Physics Corporation in 1990, he has participated in the designs of advanced marine and amphibious vehicles. He has performed detailed trials on the T-AGOS 19 SWATH ship and prepared the MSC Operator Guidance Manual for the T-AGOS 19 Class. He was involved in the design and currently heads the construction of the Hydrofoil Small Waterplane Area Ship (HYSWAS) Demonstrator. He is a member of the international Hydrofoil Society and the American Society of Mechanical Engineers.

Daniel Jordan is a graduate of the University of New Orleans and Florida Institute of Technology with Bachelors and Masters degrees in Electrical Engineering. He has worked for seven years on the design of microprocessor based control systems for advanced marine vehicles. Currently employed by Maritime Applied Physics Corporation, he is participating in the development of a motion control system for a 27ft HYSWAS Demonstrator. He is a member of the International Hydrofoil Society.

Abstract

Carderock Division, Naval Surface Warfare Center (CDNSWC) awarded a contract in 1993 to Maritime Applied Physics Corp. (MAPC) for Phase II of the Hybrid Hydrofoil/Hydrofoil Small Waterplane Area Ship (HYSWAS) demonstration project under the Navy's Small Business Innovation Research program. The objective of the project is to build a craft that offers an affordable technology demonstrator of the HYSWAS concept while concurrently providing a potential, near-term alternative for the U.S. Navy's emerging need for an unmanned, high-speed, rough-water-capable craft that is deployable from another vessel. The paper describes the concept, design, and fabrication of the 27-foot, 12-ton, 35-knot Hybrid Hydrofoil craft.

Introduction

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.

Compared to the conventional monohull, and even the hydrofoil, air cushion vehicle, surface effect ship, and small waterplane area twin hull (SWATH) "advanced vehicle" forms, Hybrid Ship concepts were 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".

The Hybrid Marine Interface Vehicle Program considered three types of lift available for surface ships: buoyancy, dynamic lift, and powered static lift. These were combined in various proportions using at least two types of lift. This early work on Hybrid ship concepts has been described by Jewel, Gersten and Meyer (Ref. 1, 2, 3).

Because of its advantages, the Hybrid Hydrofoil, and its forerunner, Hydrofoil Small Waterplane Area Ship (HYSWAS), have received attention by the U.S. Navy R&D community, and more recently, by the commercial sector, both in Japan (Techno-Superliner TSL-F) and Germany.

Early design work that contributed to development of the Hybrid Hydrofoil concept includes the Hydrofoil Small Waterplane Area Ship (HYSWAS). This form has a single long strut that connects the submerged lower body to the main upper hull to support the ship's weight along with a fully-submerged foil system on the lower body.

HYSWAS research in the 1970s was documented by Lee, Nappi, Meyer and King (Ref. 4,5,6). The investigations of HYSWAS were, to a large degree, aimed at designing a two thousand ton ship. 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. Numerous other studies, experiments, investigations followed in latter part of the 1970s and the 1980s (Ref. 7 through 20).

However, finally, under a Phase I Small Business Innovation Research (SBIR) contract in 1992, MAPC extended the range of design experience down to a 12 long ton craft that could be potentially used by the U.S. Navy in an unmanned configuration in an autonomous or remotely controlled mode. The Navy functions of the proposed 12-ton vessel could fall under the category of PICKET duty and could potentially include mine countermeasures, signature generation, standoff sensing, remotely controlled decoy, and remote reconnaissance. A rendering of the manned version of the vehicle is shown in Figure 1.

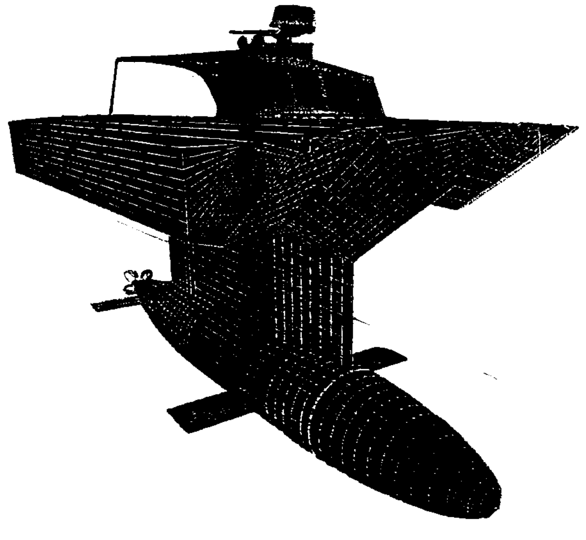

Figure 1 - HYSWAS Demonstrator

Carderock Division, Naval Surface Warfare Center awarded a contract in 1993 to Maritime Applied Physics Corp. (MAPC) for Phase II of the Hybrid Hydrofoil (Hydrofoil Small Waterplane Area Ship) demonstration project under the Navy's Small Business

Innovation Research program. The objective of the project is to build a craft that offers an affordable technology demonstrator of the HYSWAS concept.

The craft will carry a mission payload of 2500 pounds. It uses an "airplane" foil configuration with a large set of foils 9-feet aft of the bow and a smaller set of foils at 23 feet aft of the bow. The span of the main foil is 10.6 feet while the upper hull has a beam of 12 feet. When foilborne, total lift is distributed between the buoyancy of the craft's lower hull and strut, and the dynamic lift from its foils.

The HYSWAS Demonstrator is actively controlled by an automatic foil and rudder control system. The control system receives sensor input from accelerometers, engine tachometer, foil position sensors and a height sensor. The control system is similar to those presently in use on small SWATH vessels. The seakeeping performance of this small craft is predicted to be exceptional for its size. Modeling indicates acceptable motions and slamming through 6 foot seas at 30 knots and through 8 foot seas at 20 knots.

Phase II involves the construction of a 27 foot, 12 ton, 35-knot Hybrid Hydrofoil. The 21-month fabrication, shop test and builder's trials started in December 1993. Bath Iron Works is a major subcontractor who provided all the plating cut and formed for the upper hull, strut and lower hull. Automatic control system development work was performed by Dynamics Technology, Hawaii. The vessel is being assembled at MAPC, Laurel, MD.

The present 27-foot HYSWAS was conceived and designed for three purposes: a) to demonstrate HYSWAS hull form technology, b) for direct U.S. Navy application in unmanned mission applications, and c) to serve as a catalyst for commercial development of HYSWAS craft. The Phase I HYSWAS design provides a small and relatively inexpensive manned HYSWAS demonstrator while concurrently offering the Navy a craft that has direct mission applications. Since this design was developed in anticipation of the eventual use or the craft as an unmanned vessel that is operated in conjunction with the surface fleet, the size of the craft was constrained such that it could be hoisted and stowed onboard a surface combatant, and also could be constructed at moderate cost.

Commercial, or Dual-Use Technology Transfer, applications envisioned for HYSWAS technology include high-speed passenger transport, high-priority intermodal cargo movement, and specialized functions such as geophysical research, offshore platform supply, and oceanographic/environmental research.

HYSWAS Demonstrator Design Development

Design Initiation

A series of five hull variants were considered during the phase 1 design study. One of the criteria for hull form selection was operation in sea states 4 and 5. This requires a strut that is proportionately "taller" than would be the case on a larger HYSWAS designed for the same sea states. The hull form that was selected is shown in Figure 1.

Hydrostatic and seakeeping considerations dictated the placement of propulsion machinery in the lower hull. Placement of machinery in the upper hull would have resulted in a high center of gravity and a complex drive-train. A high center of gravity has negative effects on at-rest hydrostatics and on the at-speed, foilborne roll moments.

This design utilizes a single strut configuration. Other strut concepts have been used in a recent foreign design. Tow tank resistance tests on a single strut concept provided risk reduction in the present design.

Foil Selection

The selection of foils for the HYSWAS was dominated by dynamic lift require-ments for active motion control in seas with significant wave heights to 8 feet. The static running lift can be met with relatively small foils. The forces and moments required to counter dynamic loads are several times higher. The arrang-ement of the main and aft foils on the lower hull is shown in Figure 2. Roll moments have been given a great deal of consideration in the design since they impose the most taxing structural requirement.

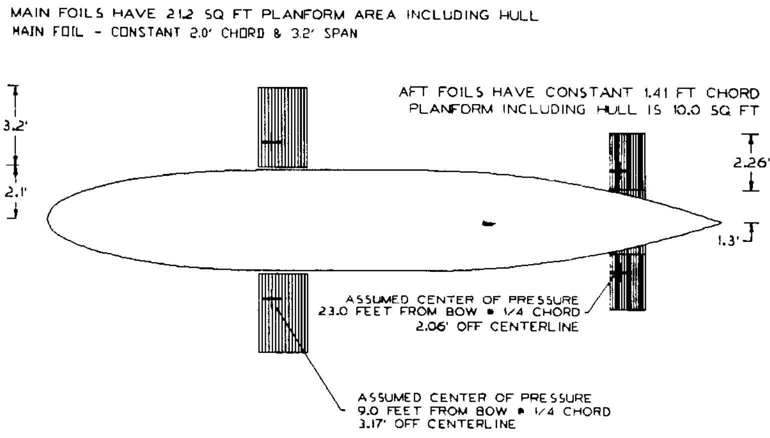

Figure 2 - Foil System Arrangement

Hydrostatics

The center of buoyancy on a HYSWAS is lower than on a conventional hull. Propulsion machinery and fuel have been located in the lower hull to keep the center of gravity as low as possible. The net result of the low center of buoyancy and high center of gravity is a requirement for a relatively large beam to provide the waterplane inertia necessary for adequate transverse hullborne stability. Hydrostatics of the foilborne HYSWAS provide a measure of the static instability of the craft and provide a first method of estimating the roll and pitch moments that must be dynamically produced to stabilize the craft. Additional pitch and roll moments are available to counter the dynamic effects of operation in a seaway.

Damage Stability

The craft is subdivided by transverse watertight bulkheads. The upper and lower hulls do not have watertight horizontal boundaries between frames 6 and 21; however, the upper and lower hulls are individually tight forward of frame 6 and aft of frame 21. See Figure 3 for an inboard profile of the vehicle.

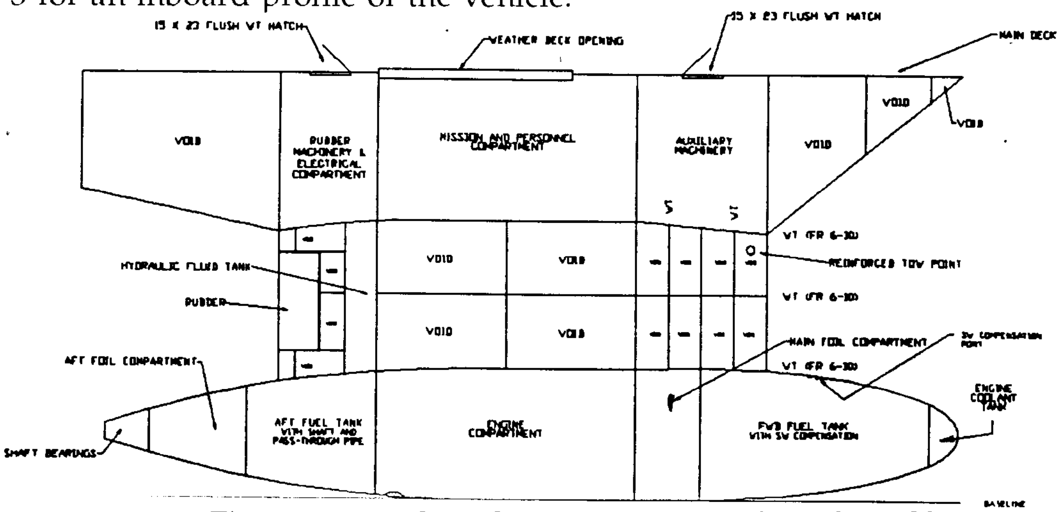

Figure 3 - HYSWAS Demonstrator Inboard Profile

Resistance and Powering

Foilborne resistance and powering calculations were performed using software developed for SWATH hullforms. The program does not account for low-speed wavemaking drag of the upper hull prior to the transitions from displacement to planing modes and between planing and foilborne modes. These estimates have been separately developed using methods for planing craft.

The drag values for the body and strut assume that the lower hull remains at zero angle-of-attack throughout the foilborne speed range. The foil drag estimates include profile drag, induced drag and aft foil drag due to downwash effects. The estimate did not include wavemaking drag from the foils since this was judged to be small.

Machinery Design

The propulsion engines analyzed in the HYSWAS design included 3 diesels and a gas turbine. To evaluate the relative weights of engine plus fuel, three different mission profiles were assumed as follows:

1) Short duration, constant speed
2) Medium duration, mix of operational speeds
3) Long duration, relatively low speeds

In each case, the weight of interest is the propulsion engine weight, plus the fuel weight, required to meet mission objectives. To accommodate differences in boat size, these are compared as weight fractions rather than absolute numbers. The gas turbine option is competitive only for the short duration high-speed missions. As a result of these studies, a high-performance Cummins diesel was selected.

The location of the propulsion engine in the lower hull is driven by hydrostatic considerations. The lower hull location results in a simple and lightweight drive line; though engine maintenance access is difficult. In larger designs, access through the strut would be practical. Access to the HYSWAS is provided via removable panels on the lower hull surface. The panels provide access for all preventative maintenance and most repair functions. All hydraulic components, including servo valves, cylinders and flexible hose segments, can be replaced via access panels. Major overhauls of the propulsion engine and reduction gear will require the aluminum hull to be cut and rewelded following the completion of repairs. The current design has a 500 gallon fuel capacity.

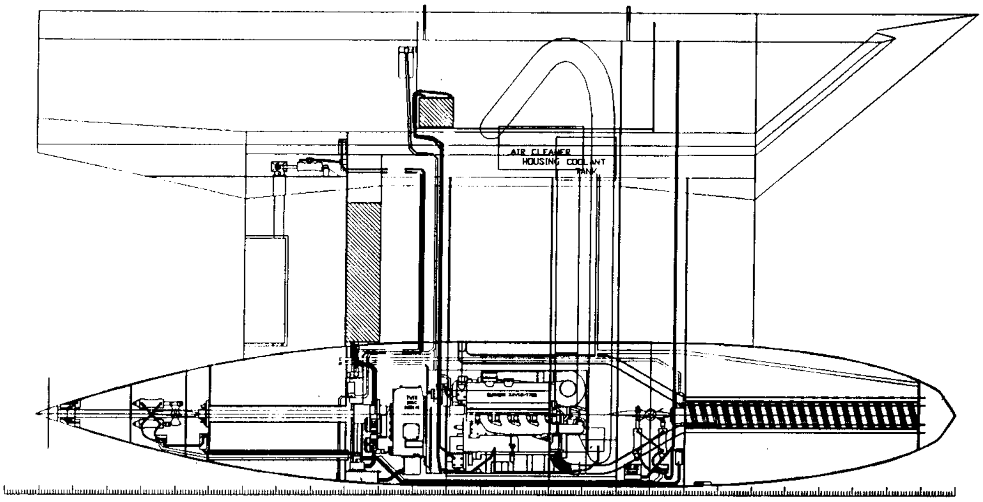

Figure 4 - Propulsion Machinery Layout

The engine and machinery installation, as shown in Figure 4, incorporates a number of features that enhance the maintainability of the remotely located components.

a) The engine oil sump is accessible from topside such that oil can be added or removed while the craft is in the water.

b) The fuel filters/water separator are located in the upper hull to allow routine bleeding of water and ensure frequent changing of filters.

c) The engine air filter is located in the upper hull.

d) Batteries and major elements of the electrical system have been located in the upper hull.

e) The lubrication ports for the control surface bearings are located in the upper hull machinery compartments.

f)The engine coolant, aftercooler coolant and hydraulic fluids can be filled through plumbing in the upper hull.

Main Reduction Gear

The HYSWAS uses a production gearbox developed for police boats. The transmission has a "trolling" valve that allows the output shaft speed to be lowered below the value that corresponds to engine idle speed. This is particularly important in a 38 knot craft where the idle speed of the engine corresponds to a boat speed of 8.5 knots. Use of the trolling valve will be necessary when berthing the vessel or when operating at speeds of less than 8.5 knots. A reversing gear further enhances the low-speed maneuverability of the craft.

Cooling System

Engine cooling is accomplished through an integral keel cooler at the bow of the lower hull. A series of baffles is used to circulate the coolant and obtain the required heat transfer. This arrangement eliminates the need for a raw water cooling system where strainer cleaning would be inaccessible. The keel cooler capacity was designed to supply cooling water for the engine and transmission. The engine aftercooler has a separate keel cooler system due to its lower fluid temperature.

Hydraulic System

The hydraulic system utilizes a variable-volume piston pump driven by the transmission's live power take-off to supply hydraulic pressure. The pump has pressure compensator control to allow fluid pressures to range from 250 to 3000 psi. The hydraulic system was designed to accommodate the maximum pump pressure if required.

The five active control surfaces are actuated by servo-driven hydraulic cylinders. A high degree of reliability was sought in the hydraulic system due both to the difficulty of reaching many hydraulic components and the critical nature of their performance. Stainless steel fittings with flange-type O-Ring seals are used on all piping to reduce problems associated with fitting vibration, and flared fitting failures.

Navigation Systems

The craft is equipped standard navigational equipment including an electronic chart utilizing a Digital Global Positioning System (DGPS). This system allows charted minimum water depths to be present at selected distances surrounding the vessel such that an alarm is sounded when the water depth criteria is violated.

Structural Design

The HYSWAS design was started assuming carbon fiber and arramid fiber composite construction. Early in the program the results of CDNSWC HYSWAS model testing were reviewed to obtain representative loads data. These data indicated complex combinations of forces and moments. The stress vectors that result from this loading are complex and stress directions tend to change significantly with location in a given panel. The directional sensitivity of composite strength was judged to be a weakness in the current design pending better measurements of stress vectors in the structure.

As a result of this data, the decision was made to design the current hull in aluminum with the option of converting to composite construction in subsequent hulls following the detailed measurement of stresses in the prototype. The aluminum alloy 5456-H116 was selected as the hull material for its superior strength, fatigue resistance, formability and corrosion resistance.

Load Criteria

Load criteria were established by using a combination of model test data and planing hull prediction criteria. The model test data was collected during testing of a 1/20 scale model of the Extended Performance Hydrofoil (EPH) at CDNSWC Maneuvering and Seakeeping (MASK) facility.

Despite differences in configuration and the lack of directly relevant roll and pitch moment data, the EPH data reported is the only measured data available for a HYSWAS design and was therefore used as a major resource in predicting the primary loads that the current design will experience.

Secondary loads on the HYSWAS design consist of slamming loads on the upper hull bottom plating and hydrostatic loads to VEE lines that start on centerline at the weatherdeck and extend outboard at an angle of 40 degrees above the horizontal. The wet deck slamming loads were evaluated as they would be on a planing craft. Slamming loads on the upper hull were the driving design criterion in the selection of shell plating and stiffeners. The methods of Heller and Jasper as well as those of Silvia for planing hull structures were used to facilitate the structural design of the upper hull.

The upper and lower hull stresses were evaluated using established criteria that are backed with a corresponding experience base (Navy DDS 100 and/or ABS Aluminum Rules). The strut, however, is a unique structure that is internally complex and is relatively highly loaded. As a result, it was deemed necessary to analyze the strut using a relatively detailed finite element model.

Foil Control System

The MAPC foil control system is built around a single board computer, which is powered by an Intel 80C186 embedded microprocessor and an 80C187 numerics processor. The single board computer uses high speed RAM to store temporary variables, and includes a lithium battery to save operator adjustable information after system power down. The software is stored in FLASH EPROMs, which can be programmed directly from any personal computer without the use of external EPROM programmers or ultra-violet erasers. In the event that software updates are required, the single board computer can be easily connected to a notebook computer via one of the two on-board serial ports.

The system includes 32 analog to digital (A/D) converters for input of analog signals from various sensors, and 8 digital to analog (D/A) converters for output of command signals to position the control surfaces. All A/D and D/A converters are 12-bit devices, which provide ample resolution for input/output signals. An individual signal conditioning module is used to scale and filter the signal from each of the ship's sensors. A variety of sensors will be used for controlling craft motions and providing the operator with system operating parameters. Craft attitude and motion information will be measured using 3-axis angle, angular rate, and acceleration sensors. Several sensors will be installed to measure control surface position, craft depth, craft speed, hydraulic system pressure, and fuel level.

The operator will have a small display unit which will provide sensor information and allow for input of various control parameters. The display unit incorporates a 4 row by 40 character vacuum fluorescent module, which produces easily readable 5mm high digits with a pleasant blue/green color. The display has four software selectable brightness levels, and operates over a high speed serial line which allows the display to be mounted remotely from the single board computer enclosure.

The entire system operates from 28 Vdc, and includes DC/DC converters to develop system voltages which are isolated from the 28 volt power supply signal and return lines. The system is designed with emphasis on minimizing EMI/RFI noise, both to and from external sources, and much attention is paid to the use of proper grounding techniques for system voltages and cable shields.

Demonstrator Applications

The attributes of the HYSWAS hull form are ideal for an unmanned picket craft. The HYSWAS hull form offers a stable and sea-capable platform in small sizes with speed attributes approaching those of a conventional hydrofoil.

The HYSWAS demonstrator craft described in this paper has a potential mission payload of 2500 lbs at the main deck level. This capacity is limited by the at-rest hydrostatics of the craft. The 500 gallon fuel capacity is not included as part of this payload. The payload capacity could increase as the center of gravity for the mission equipment is lowered.

Application options for this craft typically involve a mother-daughter relationship between the craft and a larger vessel. Those envisioned are functions where the craft serves as a remote sensor, provides a remote signature, or conducts operations that would pose an unacceptable risk to a host ship.

Several of the potential options for the HYSWAS demonstrator size vehicle with a mission payload at 2500 lbs are listed below. This list is not comprehensive and contains only an initial selection of possible applications of the HYSWAS Demonstrator or some variant in the same size category.

1) Deception
2) Mine Countermeasures equipment
3) Mine Deployment
4) Target designator

Potential Applications of HYSWAS Technology

A number of application studies clearly indicated that the Hybrid Hydrofoil HYSWAS hullform offered considerable potential improvement over current small monohulls in terms of maximum speed, motions in rough water, and range at high speed. Compared to the conventional hydrofoil with a fully-submerged foil system, the Hybrid Hydrofoil provides considerable range improvement as a tradeoff for <u>very</u> high speed capabilities.

PHM Hybrid Variant - During the 1980s, studies were made to improve PHMs and to plan for its mid-life improvement and conversion. One approach taken by researchers at CDNSWC was a PHM Hybrid variant (Ref. 21). 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 PHM Hybrid Variant consisted of the current PHM hull with major changes only to the foil system, hullborne and foilborne propulsion systems. Although, not essential for this concept, modification of the ship service power unit were also considered.

The 475-ton Hybrid Hydrofoil, shown in Figure 5, 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 offered the potential for promising benefits for fuel/military payload tradeoffs. By-products of this innovative design were low foilborne wake signature, the potential for sonar installation in the lower hull's nose section, minesweeping, increased military payload potential, reduction of weight constraints, refueling cycle improvements, long-range ferry operations.

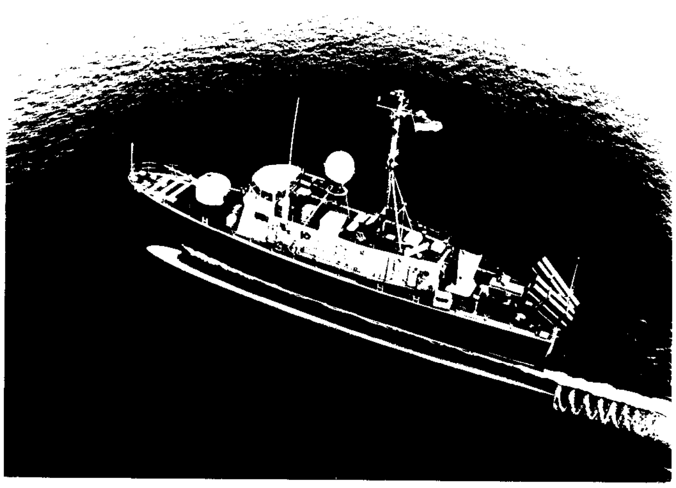

Figure 5 - PHM Hybrid Variant

Hybrid Hydrofoil Multimission Deployable Vehicle (HH-MDV) - A feasibility design was carried out at CDNSWC to satisfy a particular set of requirements for which a Multimission Deployable Vehicle (MDV) would be deployed from the well deck of a Carrier Dock Multimission (CDM) ship (Ref 22). It would operate approximately 150 nm in advance of the battle force on three to five day missions. The MDV would have the capability to act as an independent LAMPS III platform to extend the helicopter's mission duration, and therefore the MDV has landing, refueling, and rearming capabilities. The HH-MDV 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 CDM. Through removable mission modules, the MDV could play a variety of roles from ASW to drug interdiction operations. The HH-MDV would have a maximum speed of approximately 45 knots through Sea State-3 and be mission capable through SS-5.

The 416 L ton HH-MDV concept design, illustrated in Figure 6, examined in the feasibility study 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.

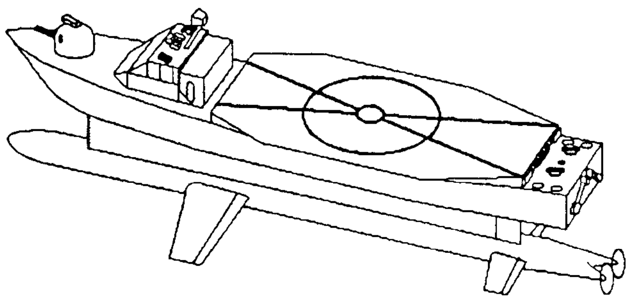

Figure 6 - Hybrid Hydrofoil Multimission Deployable Vehicle (HH-MDV)

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 operation and maneuvering capability.

Hybrid Hydrofoil Small Combatant (HHSC) - This conceptual Hybrid Hydrofoil Small Combatant is about a 2,200 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. The HHSC, illustrated in Figure 7, is essentially a derivative of the HYSWAS 2000 concept described in Reference 6 and others.

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 includes two propellers on the stern of the lower hull with the entire propulsion system (except for up and down-takes) in the lower hull.

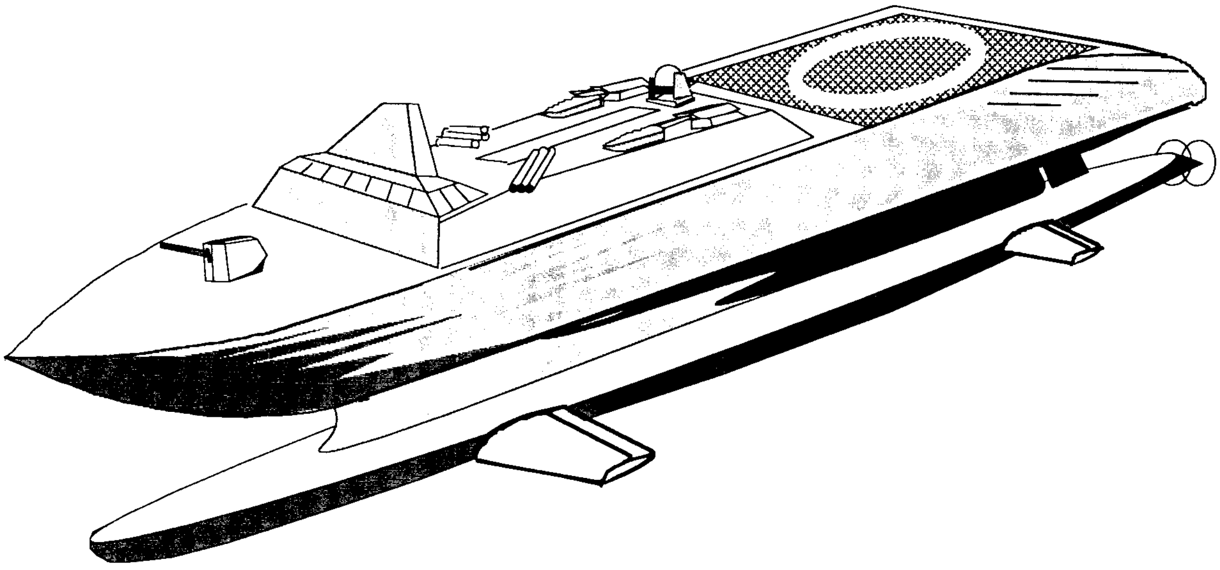

Figure 7 - Hybrid Hydrofoil Small Combatant HHSC Concept

This form of the Hybrid Hydrofoil concept provides an opportunity to incorporate a quantity of missiles in a vertical launch system (VLS). These are distributed in a double row along the centerline of the ship. There is considerable depth (about 35 feet) in this small ship from the upper surface of the deck to the bottom of the lower hull. This provides adequate space for such missiles and is a significant advantage of the concept.

Potential 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.

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FOILCAT 2900

DESIGN AND PERFORMANCE

By
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ABSTRACT

This paper describes the design and development of the first Foilcat built in Norway and presents some results from the full scale trials. Propulsive performance, seakeeping behaviour and operability are discussed.

INTRODUCTION

Yard no. 107 from Westamarin West A/S in Mandal is the first Foilcat to be delivered by the yard. The craft is a further development of previous hydrofoils and catamarans built at Westamarin West. The design work started in 1987 and will be regarded as completed when the craft has been in service for some time under different conditions.

The Foilcat is a slender catamaran hull equipped with fully submerged foils. Some of the main reasons for fitting a catamaran hull with foils has been to increase the speed in calm water, to reduce the speedloss and to increase the passenger comfort and operability of the craft.

As the foils are not surface piercing, they have no stabilizing effect. Stability is obtained by flaps on the foils, hydraulic actuators, electrically controlled valves and a Flight Control System developed by Camo A/S/Dynamica A/S in cooperation with Simrad Robertson A/S.

MAIN CHARACTERISTICS

Length over all	29.25 m
Breadth mld.	8.36 m
Depth mld. to main deck	3.70 m
Maximum draught incl. foils	3.70 m
Maximum draught reduction when lifting	1.90 m
Span of rearfoil	7.79 m
Span of front foil	2.50 m
Maximum displacement	122.5 metric tons
Main engines output	2* 2000 kW
Propeller diameter	1.25 m
Number of passengers	140-160
Service speed	44 knots
Maximum speed	49 knots
Classification	DnV +1A1, R90 Light craft, Passenger Catamaran, E0

FOIL AND STRUT SYSTEM

As shown on fig. 1 the craft is carried by 3 foils, two front foils and one rearfoil in the same horizontal level. The rearfoil carries about 60% of the weight. The strut of the frontfoils act as rudders and can be turned +/- 25 degrees.

The craft is operated by two MTU 16V396 TE74L diesels and two 4 bladed Ulstein propellers, operating as tractorpropellers on a Ulstein-Liaaen SpeedZ drive combined with the struts carrying the rearfoils.

In foilborne condition frictional resistance is the main component of the resistance. Therefore, in order to keep the resistance at a minimum and to enlighten the maintenance, the foils are made from stainless steel with the same surface roughness as on the propellers. Foil and strut sections are of the laminar type.

Each front foil is equipped with a flap and the rearfoil with three flaps, allowing the craft to be taken completely out of the water down to a speed of approximately 28 knots. The craft is fully controlled by use of the flaps.

The chordwise camber and thickness distribution of the foils are such that cavitation is at a minimum for flap angles around 2-3 degrees.

MODEL TESTS

The design started with calculations of the resistance and towingtank tests at Marintek, including a study of the performance in waves.

The original idea was to stabilize the craft only by buoyancy of the hulls. To determine if this was possible, tests with a seagoing radio-controlled model were done. These tests clearly demonstrated that the craft had to operate fully controlled and that a fully foilborne craft had much smaller resistance than a partly immersed craft.

Different foil-combinations were investigated until the version shown in fig. 1 with two separate turnable frontfoils was selected. A prior version with a single transverse frontfoil was abandoned due to bad behaviour in waves and because the rearstrut rudders cavitated and ventilated.

In order to avoid cavitation on the rearfoil caused by downwash from the frontfoils, several load distributions were tried out before we ended up with a version having spanwise variable angle-of-attack and camber. The entire foil and strut system, including operating propellers, was tested in the cavitation tunnel at the Technical University of Berlin at different immersions, foil angles and strut angles. This tunnel has a free surface allowing to study side forces and lift at correct cavitation and Froude numbers and to study propeller and strut/foil ventilation.

In order to increase the lift/drag ratio of the frontfoils they were equipped with winglets. Different winglet alternatives were tested.

Results from the tests were used in the simulation model developed for control of the craft. Fig. 2 and 3 show some results from side force and lift measurements at different yaw angles of the strut. It is demonstrated how lift and side force will drop suddenly if a certain angle is exceeded. In full scale the control system keeps the angle below the critical angle. The tests showed that cavitation would increase the foildrag considerably. Everything was, therefore, done to avoid cavitation even if it did not cause erosion.

The propellers, which are of the Newton Rader type, were designed to operate cavitation-free in the speed range of 45 to 50 knots absorbing 2000 kW each at RPM around 800.

Several propellers were then tested in Marintek's cavitation-tunnel in Trondheim. Thrust and propeller-induced drag on the rearstruts and pod of the SpeedZ drive were measured at different speeds or cavitation numbers. Fig. 4 from the tests shows the high efficiency of the propeller.

During the testing special attention had to be paid to the shaping of the fillets between foils and struts.

Because struts and rearfoil operate in the propeller wake there was a danger of propeller induced cavitation on struts and foil. This had to be considered in the design of the struts and the foil. The struts were shaped with a twist and the propeller induced velocities included in the local velocity determining the pitch of the foilsections. Different alternative strut shapes were tested.

One reason for choosing propellers was the high efficiency of tractor propellers combined with Z-drives. The tests showed that the propeller efficiency could be as high as 0.81 in service with an increase in resistance of about 3.5 % giving a total propulsive efficiency which was far above the efficiency of a waterjet. At take-off speed this difference in favour of propellers increased.

The craft operates at different drafts, sometimes with the hull in water and sometimes with the hull out of the water. Spray from the struts interfers with the hull and will increase the drag of the hull if the rear of the hull is not properly designed.

Aerodynamic forces are also important. Dependant on superstructure and tunnel shape, the craft may be exposed to negative or positive lift and moments. In order to study these effects the craft with struts and superstructure but without the foils, was tested in the towingtank at different speeds, pitch angles and immersions. Drag of hull and struts, due to aerodynamical and hydrodynamical forces, and lift and moments were measured.

PROPULSION AND RESISTANCE

The propellers have so far performed in accordance with expectations without suffering from cavitation. We were afraid that ventilation could occur since the propeller tips now and then came close to the surface.

During the trials we observed ventilation a few times, especially in waves. This ventilation was considerably reduced by adjusting the trim angle and by increasing immersion at the rearfoil under severe weather conditions. However, ventilation never reached the extent seen onboard SES vessels.

The resistance of the craft was determined based on model tests and numerical calculations. Fig. 5 shows an example of calculated resistance at a displacement of 112 tons for different immersions. It is a clear dependence on the immersion and the typical resistance-hump at take-off can be avoided by controlling the immersion as a function of speed.

It is observed that the craft at low speed can not be lifted too much by the foils without an increase of resistance. At high speed it is opposite. In practice the control system will optimize the velocity-immersion relationship.

In short waves of some height the waves will "wash" along the hull and give added resistance. Together with the wind resistance this is the main components of the added resistance. Resistance due to wave reflections and -motions are less important. The waves can even set up a propelling force.

In longcrested sea when the craft is contouring the waves, it is possible to keep the hull out of the water and the added resistance is reduced considerably.

The trials showed that the relationship between calculated and measured power was good. In fig. 6 measured power for different speeds, waveheights and immersions has been plotted. The spread is caused by the differences in immersion. If the results measured in calm water and in waves are corrected for wind and average immersion, the spread is reduced to a minimum and will be more in accordance with the trend in fig. 5.

SIMULATION MODEL

Because the craft is operating fully controlled, it was necessary to develop a control system and a simulation model describing the behaviour of the craft. This model was also used to study the behaviour of the craft at a primary stage in different extreme situations like capsizing.

The simulation program contained the following elements:

- Resistance at different immersions and speeds in waves and calm water.
- Aerodynamical and hydrodynamical lift, forces and moments on struts, hull and foils in calm water and waves.
- Lift and moments from flaps in calm water and different wave situations.
- Influence of ventilation and cavitation on struts and foils
- Propeller thrust and power for different speeds, RPM and pitches.
- Influence of immersion on propeller thrust and torque.
- Balance of forces and moments in 6 degrees of freedom.
- Motions and accelerations in 6 degrees of freedom with active flaps and control system.

The program was developed by Camo A/S/Dynamica A/S based on a numerical model describing the hydrodynamical characteristics of the craft. This model was developed at Marintek and was based on theory and experience from the model tests. Criteria for ventilation and force reduction due to cavitation had to be entirely based on model test results.

OPERATION OF THE CRAFT

HULLBORNE MANOEUVRING

During hullborne manoeuvring the propellers are controlled separately and this gives a very good manoeuvrability at low speed. The rudders are always electrically synchronized and cannot be operated separately.

The propellers can be operated by means of combined control, i.e. that the engine RPM and the propeller pitch are controlled following a programmed curve based on optimal thrust in the lower RPM range and economical operation in the upper range. Fig. 7 shows how the combined pitch/RPM curve is plotted compared to the engine's MCR-curve.

A selection of fixed RPM is included which has proven useful during manoeuvring in narrow harbours as the RPM is locked and only the propeller pitch is adjustable. The thrust is controlled rapidly and only dependant of the movement of the propeller pitch.

The stabilization system, Flight Control System (FCS), for the craft's trim and roll movements is not active at manoeuvring speed, as these functions are dependant of lifting forces given by the foils. Due to the low speed, the vessel can only be hullborne and is thereby stabilized by the hull as an ordinary catamaran.

ACCELERATION AND LIFTING

During acceleration and lifting of the craft, the normal procedure is to set the height-order to the wanted value prior to increasing the speed. As the speed increases the lift from the foils is increasing and lifting the craft smoothly out of the water. This will also give a minimum of acceleration time by using the lift as soon as it is created and reduce the hull resistance gradually.

In this way there is no exact limit between hullborne and foilborne condition, as the transition between these conditions are gradually. For the stabilization of the craft there is, however, a limit related to a lifting height where the hull cannot give sufficient stability alone. See fig. 8.

At a speed of approximately 10 knots the Flight Control System is activated. The stabilization is automatic and the trim is kept at +1 degree and the roll is damped in accordance with the available lifting forces from the foils. This limit is lower than the speed necessary to lift the hull into instability, at approximately 28 knots, as shown on fig. 8. This means that the FCS has control of the stabilization long before it is possible to enter the lifting height giving insufficient hull stabilization. The transition between the hullborne and the foilborne condition is then fully controlled, and the crew can verify proper functioning of the FCS prior to entering the unstable displacement.

It is not required to perform any special action in the moment the foilborne condition is reached, as the automatic FCS is already in operation and in control of the lifting height and the craft's trim and roll movements.

A load controller is included in the propeller remote control system, and based on fuelrack and RPM readings, this function will automatically reduce the propeller pitch if a programmed load curve is exceeded. A signal lamp will inform the crew about this action.

Height order, achieved height, trim and roll angles can be read on a screen mounted in the front indication panel between the captain and the mate. This panel gives also indications of engine RPM, propeller pitch, rudder angles and speed.

FOILBORNE

When the correct height is achieved, this can be read from the indication screen together with the values as mentioned above. The crew use this to verify that all automatic systems are functioning satisfactorily. It is the crew to decide if the lifting height and/or the speed must be reduced to keep within the operational restrictions and for the comfort of the passengers. The FCS will give warnings only when a ventilation danger occurs or when a component fails. The FCS requires no adjustments of orders or parameters in order to maintain the automatic functions. However, the crew must decide how this operation is solved and if necessary take control to avoid unwanted effects on comfort and vessel's performance.

A change of the lifting height can be done at any time when foilborne, and the speed can be adjusted as wanted within the range of the height-order given.

If a critical failure arises in one of the main units for propulsion, steering and stabilization, a signal lamp will be activated and clearly indicates which unit has failed. A buzzer will sound when a lamp is lit. Automatic reduction of speed is not included as the navigator must evaluate the current situation given by other traffic and obstacles when a failure occurs, and react accordingly.

STEERING AND STABILIZATION

The rudders are of course always controllable, and can be moved either by use of a control handle or the autopilot, common for both rudders. At a certain combination of rudder order and speed a banking angle will be introduced during the turn. This is an automatic function included to reduce the horizontal acceleration force on passengers and craft. The banking is done with the outer hull kept in position, preventing suction of air to the propeller and ventilation danger on the foils. The rudder angle is limited in accordance with the speed in order to keep the rudder deflection within hydrodynamic limitatons. The rate-of-turn is approximately constant at the same rudder order at all speeds. The rate-of-turn is also indicated on the indication panel. The maximum rudder angles are +/- 25 degrees.

CRASH-STOP FROM FOILBORNE

If a crash-stop is necessary, only one change of command must be done by the captain, and this is to reduce the output from the propeller to neutral (zero propeller pitch and idle RPM). The FCS will keep the trim and roll movements as long as the lift from the foils are sufficient. When the propeller pitch is set to zero, the propeller will act as a brake giving an increase of the drag and the speed is rapidly decreased. The propeller pitch can be set to astern when the speed drops to a value below approximately 15 knots. If astern pitch is ordered at too high speed, cavitation will occur and the braking force reduced.

A crash-stop performed may entail a retardation force to the passengers that results in passengers standing up tumbling down. This must, however, be accepted as the option available might be collision or grounding.

HEIGHT REDUCTION FROM FOILBORNE

When reducing the height from foilborne to hullborne, only the propeller output needs to be reduced. The height order does not need to be adjusted as the speed reduction will cause a reduction of the height when the lifting forces from the foils are reduced.

The available rapid stopping must be taken into consideration during a normal stop in order to avoid uncomfortable retardation forces on the passengers. The crew will soon learn how to do this by reading available indications, and uncomfortable manoeuvring can easily be avoided.

CRASH-STOP WHEN HULLBORNE

This is performed as described above, but the possible retardation forces are now too small to be uncomfortable as there is no big change in displacement as when foilborne.

OPERATONAL SAFETY

The vessel has two different operational modes, hullborne and foilborne.

At hullborne mode the hull gives sufficient stability. The foils will have a great stiffness against roll and trim movements giving a damping effect on these movements compared to conventional catamarans of the same size.

In foilborne mode using stabilization from the controllable flaps, the FCS has sufficient accuracy and performance to achieve safety and damping of unwanted movements, preventing ventilation of foils or loss of rudder forces.

The FCS monitors the sensors and actuators and if a failure occurs, alternative strategies in the FCS will prevent major effects on steering and stabilization. If the sea is too rough and the lifting capacity has reached its limit, a priority system is included and will ensure control of steering, roll and trim while the height is automatically reduced to save lift for the other functions. This interaction will only bring the vessel down to a safer hullborne mode.

Steering and propulsion systems are equipped with back-up systems giving full control if the main system fails. Most of the failures than can possibly occur on flaps and rudders, will put these in a forceless mode and avoid unwanted effects on the vessel's behaviour.

An alarm and monitoring system is installed to which a great number of analogic sensors are connected, giving the possibility to monitor the machinery and perform preventing maintenance and thereby avoiding break-downs. If a flap, a rudder or a propulsion system fails, the captain will get accurate information about this and have sufficient time to bring the vessel to a hullborne safe mode.

The interior of the wheelhouse has been arranged with great care to give a minimum of blind sectors and best possible control of the craft.

During the specification and development stages of the craft, and especially for the FCS, the yard has consulted Det norske Veritas and the Norwegian Maritime Directorate to get guidance about proper and correct rules and regulations. A Failure Mode Effect Analysis (FMEA) has been made and the systems designed accordingly. Fig. 9 shows the relationship between the different sub-systems, their documents and the final operation manual.

It should be mentioned that the captain and the mate must have a basic knowledge about the vessel's dynamic behaviour both at normal operation and also when a failure occurs. Judgements have to be taken into account within a short period of time based on factors as mode of operation, sea conditions, other traffic and navigational water. The effect of failures must be known and be a part of this judgement. The installed equipment will give all warnings that is necessary. Proper training at the yard will give required knowledge to be able to keep a safe operation.

PASSENGERS SAFETY

The limitations given to the control systems for steering and stabilization are placed well off the hydrodynamical and mechanical limitations. However, these are not identical with the comfort limitations for the passengers. The control system must allow the captain to keep the control even at extreme situations given by waves, avoidance manoeuvring or crash-stop. Even this manoeuvres will not have any dangerous effect to the passengers, but are not considered as comfortable. A planning of a voyage taking comfort for the passengers into consideration is only a matter of training.

On screens in front of their control positions, the captain and the mate can read all relevant information as rate-of-turn, vertical and horizontal acceleration and limits to ventilation danger. All exceeding of limit values will give a warning. None of this limit values will cause any dangerous situation for the passengers.

An indication panel for all doors leading to an open deck as well as for watertight and fire safe doors, is located in the wheelhouse giving warnings if one of these doors should be opened at sea.

The Flight Control System is developed with high requirements to performance speed and accuracy to give sufficient safety. Operations within the limitations regarding to the actual seastate will cause very small movements of the vessel and give an unique comfort for the passengers.

Fig.10 shows values from seatrials in different seastates. In order to compare these with values from other vessels, a curve made from measurements on a catamaran without foils are included.

OPERATIONAL EXPERIENCE

The extensive testing and trials of the vessel started in February 1992 and the final technical trial trips for the Authorities and the Classification Society took place in May, 1992. During the summer and autumn 1992 a lot of demonstration trips for high-speed craft operators were made. Finally, in the autumn 1992 a bareboat charter was signed with DSØ (Dampskibsselskabet Øresund) in Denmark with the option of buying the vessel.

The operator's plan was to compete with the airplanes on a route between the Danish capital Copenhagen and Aarhus located in Jutland. The travelling time from centre to centre of the two cities would be just 20-30 minutes more than with an airplane and the ticket fares somewhat lower. However, the operator did not succeed taking enough passengers from the air to the sea and thus passenger figures were too low to get a satisfactory economic result. Operating a single craft resulted in too low frequency (two trips each direction per day on this fairly long route of 105 n.miles) and the operator had no reserve craft available if a trip had to be cancelled because of technical problems (which have to be expected on a prototype craft). The operation, therefore, came to an end in March 1993.

The weather was extremely stormy during these winter months and the capability of the craft was really tried and proven. The craft operated in wave heights up to 3.5 metres and wind speeds up to 20 m/sec. Because of the rather strong currents in this area, the waves became very rough and short-crested. Our gurantee engineers were onboard on all trips during this period and they observed just 2 or 3 persons getting lightly seasick. We think that this is really proving the extremely good seakeeping characteristics of hydrofoil-catamarans with fully submerged foils. The accelerations due to pitch, heave and roll are far below those on conventional catamarans (as expected). Of the totally 297 trips planned, 22 trips were cancelled due to weather conditions more adverse than those mentioned above. On these occasions also some of the big passenger/car ferries operating in the same area had to cancel their trips. The weather conditions this particular winter were far worse than the normal.

What about the technical reliability of the craft during these 4 months then? As has to be expected for a prototype, we have experienced some technical problems and failures resulting in cancellations of totally 37 trips. The failures/problems were:

1.
Problems with Speed Z-propulsion: 27 trips.
The problems were particularly related to the ropeguard on the propeller pods. The bolting of these ropeguards were insufficient and resulting in broken bolts, loosening of ropeguards and also some damage to propeller blades. This problem was solved in cooperation with Ulstein Propeller and a stronger and more reliable bolting is now a standard from the supplier.

Further a serious material and production failure was detected in one of the Speed-Z struts resulting in cracks and water ingress into the Speed-Z oil. This failure was limited to a small area on the strut and was only finally and sucessfully repaired according to specifications approved by the classification society (DnVC) when the craft had started the operation in Indonesia (see below).

2.
Problems with the Robertson Inertial Platform System (RIPS) which is the 6-axis motion reference unit in the Flight Control System: 7 trips.

This failure caused us a lot of headache before finally finding out what was wrong and a new RIPS installed (see also below).

Generally the Flight Control System has functioned very well and all credit to the companies being involved in the development of the system.

The rest of 1993 the craft was positioned at out yard in Mandal making further demonstration and trial trips for possible buyers and operators. Late 1993 it was decided to take the craft to Indonesia as the Swede Ship Group signed an agreement with an Indonesian company to start a joint operation in that area.

Installation of an AC-plant and different other modifications and adjustments were carried out at our yard before finally shipping the craft as deck cargo on a German heavy-lift freighter to Singapore. The craft arrived Singapore in March 1994. The craft was then inspected and approved by Classification Society and Authorities before the craft finally was put into operation.

After some test trips on a rather long route between Indonesia and Malaysia in the northern part of the Malacca Strait, the craft was transferred to a route between Djakarta and Lampung (Sumatra). The distance of approx. 110 nautical miles on this route was more in keeping with the fuel oil capacity of the craft.

However, before starting the operation on this new route the RIPS was replaced by a Motion Reference Unit (MRU 6) made by Seatex A/S as the RIPS still caused some problems for the Flight Control System. This MRU is much smaller and of course lighter than the RIPS and is installed on a lot of the conventional catamarans fitted out with a motion damping system. After the necessary adjusting of the MRU and Flight Control System this replacement has proven to be very successfull and will also be mounted in our future crafts of the Foilcat type.

The craft has now been in operation for several months between Djakarta and Lampung and with a very high regularity.

Totally, we have logged close to 4000 running hours and in our view the Foilcat has more than fulfilled our expectations concerning motion characteristics and thus comfort for the passengers.

FURTHER DEVELOPMENT

As the market required a craft with a higher passenger capacity than the maximum 160 passengers for Foilcat 2900, we decided to start the development of a version with a capacity of maximum 200 passengers.

This work started in 1994 and extensive model tests at Marintek, both in the ship model basin and in the cavitation tunnel, have been carried out once more. The foils have been redesigned in order to get the necessary lifting capacity and the breadth of the craft has been increased to 9.55 m. The propulsion system will not be changed and the Flight Control System will be subject to only minor changes.

This craft, which is designated the FOILCAT 3000, is intended to be our series production version. Negotiations are going on with several operators for the time being and we hope to be able to sign contracts in the near future.

CONCLUSION

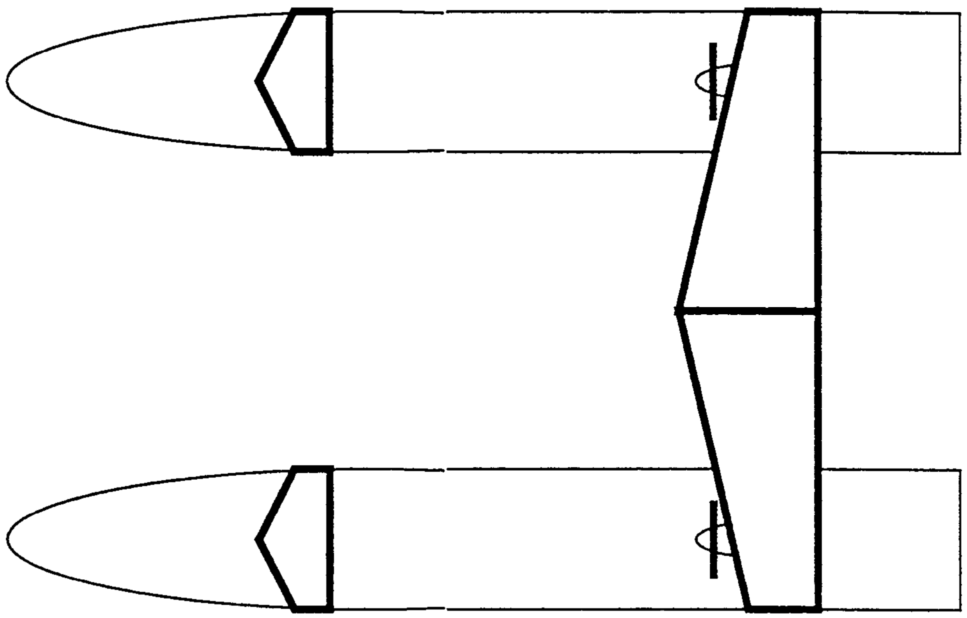
The Foilcat's performance in waves gives a new meaning to comfort. As the control system keeps the craft stable in roll, trim and height, the motions causing sea-sickness are damped to values acceptable to the passengers even on the longer voyages. The comfort combined with the high speed permit new routes to be operated at high regularity most of the year.

The Foilcat sets a new standard to the high speed passenger transportation.

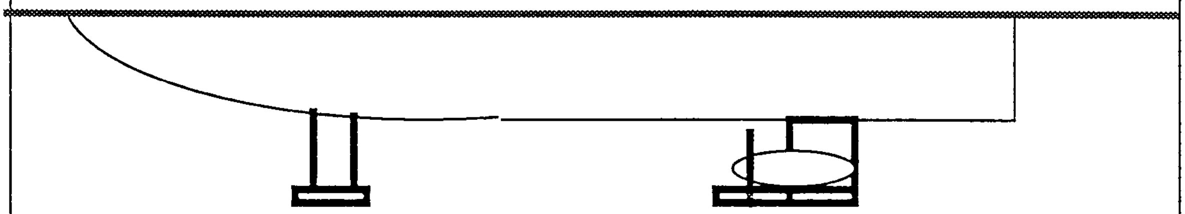
FOIL CONFIGURATION

FIG.1

BOTTOM VIEW

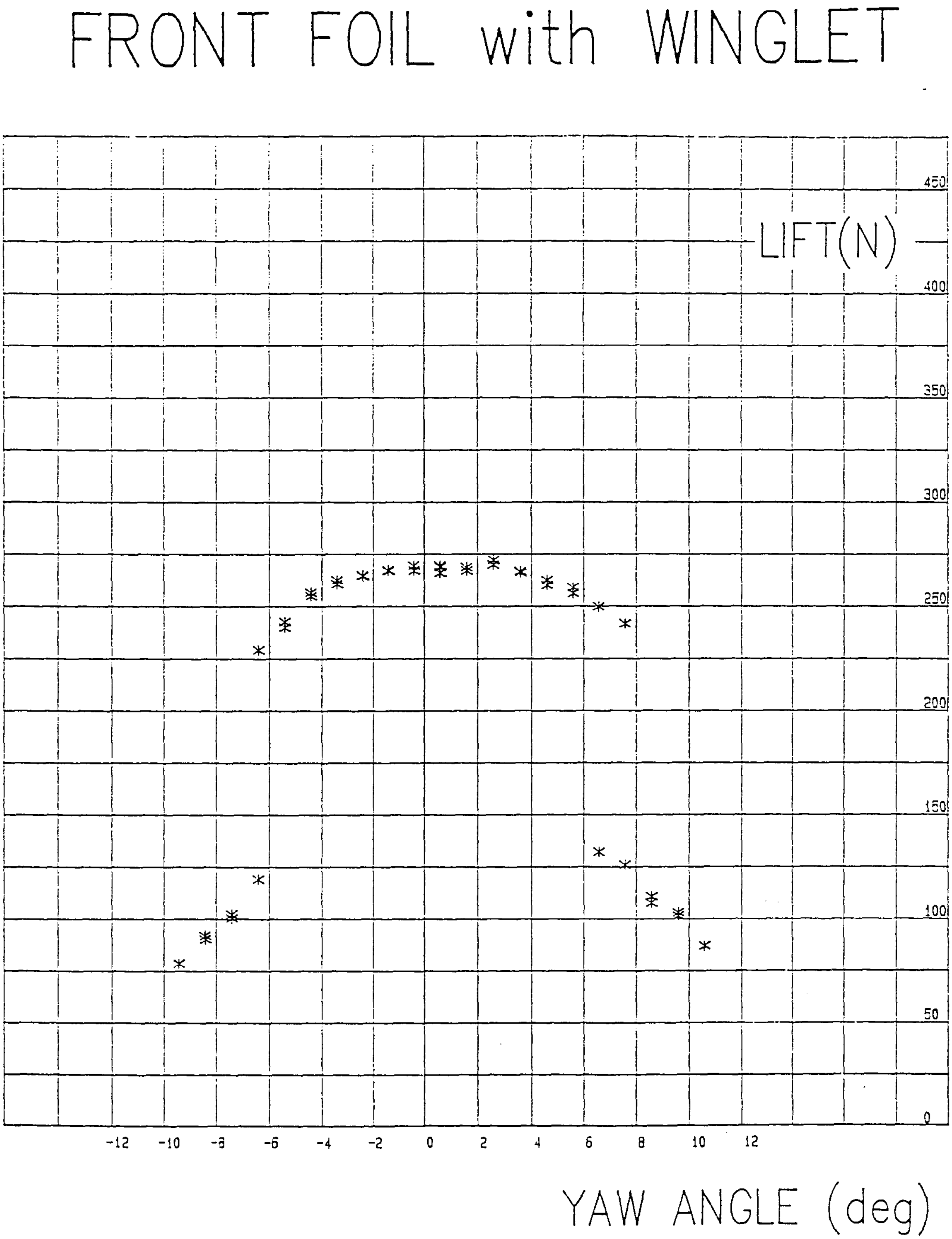


SIDE VIEW



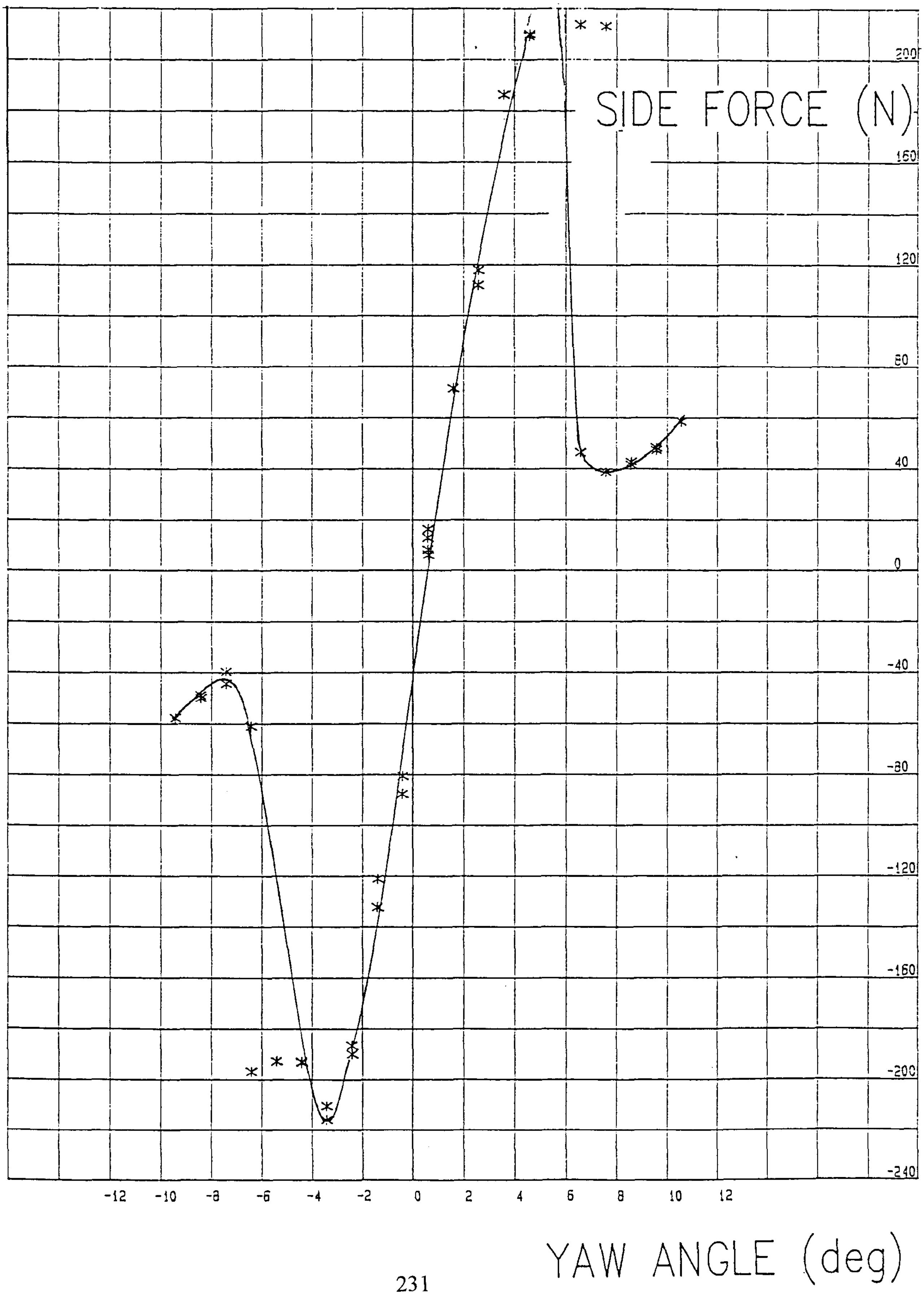
WESTAMARIN WEST A/S

FIG.2


FRONT FOIL with WINGLET
LIFT(N)
450
400
350
300
250
200
150
100
50
0
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
YAW ANGLE (deg)

FRONT FOIL with WINGLET

FIG.3



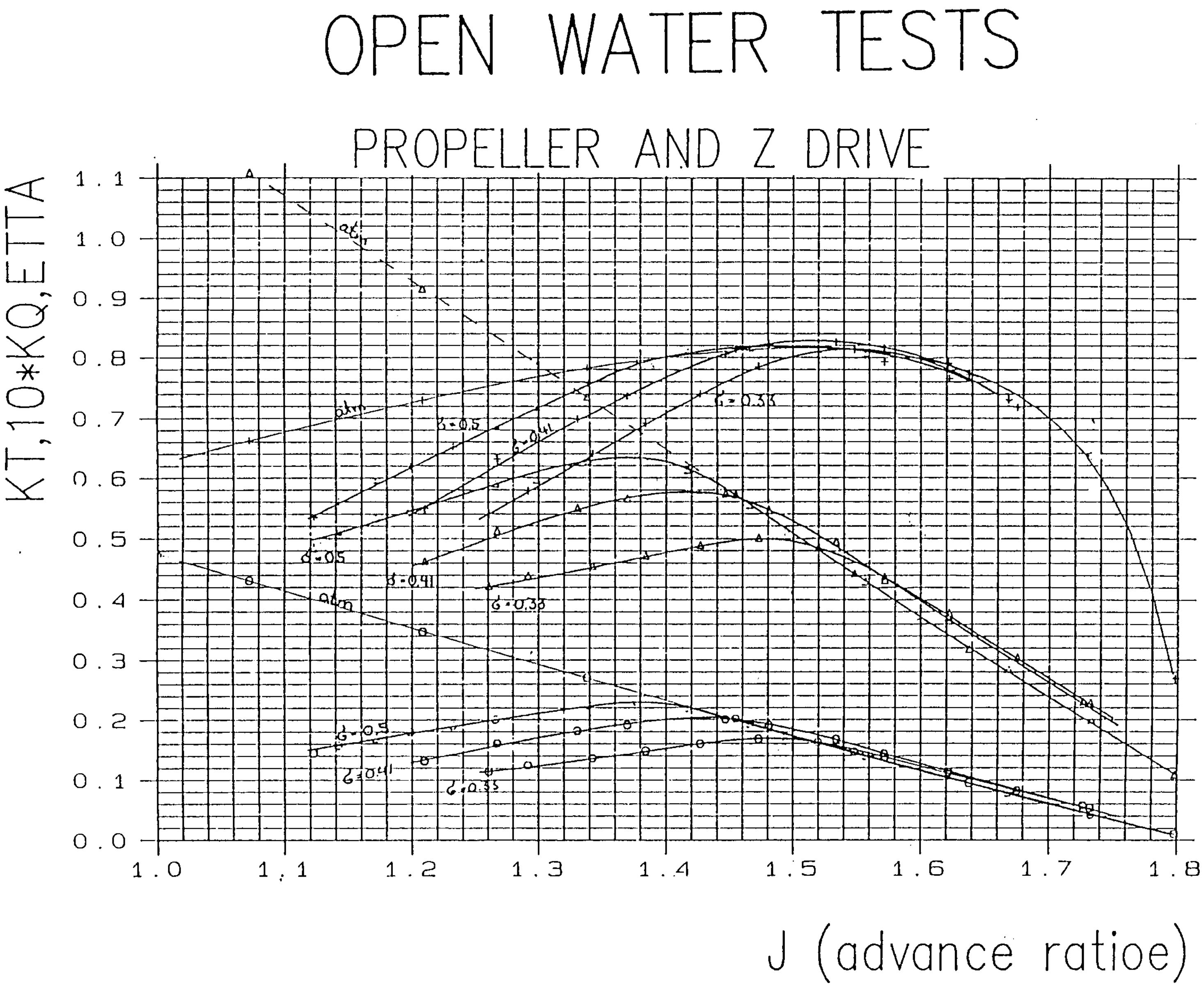

OPEN WATER TESTS
PROPELLER AND Z DRIVE
KT,10*KQ,ETTA
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
J (advance ratioe)

FIG. 4

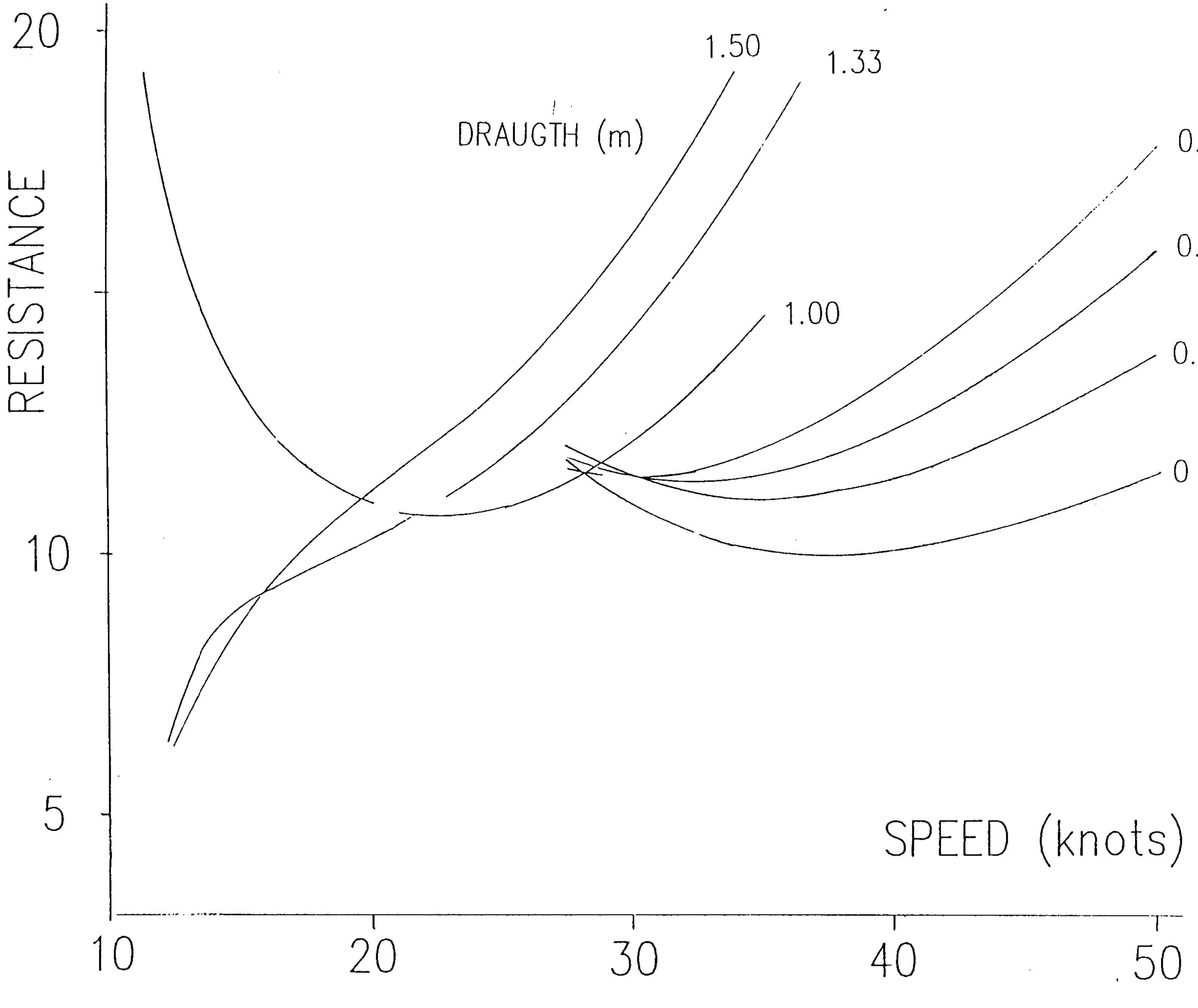

20
10
5
RESISTANCE
DRAUGTH (m)
1.50
1.33
1.00
0.50
0.33
0.17
0
SPEED (knots)
10
20
30
40
50

FIG.5

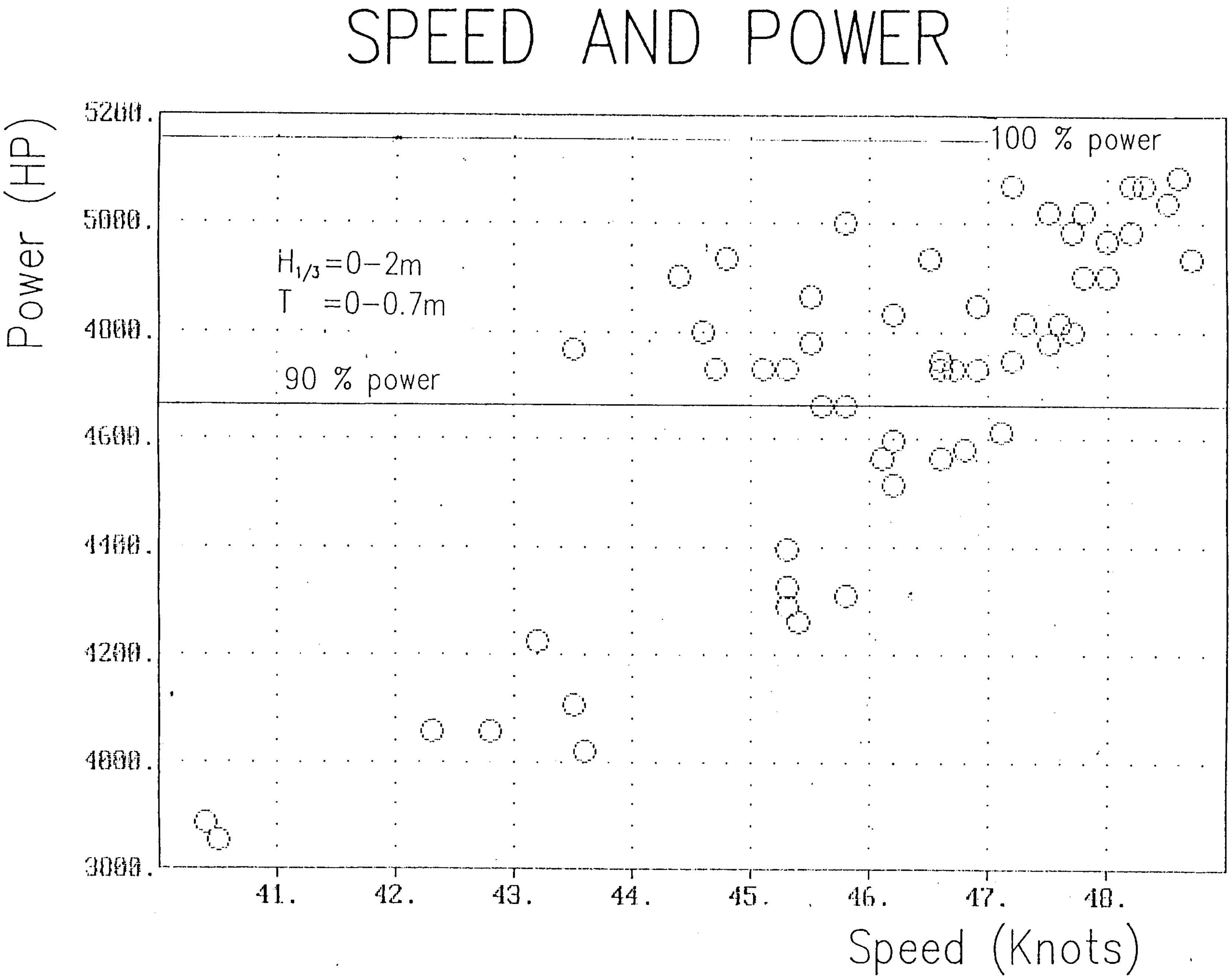
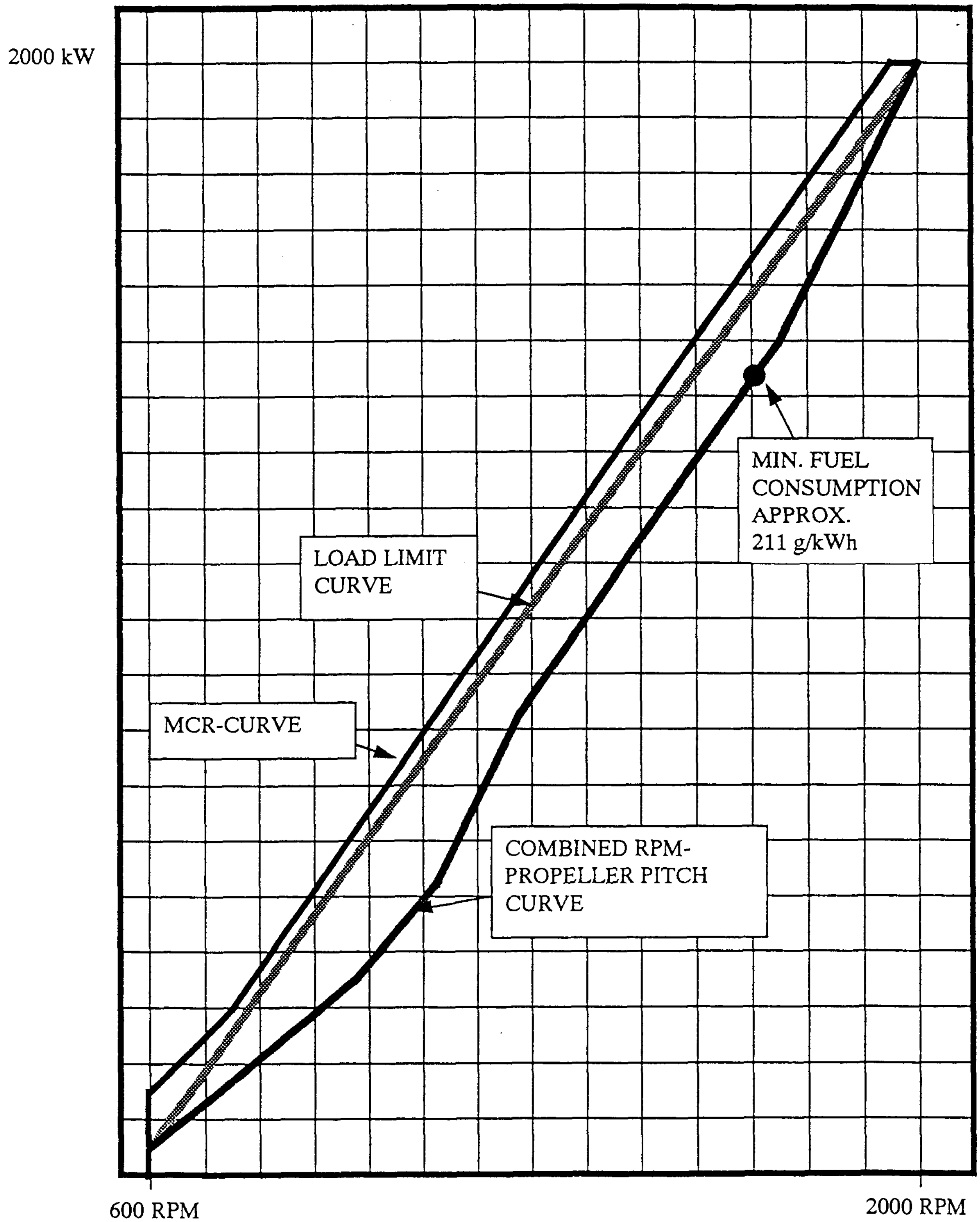

SPEED AND POWER
Power (HP)
5200.
5000.
4800.
4600.
4400.
4200.
4000.
3800.
100 % power
$H_{1/3}$=0-2m
T =0-0.7m
90 % power
41.
42.
43.
44.
45.
46.
47.
48.
Speed (Knots)

FIG.6

PROPELLER-LOAD DIAGRAM, FOILCAT

FIG. 7



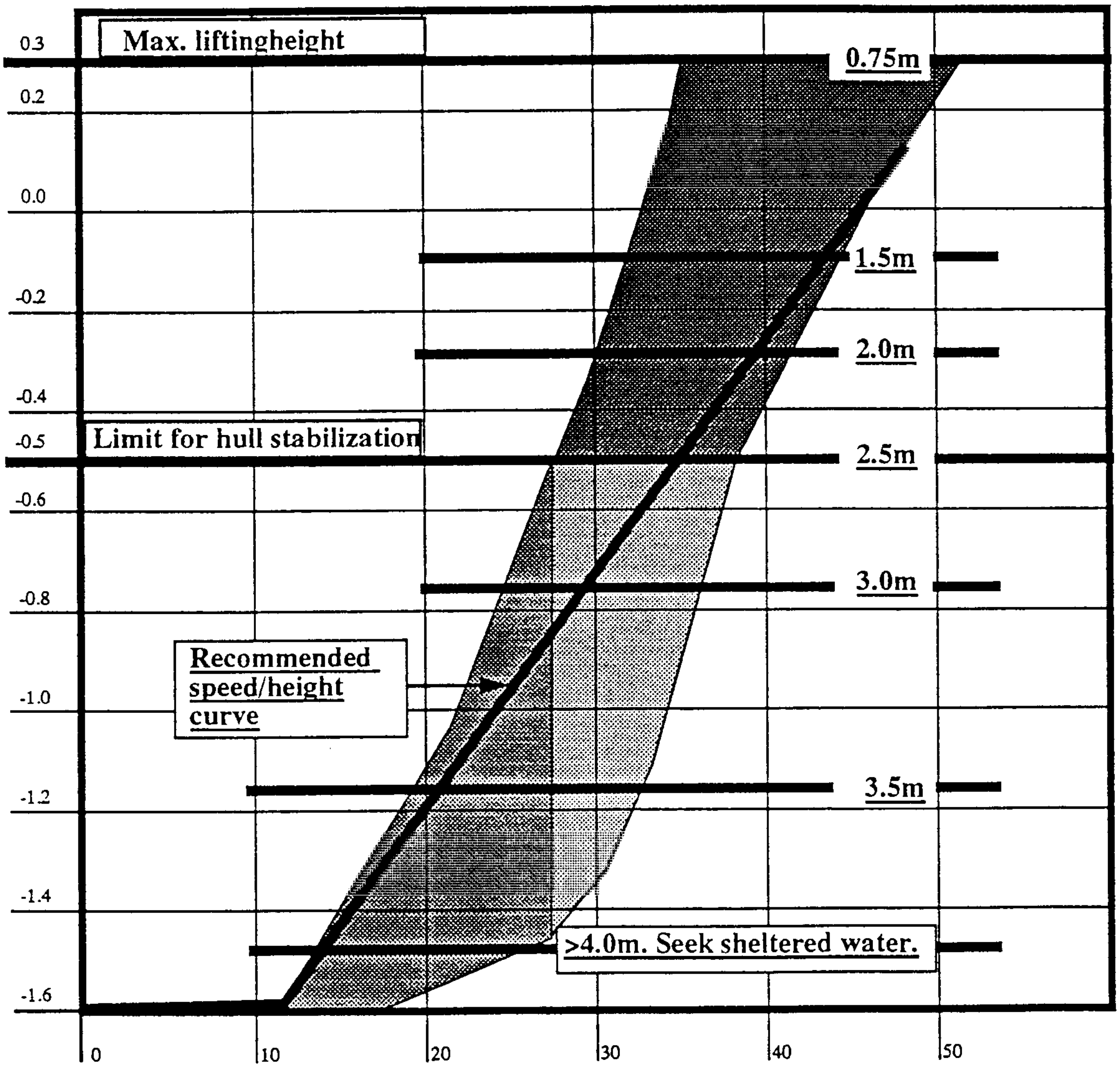
WESTAMARIN WEST A/S

FIG. 8

CRAFTOPERATION

SPEED AND POSSIBLE LIFTINGHEIGHT WITH LIMITATIONS GIVEN BY THE WAVEHEIGHT.

SIGNIFICANT WAVEHEIGHT $H_{1/3}$ (m)



HEIGHT (m)

WITH SIGNIFICANT WAVEHEIGHT > 2.5m,
FOLLOW THE LEFT LIMITATIONS OF THE CURVE.

SPEED (knots)

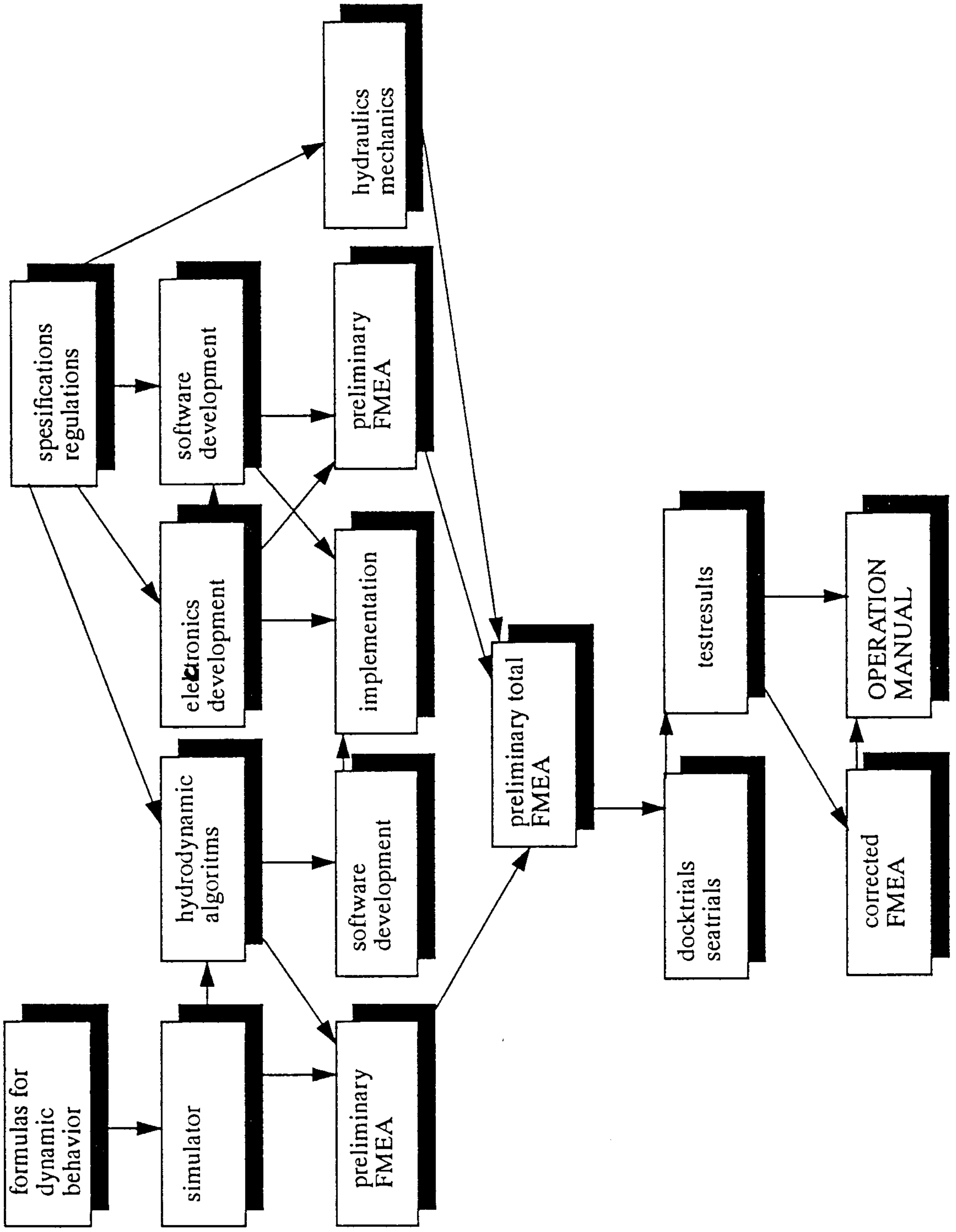
/users/egil/presenta/opbegr-FC.presenta

REV.2, JUNE 23.rd 1992

WESTAMARIN WEST A/S

FIG. 9

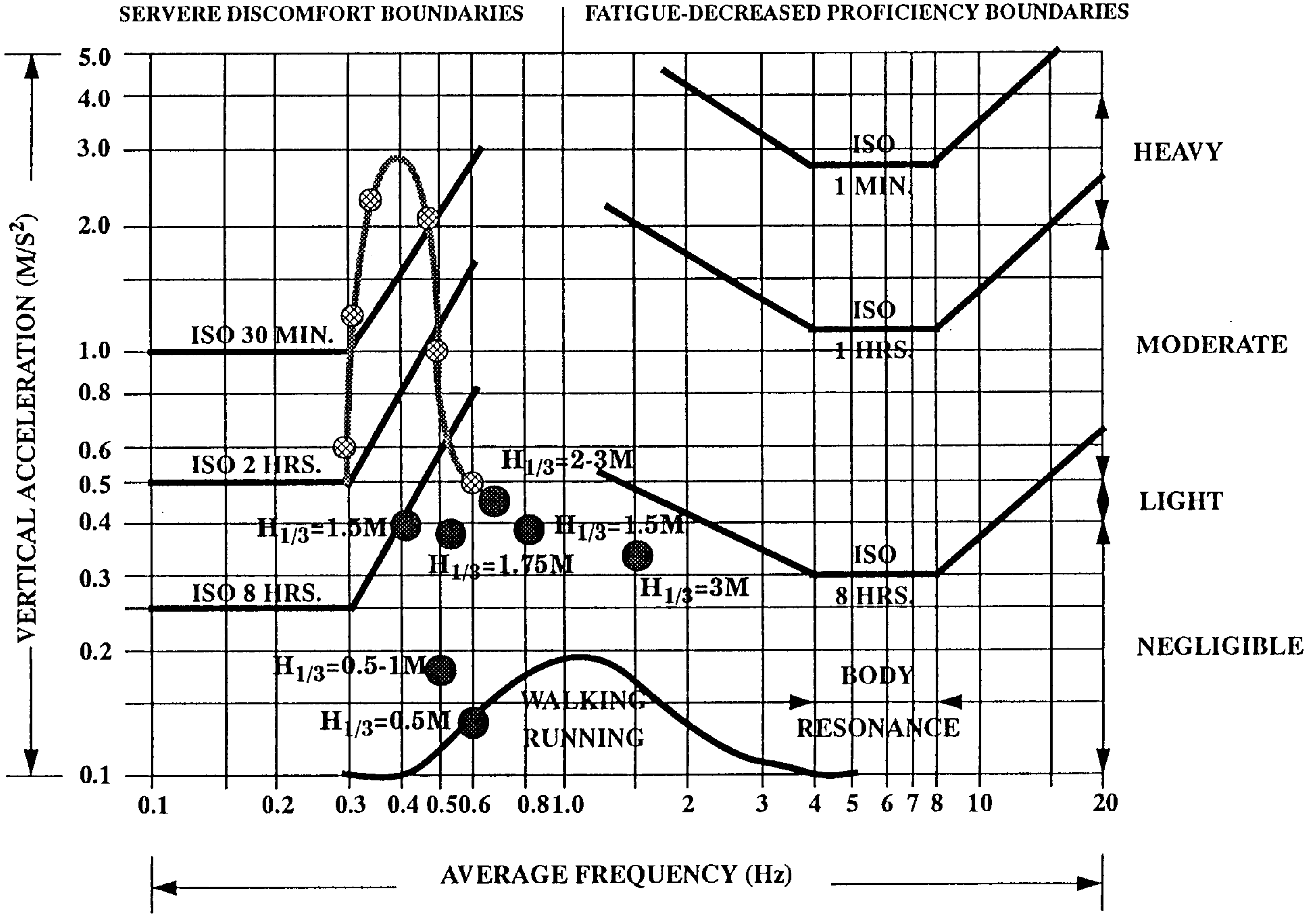
FCS DEVELOPMENT



WESTAMARIN WEST A/S

FIG. 10

BIODYNAMIC EFFECTS: COMFORT AND FATIGUE



CATAMARAN, SPEED 35 KNOTS, $H_{1/3} = 1.5$ M

FOILCAT 2900, SPEED 35-45 KNOTS

MARINE GAS TURBINES FOR FAST FERRIES

by
Carroll R Oates
Group Manager
Marine & Vehicular Propulsion
Sales & Marketing
AlliedSignal Engines

Carroll R. Oates has been with the AlliedSignal (Lycoming) Turbine Division for sixteen years. During his career, he has worked in various program management and marketing positions involving aircraft, marine, vehicular and industrial applications. He has traveled extensively worldwide and has interfaced with governments, militaries and commercial firms using and supporting Lycoming turbines for military and civil use.

Since 1988, he has been specifically involved in marine/industrial and vehicular projects. Special emphasis has been given to the promotion of marine turbines for high ferries and rail service. Mr. Oates was Manager of the team who sold the first turbines for high-speed conventional catamarans in Hong Kong.

He has delivered several papers to industry concerning modern transportation trends, market drivers and the benefits of turbine technology.

Mr. Oates holds Bachelor and Master Degrees in Business Administration, as well as having studied Engineering on an undergraduate level. He is a graduate of the U.S. Army's Command and General Staff College and the Army Executive Logistics Course. He has an extensive U.S. Army background covering more than 26 years in the field of logistics, supply, maintenance and command. He holds a USCG Captain's License.

INTRODUCTION

Hong Kong is the mecca for fast ferries. One third of all fast ferries built in the past two years went into operation in either Hong Kong or China, and at present, over thirty percent of all fast ferries in construction or on order are scheduled for this region.

The fast ferry market in Hong Kong is driven by the same demands which are causing major changes in this industry worldwide. Competition by other forms of transportation (air, rail, highways) creates a need for faster service, greater comfort, safety, reliability and superior performance.

For fast ferry operators, this emerges into requirements for vessels fine tuned for the mission and routes. Superior productivity maximizing more earning voyages per day, greater speed and capacity, shorter turn-around times, minimum down time and maintenance, reliability and overall favorable costs.

For over five years, Austal Ships has produced 32 knot, fast catamaran ferries made to Yuet Hing's specifications. They have currently delivered 18 diesel powered craft. These 40 meter aluminum catamarans optimized loading, seating and comfort options. But the operators needed more speed to remain competitive with the improving infrastructure. And they wanted that speed without negatively affecting operating costs.

After researching several options, Austal Ships recommended using AlliedSignal turbines. With no changes to hull or superstructure, three of five new vessels built in 1993 were fitted with one TF40 per hull, mounted to a reduction gearbox driving waterjets. The end results produced a vessel of some 20 less tons and approximately nine additional knots of speed. A fourth vessel was built and delivered in 1994.

Each of the hulls is divided into a fore peak, two voids, an air-conditioning plant room which also included two fuel tanks of three ton capacity each and a sullage tank, auxiliary engine room, main engine room and aft peak.

One difference here is the movement rearward of one of the bulkheads in each hull to transfer some of the space saved in the main engine room to the auxiliary engine room.

Other than the gas turbines which increased the total ship's power from 3840 KW to 6000 KW, very few additional modifications were made.

The vessels were chosen for their routes which can put the high speed to good business use. The first three vessels completed sea trials, failure analysis tests, and Chinese classification by the end of 1993, and went into service in March 1994 after passing the Hong Kong Marine Society failure management test. The fourth craft began in December 1994.

To date, each vessel has now operated over 4000 hours. The mission profiles are shown below.

Each vessel has a payload capacity of 43 tons while still maintaining at least 40 knots of speed. The engines are averaging ten to twelve hours of operation per day, and vessel #105 was the first craft order by Yuet Hing with an active night vision system.

Craft No.	Port of Call	Vessel (Light) Weight	Total Passengers	Documented Vessel Speed (Loaded)	Round Trip Distance	R/Trip Travel Time	Trips Per Day Day
Shung Jing #105	Rong Qi	118 Tons	367	44 Kts	150nm	3.20	3
Liang Gang Hu #106	Liang Hua Shan	119 Tons	367	43 Kts	120nm	2.50	2 to 3
Yixian #108	Zhong Shan	120 Tons	367	41 Kts	100nm	2.30	3
Zhong Shan #116	Zhong Shang	120 Tons	367	43 Kts	100nm	2.30	3

Design and Installation

Frankly, the use of the 2300 KG turbine/gearbox system made engine installation quite simple. An enlarged inlet and exhaust duct was fitted to the top deck of the vessel which holds the air filtration system for the dedicated air induction ports and adequate space for exhaust outlet. Since the turbine is mounted canter-levered off the gearbox and is not mounted to the deck, the usually complex alignment procedures were eliminated. Because the turbine requires no water cooling nor pre-heating apparatus, several systems could additionally be eliminated and, as the turbine causes no vibration transmitted to the hull, even more work could be forgotten. The crew has learned to leave extra lube oil at home.

Because of the propulsion system's size, the usual large removal plates from the above deck were not needed. All turbine components can be removed through the standard hatchway.

AlliedSignal provided its standard package which included a complete engine with self contained oil, fuel and electrical systems. Also, the electronic control box, instrumentation panels and all required interconnecting cables. As usual, AlliedSignal engineers participated in design reviews and oversaw the installation, start up and sea trials.

Operation

Work with the operators began simultaneously with the construction of the vessels. AlliedSignal conducted three training courses at our U.S. facility on turbine operation and maintenance. Additionally, two courses have so far been given in China. Logistics support included stockage of operator owned consumable and repairable items for a three-year operation profile and establishment of AlliedSignal owned on-hand inventory including a complete spare engine and tools. The operator has full Level I and Level II maintenance capability.

All vessel inspections and maintenance is conducted at night when the vessels are moored in Hong Kong. To date, normal daily turbine inspection checks average 15 minutes per vessel. Standard TF40 scheduled maintenance called for the first internal inspection (HSI) at 2000 hours, but AlliedSignal had decided to use Yuet Hing as a lead-the-fleet project and set up a support plan shown on the accompanying chart.

Since hours are being accumulated faster than predicted, each engine received its video borescope inspections in October 1994. Full HSI inspection took place between December 1994 and February 1995 with great results.

Each TF40 is equipped with inspection ports which allows for easy borescope screening. The local AlliedSignal Service Manager conducts these inspections on a non-interfering basis (at night) while performing concurrent training for the crew. Video borescopes require less than four hours per vessel while the internal engine inspections (HSI) take only six to eight hours per engine, and also, do not cause cancellation or delay to revenue service. Hong Kong operators normally lose as much as 28 days of operation per year to conduct internal inspections on the piston engines which require removal from the vessel. In 1994, the turbine powered craft we took out of service for only three to ten days, and that included all vessel scheduled maintenance as well. So, over two weeks of additional revenue service was recognized.

The operators are delighted with the turbine operation and overall vessel performance. Several noticeable differences over the piston powered craft have been highlighted to include clean (non-oily) engine rooms, dramatically less vessel vibration, noise, and smoke, and much less time required for daily pre and post engine inspection areas. Also, tremendous customer/-passenger interest and satisfaction in riding on a "new technology" ferry.

The only areas requiring attention to date include replacement of ignition exciters (spark plugs), speed sensors and electric D.C. starters. AlliedSignal quickly learned that the standard d.C. starters were not strong enough to survive ten to 12 starts per day, plus a long motoring-over for weekly engine washes. New and improved starters and exciters were developed and retrofitted.

So satisfied, in fact, are the Yuet Hing people that they ordered their fifth TF40 powered craft which is expected to go to sea trial late this year. Austal hull #116 will be identical to the first four turbine craft. The vessel is contracted for over 40 knots and should begin service in September 1995.

And the rest of Hong Kong has observed the TF40s success and AlliedSignal's dedication to commercial service.

Another ferry operator plans to order two TF40s for a 45 knot, 42 meter catamaran also scheduled to run a Hong-Kong-to-China route. This vessel will be built in Singapore and the TF40s will each power a separate waterjet. And yet a third operator predicts adding four to six TF40 powered ferries to its fleet, although because of the mission, some may be equipped with CODAG configurations which will allow operation on diesel power for loitering or slow speed running, and on both turbine and diesel for up to 4500 KW output through a waterjet in each hull.

Future

To continue to meet the demands of fast ferry operators everywhere, AlliedSignal continues to invest in its previously announced upgrading of the TF40. Anticipated for availability in 1997, the TF50 (4880 SHP/3640 KW) will give even more power from the same size engine. And existing TF40s will be able to be upgraded easily. This is the same engine to be used on the LCAC Mark II Expanded Mission Hovercraft with U.S. and foreign Navies.

For larger fast ferries, the company today offers fast ferry operators in Hong Kong and the world, 6000 KW power in its TF80 system which combines twin TF40 power modules to a single gearbox. This system allows the operator to choose 3000 or 6000 KW power by simply using half or the entire four ton system.

The commitment made to the commercial marine industry is evident in our performance in Hong Kong. And performance is being measured in evolution, not just revolution. Evolution is taking the Hong Kong operators to new limits of speed, reliability and overall reduced cost of ownership. Operators, shipbuilders and naval architects can see those measured results day in and day out as the fast ferries make their daily revenue runs. Just as commercial aircraft before them, the ferry industry is beginning to take advantage of the Turbine Age.

Interesting Facts

- Hong Kong is fast ferry mecca
- One third of all fast ferries built in 1993/1994 went to Hong Kong or China
- At present, over 30 percent of all fast ferries on order are for Hong Kong or China
- Over 14 million passengers ride ferries from Hong Kong to Macau annually

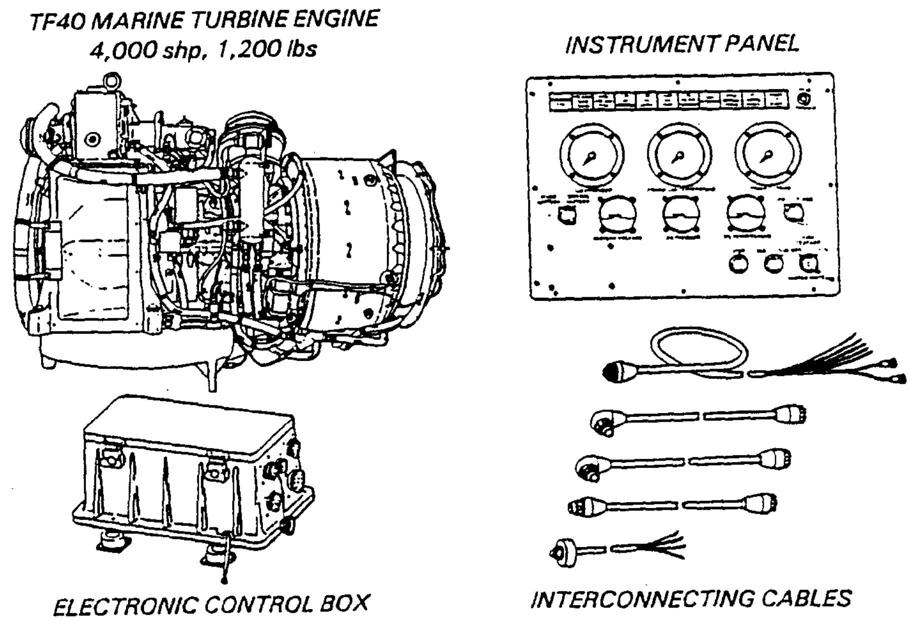
Fast* Ferries - in World-Wide Revenue Operation (1993)

Hydrofoils	400
Monohulls	150
Catamarans	425
SES	80
SWATH	6
Hovercraft	60

Source: Fast Ferry Packet Guide '93

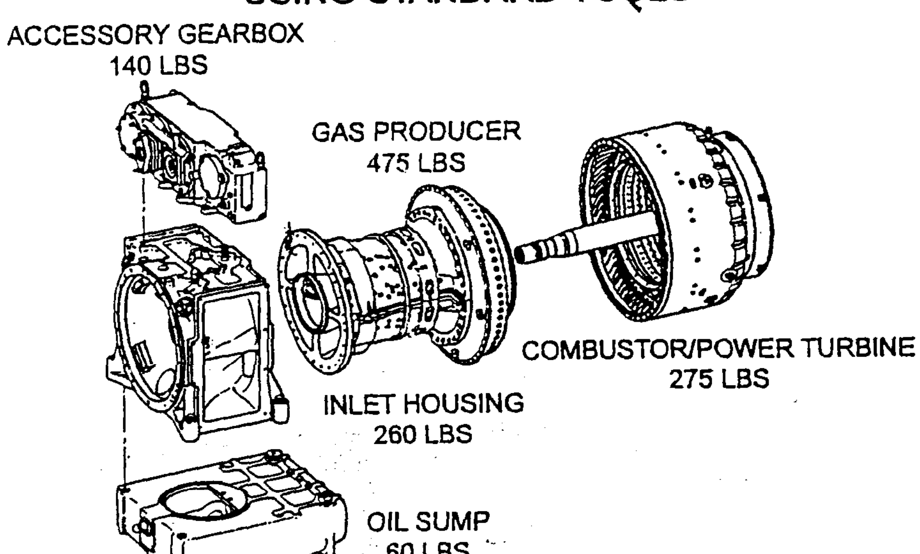
*28+ Knots

TF40 Engine System



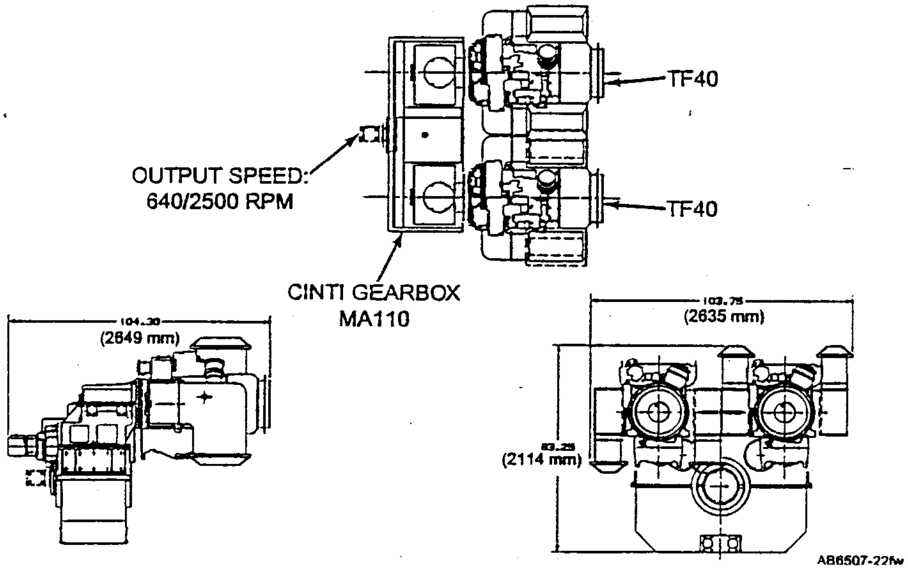
TF40 MODULAR MAINTENANCE

A MODULAR ENGINE EASILY MAINTAINABLE USING STANDARD TOOLS



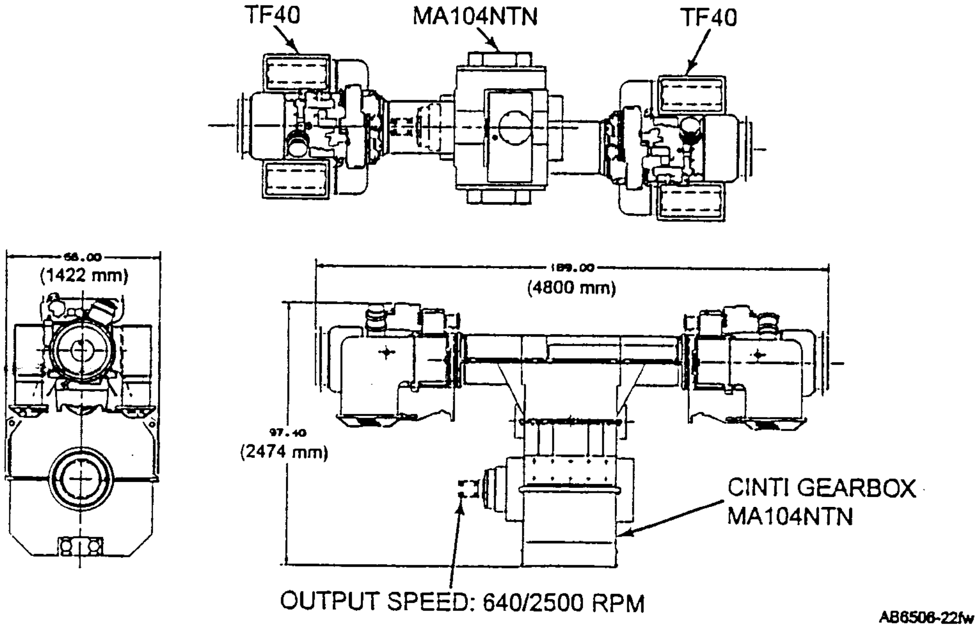
TF80 MARINE PROPULSION SYSTEM

SIDE-BY-SIDE CONFIGURATION

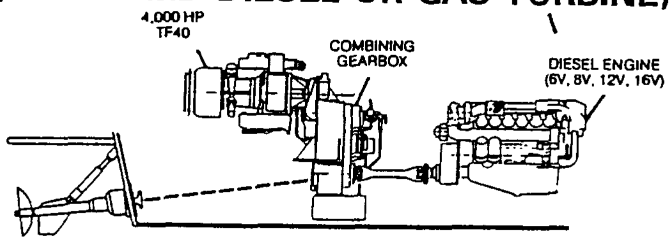


TF80 MARINE PROPULSION SYSTEM

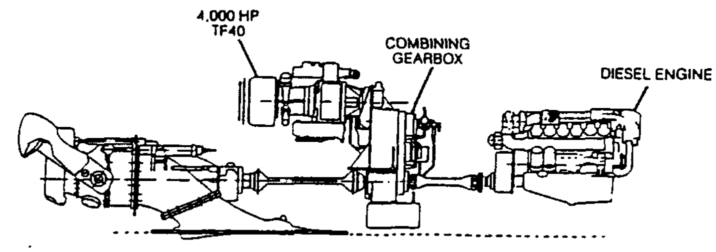
NOSE-TO NOSE CONFIGURATION



CODOG
(COMBINED DIESEL OR GAS TURBINE)



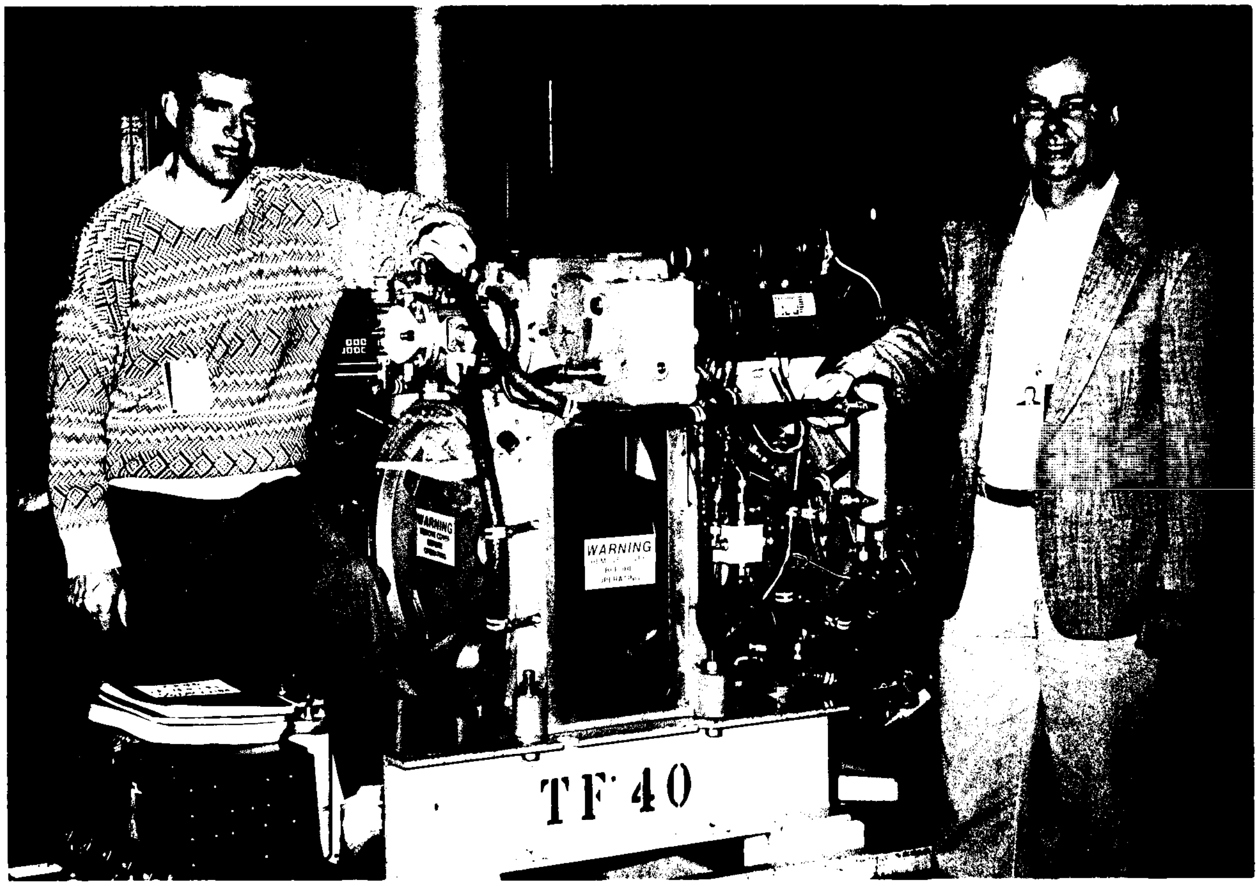
CODOG DRIVING A SURFACE PIERCING PROPELLER



CODOG DRIVING A WATERJET

AB63230-15fw

Pictured here are three of the Chinese fleet of TF40 powered fast ferries.



On 27 March 1995, the fifth shipset of TF40 Marine Turbines were shipped to Australia for installation into another 43-kt fast ferry for a Chinese customer.

Here, Carroll R. Oates (right) and Mike Lombardi (both of the Marine Group) inspect the finished product.

IMPOSED LIMITATIONS - NOT OPERATIONAL CAPABILITIES - HAVE MINIMIZED HYDROFOIL CRAFT UTILIZATION IN THE U.S.

BY

V.H. VANBIBBER

V.H. VanBibber holds a Bachelor degree in Aeronautical Engineering from the University of Illinois and Naval Architecture from the University of Michigan. Has been associated with hydrofoil development and design since its inception in the U.S. Navy. Has been associated with the utilization of the craft and has been an assigned test pilot for the Bureau of Ships during the development stages of the hydrofoil craft. He is now retired but is still doing consulting work on Naval projects related to high performance craft.

ABSTRACT

The paper points out that hydrofoil production costs in the United States has always been coupled with the costs associated with the "state-of-the-art" development costs required to make a craft operational. The combined cost of the ship manufacture and the development of reliable operational equipment made the per ship cost prohibitively high. Finally, when a reasonably reliable ship was produced (the Patrol Hydrofoil Missile Ships) there were only six of the proposed 35 produced. The six ships were used relentlessly and there was insufficient time or ships numbers to truly develop a multi-mission capability which would greatly enhance the need for this type of naval ship.

BACKGROUND

The hydrofoil ships that are in service today are an evolution of materials, hydrofoil systems, stability control, and power train development including the method of propulsion. The development of each of these items from 1952 to 1959 was being exploited beyond the reliable engineering design. The hydrofoil craft being designed were each an order of magnitude greater in size and in the equipment development than its predecessor. The three significant craft were; HS *Denison, High Point* PCH-1 and the *Plainview* (AGEH-1). Those of us in hydrofoil design at the Bureau of Ships called these ships the "Hop, Skip, and Jump".

HS *DENISON* - A high-speed seagoing hydrofoil research ship. The *Denison* was 104 feet long and had a potential full load displacement of 90 tons. It had an airplane hydrofoil configuration (main foil forward) with two surface piercing main foils forward and a fully submerged, flap controlled, foil aft. The hydrofoil system had an autopilot to assist in stability and control. The foilborne rudder was on the aft strut. The design and construction was financed by both the Government and Industry. The proposed use of the vessel was to fly between Florida and the Bahamas carrying 60 passengers at 50 knots. Figure 1 is of the *Denison*.

The *Denison* had a right angle drive in the aft strut driving a 40 inch diameter super cavitating propeller. The spiral bevel gears were designed to carry 10,000 hp transmitted through a single mesh was 3000 hp.

The first foilborne trials started in June of 1952 and by April 1953 the *Denison* had logged only 10 hours of foilborne time (see Figure 2 HS *Denison*, Foilborne Operating History).

The items 11 through 26 are all related to the *Denison* lower gearbox failures and as can be seen in Figure 2, there was very little Foilborne time in the first year of operation. The Grumman Aircraft Engineering Corporately decided there must be a better way to solve the problem. The engineer designed a water tank to enclose the aft strut and hydrofoil. The tank would be filled with water and pressurized to simulate the 50 knot hydrodynamic pressure. The gearbox pod and the lube oil system were well instrumented to determine the exact failure areas. The entire aft unit was operating at the foilborne 50 knot condition. The gearbox problem was resolved and as can be seen in Figure 2 the next year are 210 hours foilborne.

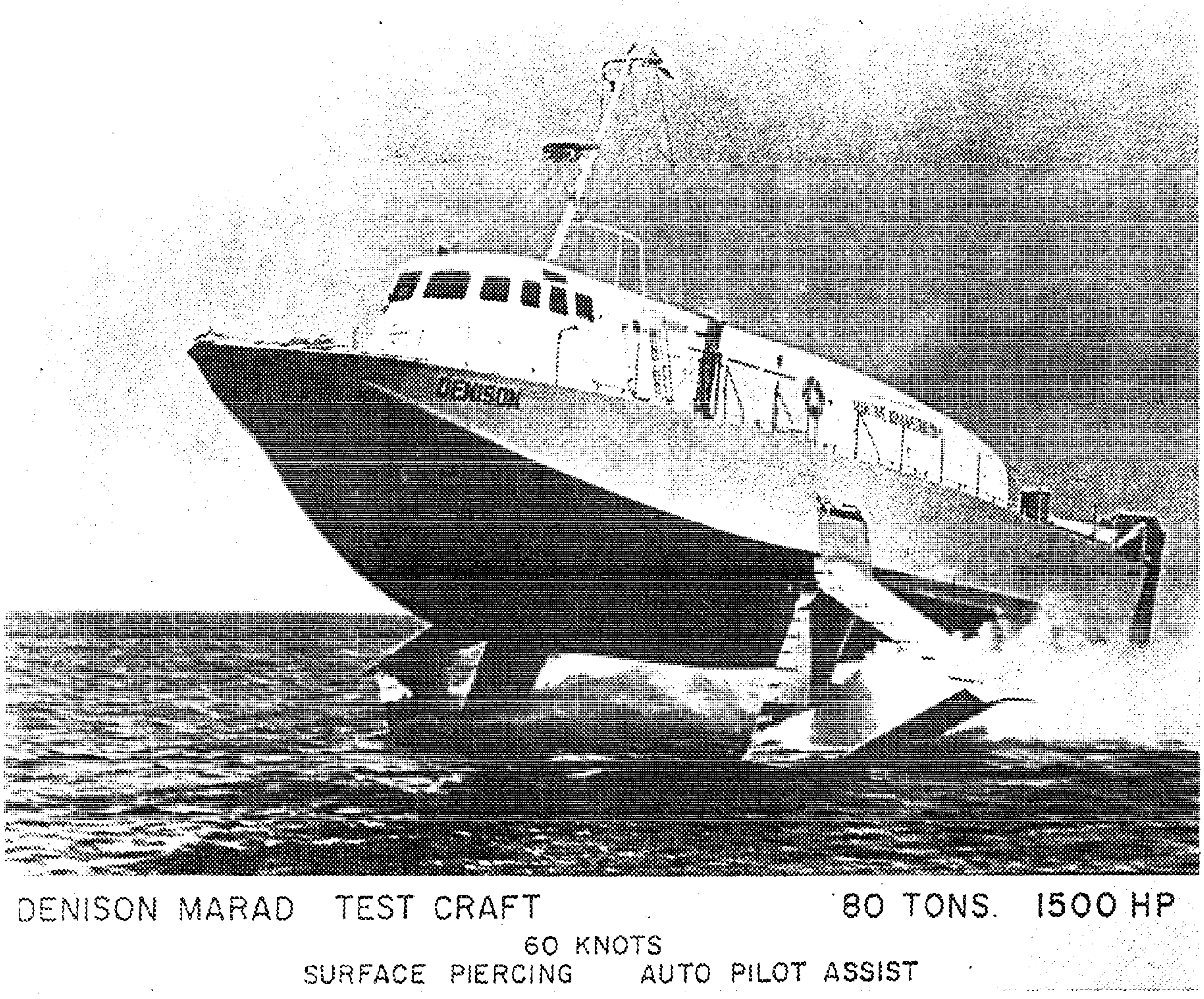


FIGURE 1. *DENISON* MARAD

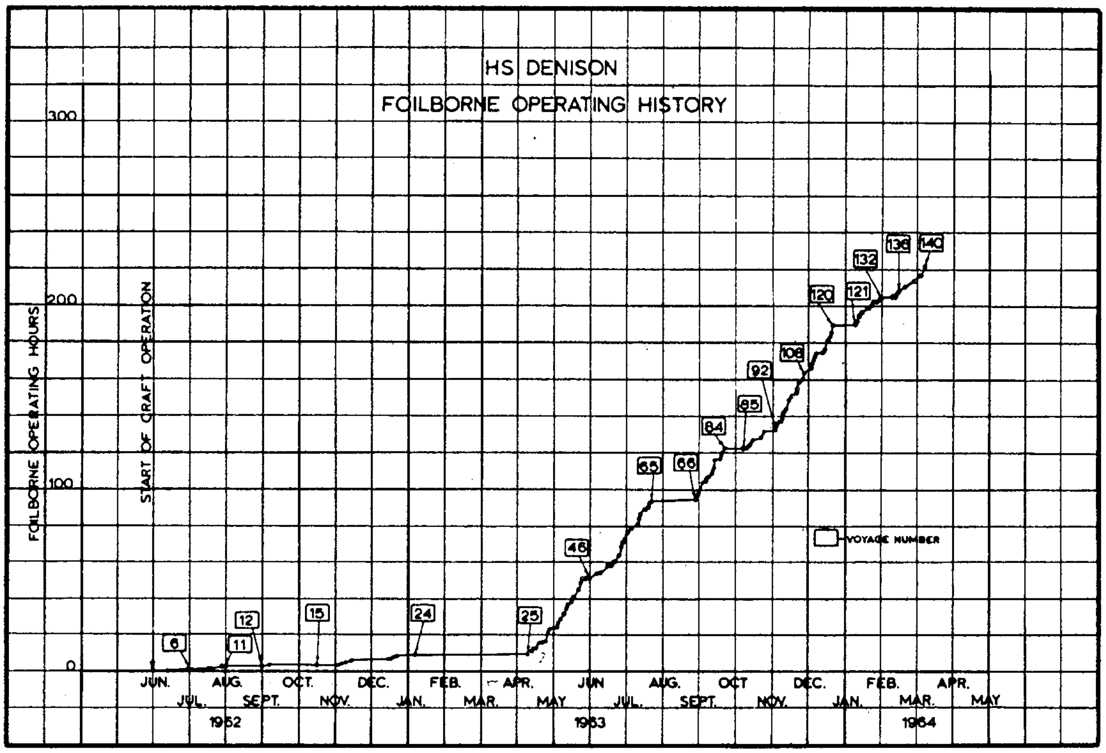


FIGURE 2. HS *DENISON* FOILBORNE OPERATING HISTORY

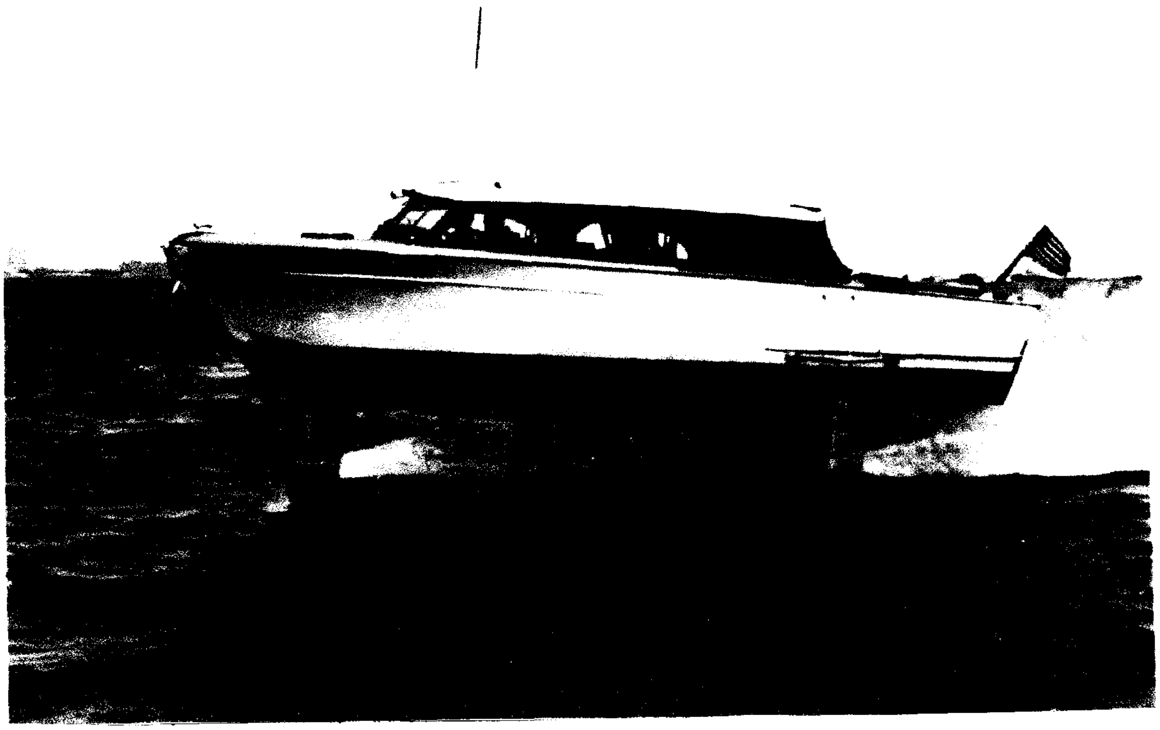
Note that the Government invested about 3 million out of 9 million grand total. The industry was contributing two to one for the *Denison* evaluation.

High Point PCH-1 - The Patrol Craft Hydrofoil was 110 feet long and had a design displacement full load of 110 tons. The PCH had a canard hydrofoil configuration (main foil aft) and it had a fully submerged hydrofoil system with an Automatic Control System (ACS). The hydrofoil system and the weight distribution on the hydrofoils was taken from the manned model test craft called "*Sea Legs*". This manned model had the first operational autopilot developed for a fully submerged hydrofoil system that functioned very well. Figure 3 is the *Sea Legs* operating in sizable seaway.

The PCH had two proteus gas turbine engines. Each engine powered two propellers on port and starboard side of the ship. The propellers were on each end of the nacelle as can be seen in Figure 4. The hydrofoils retracted vertically with cables and in the center of the ship was a dunking sonar that would retract into the hull for foilborne operations.

The "*High Point*" like *Denison* had many problems and the majority of these were because the design capability of the ship and various components were extending the "state-of-the-art" too far to assure reliability. Note the *High Point* was funded to be an operational ASW Patrol Craft.

The ship as launched originally had the main foil (aft) extending from and attached to the nacelle. The forward strut was shorter than the aft strut and the rudder was a flap in the strut (see Figure 5). There hydrofoil and rudder positions were taken directly from the *Sea Legs* manned model.



SEA LEGS USN 1957

FIGURE 3. FULLY SUBMERGED HYDROFOIL SYSTEM

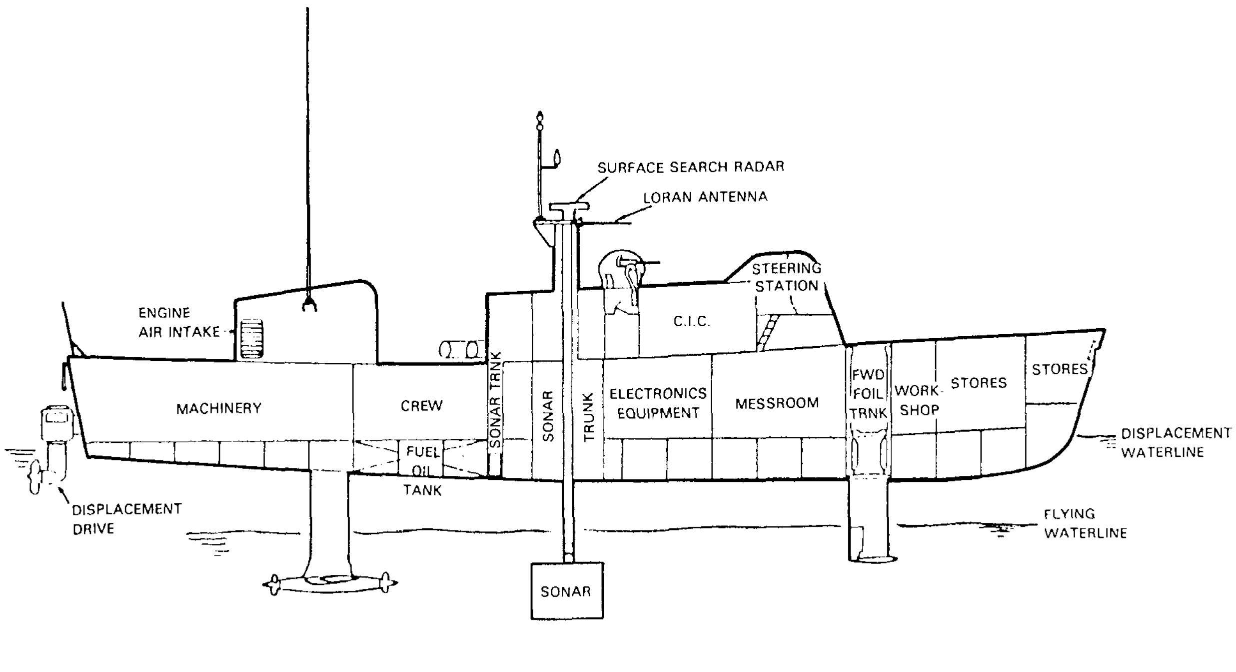


FIGURE 4. *HIGH POINT* ORIGINAL LAYOUT

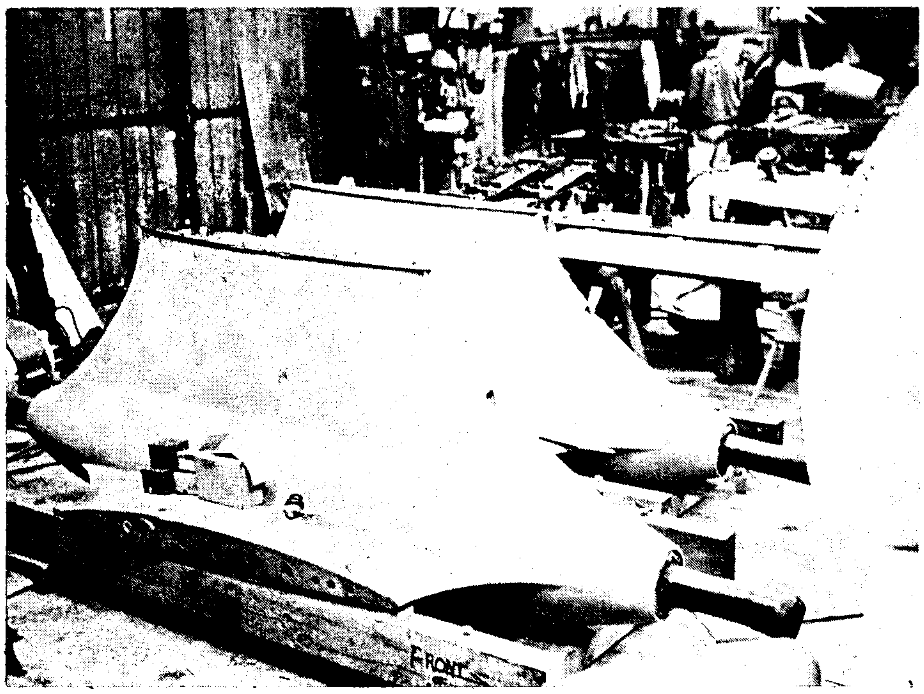


FIGURE 5. *HIGH POINT* ORIGINAL AFT POD DESIGN

From the initial launch, like the *Denison,* the *High Point* had many hours on drydock compared to the foilborne operational time. Some of the problems were similar to those of the *Denison* and some were new to this "first" fully submerged ACS controlled hydrofoil ship.

The seawater intrusion into the gearbox lube oil caused gear failures. The retraction was troublesome and engaging and disengaging the main foilborne gearbox was difficult. The hydrofoils were subject to considerable leakage, and the dunking sonar did not function well.

When foilborne the *High Point* helmsman would find he would lose steering control in moderate seaways. *The steerage problem I had noticed on Sea Legs and by hanging on the aft foil fender guard I was able to see the ventilation. I had recommended installing a rudder below the foil and welding the flap to the strut.* One of the more inopportune malfunctions occurred on a demonstration foilborne trial with several dignitaries onboard to aid in promoting the hydrofoil craft program. The *High Point* was performing eloquently when, without warning, the craft healed erratically running water over the sheer almost touching the deckhouse. The rapid foil broach caused several people to be injured including one Naval dignitary. The PCH had a newly developed static invertor for the AC to DC current. Part of this DC current was used for the autopilot. The failure caused the autopilot to malfunction differentially and the craft rolled. The newly developed static invertor was bench tested and maximum power output for a 1000 hours having no failure. However, when it was tested with the insurgent loads, as required for the ship, it failed as it had done during the sea trials demonstration. This mishap caused a "hold" on the hydrofoil development funding.

There were also other problems one of which was the propellers. The propellers on the aft end of the pod was frequently damaged from cavitation erosions in very short time periods (see Figure 6).

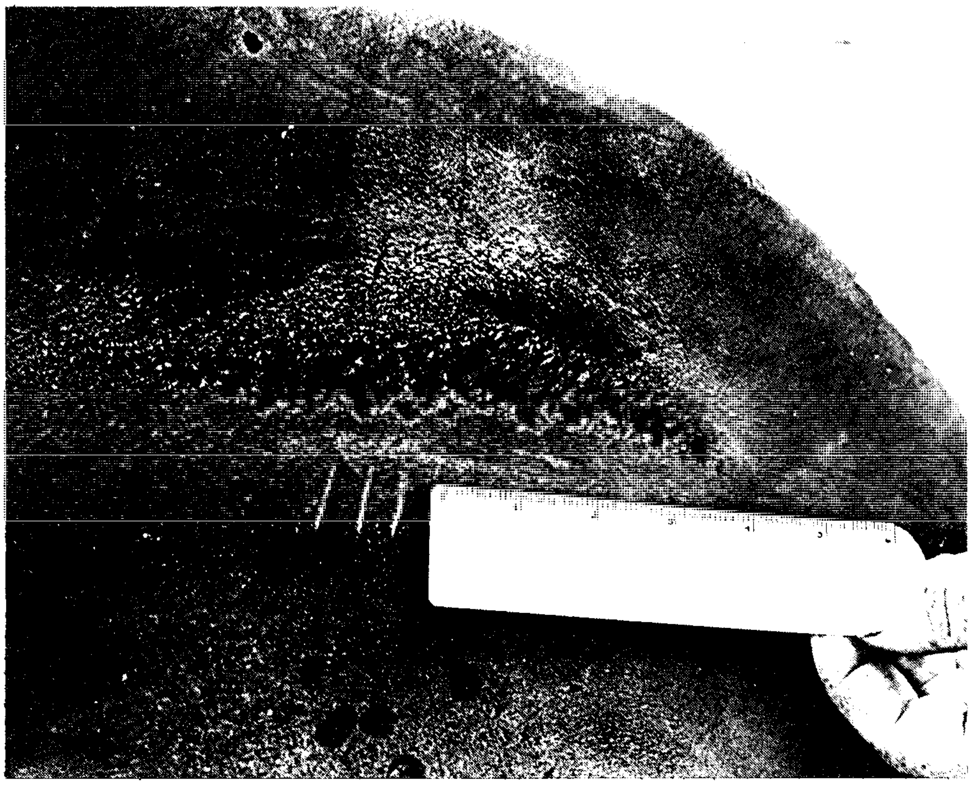


FIGURE 6. PCH Propeller Cavitation Erosion Damage

The Boeing Company had assembled a group of competent engineers that were innovative and well understood the needs for an operational hydrofoil ship. They made numerous recommended modifications for the PCH hydrofoil and the ACS control systems. The hydrofoil system was modified to the maximum extent possible to improve the system performance and utilizing most of the original design. Note the modifications in Figure 7.

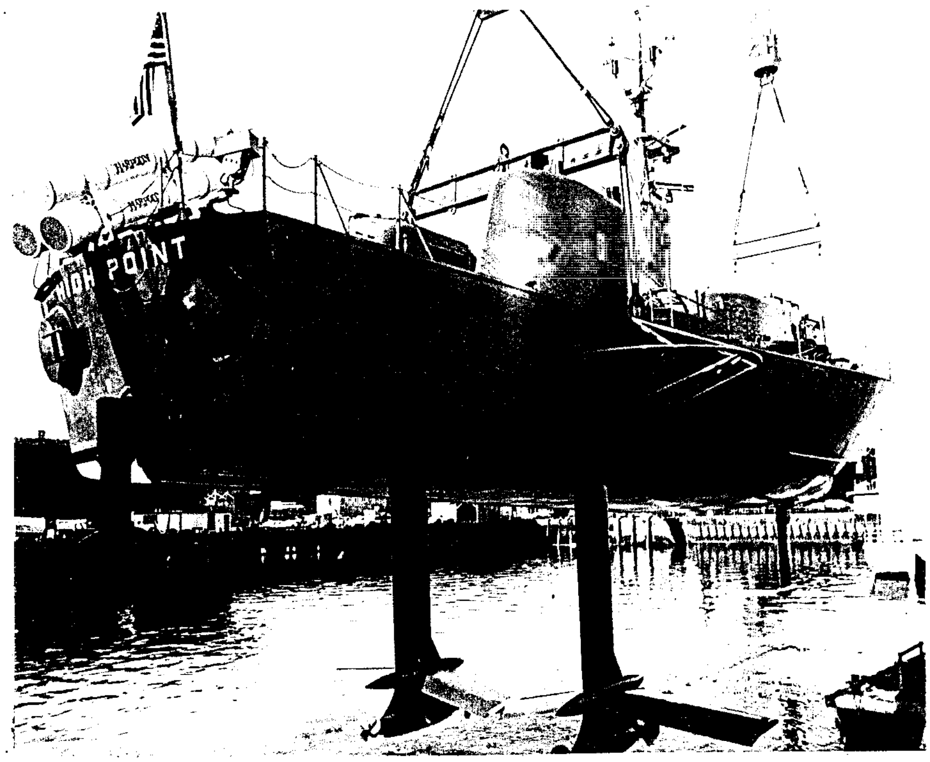


FIGURE 7. *HIGH POINT* MODIFIED HYDROFOIL SYSTEM

At this time the Chief of Naval Operations decided not to deploy the *High Point* to the Fleet but to make it a Research and Development ship. The PCH was very well instrumented to record operational data that was very useful for future hydrofoil development. The modifications greatly improved the performance of *High Point* and enhanced the recommendations for the appropriation of funds to design and develop hydrofoil ships.

The initial foilborne operation was more successful than that of the *Denison.* Note however, on Figure 8 "PCH-1 Foilborne Time and Major Milestones" that after 50 hours of foilborne time the ship went in for MOD 0 for two years. The foilborne operational hours were greatly improved after the next launching.

PLAINVIEW (AGEH-1) - Auxiliary General Experimental Hydrofoil ship. It was 212 feet long and a design displacement of 320 tons. The *Plainview* had an airplane hydrofoil configuration, fully submerged, and an ACS control system. The hydrofoil design and operation was markedly changed from the previous two designs. The hydrofoils were fully articulated rather than an "elevons" (see Figures 9, 10, and 11).

The entire hydrofoil would rotate on a single pivot pin mounted in the pod. The actuation system required to move the main foils was inordinately large. The hydraulic system was considerably larger than anything ever developed with the hydraulic fluid flow rate required. Constructing the largest hydrofoil ship in the world - with a markedly different hydrofoil system and having very little operational data for reference - made the engineering difficult to say the least.

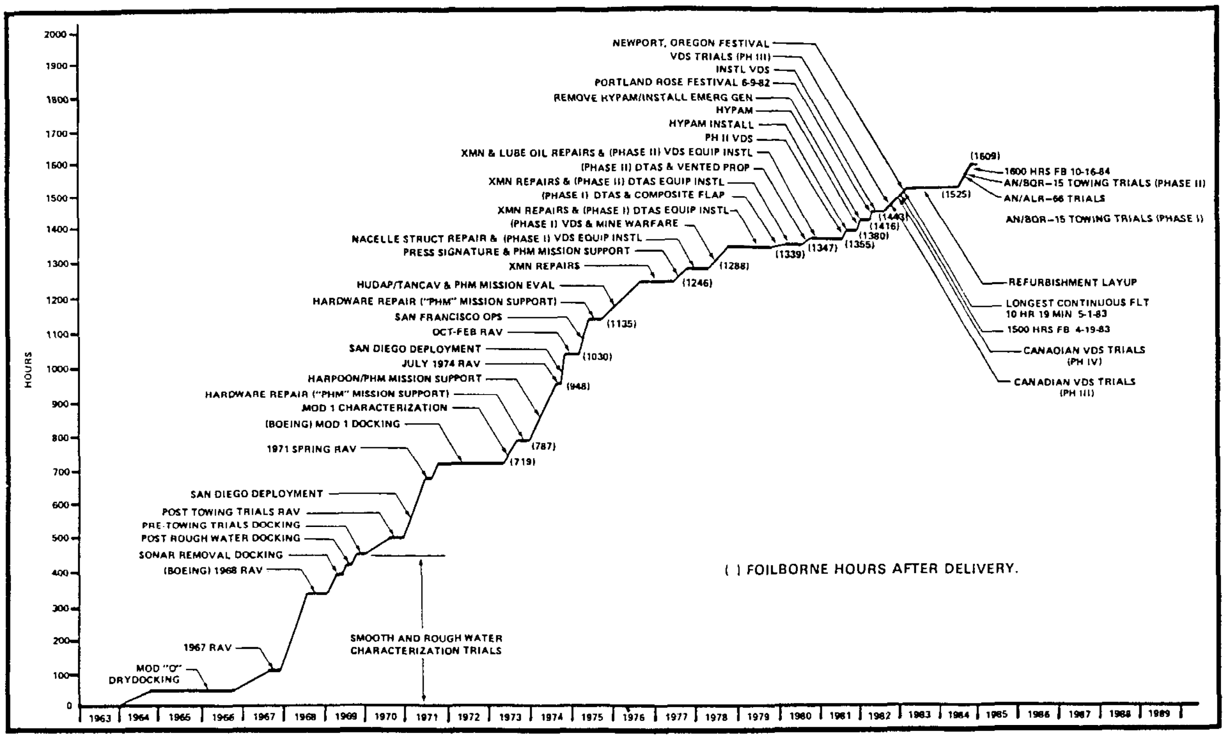


FIGURE 8. PCH-1 FOILBORNE TIME AND MAJOR MILESTONES

FIGURE 9. *PLAINVIEW* MAIN FOIL

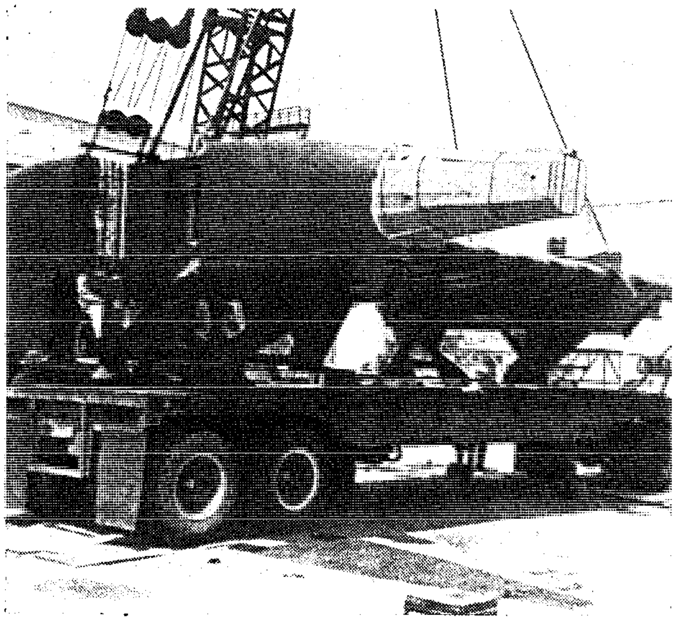


FIGURE 10. *PLAINVIEW* MAIN STRUT AND POD

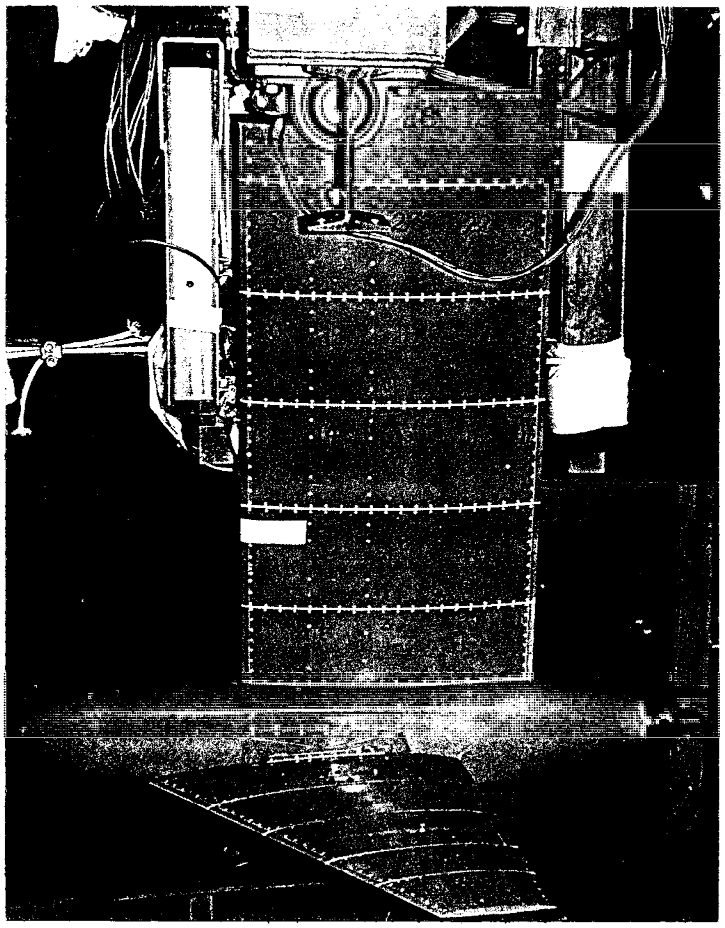


FIGURE 11. A 1/6 SCALE MAIN STRUT ASSEMBLY OF *PLAINVIEW*

The *Plainview* had a shorter initial foilborne time than that of the *Denison* or *High Point.* Unfortunately, even with modifications it had a very short service life.

Each of these three hydrofoil ships had inordinate delays in the foilborne Test and Evaluation. Each ship used some components that were new and the pre-tests such as "bench or mock-ups" were always inadequate to simulate operational conditions. Those of us in the Preliminary Design Decisions were fully aware of the inadequacy of component testing. Utilization of these parts on an operational hydrofoil craft caused failures at the most inopportune times and would frequently cause funds to be deferred, delayed, or withdrawn.

The last Navy hydrofoil ship buy was the Patrol Hydrofoil Missile Ship (PHM). This proposal was linked with a possible 35 ship buy after the first three (3) ships had completed all sea trials and all modifications had been incorporated on the prototype production ship then an additional 32 ships would be constructed. The PHM's used the canard configuration. The hydrofoil design was very similar to the *High Point.* The data accumulated from the many hours of foilborne operation of was very reliable. The major modification was utilizing a waterjet for the main propulsion. The elimination of the gearboxes, seal problems, and complex propeller designs improved the operational reliability of the foilborne propulsion system.

The tooling for a production run and the fabrication techniques for manufacturing of the hydrofoils was under estimated and the cost of the first PHM soared. The contractor however, was building jigs and fixtures to assure that each vessel would be just like the sister ship. These costs were amortized over a six ship buy instead of 35 PHM's. This was very discouraging to the contractor and to those of us who consider the hydrofoil ship a very useful military vessel.

The Navy always has had the need for ships having multi-capabilities. The hydrofoil ship has that latent potential but it could not be fully demonstrated or exploited with only the six ship squadron. Hydrofoil ships for naval use are like aircraft - with only one squadron available in the United States what could they develop in defense and in counter-defense. Like aircraft, a replacement aircraft must be available at all times to assure a complete squadron is on the flight line.

The hydrofoil ship for naval use must be just as demonstrated by the PHM squadron. They must be very maneuverable, operate well in a seaway and be able to go to sea in a moments notice. It has been stated that they are difficult to maintain however, it seems they are never thought of a foilborne flying vessel no different than an aircraft - they need daily maintenance. Had there been a 35 PHM procurement the Navy would have a Landing Ship Dock Hydrofoil (LSDH) and it would be available anywhere in the world with it's squadrons of hydrofoils.

The PHM hydrofoil has already demonstrated some mission capabilities such as interdiction and ASW warfare. However, there were numerous potentials that were never fully exploited because the single squadron could only be assigned so many duties at one time. Mine Countermeasures (MCM) is one example. Because of the ships superb directional stability, a pattern for sweeping can be established with great reliability. Accurate course keeping capability assures minimum need for overlap and maximum sweep potential in minimum time. The same would apply to mine laying. They could be accurately disbursed in minimum time. Scott Truver has addressed mine countermeasures twice in the Naval Institute Proceedings. First, the "Mines of August and Who Done It" related to the Suez Canal and the other "Desert Shield Operations". In both cases I addressed his discussion from the viewpoint the operation was not done within a reasonable time limit. Lt. Gen. Boomer, USMC at the "Intersociety High Performance Marine Vehicle Conference" in June 1992 indicated a great improvement in MCM is required. When sweeping a minefield near an enemy shore it must be done accurately and rapidly because of the imminent danger to the sweep operation.

Frequently, it was stated that the PHM's have too short a range capability to be a useful military ship. Hydrofoil ships like aircraft have been refueled from the air as seen in Figure 12. In MCM, we have successfully operated two of the older ships together the PCH and the AGEH as shown in Figure 13. The *Pegasus* PHM-1 was successfully used by itself to demonstrate the potential of hydrofoil craft in MCM in Figure 14. The PHM can also work well with the LCAC because of there speed as can be seen in Figure 15. The PHM would provide a needed protection for an LCAC evacuation operation.

The imposed limitations on hydrofoil craft for naval use was because the full development of any mission was hampered because there was only one squadron available. Demonstration of long range operation is no different than of aircraft they must either refueled in flying operation or have a docking maintenance ship (carrier ship).

Interdictions and MCM cannot be accomplished on an unavailable basis. ASW with the fast maneuvering hydrofoil especially in squadrons is equal to any destroyer. Lastly, like aircraft each generation of hydrofoil craft is a markedly better vessel than its predecessor.

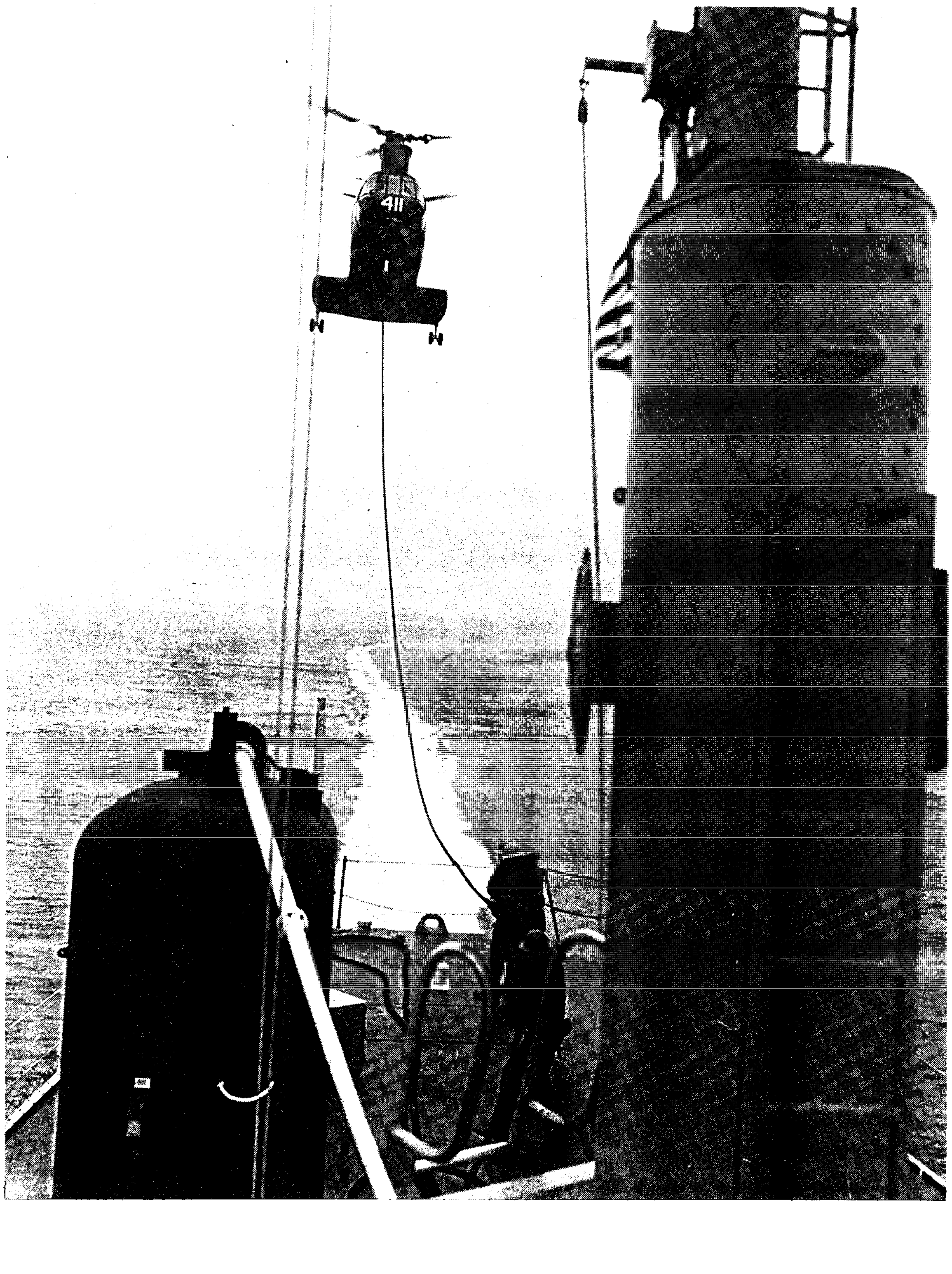


FIGURE 12. REFUELING THE UNDERWAY

FIGURE 13. RANGING TWO HYDROFOIL SHIPS FOILBORNE

FIGURE 14. RANGING THE PHM FOR A MINE COUNTERMEASURES POTENTIAL

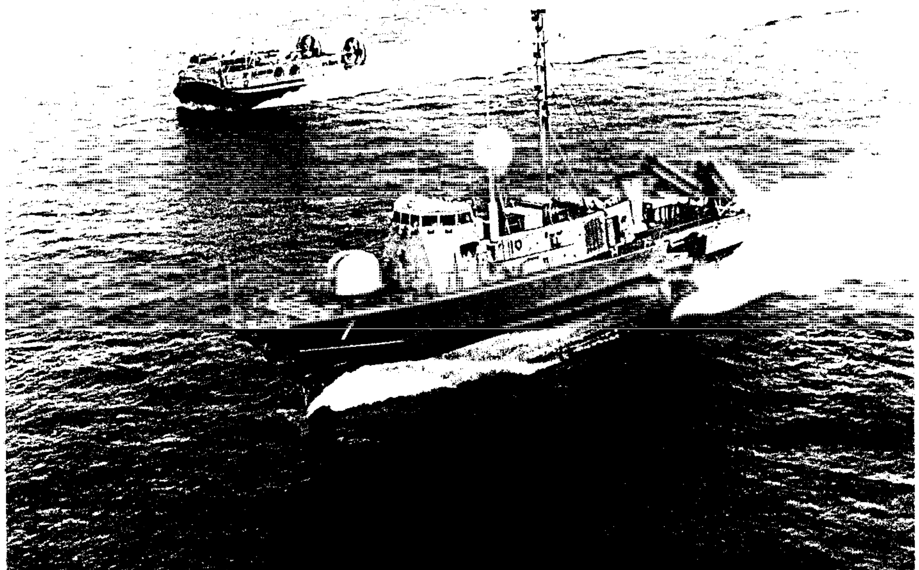


FIGURE 15. PHM OPERATE WELL WITH LCAC - PROVIDE PROTECTION IN EVACUATION OPERATIONS

HIGH SPEED FERRIES FOR SOUTHERN CALIFORNIA

By
Stanley Siegel

Stanley Siegel is a graduate of New York State Maritime College in Marine/Mechanical Engineering, and Santa Clara University in Nuclear Engineering. He is presently employed by McDonnell Douglas Technologies, Inc. He started as the Director, Naval Programs in 1987 with the responsibility to develop a business base for MDTI (then ALCOA Defense Systems, Inc). After McDonnell Douglas acquired the company, he became the Director, Advanced Programs with responsibility to transition all MDTI technologies into the broad customer base. Previously, he was with Aeronautical Research Associates of Princeton (ARAP) as a Senior Consultant in Applied Technology Operations. Earlier, he worked at the Defense Advanced Research Agency (DARPA) as the Program Manager for a major R&D activity that required development and introduction of several new technologies for U.S. Navy surface ships including design of advanced hull forms, surveillance concepts, and low observables. From 1975 to 1979, he worked as the U. S. Navy's Program Manager in the NATO Patrol Combatant Hydrofoil (PHM) program with the responsibility to integrate ongoing hydrofoil research with advanced sensors and combat systems into a mission capable ship. He represented the U. S. interests in negotiating technical and financial matters with our NATO partners and had responsibility for completion of design and testing activities. From 1962 to 1975, he worked in a variety of positions in ship acquisition programs for the U.S. Navy, including completion of preliminary design for the A0177 class of ships which transitioned to a major shipbuilding program; design and construction of seven AOR's; was senior civilian at a Navy contract management field office for ship construction; and completed significant design projects in a Navy shipyard for construction and repair of Navy ships.

Abstract: The paper is an overview of the Southern California area between San Diego and Santa Barbara to consider the potential creation of a market for high speed ferries. The paper identifies potential routes and provides some limited cost/benefit analysis. The merits for different high speed vehicles are considered along with some preliminary conclusions.

In this paper, we will consider the factors that could lead to a viable market for high speed ferries in Southern California. The paper will examine the conditions that would lead to such a market rather than the technical aspects of the system; these will have to come later.

Everyone recognizes the things that have come to symbolize living in Southern California - warm sunny weather, young athletic looking tanned bodies playing beach volleyball, the hills of Hollywood, backyard swimming pools for sunbathing, etc. Obviously, a common theme is lots of outdoor activity to take advantage of natures' gift; a warm climate and gorgeous geographic features for our personal enjoyment. And yet as shown in Figure 1, we have created a notorious nemesis in that getting around in the area has come to mean driving the freeways in our automobiles. We all know the consequence of that. Remember that warm sunny weather I mentioned; well, the result of our automobiles has led to what the residents call "brown stuff", which to the rest of the country is known as air.

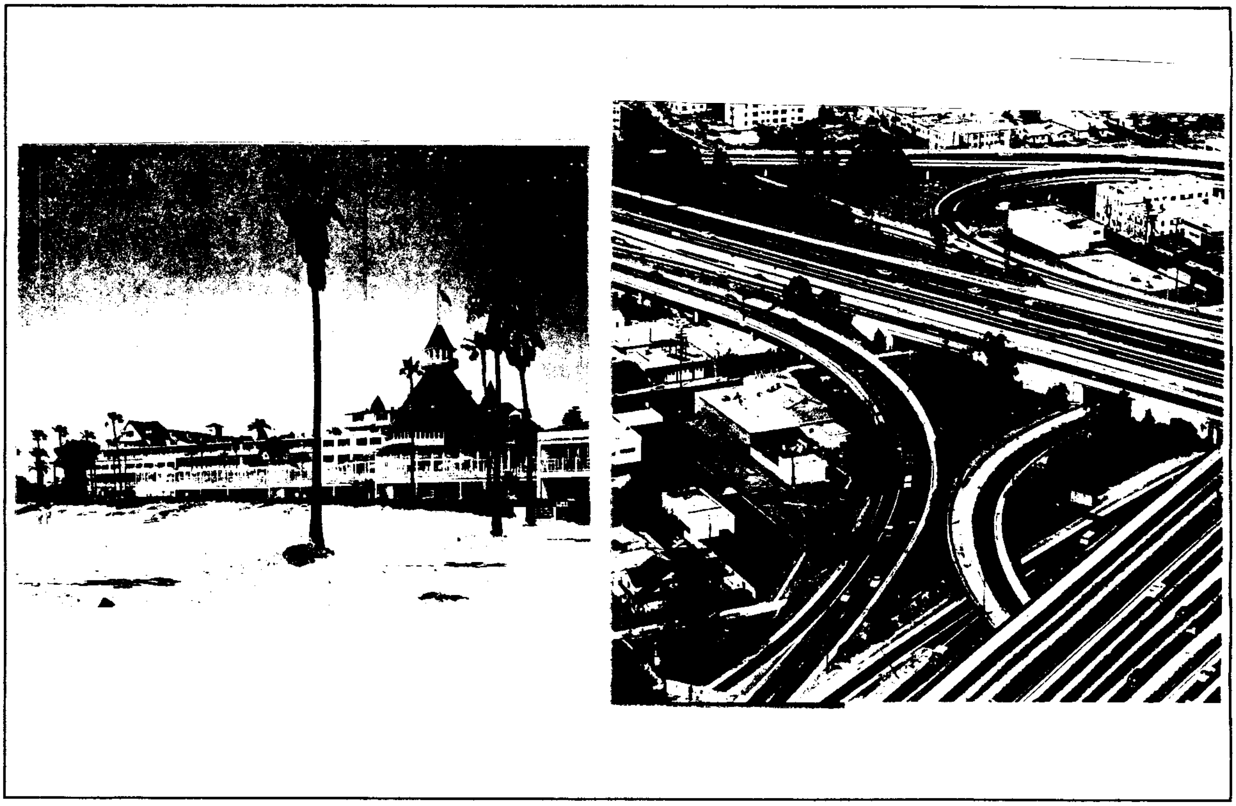


Figure 1. The outdoors in Southern California is a dramatic contrast between natures' beauty such as this pristine beach on Coronado and the man-made freeway system necessary for commuting; "The beauty and the beast".

The air pollution in Southern California has become notorious; fortunately, I believe the air quality is actually improving a little. The improvements have been the result of costly and sometimes questionable transportation changes that include:

- encouraging carpools, sometimes through penalties
- introduction of clean burning gasoline at higher cost
- some vehicles beginning to run on compressed natural gas (CNG), which is a double benefit since there is an abundance of natural gas in this country
- a new subway system being created in Los Angeles to attempt to unload the freeways (It will still be necessary to get people out of their cars!)
- the "Coaster"; a new light rail system that runs between Oceanside and San Diego
- a growth in commuter airlines
- the coming of zero emission vehicles (ZEV), which have been legislated to show up over the next couple of years. Most believe however, that the battery technology to make ZEV practical is at least ten years away.

The point of this is that everything has been thrown on the table for potential transportation improvements; that is almost everything. So far there has been no serious discussion of using a nearby abundant resource, the Pacific Ocean. The point of this paper is to open up a discussion of this transportation potential.

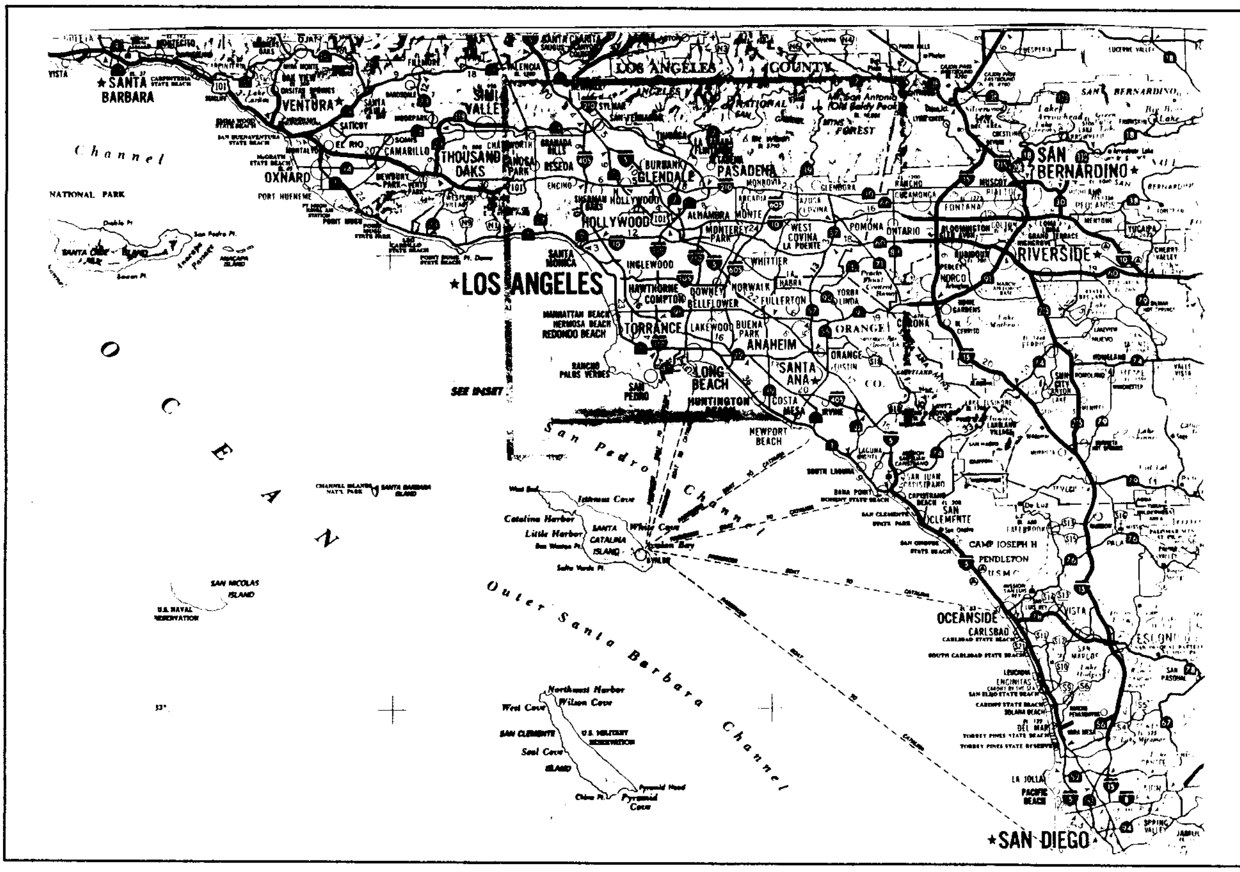


Figure 2. Southern California's coastline parallels much of the freeway system.

In considering the coastline picture shown above, it is appropriate to mention another important consideration. Under the North American Free Trade Agreement (NAFTA), the border between the United States and Mexico will become more open over the next several years. This openness will apply to both the movement of people as well as cargo. (Of course, this leads to a huge political issue in the form of keeping the border closed to illegal aliens. That issue will need to be dealt with regardless of ferries.) At least in partial recognition of this fact, the port of Ensanada is undergoing a large expansion and modernization project. A very natural set of linkages will begin to emerge between the port of Long Beach/San Pedro in the Los Angeles area and this modernized Ensanada in Mexico's north. There is considerable discussion in the San Diego port district to focus on the question of where does San Diego fit in this international economic puzzle. Perhaps this picture can be helped if there is a ferry transportation system that serves the region.

If we consider the region between San Diego to the south and Santa Barbara to the north, we see in Figure 3 that this coastline can be broken into pieces that can be treated as transportation routes.

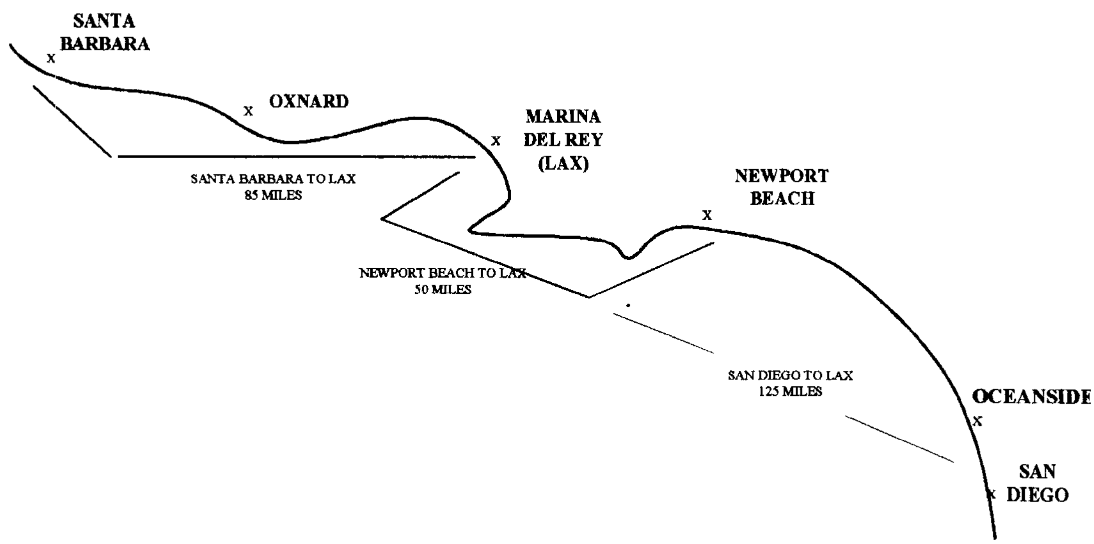


Figure 3. The California coastline and Santa Monica Bay offer natural ferry routes.

In considering Figure 3, some comments are worth noting relative to the cities that can become future routing points for ferries.

- Marina del Rey - is an optimum focal point for the system. It is a 10 minute ride to Los Angeles International Airport (LAX) with obvious ties to worldwide transportation. From LAX, there are the other existing ground transportation links to the sprawling greater Los Angeles.
- Santa Barbara - at the northern end of Santa Monica Bay is a natural tourist location and commercial fishing port. Many of the residents of Santa Barbara and Ventura Counties work in the Los Angeles harbor area. The current approach for driving in from this area requires using the Route 101 freeway which is one of the older and more crowded routes in Los Angeles.

- Newport Beach - is in close proximity to Orange County's large business park where daily commuters could be served, as well as the "Gold Coast" for regional shopping. Orange County's commuting population is tied to driving the Route 405 freeway, another notoriously unreliable route.
- Oceanside - where use of the local marina for transportation to San Diego (competing with a marginally effective "Coaster" light rail system) is attractive. There are many endemic problems with this system that include the fact that the region has only a single track. Adding another track for legitimate two-way traffic will be very costly. To my knowledge, there is no current plan to add the second track.
- San Diego - for transportation between Los Angeles to the north and Ensanada to the south for moving people and "niche" cargoes.

Before discussing the specifics of potential ferry routes, we should state some ground-rules for the discussion. The considerations for ferry routes in Southern California (SOCAL) will be unconventional in that ferries generally are of most value in **crossing** bodies of water where they are generally an alternative to bridges. In the SOCAL case, the ferry potentials we will be discussing are obviously not going to cross bodies of water but will instead be considered as an alternative to three existing modes of transportation:

- driving on the freeways;
- riding the AMTRAK train which parallels the freeway in some areas; or
- flying.

We will briefly discuss these three existing modes:

1. The alternative to driving:

An obvious feature that shows up when one considers the set of routes for ferries shown in Figure 2 is that the routes tend to be of fairly long distances as seen below; this becomes a critical observation.

ROUTES	DISTANCE (Miles)	DRIVING TIMES	AVERAGE SPEED
1. Santa Barbara to LAX	85	2 to 3 hours	34 MPH
2. Newport Beach to LAX	50	1.5 to 2.5 hours	25 MPH
3. San Diego to LAX	125	2.5 to 4 hours	38.5 MPH
4. Oceanside to San Diego	40	1 hour	40 MPH

Table 1. Potential routes for Southern California ferries.

Why would a ferry system make sense? The answer must lie in improved transportation for commuters and/or lower cost. We can see from Table 1 the nature of the driving times for commuters. It is also obvious (particularly to anyone who has driven on the Los Angeles freeway system) that there is a lot of uncertainty in the driving times.

The uncertainties are the result of freeway dynamics; accidents, construction and just general overcrowding.

We know that for ferries to make sense for these routes, the transit times must be less than the driving time and/or using the ferries must be attractive for commuters to be willing to get out of their cars. Another way to approach this would be to set up a ferry system for door-to-door service such that commuters never get in their cars for their daily routine; this may be an important key to success. From considering Table 1, we see that the average driving time which the ferry must compete with for the identified routes is about 40 MPH.

2. The alternative to riding the train.

Shown in Table 2 is the 1994 published routing system that AMTRAK offers for the SOCAL region.

City/Train Number	581	783	585	587
San Diego	2:50P	4:45P	6:45P	8:45P
Del Mar	3:25P	5:24P	7:20P	9:20P
Oceanside	3:44P	5:41P	7:39P	9:38P
San Juan Capistrano	4:18P	6:17P	8:14P	10:08P
Irvine	4:32P	6:31P	8:28P	10:22P
Santa Ana	4:44P	6:44P	8:49P	10:34P
Anaheim	4:51P	6:53P	8:49P	10:44P
Fullerton	5:00P	7:02P	8:58P	10:54P
Los Angeles	5:49P	7:47P	9:43P	11:40P

Table 2. Amtrak's afternoon routing system for Southern California

This routing is for afternoon service with a similar schedule being offered in the morning. In addition, there is limited commuter service being provided between Los Angeles and Santa Barbara with stops in Burbank, Van Nuys, Chatsworth, Simi Valley, Moorpark, Oxnard and Ventura. The service that AMTAK offers should be considered complimentary with ferry considerations rather than competitive. For example, from Santa Barbara through Ventura and Oxnard the route heads inland through Burbank into downtown Los Angeles. The system then heads east and south through Santa Ana and Irvine before returning to the coast to continue south through Oceanside into San Diego. It can be seen that the system does not directly serve LAX or Newport Beach. Furthermore, in the areas where the system provides coastal service, the commuting times are similar to the freeway times noted in Table 1 above. For example, from San Diego to Oceanside the train takes about 55 minutes while the driving time shown is 1 hour.

3. The alternative to flying.

Again, I believe the correct way to think about ferry transportation vis-à-vis flying is complimentary rather than competitive. For someone living in Santa Barbara or San Diego needing to fly to Chicago, it probably makes sense to fly from those regional airports to LAX and then fly east. For someone living in Newport Beach however, taking a ferry to LAX could be made more attractive than driving. The real consideration for ferries must be more as a commuters' daily traveling alternative rather than another way to get to the airport, although airport commuting is significant. Some data extracted from reference (1) is illuminating. While the data is several years old, it is the most recent compilation available, although I am told that a new LAX usage study is being performed. Total annual air passengers using LAX was in excess of 44 million, of which nearly 36 million were originating or terminating in Los Angeles. For visitors and residents, Figure 4 shows the county of origin which provides insight into where people are driving from. For example, we can calculate that for Orange County, the number of commuters driving to LAX on a given day is:

Commuters = Total passengers (44 million) x
Percent Originating (80%) x
Orange County (13%) /365 days

= 12,537

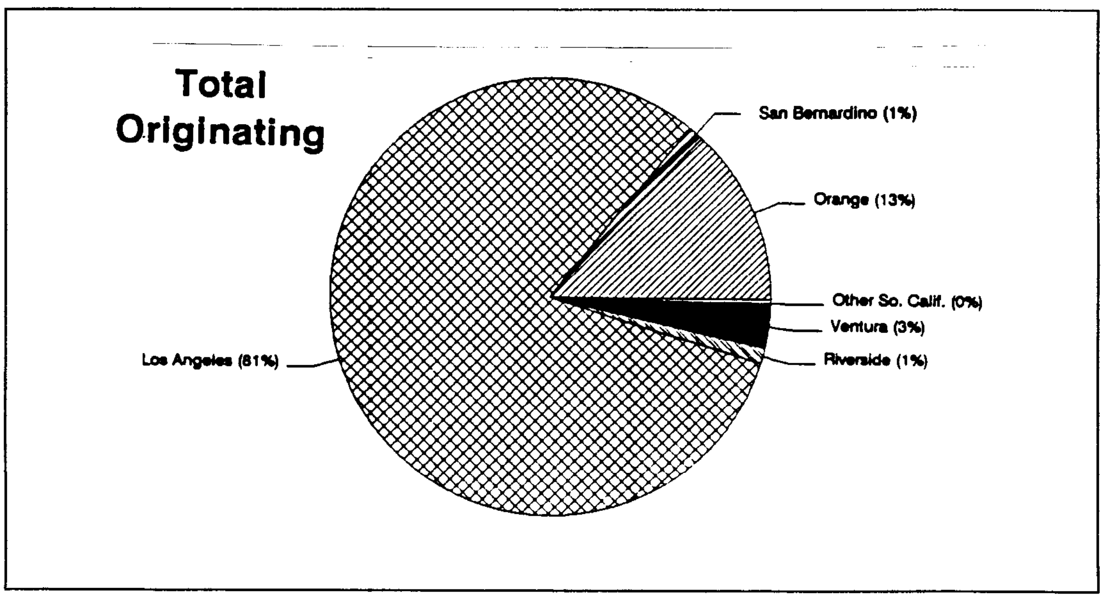


Figure 4. A ferry service can impact a portion of Orange County (13%) and Ventura County (3%); i.e. 17% of 36 million annual passengers or 16,767 daily

Figure 5 is interesting in showing how people travel to and from LAX. The category listed as "Other" consists of limousines, buses and hotel shuttles.

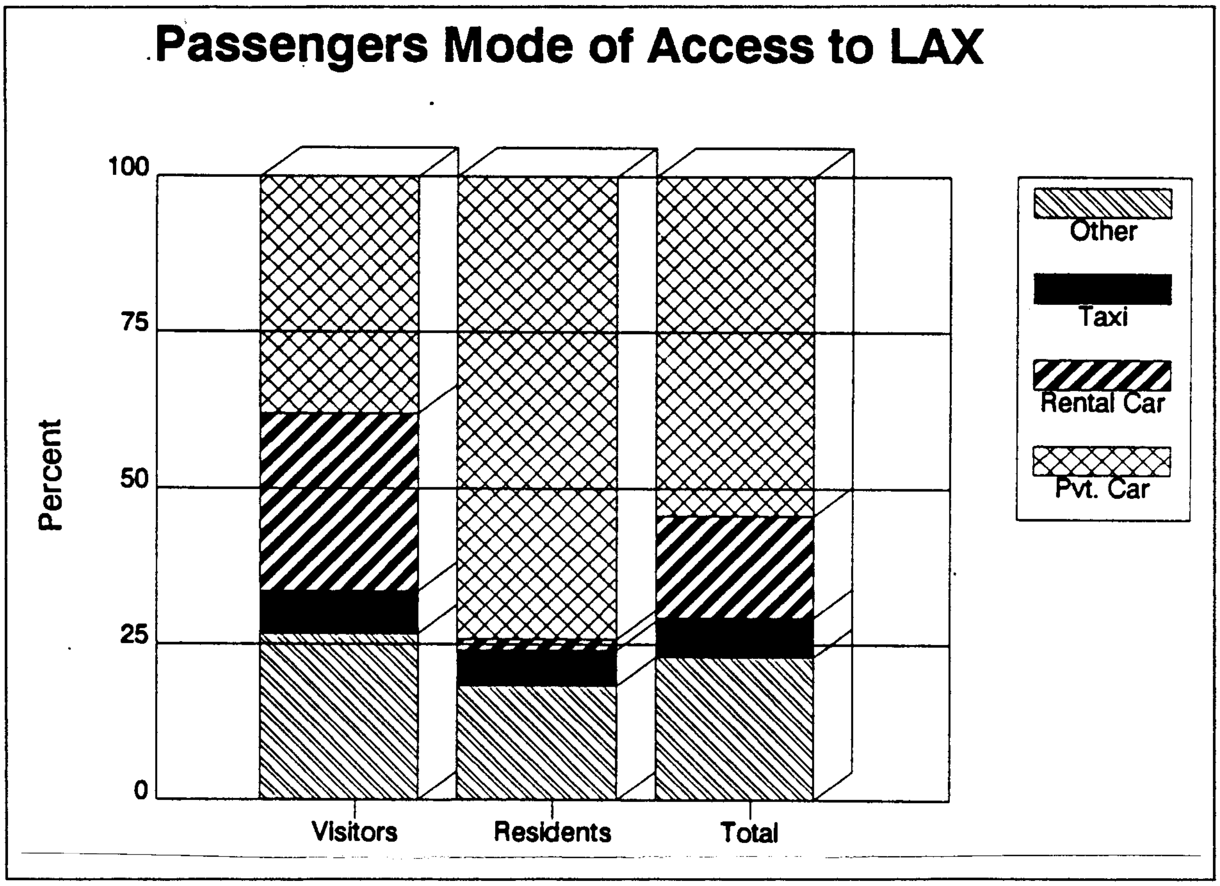


Figure 5. All passengers at LAX use freeways and street conveyances to get to the airport

Transporting passengers to LAX could be a significant market for ferry transportation satisfying two of the routes discussed above. Other data in the study shows that 53% of the passengers are traveling alone while another 30% are in parties of two.

In reference (2), it is reported that the total daily commuting population from Orange County to Los Angeles was nearly 1 million person-trips. The potential market is huge! Only 1% of this would be 10,000 passengers per day. These figures only illustrate the magnitude of the commuting population. An operating ferry system can make a small dent in this; this small dent however could become a major ferry system.

Let us discuss some of the considerations for the type of ferry that could make sense for serving the SOCAL region. Some useful criteria for considering the viability of a ferry system are identified in reference (3): comfort, travel time, reliability, availability of seating, system cost and environmental friendliness. We will briefly discuss these criteria in considering the SOCAL situation.

Comfort The considerations for passenger comfort are paramount. Nobody will ride in a boat in which they are not comfortable. The first order considerations are to offer a smooth ride throughout the sea conditions expected during the entire year. For the SOCAL routes discussed above, the ferries will largely operate in open ocean conditions and will therefore have to deal with short chop as well as long swell. This will have to be the prime consideration in selecting the correct hull form.

Travel time Another critical criteria where the routes we discussed previously will have a major emphasis is in the speed of the selected ferry alternatives. We showed before that the average speed for driving in most of the ferry routes is on the order of 40 MPH. Given that the ferry parallels much of the freeway system, that is probably a good starting point for considering ferry speed. However, since we want to induce commuters to "give up" their automobiles, we need to do better. The commuting time for people to use a ferry alternative must be no more than it currently takes which suggests speeds > 40 knots.

Reliability People must believe they can rely on a transportation system, in order for it to be successful. This means that the system needs to be able to keep to its schedule every day and do so in all but perhaps the most extreme of weather conditions. Fortunately in the SOCAL region the weather is mostly benign. Winter storms will provide unique challenges and the ferry boats and terminal infrastructure will need to accommodate these conditions. There are significant periods of reduced visibility that will offer some technical challenges related to high speed navigation although a lot of progress has been made here and systems are commercially available. People must also feel confident that the boats are safe and well maintained.

Availability of seating The ferry system must be adequately sized for the market it will serve. If the system is oversized, it will not be profitable. This is an interesting consideration in that many forms of "public transportation" are operated at such levels that they rely on subsidies to offset major portions of their operating costs. This is due to many factors some of which lead to the system having excess capacity. While subsidies are enticing (and may be necessary), they are politically unreliable. The ferry system must also not be under-sized for its market or it will quickly become unreliable for commuters. In fact, as reported in Reference (3) the New York Port Authority describes the "Hoboken Ferry" as "the latest and perhaps most successful ferry service in the harbor" and attributes much of the success to having understood the market at the onset and sized the selected vessels and the schedule to meet passenger's needs.

System cost This is one of the most important and most complex of considerations. The system cost must obviously include acquisition cost as well as operating costs. Since, as we have discussed, the potential for ferries must be considered in light of other transportation alternatives the approach shown in Table 3 below is useful.

	Busways	Commuter Rail	High Speed Rail	SOCAL Ferries
Right-of-way difficulty	Moderate	Difficult	Very difficult	No issue except for terminals
Vehicle capacity	75 to 130 per vehicle	190-340 per car @ 3-10 cars	400-500 seats	200-500 seats
Avg. trip length	15 miles	10-60 miles	100-500 miles	40-125 miles
Maximum speed	50 to 75 MPH	55-100 MPH	150-250 MPH	40-60 knots
Capital cost per mile	$10-35 million	$10-35 million	$30-40 million	$1-2 million

Table 3. A system comparison of ferries with other transportation alternatives

The data in Table 3 for the busway and rail alternatives is presented in reference (4) where SCAG presents some transportation ideas; they do not include the ferry. However, if we add the ferry considerations to this mix, some important attributes show up. One of the bigger problems urban planners have to contend with in developing transportation improvements, is the issue of right-of-way. Complex problems like land acquisition as well as impacts on other forms of transport become major cost drivers. For the ferry, these conventional issues go away. There may become some right-of-way costs in terms of the establishment of operating channels in harbor areas, but the need isn't clear. The ferry right of way costs are based on assuming that boats could be acquired for $10 million (this assumption is currently unvalidated). System studies have shown that for the Newport Beach to LAX route, a 7 boat system would provide 24 hour a day operation with departures every 30 minutes. For the 40 mile route, and assuming $1 million for terminal facilities at each end, the capital cost per mile is $1.9 million. The ferry would appear to be very competitive in cost with these other forms of transportation.

Obviously, serious design work is needed for the boats and the terminals to derive real cost projections. Ultimately, the system cost must be a balance of capital investment and revenues; more on this later.

<u>Environmental friendliness</u> This is another area where there are no simple answers because there are many biases to be dealt with. On the one hand there are those who will readily agree that anything that can remove automobiles from the freeway system is environmentally helpful. At the other extreme will be those that will argue that the high speed boats will be potentially harmful to marine life. There are many positive attributes for SOCAL ferries, some of which are:

- most of the operation is in the open ocean where the marine ecosystem is fairly durable
- all of the identified potential terminal points have existing pier space so there will not need to be a lot of construction
- the boats will naturally operate at low speeds in marina areas both for safety as well as wake concerns; these are relatively short runs to the ocean channel. Once in the open ocean, the wake from the boats is no longer of concern.

- all the terminal points have locations with easy access to major street or freeway thoroughfares such that major new road construction will not be necessary

- the boats can operate on compressed natural gas (CNG). According to reference 5 - 10,000 automobiles driven 12,000 miles each produce

- NOX 53 tons/year
- CO 924 tons/year
- HC 54 tons/year

CNG has been shown to reduce NOX and HC emissions by 90% and CO by 65% and is a plentiful fuel in the United States. A two boat ferry system taking only 1,000 passengers/day out of their automobiles will save

- NOX 5 tons/year
- CO 60 tons/year
- HC 5 tons/year.

Obviously, the potential for improving air quality is significant. On balance, I believe that the environmental considerations will favor the ferry.

The type of ferry !

The six factors we have just discussed - comfort, travel time, reliability, availability of seating, system cost and environmental friendliness - lead us to some conclusions regarding the type of boat that would b right for SOCAL ferries. Some are:

- smooth riding in open ocean sea states
- speeds in excess of 40 knots
- safe navigation in all weather conditions
- boats sized for the market. Since boat size will be directly tied to the required capital investment, this will be a critical decision point in defining a system. Economies in scale will suggest that a larger boat will allow lower fares. On the other hand, the larger boats will require a bigger investment and, given the pier facilities in several of the locations (Marina del Rey, Santa Barbara, Oceanside), the boats should not become a burden operating in the confines of the harbors. Boats of about 120 feet in length which provide about 300 to 400 passenger capacity seems to be as large a boat as the current harbors will accommodate.

While these criteria are very broad and can lead in a variety of directions, they do point to using high speed boats. Based on boats that reflect well demonstrated technology, several alternatives will need to be considered:

HYDROFOILS

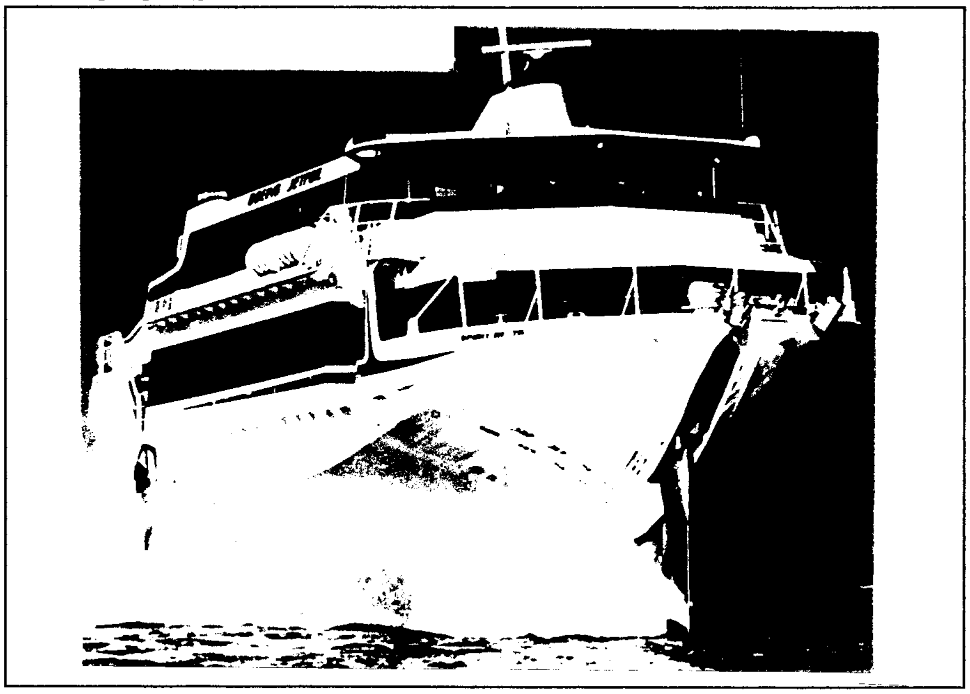


Figure 6. Hydrofoil ferries are in widespread use around the world.

Figure 6 shows the Boeing Jetfoil which satisfies most of the selection criteria mentioned above. It is 90 feet in length with excellent ride comfort at 40 knots and has a capacity up to 300 passengers. Its fully submerged hydrofoil system however is expensive to build and maintain. A hybrid hydrofoil could be an approach for exploiting some of the hydrofoil attributes while solving some of the cost problems.

Surface Effect Ship (SES)

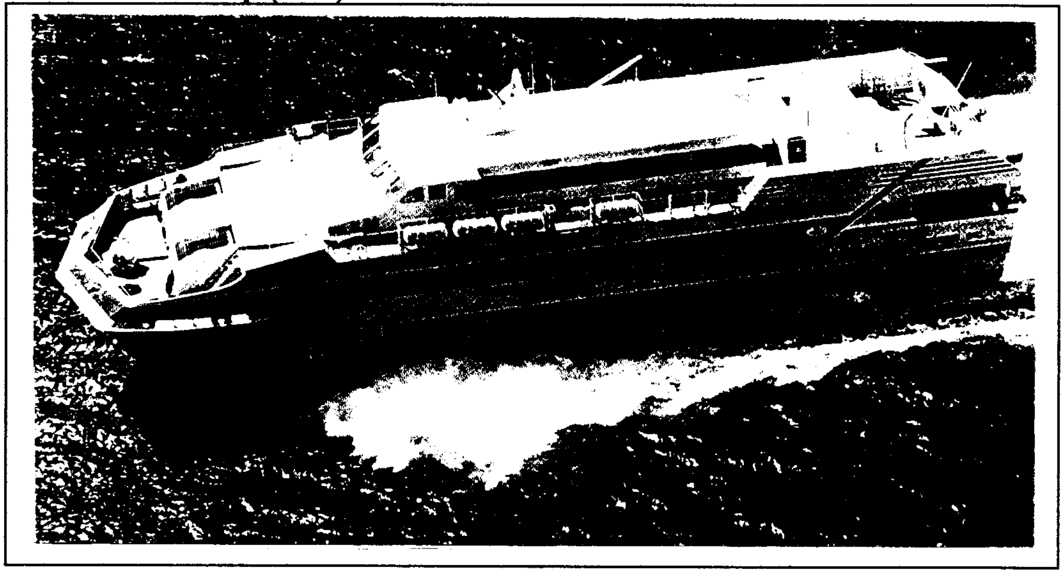


Figure 7. Several SES ferries have operated around the world and are currently in construction

Figure 7 shows an SES underway in a ferry configuration. As in the hydrofoil, the SES satisfies most of the SOCAL selection criteria mentioned above; typically of 120 foot length with comfortable speeds in excess of 40 knots and capacity of about 360 passengers. The SES may prove to be more affordable than the hydrofoil in fabrication and operation. An SES ferry system operated briefly between San Diego and Ensanada Mexico; the boat operator had serious engine problems and the service was terminated after only a few months.

High Speed Catamaran

Figure 8. High speed catamaran ferries are providing reliable low motion service.

Figure 8 shows an Australian Lock Crowther design operating in Taiwan. This is a 110 foot long, 400 passenger design operating at 26 knots. While this design falls short of the SOCAL requirement for a speed of > 40 knots, the company's brochure claims to have designs where they have utilized hull shaping and buoyancy distribution to maintain a low motion ride up to 40 knots. This could be an attractive approach if adequately powered.

Wing-in-ground (WIG)

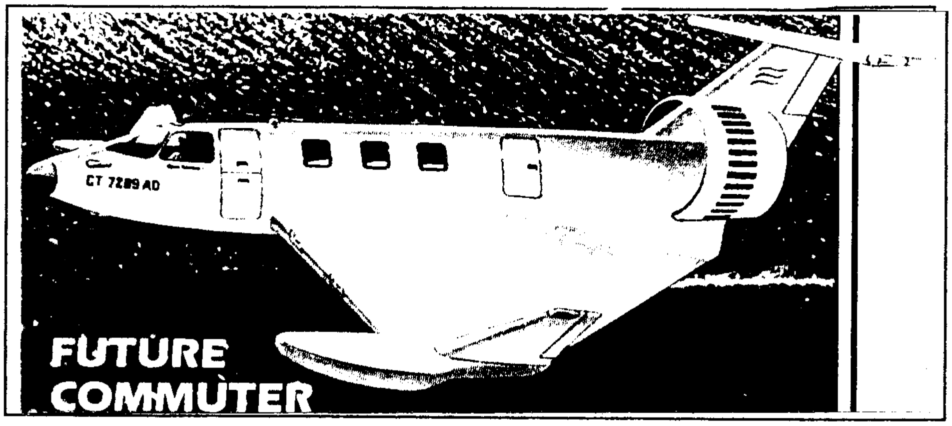


Figure 9. A future version of a WIG ferry

Figure 9 represents a concept offered by Flarecraft Corp. of Connecticut. While a WIG ferry is not a present day option, the SOCAL routes represent a case where the long distances could take advantage of the high speeds offered (~ 100 knots). Operation in rough water would have to be demonstrated before this is a viable option.

The selection of a hull type for the ferry system will need to be made as part of a preliminary design. My belief is that the SES will offer the best opportunity for a near term system that will satisfy all of the SOCAL requirements and allow speeds approaching 50 knots.

Starting a new ferry system will be tough. Until the market is established, we speculate about most of its attributes. An investment will be required to validate the market. If we consider the economics of the SOCAL ferry system, there are a large number of variables. However, in making a number of assumptions we can see some factors that will have a lot of leverage. The approach shown in figure 10 includes estimated cost of acquisition and operation of the ferry system based on the following assumptions:

Boat cost:	$10 million
Interest Rate:	4%
Annual operating costs:	$5 million
Operation:	300 days @ 2 trips/day
Passenger load:	300

Based on these assumptions, and assuming that the system must be profitable, figure 10 shows two sets of conditions. The baseline case assumes a totally private system which receives all of its revenue from fares. The case labeled ISTEA assumes that some combination of subsidies is made available to the system operator; the formula used for the subsidy is as outlined in the U.S. Department of Transportation Intermodal Surface

Transportation Efficiency Act (ISTEA) of 1991. An assumed 80% construction subsidy and a 50% operating subsidy was used.

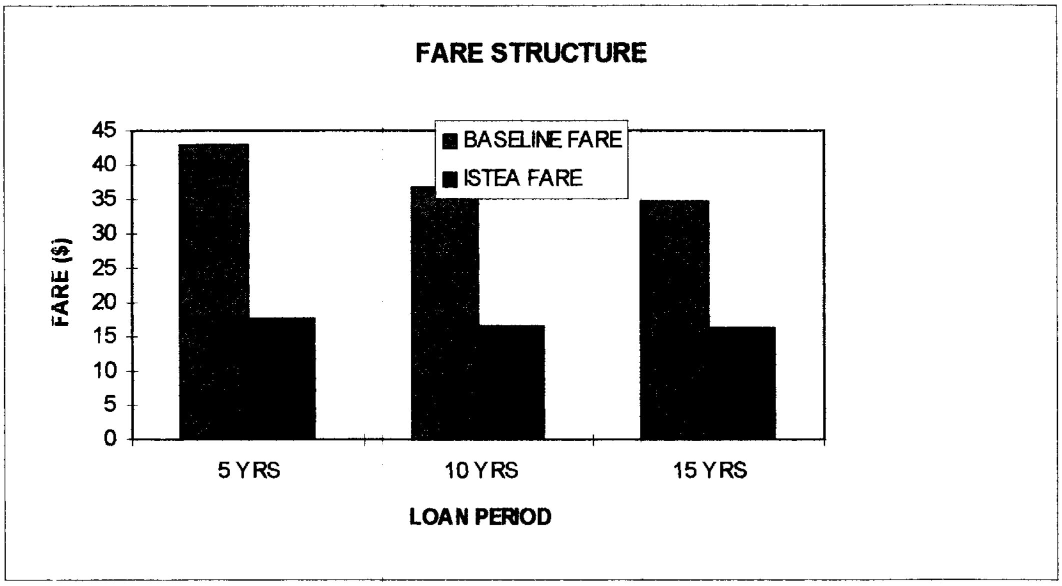


Figure 10. Required fares can be heavily influenced by transportation subsidies.

Figure 10 shows that, for the baseline case, the fares vary from about $35 to $45 per passenger. With the assumed subsidy formula, the fare reduces to about $17 to $20. How much will passengers be willing to pay? If we assume that the cost of ownership for a private automobile is $.65 per mile, a 40 mile trip costs $26, while a 120 mile trip costs $78. These figures are in the same ball park as the fares required for the ferry alternative. The challenge in developing this market will be: **Can we get people out of their automobiles?** Time will tell.

Reference:

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2. 1987 Base Year Travel Information Digest for the Southern California Region published by the Southern California Association of Governments in December 1990
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Commercial and Industrial Applications of Advanced Marine Vehicles

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Introduction

The designation "Advanced Marine Vehicles" (AMV's) encompasses a broad family of transport devices. The boundaries of this family are ill defined and may include distant but related cousins. These extended family members bear a closer resemblance to aircraft and submarines than to any generic Advanced Marine Craft. Classically AMV's have been thought of as 'fast' marine craft but even this is not strictly valid in the case of the semi-submerged platforms.

A degree of order can be developed in this complex scenario by collating the AVM's according to the major lift or support mechanism involved. Figure 1 depicts one such formulation. This approach has first been discussed by D. Jewell, DTRC. Three types of lift forces are identified. The ordinate, or 'y' axis represents buoyancy or displacement forces. The 'x' axis identifies dynamic lift which includes planing dynamics and hydrodynamic lift of airfoils and hydrofoils. The third axis covers the so-called aerostatic lift concepts. These are vehicles such as helicopters and air cushion systems that require onboard power to hold their vertical position. Strictly speaking, the aerostatic systems are dynamic lift devices. Fan and rotor blades impart momentum to the ambient fluid (air in this case) indirectly establishing a 'static' pressure support field.

Most vehicles start off in the buoyant mode and transition, "take-off" into the cruise configuration. The transfer from one lift mode to another follows the sides of the triangular support field. The usefulness of this type of characterization is in that it allows the representation of "hybridized" concepts. For example, a vehicle having coordinates 1, 5 and 4 is 10% buoyant, 50% planing lift and 40% cushion. A possible configuration would be a catamaran with hydrofoil and air cushion lift augmentation.

In the real world however, real AMV's must move not only in calm water but in a real sea-state as well. An interesting question is "how do these craft handle in a sea-state?" The rationale is addressed with the aid of Figure 2. At high speed, waves tend to be very unforgiving. The kinetic energy of a vehicle is a velocity squared relationship. At high speed any contact with a wave tends to reconfigure the linear forward momentum of the vehicle to body centered dynamics - ultimately leading to a drastic production of entropy. In AMV's its not how fast one goes, but how safely one goes fast.

Technically the interface relative roughness issue can be solved in one of three ways. One way - the obvious approach - is to remove the vehicle from the interface. Clearly an aircraft and a submarine accomplish this. The more interesting approach is to 'decouple' from the interface by struts or an air

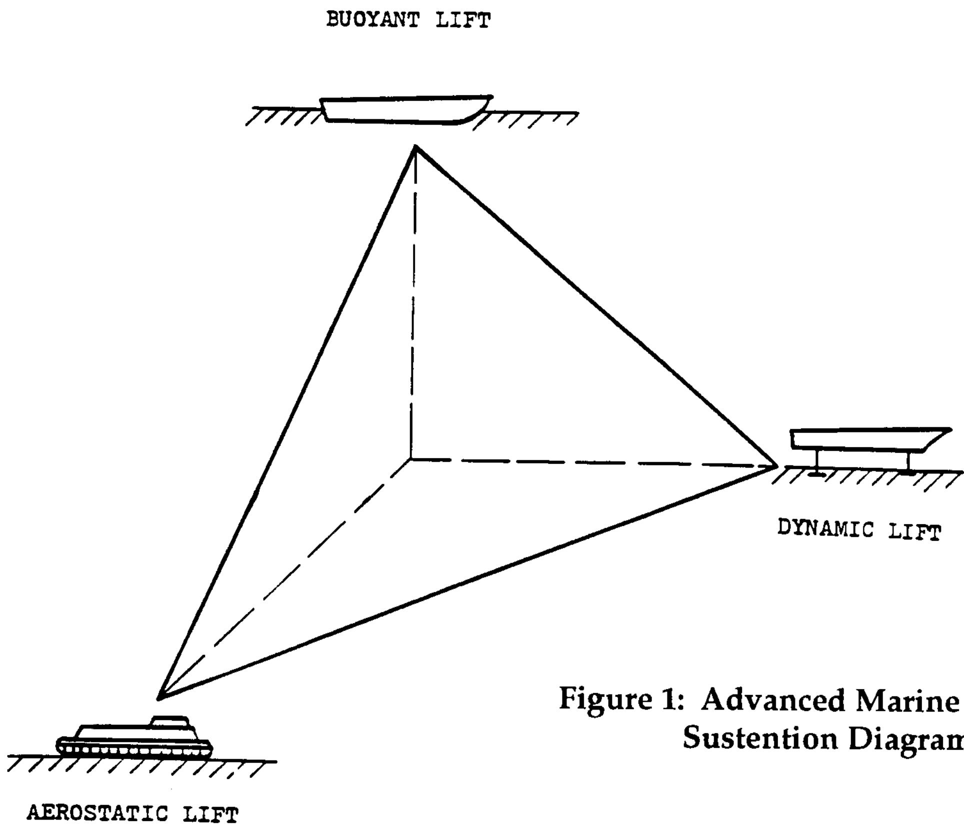


Figure 1: Advanced Marine Vehicles Sustention Diagram

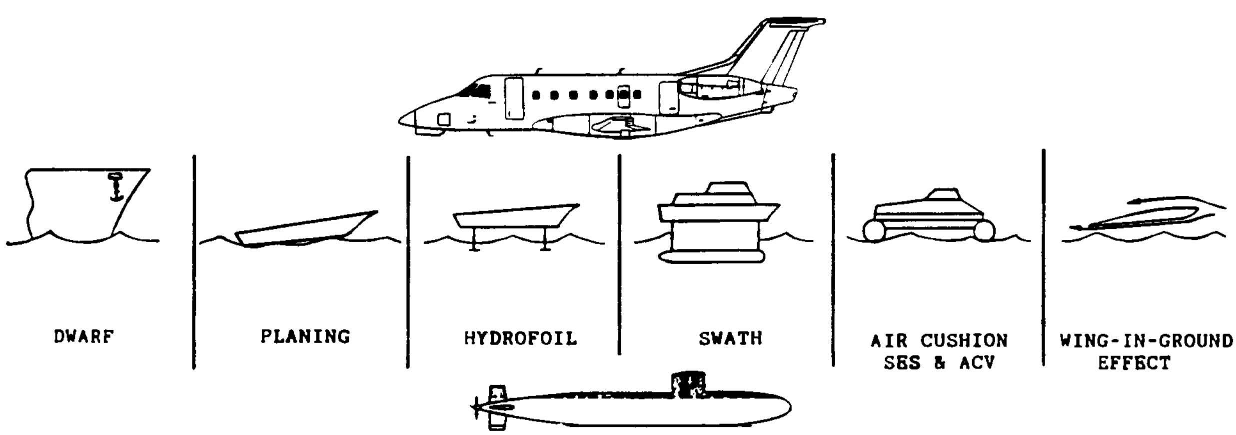


Figure 2: Decoupling Mechanisms

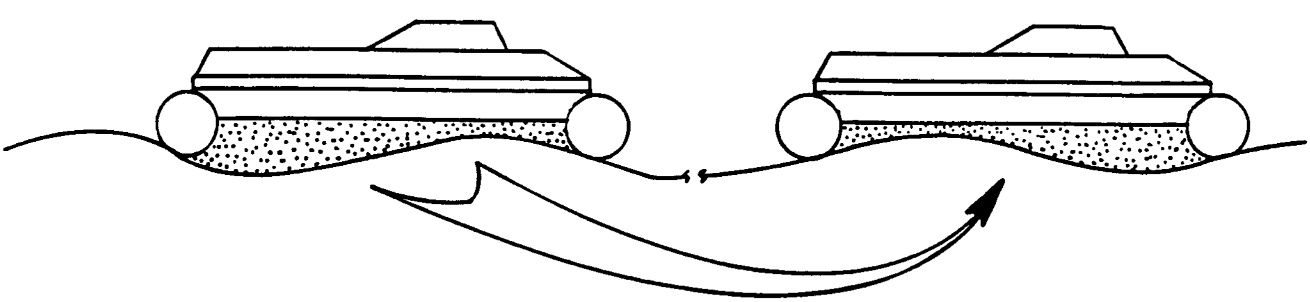


Figure 3: Cushion Volume Reconfiguration

cushion system. Of course there is always the option to 'dwarf' the interface. This approach, however, has limited economic viability for short range and short duty cycle applications.

The decoupling mechanism of struts and cushions is at the heart of all AMV's. Struts provide a "low waterplane area" to the sea-state. As a result, buoyancy force changes due to surface perturbations - waves - are minimized. Fully submerged foil hydrofoils and Small Waterplane Area Twin Hull (SWATH) vessels separate the lift generators - foils and buoyancy hulls - from the payload struts by such struts.

Cushion decoupling systems are often thought of as a pneumo spring suspension system. At the low cushion pressures of air cushion vehicle systems, air, just like water, is incompressible. What the air cushion does is provide a low inertia medium (air) which in turn permits a rapid reconfiguration of an interface volume (Figure 3). The air cushion thus separates or decouples the mass of the vehicle hull from the mass of the surface irregularities - waves.

The question of sea-state operation of AMV's can be comparatively illustrated with the aid of Figure 4. Two parameters are identified, relative roughness parameter and an obstacle parameter. The former involves motion excursions which are within the geometric capability of the decoupling system. The latter involves issues of obstacle, the dimensions of which, are of the order of magnitude of the vehicle size itself.

In the case of the planing hull the lift is generated by a high pressure planing surface which imparts a downward momentum to a mass of water. Operations in waves - Figure 5 - results in excursions in the active lifting area. In turn, this generates changes in the vertical forces on the craft. As long as the incident waves are within the design limits, the ride can be acceptable. When wave heights greater than design are encountered lifting area changes may be of several hundred percent. "Slamming" ensues with discomfort to the payload and passengers, which could cause damage or injury.

Strut based decoupling concepts like hydrofoils and SWATHs attempt to increase the practical range of the 'relative roughness' parameter. When the incident sea-state is within the dimensions of the decoupling capability of the struts the ride is relatively smooth and the vehicle system is 'platforming', (Figure 6). On the other hand, if the wave length is very large relative to the vehicle then the craft 'contours' the surface profile. Unfortunately the real world often presents a situation where the relative roughness parameter and the obstacle parameter are nearly equal. The combination of vehicle speed and sea-state establishes the frequency of encounter and dictates the vessel mode of operation - platforming or contouring.

To illustrate the preceding rationale a number of scenarios are pained that identify future AMV opportunities. These deal with a range of technologies, vehicle systems and total integrated usage scenarios. The applications develop as follows:

- Seamless Fast Ferry
- Notional Arctic Mobility Base
- Ship - Shore Amphibious Transporter
- Amphibious Oil Spill Remediation

These opportunities are structured not for any specific target but only as indications of what is possible and what could be.

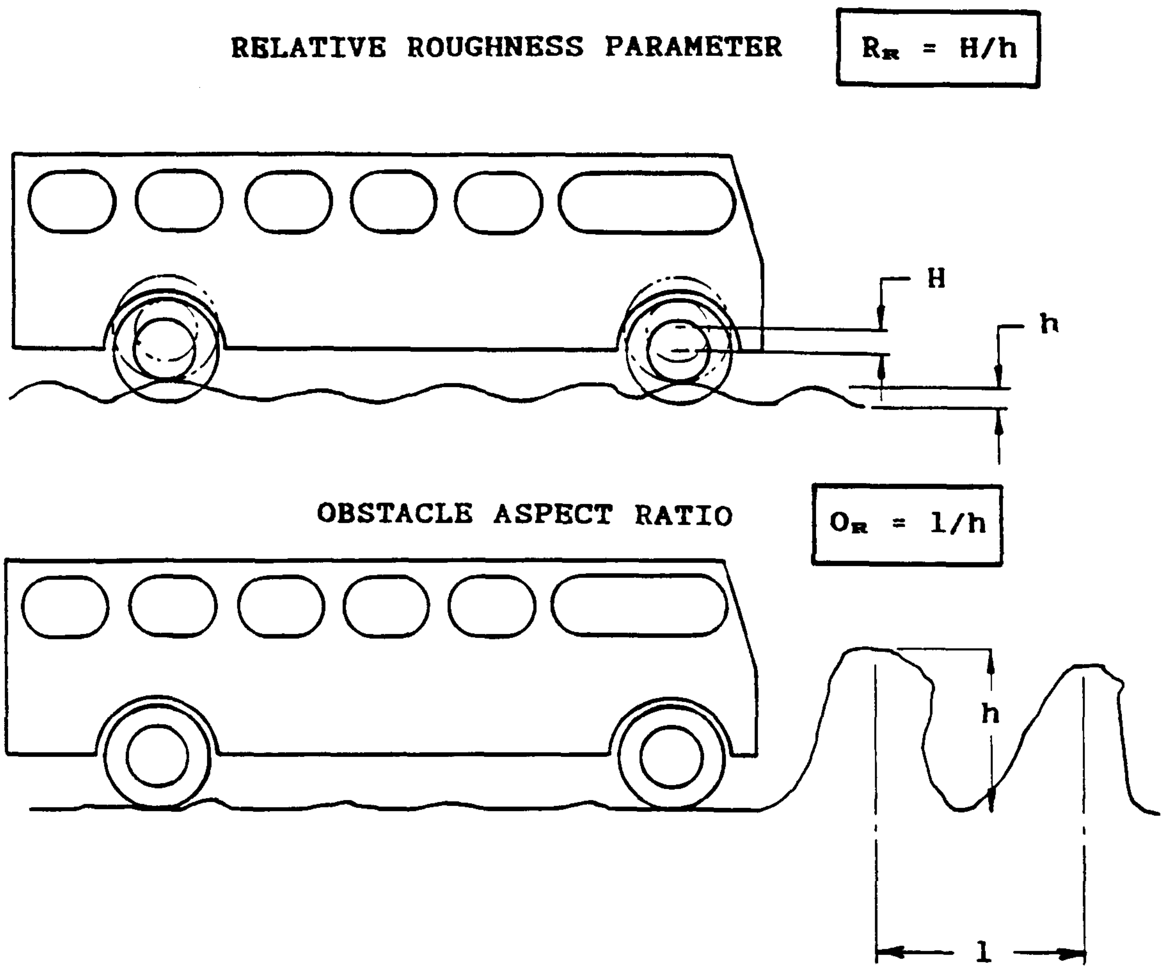


Figure 4: Motion Issues

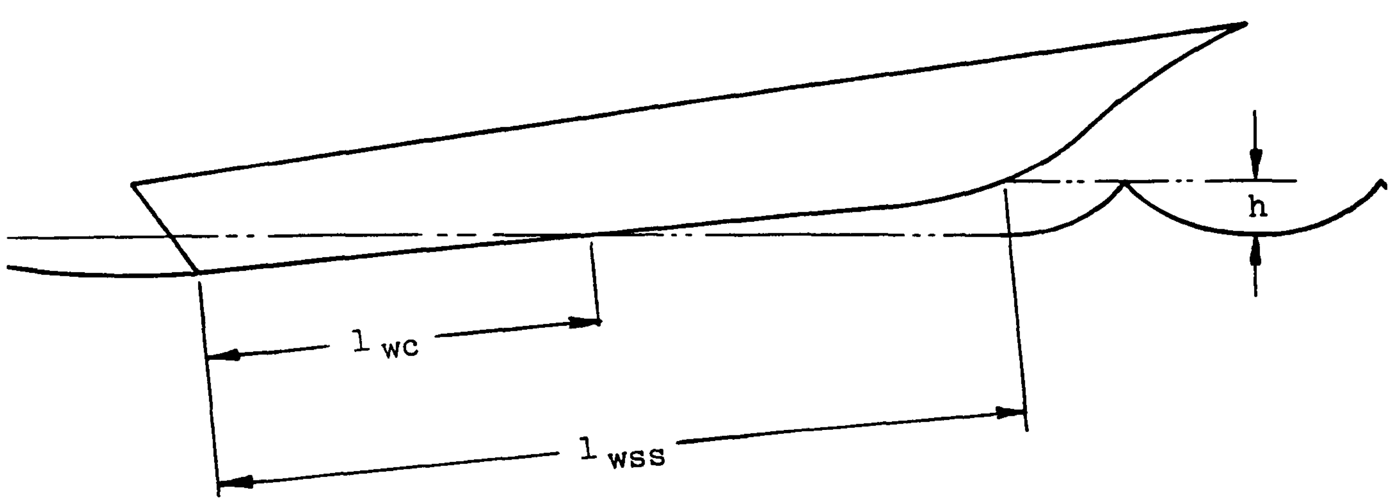


Figure 5: Planing Impact

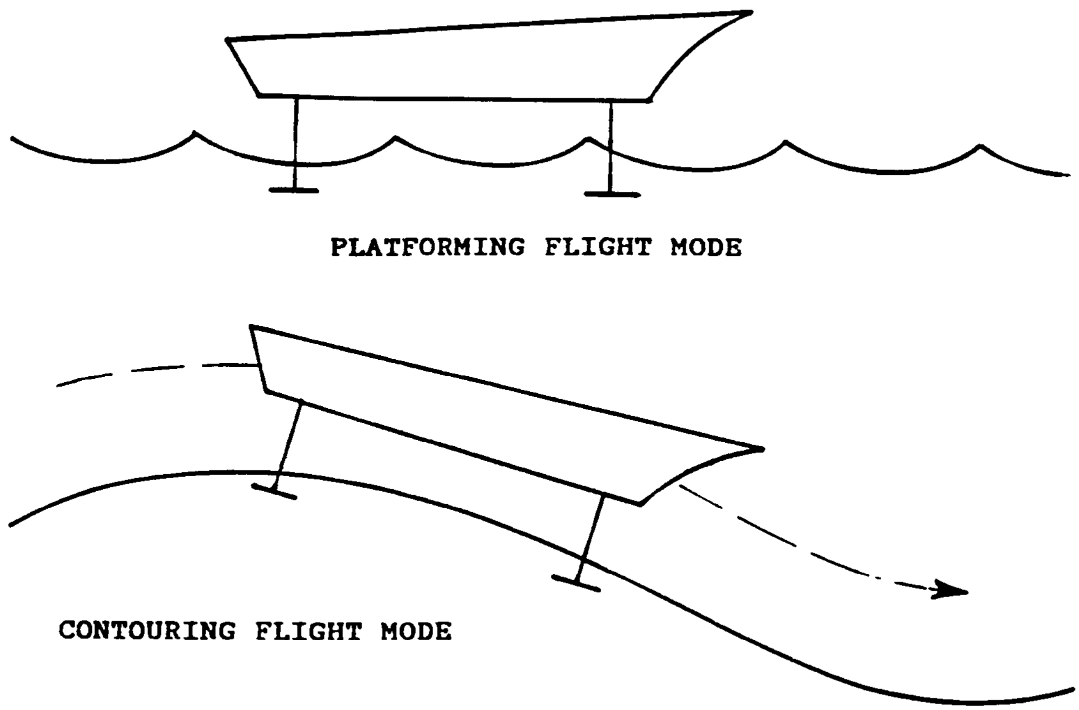


Figure 6: Flight Modes

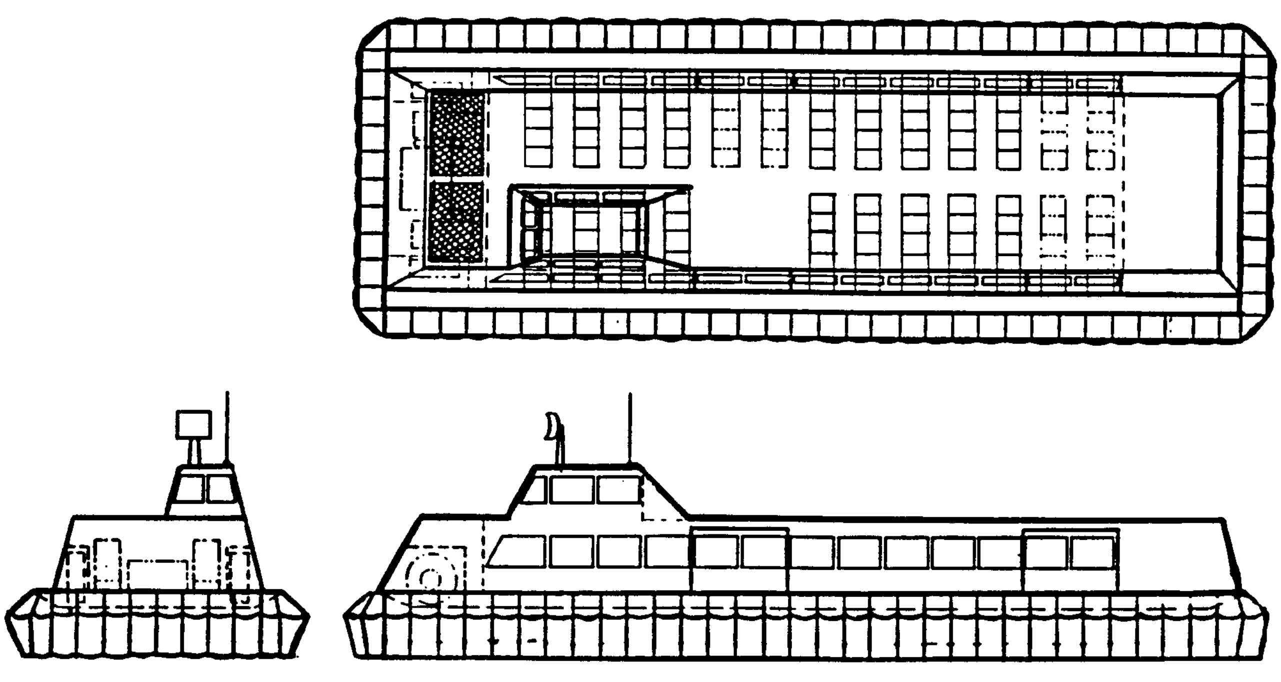


Figure 7: Hybrid Air Cushion Transporter
Internal Seating Arrangement

Seamless Fast Ferry

The suggested Seamless Fast Ferry takes the luxury of a clean start and describes "what could be". The point of departure for the concept formulation is a broad based requirements perspective encompassing diverse interests - including those of the customer (ferry passenger), the operator, builder, designer, investor and even the politician.

A logical question would be - "What does the ferry passenger want?" Generally what he does not want is to ride a ferry. Probably a marine version of "Beam me over Scotty" would be ideal. What the passenger gets however is a transit involving 3 or 4 modes of transport, several interface transfers and generally tight and inflexible schedules. Even a cursory analysis reveals that the total trip time tends o be dominated by terminal times. For stage lengths of up to 15 nautical miles the vessel speed is not the determinant factor in the total trip time. A reduction can only be made by reducing the terminal time.

The desirable attributes of a candidate vessel would include the following:

- The vessel should be draft independent and debris insensitive. This will free the route structure from traffic congested channels and will permit over ice operations.
- The vessel should be amphibious to allow landing at 'land' terminals and thus eliminate pier - side maneuvering.
- The vessel should exhibit 'environment friendly' characteristics such as small wakes, low noise and a pleasant appearance.
- The vessel system should exhibit viable economics in keeping with its mission and productivity.

One platform option is an amphibious fully skirted hovercraft. A notional arrangement of a 140 passenger craft is shown in Figure 7. The vehicle has a length of ≈ 100 ft., a beam of 24 ft. and a design cruise speed of 35 knots. The optional machinery arrangement is depicted in Figure 8. In addition to the lift system module the vessel is fitted with a bow undercarriage for propulsion on terminal ramps. Propulsion may be by marine propellers or preferably by the amphibious Surface Impulse System (SIP). A typical ramping sequence is described in Figure 9.

The amphibious vehicle forms one key part of the total ferry system. The terminals are a vital link between the marine transit element and land mobility. The system's main operating terminal and maintenance base is shown in Figure 10. A smaller 'bus stop' terminal is described in Figure 11. Perhaps the configuration that shows the greatest promise is a barge mounted terminal system (Figure 12). This approach will permit flexibility in size and location, will allow relocation capability and will minimize environmental and political 'permitting' issues.

The execution of a scheme of this scope would need to be implemented by a comprehensive organization. Again taking the luxury of a clean piece of paper one structure suggests itself (Figure 13). This notional High Speed Transport HST Corporation is vertically integrated with total service capability. There are three divisions within the proposed organization: design, construction and operation groups. The rationale for this approach is as follows:

- The **POLITICIAN** Perspective

  The approach to regional transportation authorities would be through an attractive offer to install and operate a fast ferry system over specified routes. The offer would be made on a take-it-all basis. The politician thus need not expend resources and 'call in favors' to 'design' a complete system. He may simply present the offer to the local decision making authorities. The proposed arrangement can be tailored to the peculiarities of the geographic regions and the demographics of specific cases.

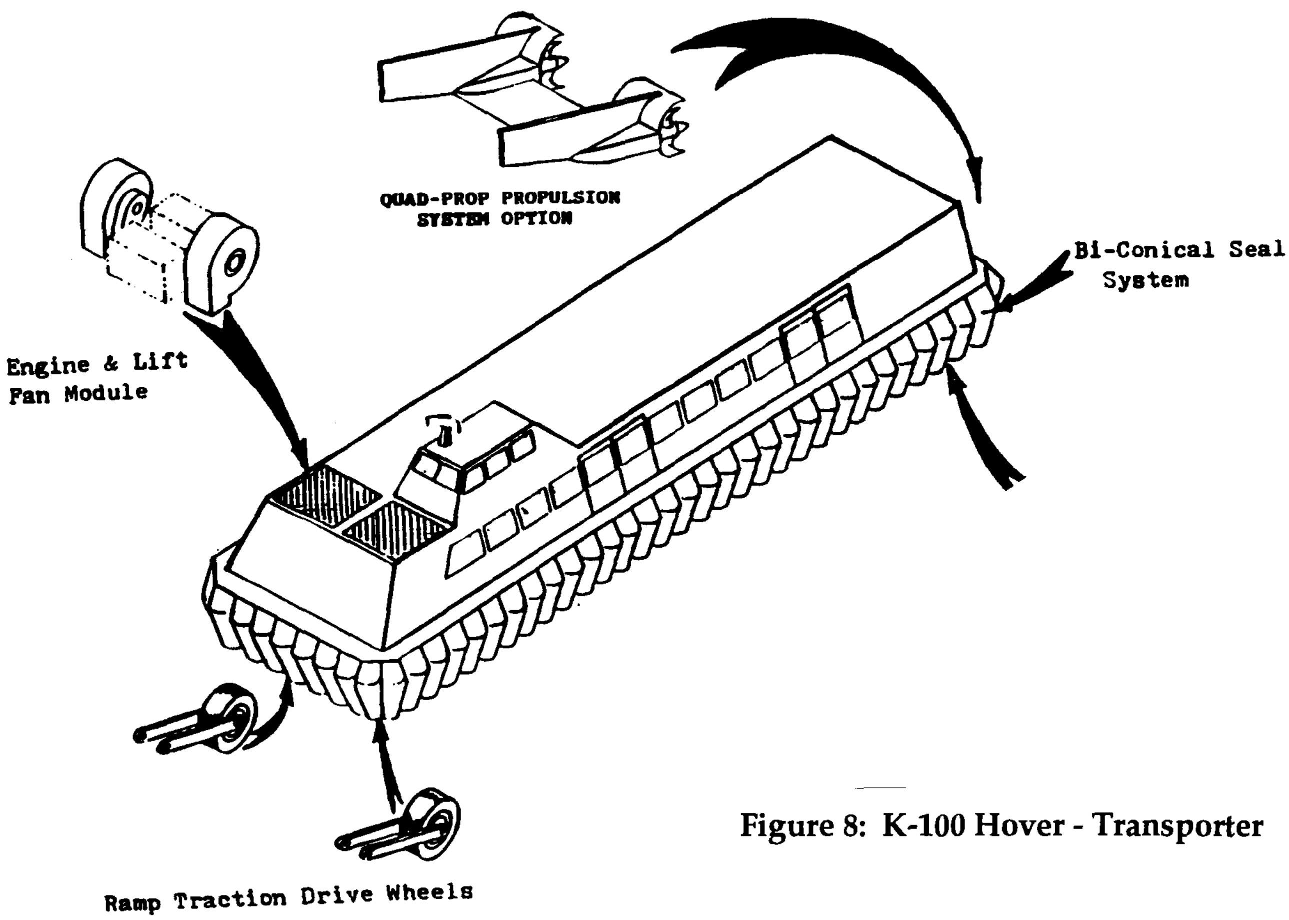


Figure 8: K-100 Hover - Transporter

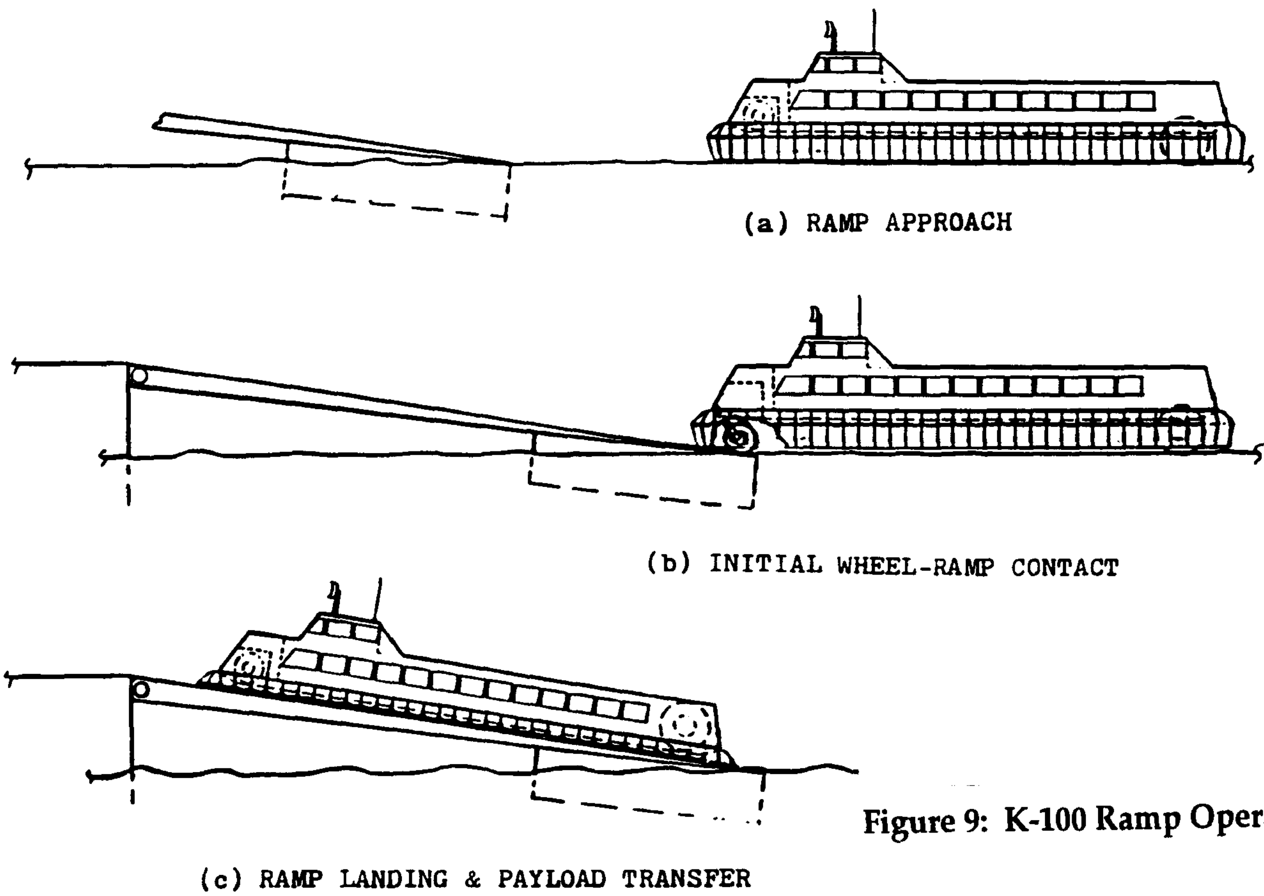


Figure 9: K-100 Ramp Operations

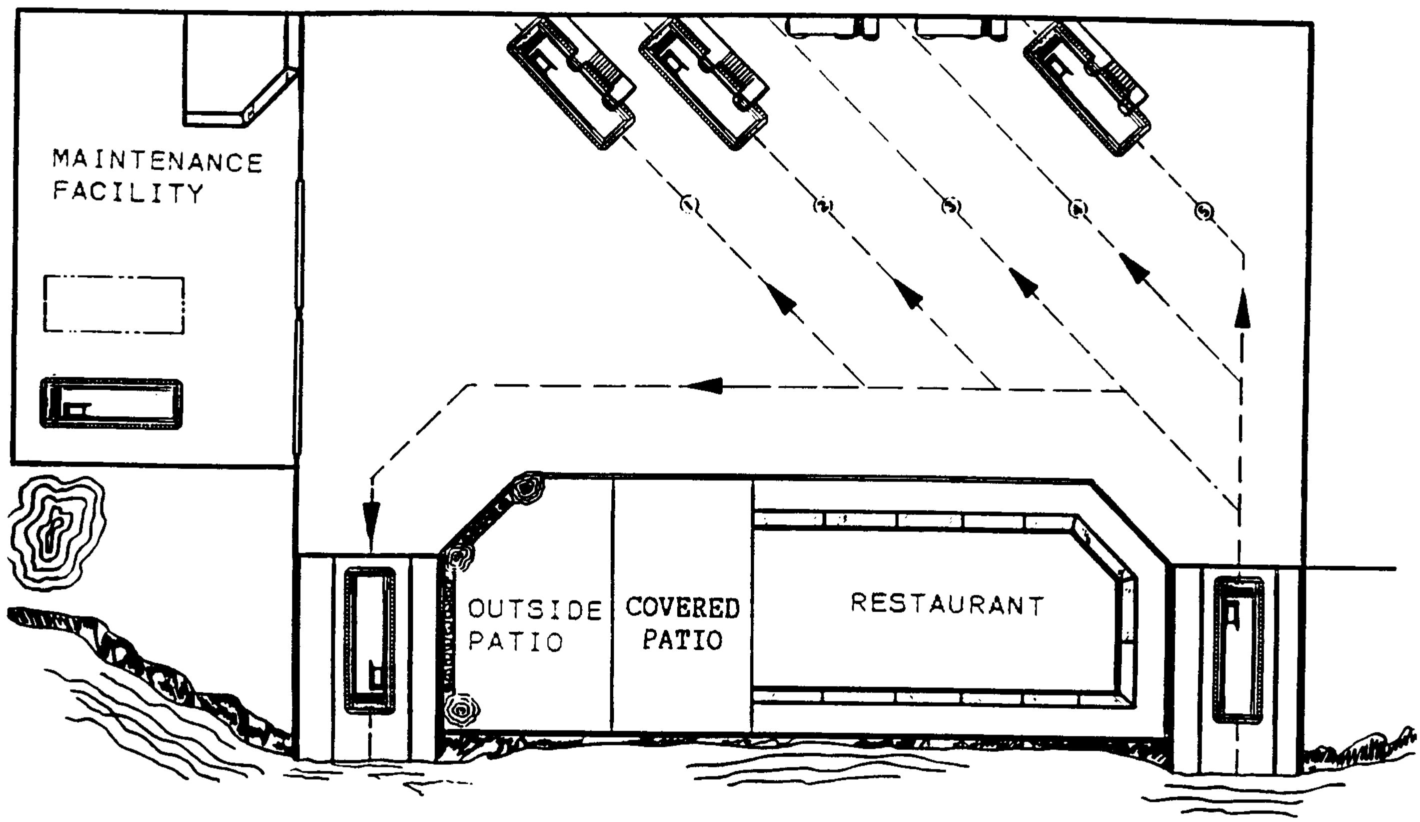


Figure 10: Main Base Concept

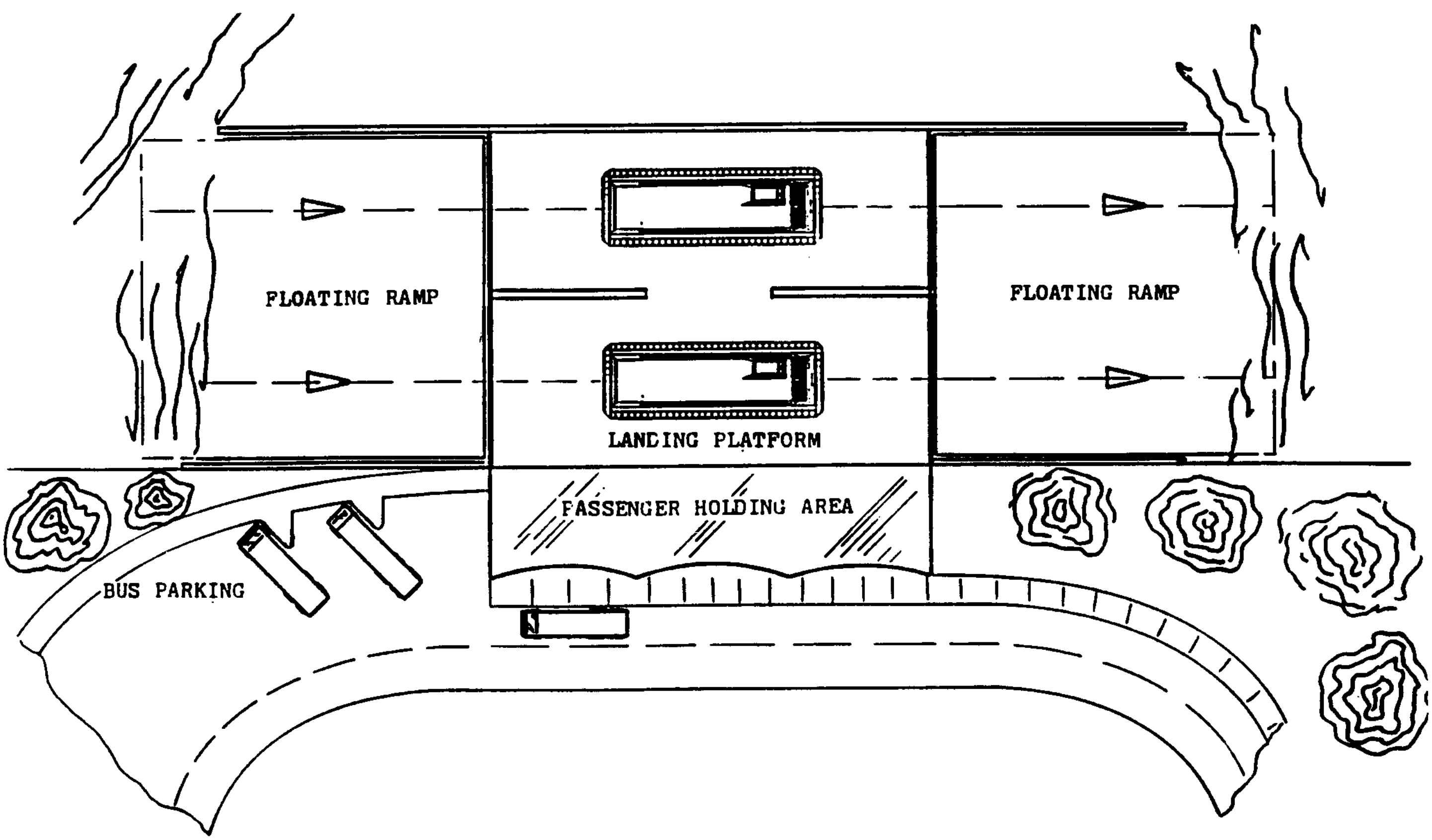


Figure 11: Bus-Stop Terminal

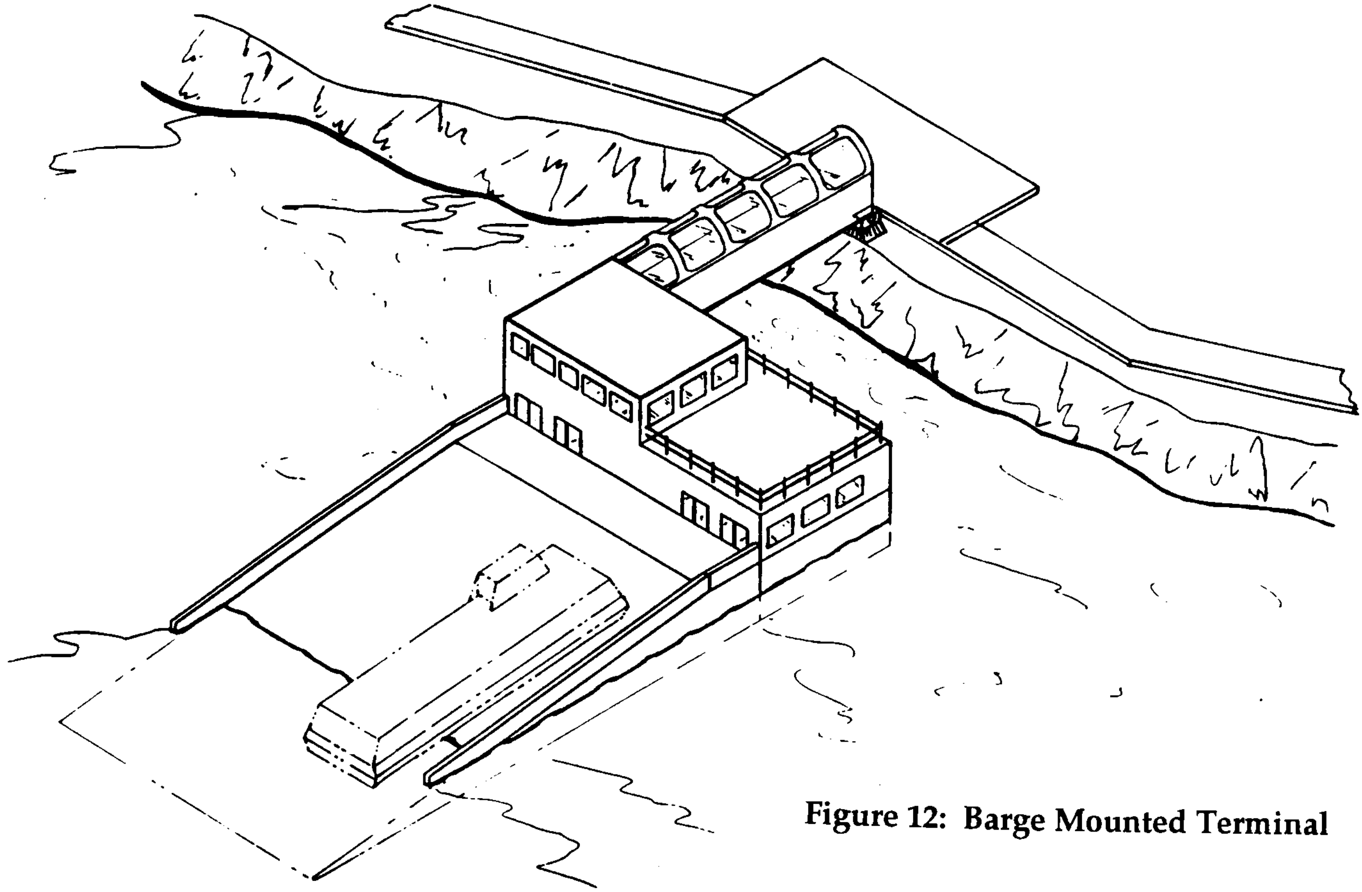


Figure 12: Barge Mounted Terminal

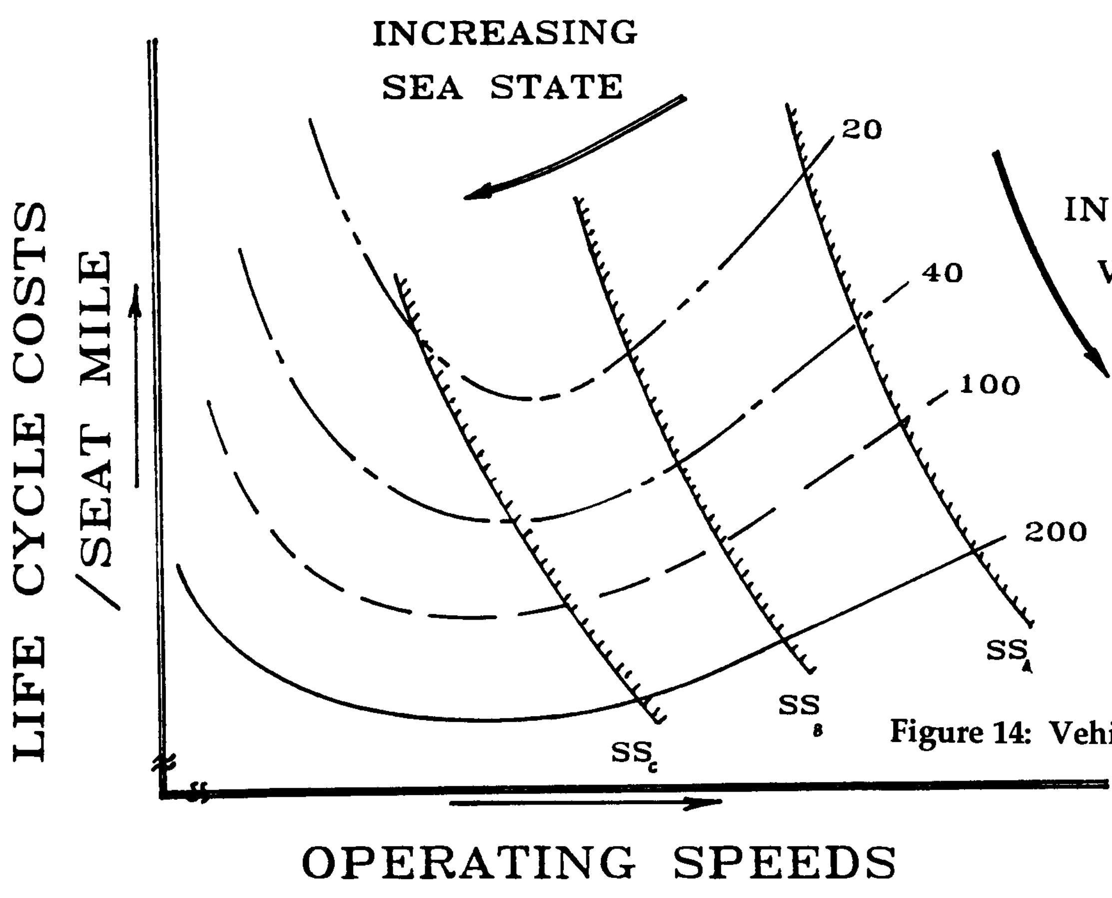


Figure 14: Vehicle Size Sensitivities

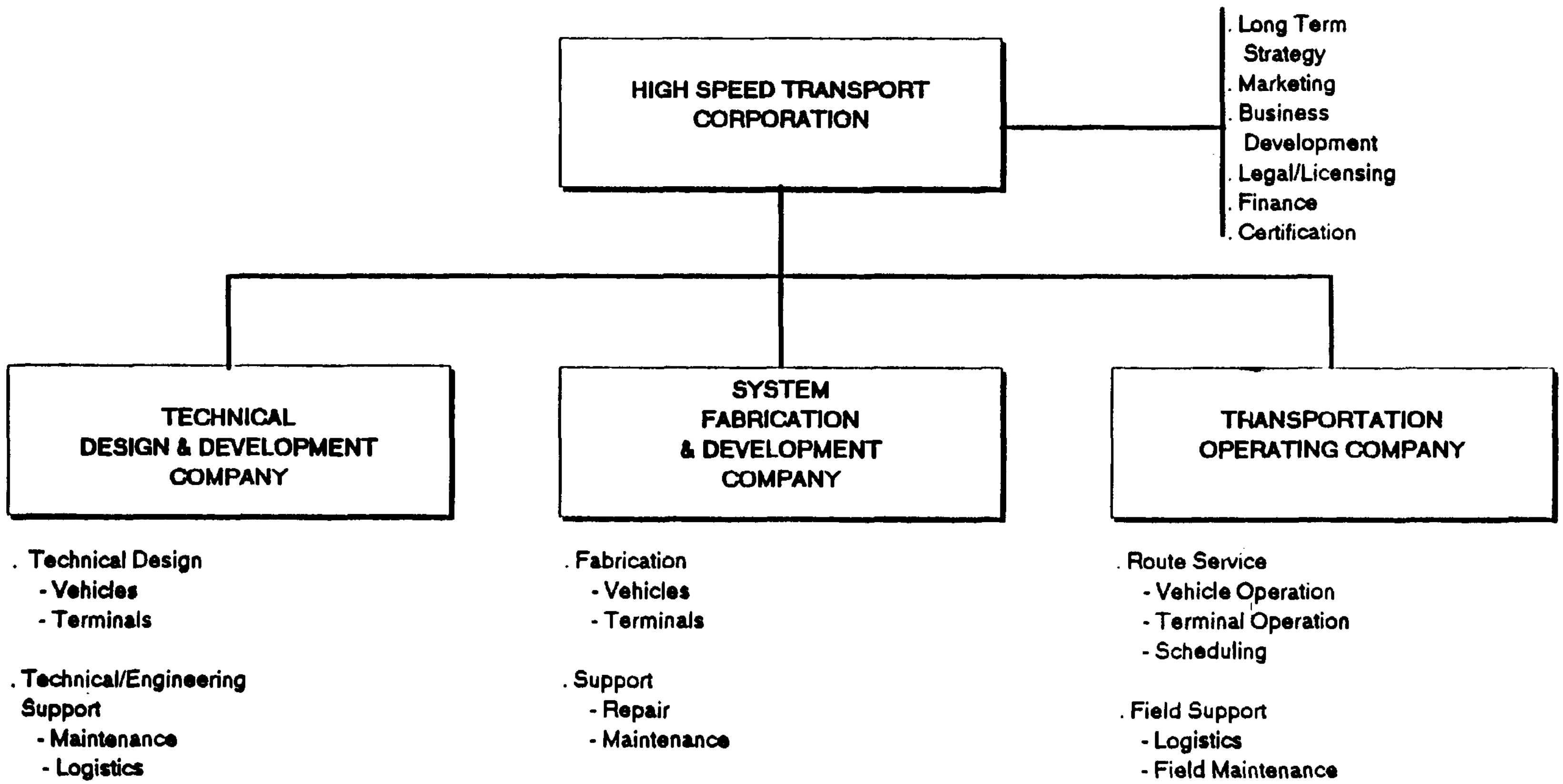


Figure 13: HST Organization

- The **VEHICLE** Perspective

  The proposed baseline vehicle is an amphibious air cushion craft. The rationale is as follows:

  - Being amphibious, the craft is independent of ship channels. Generally the route can be significantly shortened.
  - Being amphibious the craft is independent of floating debris and surface ice conditions.
  - Being amphibious the craft can turnaround at 'land' terminals and thus avoid harbor and port facilities with their associated congestion and restrictions. Thus, turnaround time is likely to be significantly shortened.
  - Being able to operate at post hump speeds the vehicle wake is minimal.
  - An air cushion system will minimize environmental issues. Dredging is not needed and the vehicle footprint is benign.
  - Air cushion vehicle prices can be drastically reduced. Present high prices due to limited production, novelty, and a degree of aircraft standards and procedures. These can be significantly reduced to achieve first costs comparable to aluminum craft practice. Figure 14 identifies a typical vehicle size sensitivities.
  - Being non air propelled the noise (internal and external) is significantly reduced.

- The **INVESTOR** Perspective

  The vertical integration aspects, the air cushion vehicle and the terminal structure is attractive from the investors point of view. The key elements are as follows:

  - The HST Corporation will select the routs or areas where to propose service. Thus there is the opportunity to match the system capabilities and thus ensure the economic success of the system.
  - The investor, through HST Corporation, remains in control of the capital assets of his investment.
  - The land side terminals (whether on shore or barge mounted), remain a moveable asset that can be rapidly relocated as a result of business decisions and/or seasonal traffic demands. Investment is not placed in fixed concrete pierside facilities.
  - The potential growth of this approach is global.

Notional Arctic Mobility Base

Perhaps nowhere more than in the Arctic is the transportation situation more suited for hovercraft platforms. Missions that encompass scientific explorations, oil and gas field work and natural resource recovery can make ideal use of the air cushion vehicle system. However performance parameters are very different from those of the ferry vessel. The Arctic mobility base will see sustained operations at low speed over rough terrain and ice conditions. The system will need to operate as a self contained unit in extreme wind and temperature excursions.

A conceptual arrangement is depicted in Figure 15. The Arctic Mobility Base consists of a train of articulated air cushion units. Each unit is self contained as far as lift, propulsion and hotel power. The system is built around a common hull unit (Figure 16). This hover unit is optionally outfitted with service modules that may include: personnel housing, helicopter field unit and cargo container system.

There are two power modules in each hover unit (Figure 17). The power unit involves a diesel prime mover and a hydraulic power take-off that drives hydraulic motors in the traction elements. Should the traction wheels become unloaded there is an automatic cross-over in the hydraulic power circuits that

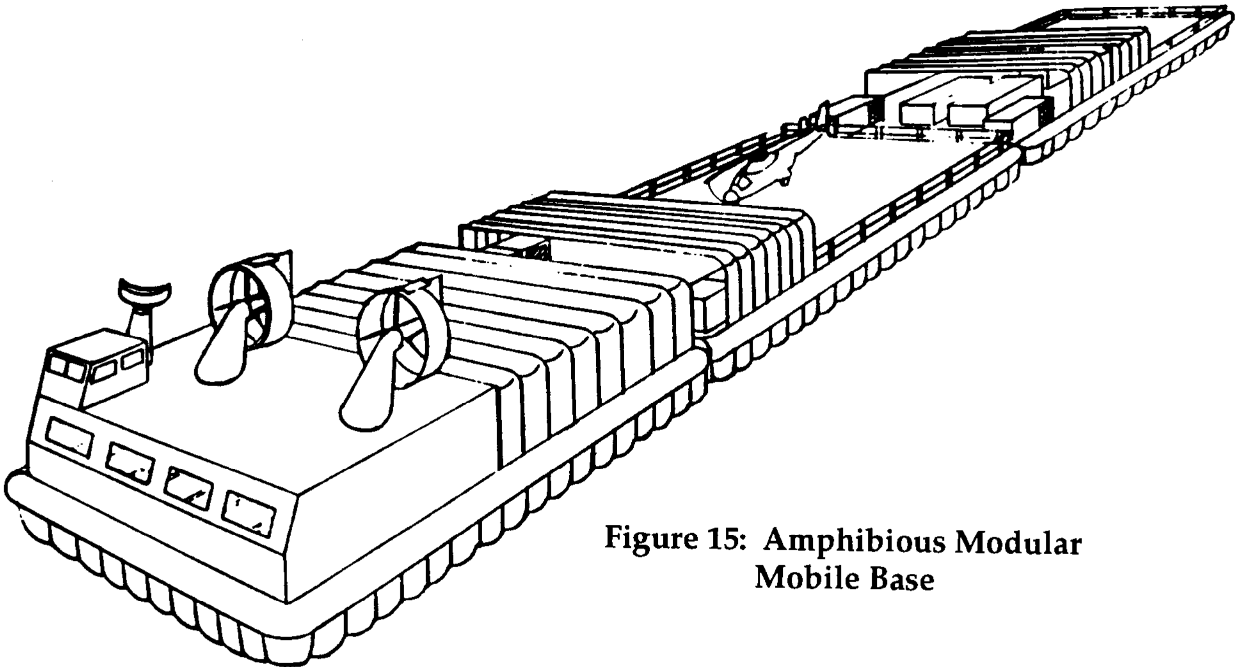


Figure 15: Amphibious Modular Mobile Base

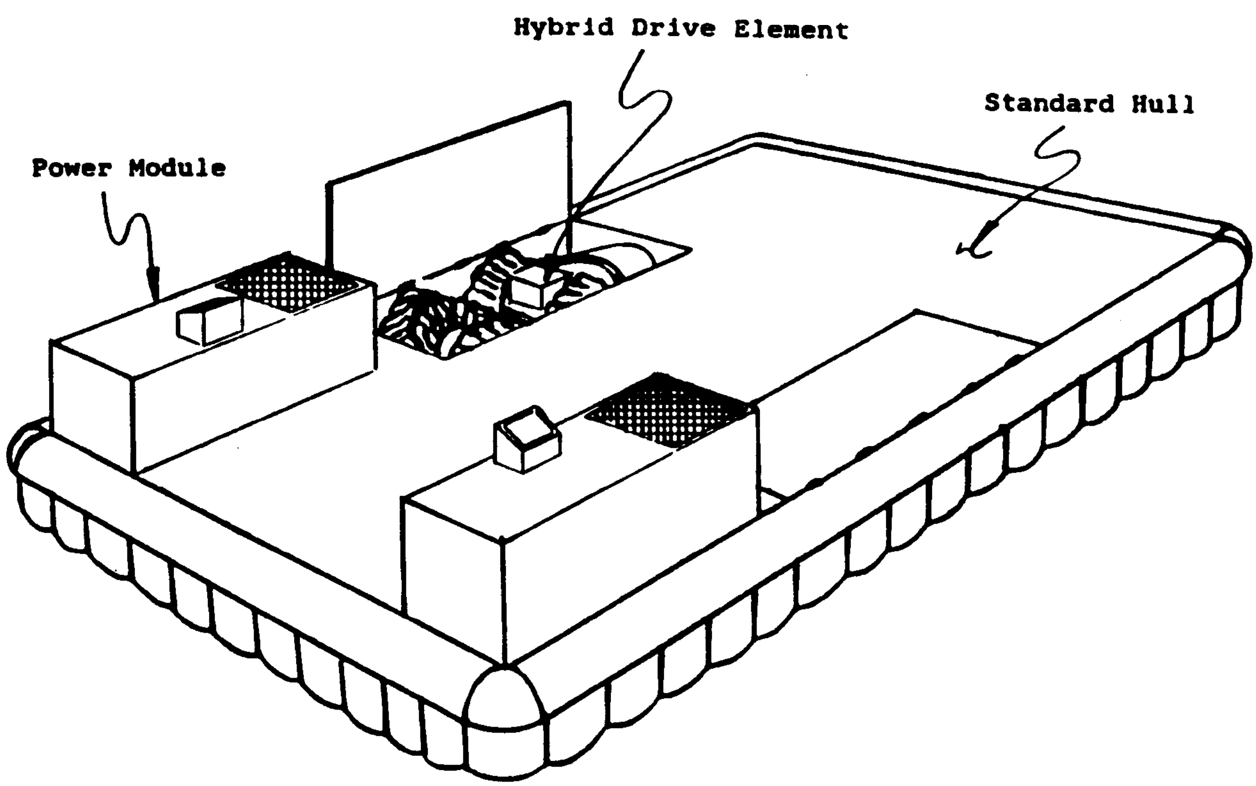


Figure 16: Core Module Concept

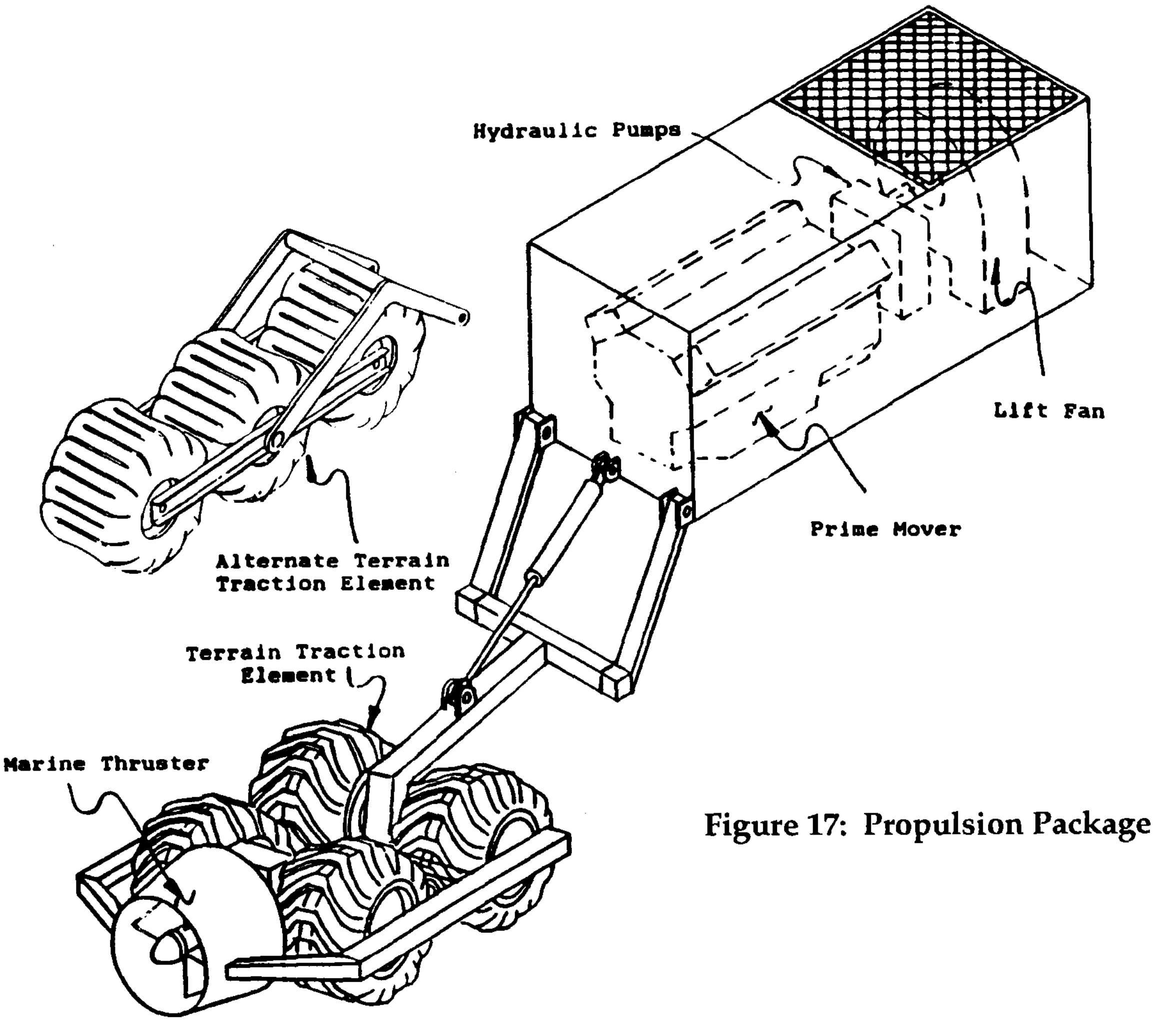


Figure 17: Propulsion Package

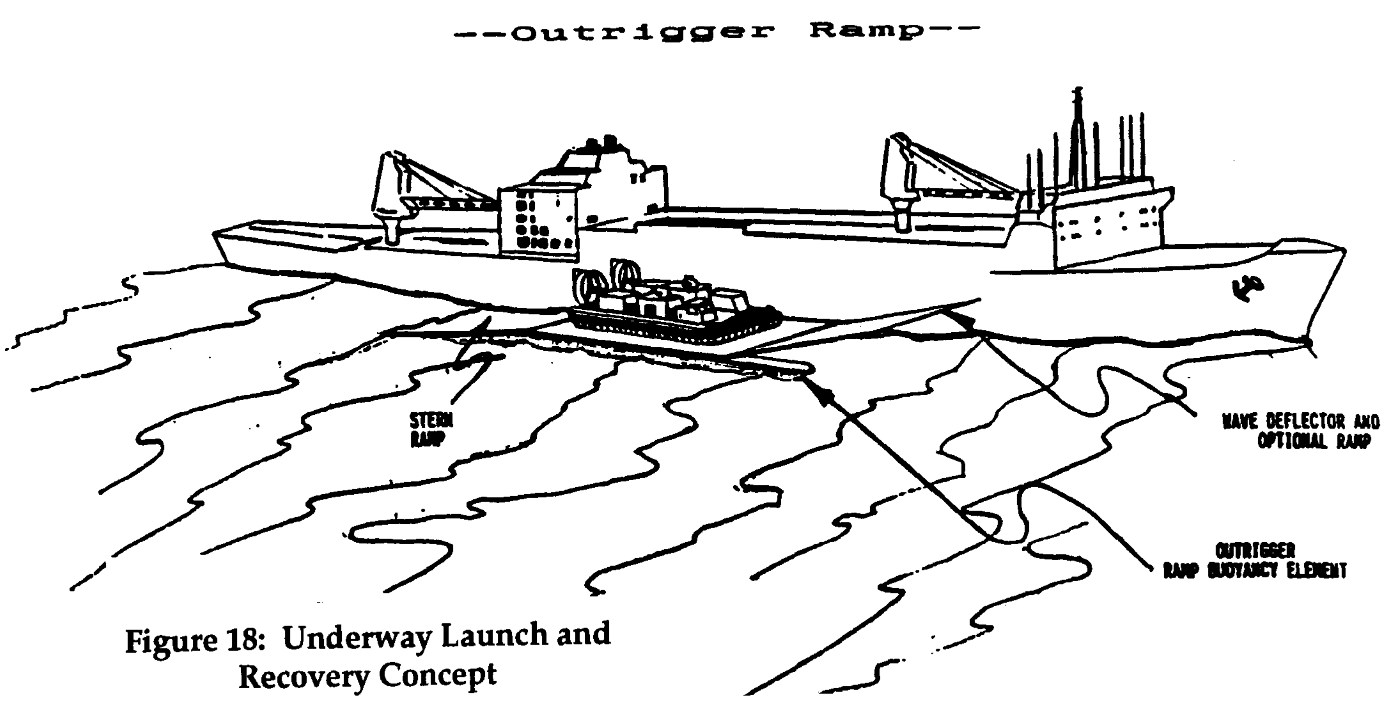


Figure 18: Underway Launch and Recovery Concept

transfers power to the marine thrusters. In this way the power is shifted from wheels to propeller passively as the propulsion bogie rolls on the bottom.

Ship-Shore Amphibious Logistics

Many coastal areas are accessible only by sea or air. In general heavy equipment and significant cargo can by delivered economically only by ship. In turn transport ships need pier side load/unload facilities with appropriate deep draft clearance. Conversely shore side opportunities could be exploited if reliable access to them was established. Furthermore; seasonal and smaller shore opportunities could be developed if ship access did not have to involve dredging, did not require installation of heavy shore side cargo handling equipment and did not depend on seasonal - particularly ice - variations.

A notional concept that proposes to expand the flexibility of ship-shore cargo transfer is called the Outrigger Platform. The Outrigger Platform concept is specifically designed to allow:

- rapid and inexpensive conversion of commercial shipping in support of ship-shore supply operations
- launch and recovery of amphibious transporters while ship is underway
- routine operations in conditions exceeding sea state 3.

Figure 18 depicts the deployed arrangement of the Outrigger Platform system. A slender outrigger hull is configured to support one half of the projected platform load. The space between the outrigger hull and the ship hull is bridged by the landing platform. The platform itself is attached to the ship hull by a hinge mechanism that allows the outrigger system to pivot and thus heave as a function of sea state and platform loads. The rear of the landing platform is fitted with a ramp to permit and run-up of amphibious transporter vehicles. A similar ramp is fitted at the front of the landing platform. This forward ramp can be fixed in a slightly elevated position (as shown in Figure 18), in which case it will act as a wave suppresser when the ship is underway. The forward ramp can be lowered when the ship is stationary to allow forward exit of the amphibious transporter.

The entire Outrigger Ramp system can be rapidly stowed as shown in Figure 19. Lines from the ship's cranes can be used to attach to the outrigger hull and, by lifting, pivot the entire Outrigger Ramp about the system attachment hinge line. The Outrigger Ramp is thus flat and snug against the hull.

There are several options and variations on the Outrigger Ramp concept. Two are shown in Figures 20 and 21. Under some circumstances the ship type may permit the retrofitting of side openings. The opening size may be small and thus allow only forklift passage for loading cargo pallets onto the amphibian transporters positioned on the Outrigger Ramp. At the other extreme is the possible retrofit of a full-size opening, thus permitting the entry and internal loadout of the amphibious transporter vehicle.

The Outrigger Platform ramping system has a number of advantages. These are summarized as follows:

- The Outrigger Platform system can form an 'as needed adjunct' to almost all commercial ships.
- It is relatively inexpensive and fail-safe.
- By itself the Outrigger Platform forms a passive interface decoupling platform between ship motion characteristics and much smaller transporter elements. Thus cargo transloading is possible in conditions exceeding sea state 3.
- The Outrigger Platform would allow launch and recovery of amphibious transporters in sea state 3 and while the ship is underway.

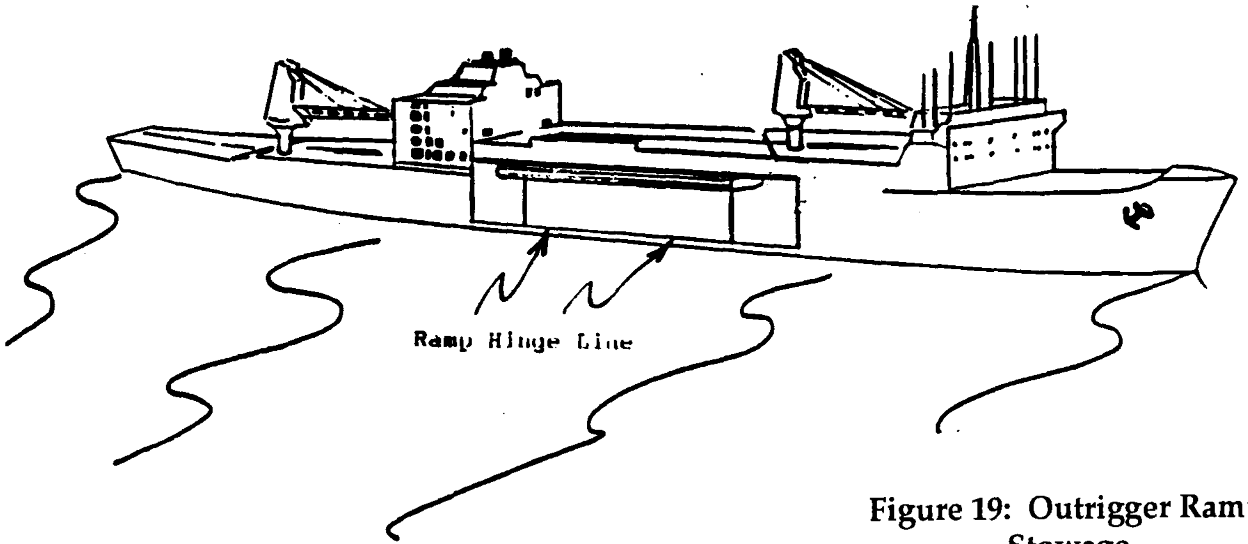


Figure 19: Outrigger Ramp Stowage

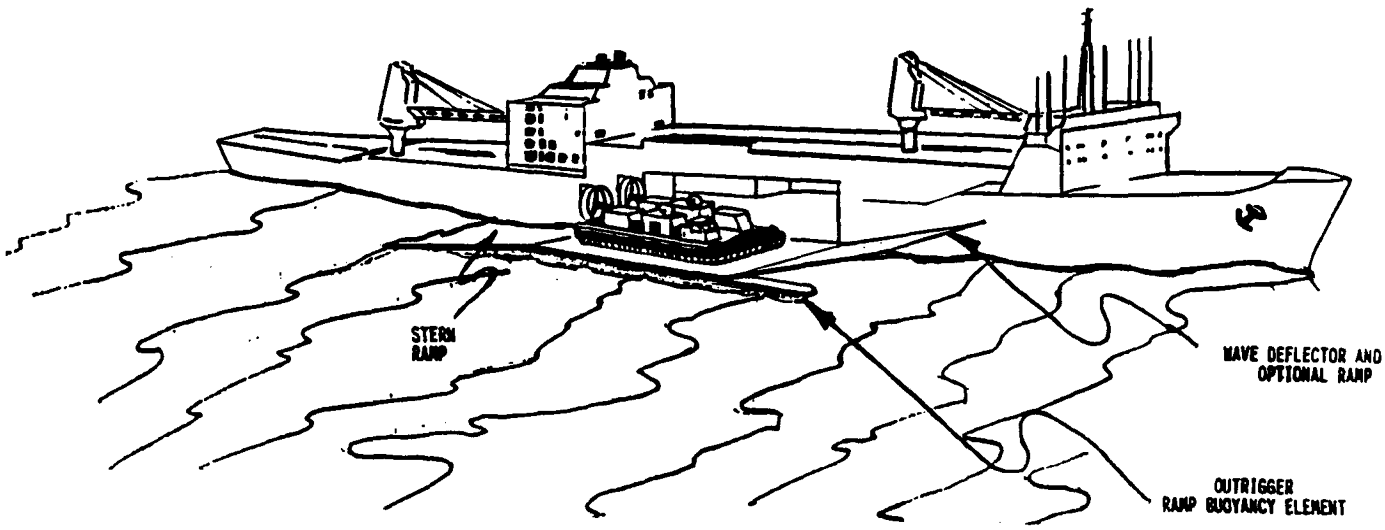


Figure 20: Side Hull Access

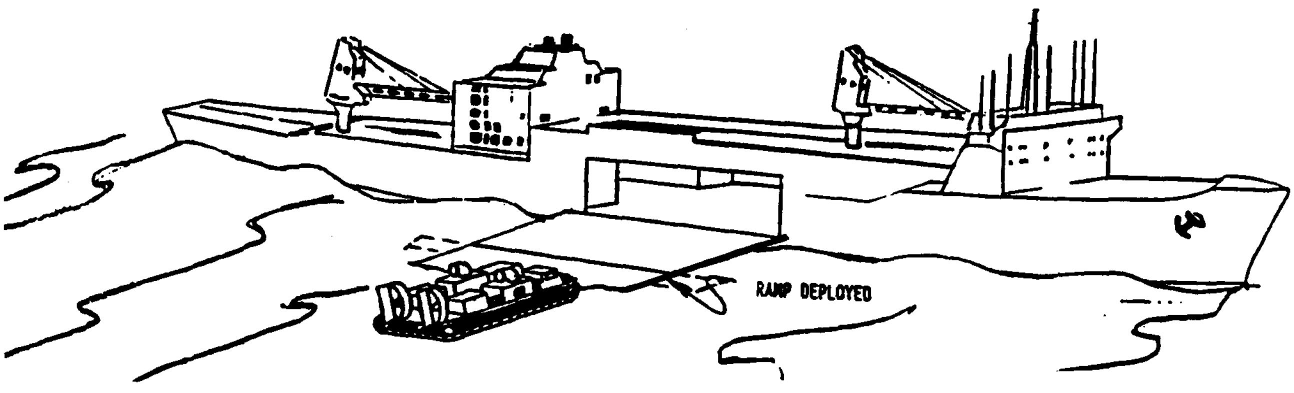


Figure 21: Drive-In Access

Amphibious Oil Spill Remediation

An oil spill can be environmentally devastating. It can occur anytime and anywhere; have any size, shape or form; and be subject to the whims of natures tides, currents, winds and temperatures. Also, both the short and long term consequences of an oil spill are very unpredictable, non-uniform and unlimited by geographical location. As a result oil spill control and containment is much like a battle. Like a battle there are a number of attributes that tend to control the outcome of the conflict. Early action (or inaction) results tend to have a cascading (or domino) effect throughout the event. Consequently, a flexible response strategy is more useful than strict performance following a set of fixed predetermined actions.

The key to a successful containment of a shallow water/sensitive environment oil spill is rapid control and remediation response. The difference between what could be a short term concern and what could become an expensive environmental disaster is the response time. If the response time is prompt, it is possible to keep the shallow water oil spill from having a major environmental effect on the adjacent shoreline and tide flats.

The response actions in an oil spill prior to beach/tidal zone incursion are different than those taken after the oil has penetrated shallow water and coastal terrain. Successful pre-shoreline penetration containment requires:

- rapid response time
- booming
- bioremediation (use of dispersants, sorbents and oil absorbing microbes)
- skimming vessels
- multi-mission environmental vessels

Once the oil spill has gone through a tide cycle and begins to penetrate the spill zone shoreline, the containment situation becomes extremely complex. The pollutant material is now distributed among the coastal rocks, sand, vegetation, swamps, march lands and reed grasses. In this zone, the effect on the coast flora and fauna is immediate and drastic.

When the coastlines are affected by an oil spill event, successful remediation requires a systematic - at times rock by rock and foot by foot - manual clean-up. All this, in a terrain that at the best of times does not lend itself to high speeds of advance. The coastal response and remediation mission becomes a problem of transportation. Equipment must be brought in either from a deep draft vessel standing offshore or along the beach from a land staging area. The 'logistics tail' to the event site includes cleaners, chemicals, sorbents, steam generators, booms, sprayers, etc. The crews, operators and general clean-up personnel need to be transported to and from the site on a daily basis. The remediation crews must be sustained with personnel needs such as food, water, clothing, shelter and other human comfort services. All this places a heavy burden on the supply lines. Ultimately, the collected waste must be transported out of the beach area for approved treatment and disposal elsewhere.

Today, the classical mode of transport, both in and out of the beach zone, is by helicopter. While expensive, the helicopter is a viable and very useful tool. It is fast and can deliver required elements of the remediation strategy with pin-point accuracy. On the other hand, the lift capability, relative to what is required, is rather limited. Weather and darkness often limit the flight hours, and the near ground hover zone of the flight envelope is the least safe, and is very fatiguing for both the machine and the pilot.

The Requirements

It is clear that a successful shallow water/beach zone remediation mission requires a very versatile transportation system. In addition, the transporter should be inexpensive, robust and efficient.

A wish list of favorable attributes for a response transporter can be structured as follows:

- amphibious capabilities for water and land operation
- minimal or no draft requirements
- insensitive to terrain load bearing characteristics
- insensitive to reasonable debris and ice conditions
- speed, sea-state and range capability in keeping with the mission scenario
- performance turn-down capability to match various environmental conditions
- reliable, efficient and cost effective operation
- rapid mission reconfigurability, particularly in the payload modules
- reasonable maintenance and servicing requirements
- easy to operate.

There are a number of vehicles/transporters that meet some of the above characteristics. In addition to the previously mentioned vertical lift helicopter systems, there are a variety of shallow water draft vessels which include Jon boats and Zodiacs, and a selection of land transporters on soft TERRA tires. None of these have true amphibious capability and benign footprints so needed for biota sensitive terrain.

A Candidate Solution

A vehicle system that meets this crucial requirement and many of the others is the Air Cushion Vehicle (ACV). A candidate ACV configuration is illustrated in Figure 22. The baseline hovercraft has self-contained lift and propulsion modules, forward and aft ramps, a driving station and open payload deck space. The hovercraft is capable of rapidly transporting heavy payloads with access to virtually any shore, beach or coastal zone. This includes the capability of transporting remediation equipment and personnel to and from the coastal spill zone; waste storage materials (bags and containers) to and from land or vessel staging zones; and rock barrels, wildlife catchers, wildlife cages and dead wildlife containers to and from their destinations.

The specific attributes of the ACV system that make it an attractive transport alternative can be identified as follows:

- terrain insensitive - due to low footprint pressure
- depth insensitive - permits operation over most terrain, including ice
- direct route capable (independent of ship channels and traffic) - providing rapid response times
- road, ship and air transportable - for rapid site deployment and long range staging
- beach-side rigging and launching; minimal equipment and site preparation requirements - no cranes or launching ramps
- full walk-around access for load-out
- motion free cargo tie-down ops. and general maintenance
- wide open deck for mission payloads
- simple operator controls for predictable and safe man-machine interface

A perspective of the candidate vehicle is depicted in Figure 23. The hard structure is 12 ft. wide by 30 ft. long. Lift fans and propulsion system modules are located in the wing-wall sections. The hard structure, wing-walls and ramps are connected to a reinforced hull platform.

An important requirement for the response transport vehicle is the flexibility to reconfigure the payload for a specific mission scenario. This candidate ACV transporter takes advantage of a modular payload strategy. The baseline flat deck platform can be equipped with a range of mission specific function modules. A payload option matrix is depicted in Figure 24. A notional selection may include the following:

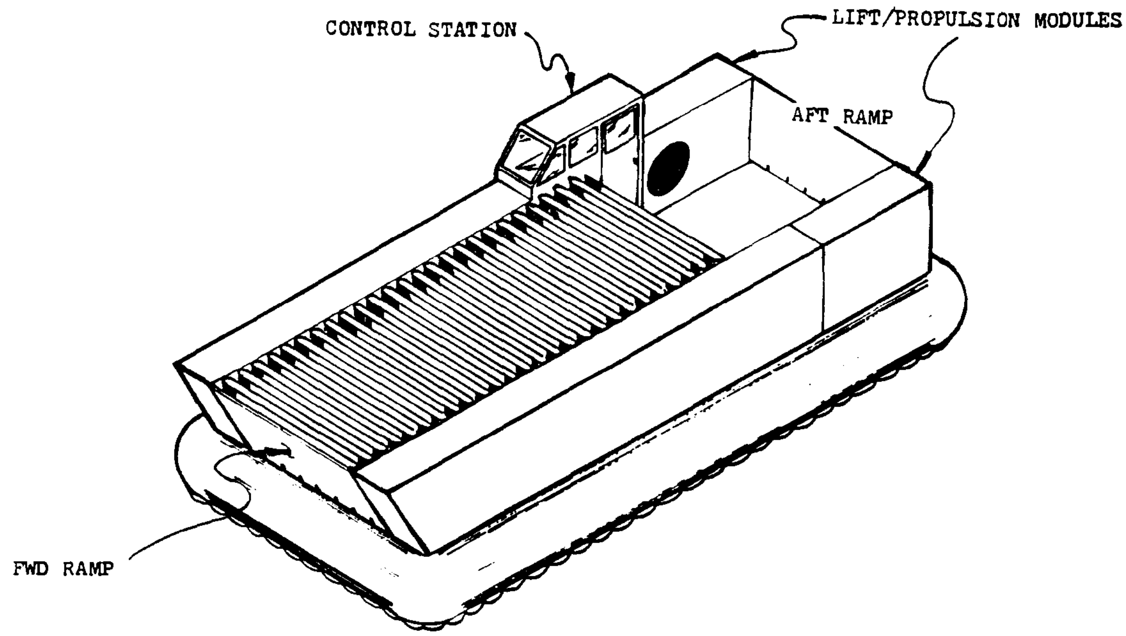


Figure 22: K-30 Air Cushion Vehicle System

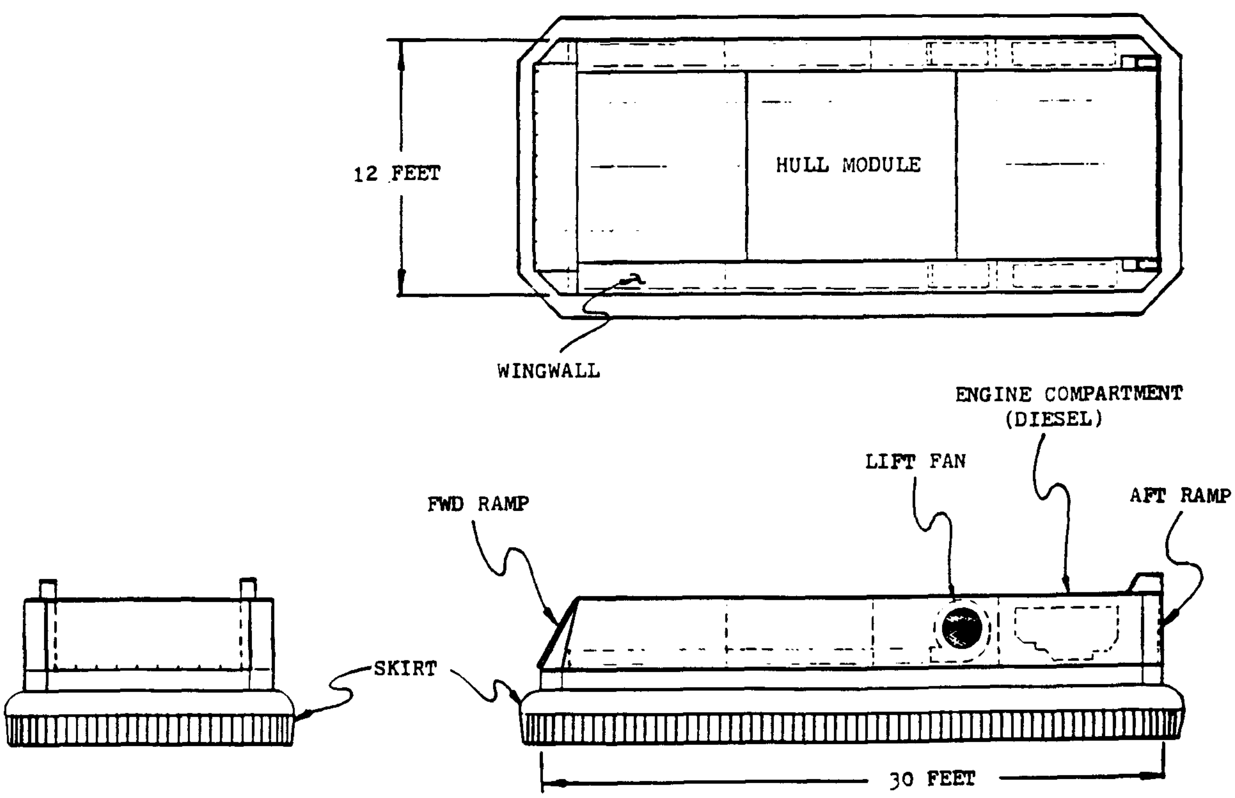


Figure 23: Air Cushion Vehicle "K-30"

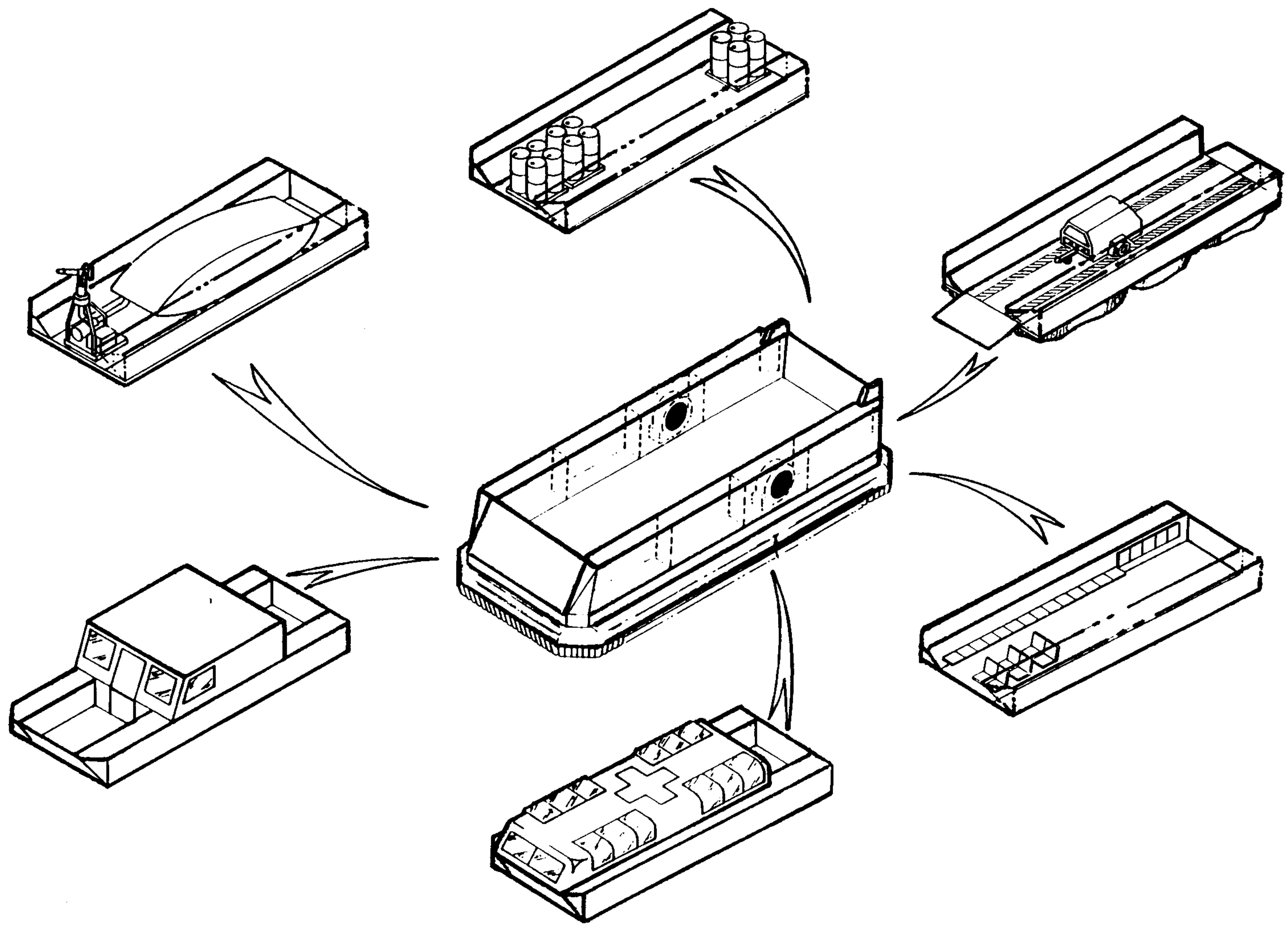


Figure 24: Payload Option Matrix

- bioremediation chemicals and agents dispersal systems
- material transport such as water bags and containers
- personnel transporter (response, cleaners, surveyors, etc.)
- medical-evacuation module to provide emergency treatment in disaster situations
- command module for patrol, survey and SAR (Search and Rescue)

The modular philosophy is also carried into the propulsion subsystems. The thrust generators are configured as strap-on modules. Thus, the operator has the flexibility to select a propulsion system that will match his specific conditions. The intent is to maintain a wide range of options rather than to make specific recommendations. The family of propulsors includes:

- Conventional hard tires for mission scenarios that involve prepared surfaces - such as airports and marshaling yards
- Low Pressure Tires ("TERRA" Tires) for operations on soft and non load bearing surfaces - sand and tidal zones
- Marine propellers for water borne operations
- Ducted air propellers for non surface contact propulsion
- Surface Impulse Propulsor (SIP) for amphibious propulsion over land and water surfaces

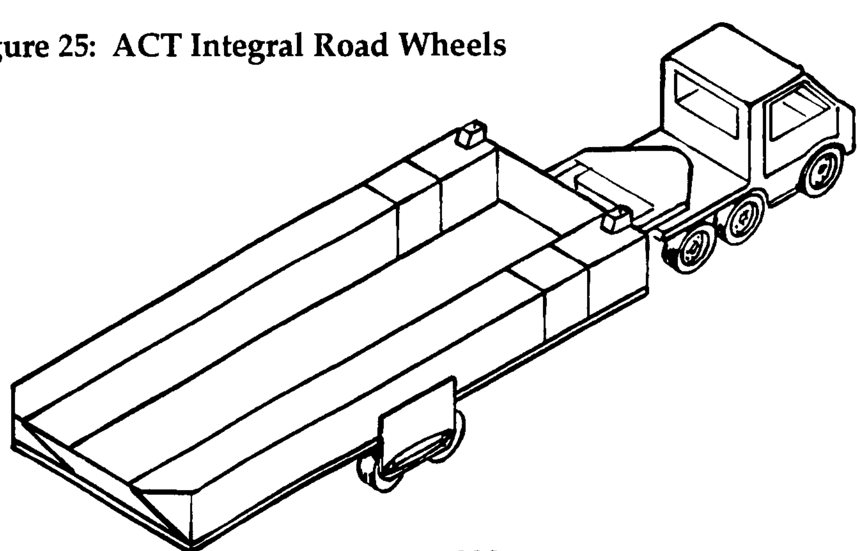
In this group of propulsors, only the ducted air propellers and the Surface Impulse Propulsor (SIP) are truly amphibious. However, many operating scenarios may require only single mode thrusters such as marine propellers or land traction propulsors. The operator has the flexibility to select the propulsion subsystem that best meets the mission requirements.

The proposed ACV system is air and road deployable. The baseline vehicle hull folds to a maximum width of 8 ft. Provisions are made to attach an undercarriage to the ACV, thereby giving the system immediate trailerability (Figure 25). The 8 ft. width permits air deployment in a C-130 or comparable aircraft.

Summary

Advanced Marine Vehicles are a complex and optimized systems. AMV's are weight critical, tender and expensive. All ships operate at some level of degraded capacity - some significantly so - but still perform their mission with reasonable effectiveness. AMV's are not fault tolerant. When used off design or in degraded operating states mission effectiveness collapses. There is a clear need to recognize AMV's for what they are, how they are applied, and how they are designed, fabricated and maintained.

Figure 25: ACT Integral Road Wheels



IHS PANEL DISCUSSION

By
William Hockberger

The first paper following ADM. Zumwalt's keynote address on Wednesday morning will be a retrospective look at the first 25 years of the IHS, by Bob Johnston. As a counterpoint, and a suitable wrap-up after two days of papers and discussions, the Conference will conclude with a panel discussion on "Hydrofoils and the IHS -- The Next 25 Years." The panel members are Mark Bebar (Naval Sea Systems Command), William M. Ellsworth, CAPT. William Erickson (Naval Operations, N86F), Robert J. Johnston, William C. O'Neill, and Joseph F. Sladky (Kinetics, Inc.).

This session will be lively and interesting, and maybe even entertaining, but there is a serious purpose behind it, too. We will gain some real insight into the future of the hydrofoil, and with it the future of the IHS. If hydrofoils do not have a real future, neither does the IHS, except as a focus for occasional nostalgic get-togethers. But if hydrofoils do have a future, the IHS should move with it and in fact help lead it. Those on the panel are well qualified to look into the future and discern what may lie ahead.

The basic framework for discussions is as follows:

First, the markets and military uses for which hydrofoils may be suited will be discussed. We will start with the overall market for marine transportation of passengers and high value cargo (High-Value Time-Sensitive, or HVTS in current jargon) and filter it down to find the parts that seem particularly suited to the hydrofoil. Bob Johnston, for the commercial markets, and CAPT. Erickson, for the military markets, will lead off in this segment with their views. The other panel members will next be able to comment on those views and broaden the range of the discussion. The discussion will then be opened up to all attendees for comments and questions.

Next, the possibilities for designing hydrofoils to meet those uses will be covered, with discussion of the technology to support it and projections into the next 25 years. The same general pattern will be followed as before, this time beginning with Mark Bebar for a designer's viewpoint, and continuing with Bill O'Neill and Joe Sladky for an expanded view of hydrofoil technology development. Again, the rest of the panel will offer additional views, and the discussion will lastly be opened up to all other commenters.

We will do the same for the political and economic factors. Bill Ellsworth and CAPT. Erickson will lead off, with the others adding their views and the other attendees commenting from the floor.

The last segment of the panel discussion will be devoted to the IHS itself and the prospects for the next 25 years. Once we have heard the views of the experts on the future of the hydrofoil, we will have a good basis for judging what may lie ahead for the IHS. Each panel member will offer his opinions on what the IHS may be able to contribute to the hydrofoil's future and how we might best do that.

THE PROSPECTS FOR HYDROFOILS:

1. Markets -

a. Commercial - What is the present total market for marine transportation of passengers and high value cargo? How is this market likely to change over the next 25 years? How will it vary from one area or country to another?

Of that total market, which segments might lend themselves to service by high performance vehicles? (Delivery urgency and ride quality are primary considerations.) What are the factors inhibiting greater use of them (e.g., technical, operational, business/economic, political)? How is this situation likely to evolve over the next 25 years? Are there services in which high performance vehicles might operate in some cooperative fashion with conventional ships?

Of the different applications potentially appropriate for high performance marine vehicles, which might best be served by hydrofoils? What passenger and cargo capacities would be desired, and what speeds and operational reliabilities would be necessary? What overall ship sizes are we talking about?

b. Military - What are the present high value roles for ships, and which ones particularly lend themselves to being done by high performance types? Of the latter, are any especially appropriate for hydrofoils? How is this likely to evolve over the next 25 years? Police and other civil enforcement applications should be considered, in addition to Navy and Coast Guard. What ranges of ship size and capability are implied?

c. Politics - What are the political factors tending to inhibit the development of commercial markets or military uses for high performance marine vehicles? Are any trends apparent? What would have to happen to remove these inhibiting factors?

2. Technology, Design and Performance -

a. Design and Performance - What configurations of hydrofoils -- including hybrids -- are now feasible, and in what sizes? What are the technical factors that set those limits? How do those configurations differ in their operational characteristics and performance, and how does one choose among them for a specific application?

To what extent can present technology support the design and construction of hydrofoils of the sizes and performance required to serve the commercial or military applications discussed previously? In the applications for which other types of high performance marine vehicles could be competitive, does present technology also support their design and construction? What comparative trends can be discerned between hydrofoils and other types of high performance marine vehicles, on into the future?

Certain operational restrictions -- on wake, draft, speed, night operations, etc. -- limit the use of hydrofoils. Such restrictions are more likely to increase than to decrease. What changes in design might reduce or eliminate the factors that lead to such restrictions?

b. Technology - Our present hydrofoil configurations and designs and the levels of performance achievable are determined by the technologies of materials, structural design, propulsion systems, foil systems, control systems, etc. How are those technologies likely to evolve over the next 25 years, and what changes in design and performance will become feasible as a result? How will that affect the kinds of applications hydrofoils may be suitable for in the future?

Are there any comparable trends in the design and performance of other types of high performance marine vehicles that might enable them to attain or maintain or increase a comparative advantage over hydrofoils?

3. Economics -

a. Reality - Hydrofoils tend to be considerably more costly, both in acquisition and in operation and support, than hydrostatically supported ships designed for the same nominal uses. They can be either more or less costly than other high performance ship types in those uses. In certain applications, however, they can make up for those higher costs with even higher productivity.

How do costs between hydrofoils and other ship types compare today? What changes could be made today to reduce their costs and expand the range of applications for which they are attractive? What are the prospects for further comparative cost reductions resulting from improving technology over the next 25 years?

What are some commercial and military applications for which higher per-ship costs can be more than offset by the system-wide efficiencies made possible by a hydrofoil's higher performance?

b. Perception - Hydrofoils have an image of being complicated and expensive, even if their operational superiority would more than offset that. Other high performance types have the same problem. It is important that the alternatives be compared on a total-system, total-life cycle basis, not simply ship to ship on acquisition cost, so as to show the overall operational and economic benefits as well as costs.

FUTURE OF THE IHS:

Given the foregoing discussions, what is the role of the IHS?

1. Keep together a group of people who know about and care about hydrofoils, against the time when serious interest revives. Preserve the knowledge of hydrofoil developments and experience.

2. Maintain a track on the state of hydrofoil technology and design, in the absence of a solid U.S. Navy or U.S. commercial program that would do it.

3. Maintain a track on the state of the markets for high performance marine transportation -- and keep alert for unrecognized areas in which hydrofoils could be cost-effective.

4. Share information, so IHS members remain aware of what is happening and stay alert to new ideas and are stimulated to think about them and come up with other new ideas.

5. Assemble information on hydrofoils and hydrofoil technology for use in informing and educating potential users and supporters.

6. Foster some continuing work important to the field.

7. Motivate members periodically to write papers that capture new developments and fit them into the current context.