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SSP Kaimalino; Conception, Developmental History, Hurdles and Success

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ABSTRACT

This paper was specifically prepared for the History and Heritage Session of the American Society of Mechanical Engineers. The U.S. Navy's 227-ton SSP KAIMALINO, launched in 1973, represents the first high-performance SWATH (Small Waterplane Area Twin Hull) vessel. The SSP (Stable Semi-Submerged Platform) is an 88-ft (27m) ocean-going vessel consisting of two parallel torpedo-like hulls under the water, each connected by a pair of streamlined struts to a cross structure supported above the water. Two controllable canard fins are attached near the hull bows, and a full-span stabilizing fin is located near their sterns. The SSP's uniqueness centers on her very low motion in waves, either at rest or underway. The SSP design was initiated after only one man-year of research followed by a half year of work by several researchers. Since the launching of the SSP, many other SWATHs have been built and successfully operated in the 12 to 27 knot range having displacements up to 3,500 tons. All of these SWATHs utilize the stabilizing fin and canard fin concepts first introduced for the SSP. SWATH vessels have alternatively been called Semi-Submerged Ships (S^3), and Semi-Submerged Catamarans (SSC).

INTRODUCTION

SSP KAIMALINO

This paper presents the developmental history of the SSP KAIMALINO (Figs.1,2,3), with emphasis on the ideas, hurdles, and changes that led to her final design. A full description of the SSP KAIMALINO is presented in [1]. The vessel is typically referred to herein as the SSP for brevity. The unique characteristics of the SSP are its unusually low motion in waves, large deck area, center well, speed capability, underwater viewing dome, and its ability to maintain speed in large waves with low drag.

Invention, Research and Design

The SSP design proceeded swiftly, even though the design path contained many meanders and hurdles. Some of the research was done in parallel with the design work. The SSP story follows this introduction, and shows how invention, research, and design; in combination with people, talents, facilities, and organizations; produced the operational prototype.

Other SWATHs

This paper relates primarily to the SSP. As such, it will not address the large amount of work conducted by the Naval Ocean Systems Center (NOSC) and other establishments on subsequent SWATH designs, unless such work was related to the SSP. A brief section, however, is included later on recent SWATH developments.

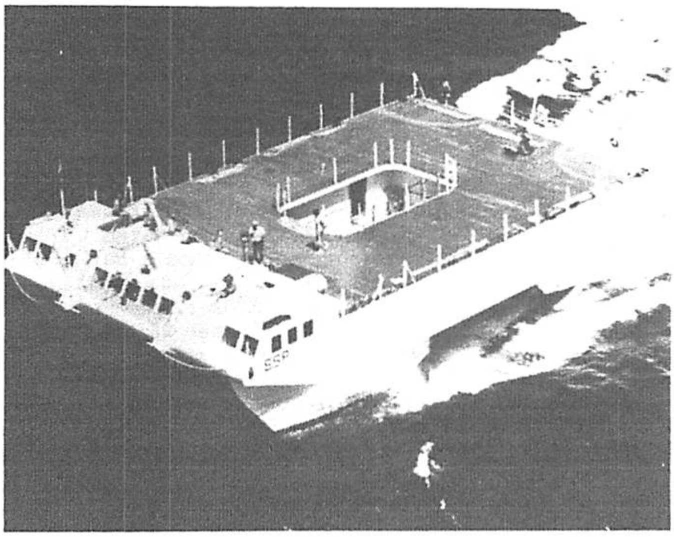

Fig.1. 227-ton SSP KAIMALINO operating in Hawaii offshore of its home port at the Naval Ocean Systems Center on Oahu. (U.S. Navy photograph)

ORIGIN OF THE SSP CONCEPT

Generation of the Idea.

My invention of the SSP concept spanned nearly two

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decades. My background in the field of ship design was limited; I was unfamiliar with older concepts that might have been related to the SSP concept. However, I had a good foundation in mechanical, civil, and aerospace engineering with degrees from Caltech, USC, and Pennsylvania State University. Also, I had developed a specialty in the field of hydrodynamics, and had gained experience in design, research, and invention in a variety of vehicle design fields. Furthermore, I was interested in new concepts and ideas, and had hobbies that led to the development of the SSP concept.

One of the hobbies was especially significant; this was the design, construction and testing in the 1950's of new types of outboard-powered hydrofoil boats. My father helped with the construction and testing (Fig.4); together we developed twelve different hydrofoil boat configurations. I applied for a patent on the last design, and licensed the Up-Right company in Berkeley, California to manufacture and sell hydrofoil kits for boats; about 80 were sold around the world.

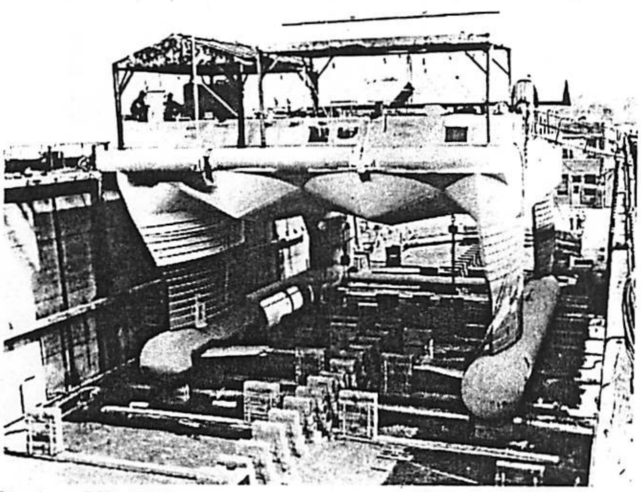


Fig.2. SSP KAIMALINO under construction in 1973 at the U.S.C.G. Yard at Curtis Bay, MD. (Note the canard fins mounted near the bows of the lower hulls, and the full-span stabilizing fin mounted aft. (U.S. Navy photograph)

The hydrofoil hobby led to a parallel goal in the early 1950's, which was to develop an alternative to hydrofoils for lifting a hull above the water. I began with ideas to lift a person, rather than a hull, above the water. I sketched many ideas, including two parallel, submerged, streamlined bodies, one attached to each foot. I then modified this "water walker" concept into an idea for lifting hulls by sketching designs which showed two parallel underwater bodies that supported boat hulls, house boats, and other box-like platforms above water. Variations included the use of from one to five underwater bodies. Although the new ideas came at odd times of the day, they most often came while I was purposefully trying to sketch such new ideas. Occasionally, I would stop sketching and calculate the displacement and drag to predict the power required for propulsion. I studied many variations in size and shape of the different configurations. The underwater bodies were sometimes equipped with fin appendages, including aft stabilizing fins; occasionally, I added small fins located forward on the bodies. The introduction of stabilizing fins to SWATH ships insures pitch stability at moderate to high speeds, and aids in damping motion. Small fins located forward are called "canards," which further aid in damping motion.

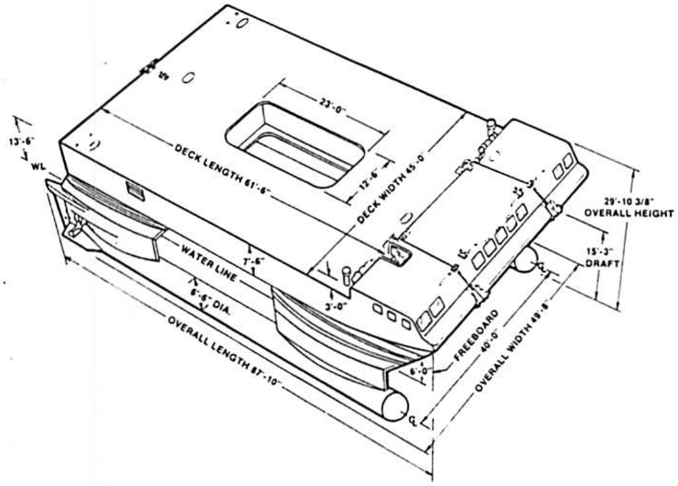


Fig.3. Basic Dimensions of the SSP KAIMALINO. (U.S. Navy Photograph)

From time to time in the mid and late 1950's, other ideas came to me for supporting hulls above the water. These included boats with ram wings, air cushion vehicles (also called hovercraft, ground effect machines, or GEMs), and surface effect ships (also called captured air bubble craft, or CABs) having air cushions and sidewalls. Occasionally, I made calculations of lift, drag, power, air pressure, and curtain power to help determine the feasibility of these ideas.

During the early 1960's, the ideas utilizing underwater bodies tended to center around two parallel bodies, with occasional sketches showing one submerged body with some type of surface-piercing roll-stabilizing means. The ideas for the SSP concept crystallized in the early 1960's. The resulting SSP concept, consisting of twin submerged hulls, vertical struts, and controllable fins, provides unusually low motion in wave, low wave-making drag, a high degree of controllability, and long natural periods in heave, pitch, and roll. Work on the SSP idea, however, temporarily halted from January 1965 to June 1968 while I earned a PhD degree in Aerospace Engineering at the Pennsylvania State University. While there, I wrote a thesis on a generalized engineering design procedure [2] which included examples for the design of airplane wings, hydrofoils, and submerged vehicles. The methodology was useful throughout the design of the SSP, and was also useful in planning the associated research.

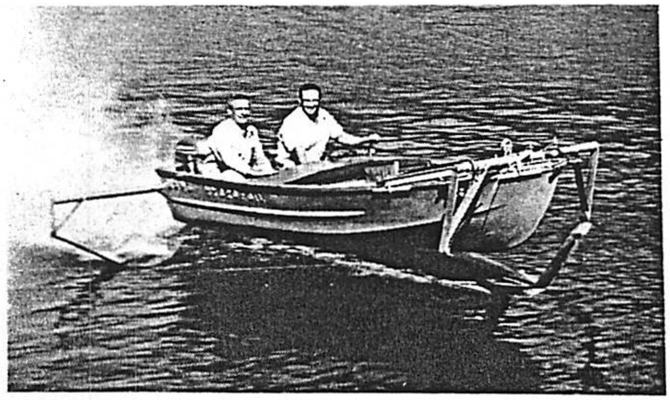


Fig.4. 14-foot hydrofoil boat developed in 1954 by the author and his father, Glenn I. Lang.

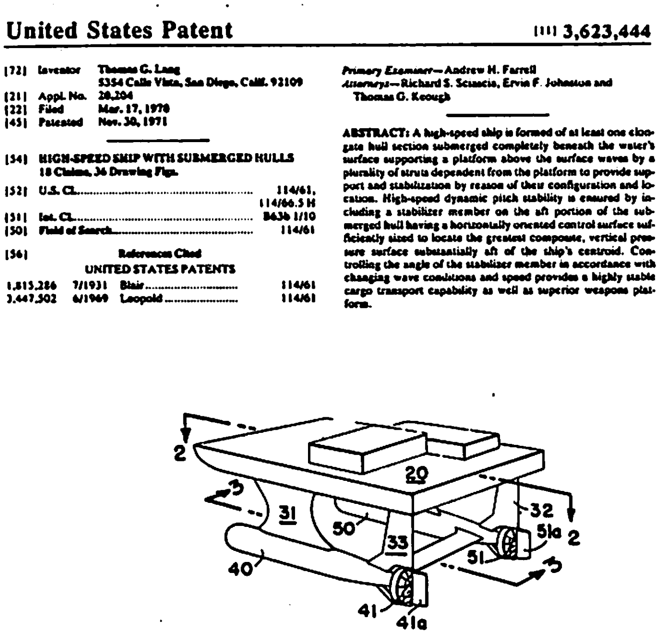
Introduction of the SSP Idea into the Navy

After returning to the Navy laboratory in California where I worked (now called the Naval Ocean Systems Center, and referred to herein as NOSC), I was asked by W.E.Hicks of NOSC to join a design group that was working on a new type of underwater vehicle. Later in 1968, I was asked by J.Bartling, another member of that group, to search the literature for a small mother ship to provide support for the vehicle, and one that would be very stable at high speed in large waves. I could not find an acceptable ship type. As a consequence, I suggested that the SSP concept, which I had been working on as a hobby, be used for the mother ship. The group thought this was an excellent idea, and recommended that I describe the SSP concept to the laboratory's technical director, the late Dr.William B.McLean.

Dr.McLean was highly supportive of the new concept, especially since he had been urging the Navy to develop a combination of submarines and small surface ships. The SSP concept fit nicely into this goal since it would make small ships more practical since it would greatly reduce their motion in waves. However, the mission of NOSC was anti-submarine warfare (ASW) systems, and not the design of new ships. Consequently, Dr.McLean asked me for a proposal to study the feasibility of the new SSP concept and determine how it might effect ASW systems, and Naval systems in general. He immediately accepted my resulting proposal dated 9/30/68, and allocated IED (Independent Exploratory Development) funds to conduct a technical analysis of the SSP concept, including recommended Naval applications. (Authors note: from here on, the SSP concept will be referred to as the SWATH concept in order to distinguish it from the specific SSP design initiated later.)

Patents

Figure 5 shows the first of several patents that I have received on SWATH vessels. This U.S. Patent #3,623,444 is the first patent to issue which covers all of the features of modern SWATH vessels, including stabilizing fins and optional canard fins. Also, it covers either one or more struts per side. The U.S. Government has license-free use of this patent. I was able to retain the commercial rights in view of inventing the basic idea outside of work, and the fact that ship design was not within either the mission of the Center or my work duties at that time.


United States Patent [11] 3,623,444

[72] Inventor Thomas G. Lang
5354 Calle Vista, San Diego, Calif. 92109
[21] Appl. No. 20,204
[22] Filed Mar. 17, 1970
[45] Patented Nov. 30, 1971

[54] HIGH-SPEED SHIP WITH SUBMERGED HULLS
18 Claims, 36 Drawing Figs.

[52] U.S. Cl. .... 114/61, 114/66.5 H
[51] Int. Cl. B63b 1/10
[50] Field of Search 114/61

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Primary Examiner—Andrew H. Farrell
Attorneys—Richard S. Sciascia, Ervin F. Johnston and Thomas G. Keough

ABSTRACT: A high-speed ship is formed of at least one elongate hull section submerged completely beneath the water's surface supporting a platform above the surface waves by a plurality of struts dependent from the platform to provide support and stabilization by reason of their configuration and location. High-speed dynamic pitch stability is ensured by including a stabilizer member on the aft portion of the submerged hull having a horizontally oriented control surface sufficiently sized to locate the greatest composite, vertical pressure surface substantially aft of the ship's centroid. Controlling the angle of the stabilizer member in accordance with changing wave conditions and speed provides a highly stable cargo transport capability as well as superior weapons platform.

Fig.5. U.S. Patent #3,634,333 by the author on SWATH ships, 11/30/71.

THE NAVY'S FIRST SWATH PROGRAM

Technical Analysis

The SWATH Technical Analysis Study sponsored by NOSC IED in 1968 was the first Navy study on SWATH; also, it was the first known study on fin-stabilized SWATH ships. An initial step in the study consisted of sketching various shapes and sizes of SWATH Naval ships, together with estimates of their speed and power. Using these results, a nondimensional relationship was developed for power as a function of size and speed which was valid over a large range of ship displacements. This relationship was accomplished with the aid of the methodology developed in [2]. The resulting nondimensional SWATH power relationship (Fig.6) was graphed together with similar relationships developed from published data on monohull ships, submarines, planing boats, hydrofoil boats and hovercraft (GEMS). The SWATH curve was labeled S^3 (for semi-submerged ships) in Figure 6. The results showed that SWATHs are more efficient than monohulls in the speed region between displacement monohulls and planing monohulls.

Another part of the technical analysis was the development of equations for calculating intact roll stability and the natural period in roll. Also developed was a preliminary analysis of strut stress as a function of the spreading and crowding loads that act on the lower hulls and struts.

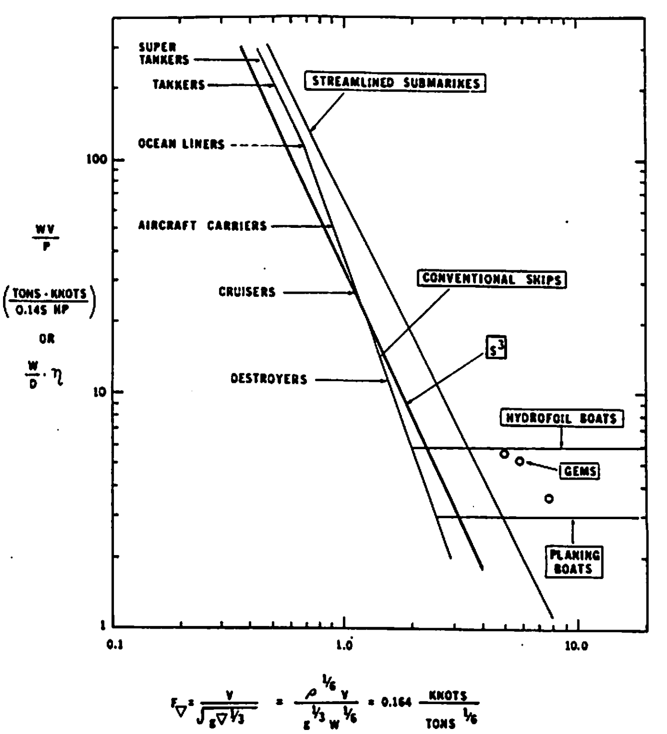

Fig.6. Original representation of SWATH (S^3) efficiency relative to other types of marine vehicles, 1968.

PSAC Presentation

Work proceeded rapidly on the new concept. On 11/25/68 Dr.McLean arranged for me to give a presentation on the SWATH concept to the President's Science Advisory Committee (PSAC). Figure 6 was presented, together with others in addition to a discussion on possible naval uses of SWATH. The concept was of interest to the Committee, which recommended that model tests be conducted.

Technical Analysis Report

The SWATH Technical Analysis Study was completed in May 1969 [3]. Many of the descriptions included in this first SWATH report are still used today, some 17 years later. The following are selected excepts from [3]:

> The new ship concept consists basically of two parallel deeply-submerged torpedo-like hulls which are each attached by a pair of hydrofoil struts to a platform located well above the water surface. Horizontal hydrofoils are attached to each of the torpedo-like hulls at their bows and sterns for increasing dynamic stability and to provide control in pitch, heave, and roll. Ballast tanks in the submerged hulls are utilized to statically position the water level midway between the hulls and the platform. In order to reduce the draft in harbors to that of conventional ships, sufficient ballast is blown to position the water level at the top of the submerged hulls. The four vertical struts are widely spaced and are of sufficient size so that the ship is statically stable in both pitch and roll under all weight and trim conditions. The horizontal hydrofoil control surfaces should provide a nearly level ride at cruise speeds in sea states through 6 or beyond. These control surfaces may span the gap between the two hulls or they may be fins attached to each hull.
>
> In general, the power plant, fuel, ballast tanks, ammunition, and sonar would be placed in the submerged hulls. The personnel, weapons, aircraft, etc., would be housed in or on the upper platform. The vertical struts provide access to walkways which extend the length of each submerged hull. Propellers or pumpjets would be placed at the tail of each hull for propulsion. Such a location provides high efficiency when the propulsor is designed for induction of the boundary layer water, as in the case of torpedo propellers. The rudders are positioned at the trailing edge of the aft vertical struts, and generally extend rearward of each propulsor in order to provide control in harbors and at low speed by deflecting the propulsion jet. At normal operating speed, the rudder and strut combinations should provide excellent maneuverability and a high turn rate.
>
> ... In regard to stability, it is believed that strut displacement, in combination with fixed horizontal stabilizing fins, will provide adequate stability up to fairly high speeds. It is likely, however, that beyond a certain speed, particularly in high sea states, that the horizontal control fins will not only be a desirable ride-leveling feature, but a necessary control means to provide stability. Model tests should help to determine whether this critical speed lies in the prototype operating speed range.

The study summary stated that SWATH ships show considerable promise for updating the Navy in a variety of areas, and stated that a towing tank test program was being planned in preparation for the design and testing of a man-carrying test craft. As shown later, this man-carrying test craft evolved into the SSP KAIMALINO.

Possible Applications

Various SWATH Navy applications were recommended in [3]. These included: (1) 2-ton utility boat, (2) 10-ton, 35-ft (11m) oceanographic research boat with twin plexiglass bow domes for underwater viewing, (3) 80-ton oceanographic research vessel, (4) 150-ton tender for the CURV underwater remotely operated vehicle, (5) 300-ton ASW escort craft, (6) 500-ton submersible tender, (7) 1,000-ton oceanic research ship, (8) 2,000-ton helicopter carrier or ASW ship, and others up to a 200,000-ton tanker. Many of these applications remain viable candidates today, some seventeen years later.

EARLY MODEL TESTS

Early Models

As part of my continuing hobby on SWATH, small models were made at home and tested in a bath tub; the models exhibited very little motion in waves, and showed high damping of forced motions. One of the models (Fig.7), was towed on 3/1/69 and demonstrated little evidence of wave-making drag; also, it showed very little motion when towed in waves.

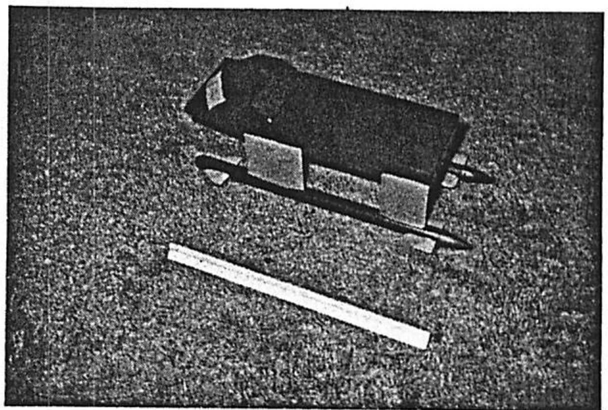

Fig.7. Early hydrodynamic model of a SWATH, 3/1/69.

Model Test Alternatives

I considered proposals for Navy-sponsored towing tank tests as early as September, 1968. In a discussion on 9/16/68 with Dr. McLean, he suggested a man-carrying version, instead of a model, that would be made using two existing torpedo hulls. Calculations later showed that torpedo hulls were too heavy, so I made alternate calculations on a variety of sizes and types of models and manned test vehicles. Several meetings were held with W.B.Barkley, manager of the Convair General Dynamics 315-ft (96m) long Towing Basin Facility in San Diego, to determine limits on towing speed, waves, model size, type of test data, and model set up. In April 1969, I proposed a program starting with tests on a variable-geometry tow tank model. This would be followed by the development of a 1-ton man-carrying test craft, and later by a 25-ton, 46-ft (14m), 20-kt (10m/sec) SSP oceanographic vessel which had plexiglass underwater observation domes at the bows of the lower hulls.

Funding

Early in 1969, information on the new SWATH concept was given to the Naval Ship Systems Center in Washington, D.C. (currently called the Naval Sea Systems Command, and referred to herein as NAVSEA) and funding was requested for model tests. The request was turned down, based upon a recommendation by the Naval Ship Research and Development Center (now called the David Taylor Naval Ship Research and Design Center, and referred to herein as DTNSRDC). The basis for this negative recommendation was hazy, but apparently DTNSRDC had previously tested a single-hulled semi-submerged "Engelmen" model without stabilizing fins, found it to be unstable in heave and pitch, and had thought that our new twin-hulled design would also be unstable.

As a result, Dr.McLean funded the proposed model tests from the Center's IED program. The objective was to obtain not only the usual hydrodynamic data, but to also obtain motion pictures of the model when free to heave and pitch in order to prove that it was stable.

Towing Tank Tests

I completed the model design and test plan on July 2, 1969. Model A was 52-in (132cm) long with a hull centerline spacing of 26.4 in (67cm). Model B was 64-in (163cm) long with a hull spacing of 30.1 in (76cm). Model C was the same as A, but had no stabilizing fins. All models had two 4-in (10.2cm) diameter lower hulls, and arc-shaped struts in tandem on each side. The primary model difference was the fore-and-aft locations of the struts. The variables in common were hull nose shape, vertical center of gravity, forward strut thickness, and stabilizing fin geometry. The latter was a choice between a single full-span fin and a pair of cantilevered fins near the stern of each hull. Although canard fins were planned for any prototype, as illustrated in [3], they were not tested on the model since it was intended that they be free to pivot, with control accomplished by means of shaft torque control. Consequently, without torque control the canards would have had essentially no effect on the model dynamics, and were therefore omitted for simplicity.

The test variables were draft; wave height, length, and direction; model speed; model metacentric height; pitch angle; yaw angle; model restraint in heave and pitch; and wind direction when free to drift. The data included five components of forces and moments, and three components of model motions. Both still and motion pictures were taken.

Test Results

About 500 test runs were conducted during August and September, 1969 (Fig.8). The results showed that stabilizing fins were indeed needed to prevent pitch instability at moderate to high speeds. Also, the larger longitudinal spacings between struts were found to be beneficial in following waves. Good motion characteristics in beam waves and winds occurred when the transverse metacentric height was between 0.5 and 1.0 hull diameter, which corresponded to about 8% to 16% of the beam. Comparative tests with a conventional ship model showed that the new SWATH model had greatly reduced motion in waves.

NAVAL FEASIBILITY STUDY

Sponsorship

Later in 1969 I again visited NAVSEA, and showed model data and motion pictures that verified the dynamic stability of SWATH vessels. This time there was greater interest, but still no funding. As a consequence, I approached the Naval Air Systems Command (NAVAIR), Office of Naval Research (ONR), and the Advanced Research

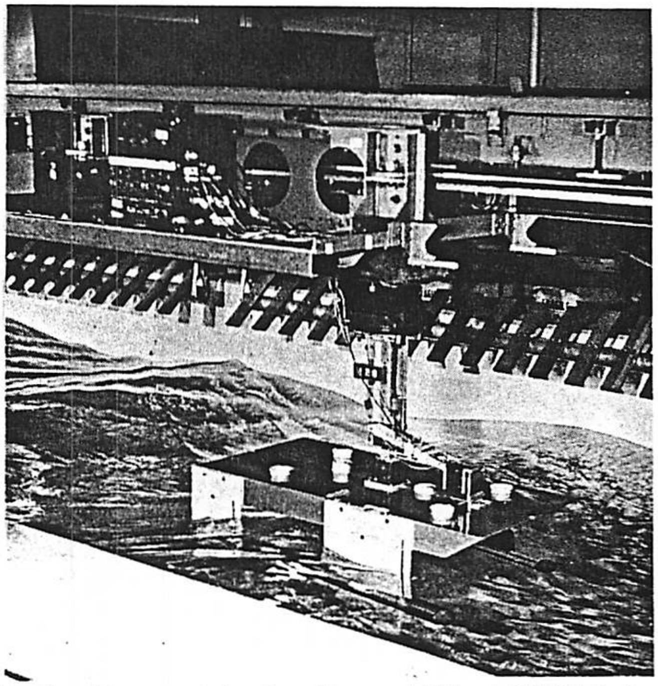

Fig.8. First model of a fin-stabilized SWATH being tested in the 315-ft (96m) Convair/General Dynamics Towing Tank in San Diego, CA, August 1969. (U.S.Navy photograph)

Projects Agency (DARPA). Interest was high, especially by R.Krida in NAVAIR Code 303 who saw the potential as a carrier for helicopters, V/STOL aircraft, remotely piloted vehicles, missiles, and Naval aircraft. He was the first to provide outside funding; the funding was to be used for a naval feasibility study on SWATH to support air systems. Following his support, I was able to obtain funding from J.Smith and CDR R.Hanford in ONR Code 462 to study technical questions related to SWATH dynamics, propulsion, and structures. This sponsorship led to another group in ONR, headed by CDR S.Gordon in Code 463, who supplied funding for a detailed analysis of the SWATH towing tank data. DARPA was also interested, but not to the extent of sponsorship. With this funding in hand, I went back to J.Haines in NAVSEA 03411 who now agreed to sponsor a generalized SWATH ship feasibility study.

Since each sponsor was interested in different aspects, it was decided to integrate the effort into an overall SWATH Naval Feasibility Study and publish the results in parts, each being a portion of an overall report. This is probably one of the few times that a feasibility study has been sponsored jointly by NAVAIR, ONR, AND NAVSEA.

Project Personnel

Work on the SWATH Naval Feasibility Study began in January 1970. With the management support of Dr. McLean, Dr.G.S.Colladay, J.Jennison, and Dr.W.D.Squire at NOSC, I obtained the part-time assistance of several NOSC personnel. These included P.D.Burke for the structural analysis, J.L.Wham and R.M.Anderson to explore the sonar potential of SWATH Navy ships, W.J.Sturgeon (contractor) who developed the ship general arrangement drawings and drew the concept drawings, and R.LaMoglia who gathered background material for the systems analysis study. The late Dr.P.L.Warnshuis transferred into my new group to lead the operational utility study, and

H.E.Karig transferred in for the propulsion system analysis. I was able to hire Dr.D.T.Higdon in 1970 to explore SWATH ship motions and automatic control. These latter personnel formed the beginning of the Advanced Concepts Group that I initiated and headed for the next eight years (the Group worked not only on the SWATH ship concept, but many other types of new Naval vehicles, new sonar concepts, batteries, and Naval systems). Other NOSC personnel who provided ideas on SWATH and reviewed our reports were Hicks, R.Sulit, J.Avery, and D.Schultz.

Results

The SWATH Naval Feasibility Study was completed in September 1970, and a seven-part report was published [4]. The report concluded that the SWATH concept was technically feasible in all respects, and that many potential Naval applications existed. Chief among the recommended SWATH applications was its use for basing aircraft or missiles, for sonar and anti-submarine warfare, patrol, mine detection, oceanic research, submarine rescue, and for hospital ships.

INITIATION OF THE SSP PROGRAM

Early SSP Designs and Proposals

Returning to the 1968 and 1969 period when I studied various sizes and shapes of manned SWATH vessels, my first proposal for a manned SWATH was dated 5/28/69; this was for the construction of a 1-ton version to be followed by the preliminary design of a 25-ton SSP having plexiglass bow domes on the lower hulls for underwater viewing. (Although the acronym SSP for Stable Semisubmerged Platform was coined later, it will be used here to denote that particular design which directly evolved into the final SSP design.)

H.V.L.Patrick of NOSC assisted me in the late summer of 1969 in conducting the towed model tests, and in helping to detail the design of a proposed 3-ton SWATH to replace the earlier 1-ton proposal. On 9/8/69 I proposed to NAVAIR to build the 3-ton version. At the time, however, NAVAIR preferred paper studies, so our SWATH design work continued under NOSC IED funding.

Dr.McLean had always endorsed the early construction of experimental prototypes, as had Dr.J.S.Lawson, the Director of Naval Laboratories (DNL). On 12/10/69 Dr.McLean called DNL regarding my proposal for the sequential development of a manned 3-ton model and a 25-ton oceanographic SSP. He discovered that DNL had IED funds for building prototypes of new concepts, and that he was very interested in our SWATH proposal.

Dr.McLean suggested that I propose a larger SSP than 25 tons to follow the 3-ton boat development; preferably one that could be used at NOSC San Diego for supporting the CURV (a tethered unmanned undersea vehicle), and for testing sonar arrays, etc. As a consequence, I sketched the design of a 50-ft (15.2m) SWATH vessel for oceanic research which had two 5-ft (1.5m) diameter plexiglass bow domes. This proposal was received with great interest by DNL when Dr.McLean and I visited him on 1/14/70. Dr.Lawson seemed to be our best hope for sponsorship since a NAVSEA representative told me later on 3/19/70 that a 50-ft SSP development was premature since tests on a ModCat model (SWATH without fins) under a newly-started SWATH program at DTNSRDC indicated that a small 50-ft version would swamp in the ocean.

While the proposal was being considered by DNL, work continued at NOSC under IED funding on ideas and early designs for the 3-ton manned model and the 50-ft SSP. In parallel, intensive work continued on the SWATH Naval Feasibility Study. On 2/12/70 I gave a presentation on the SWATH concept to the NOSC Advisory Board, who strongly supported the concept.

In March 1970 Dr.McLean asked me to travel to the NOSC Hawaii laboratory to visit J.D.Hightower (JDH) who was managing the RUWS program (Remote Undersea Work System, a larger and deeper-diving version of the CURV). The object was to explore the possibility of using the 50-ft SSP at NOSC Hawaii to support the RUWS instead of basing it at NOSC San Diego to support the CURV. Also, Dr. McLean asked me to explore the possibility of enlisting the aid of JDH in getting the vessel built in Hawaii, if it was found desirable to use it there. I briefed JDH in Hawaii on March 30-31, showed him SWATH films and slides, and gave him copies of our SWATH work including an outline of a 50-ft SSP development plan. He liked the idea of using the SSP to support RUWS, and suggested that a center well be included in the SSP to lower the RUWS into the ocean. Having made previous calculations on the structure, I readily agreed since a 4-strut SWATH configuration requires no structural members in the center region. Also, I found that it was necessary to enlarge the SSP in order to operate best in the rough seas off the Hawaiian Islands.

The next day in Hawaii, I made the necessary calculations and laid out the design of an 80-ft (24.4m) SSP with 6-ft lower hull diameters. The vessel had a water clearance of 6 ft (1.8m), a hull centerline depth of 12 ft (3.7m), a transverse metacentric height of 4.0 ft (1.2m), strut chords of 20 ft (6m) forward and 17 ft (5m) aft, rudders aft of props, plexiglass bow domes, stabilizing and canard fins, and a displacement of 146 LT. The calculated power at 20 knots was 1305 SHP. There was manned access down each strut. Many aspects of this particular SSP version carried through to the final design of SSP.

After returning from Hawaii, I met with Dr.McLean who then made the decision to build and use the 80-ft SSP in Hawaii. He recommended that we eliminate the intermediate 3-ton step because the boat might tilt too much when people moved around; also, he thought that it would introduce an unnecessary delay in the program. I then suggested we substitute a 5-ft radio-controlled model for it, and he readily agreed.

Later, in order to expedite the program, JDH and I agreed that the SSP, if funded, would be a joint program between us wherein I would retain the responsibility for all of the SWATH-related aspects in San Diego, and he would be responsible for the structural and mechanical design in Hawaii, and for getting it built there. Throughout the program, however, Dr. McLean held me personally responsible for the performance of the SSP, and requested that I sign the final drawings of the SSP.

SSP Sponsorship

Work at San Diego and Hawaii on the 146-ton version of the SSP began on 3/31/70, and continued to 6/30/70 under the current IED program sponsored by Dr.McLean which listed me as principal investigator. Meanwhile, during a trip on 4/15/70 to Washington, D.C. to present progress reports to sponsors of our SWATH Naval Feasibility Study, I laid the groundwork for JDH and me to present a new SSP proposal the following month. On the same trip, at DNL's suggestion, I proposed a joint effort between NOSC and DTNSRDC for tank testing a 12-ft (3.7m) SSP model. Following my return, JDH and I developed the new SSP proposal as a range support craft for NOSC Hawaii.

On 5/18/70 JDH and I presented the proposal to eleven different Navy offices in Washington, D.C.; these included NAVMAT, NAVSEA, OPNAV, DARPA, NAVAIR, NAVOCEAN, and DTNSRDC. As a result, Dr.Lawson (DNL in NAVMAT) agreed to provide $250K, and Krida in NAVAIR matched it. Admiral J.Langille (then a Navy Captain in DNL's office) was a great help and convinced NAVSEA to also match DNL's funding.

On 6/5/70 Captain C.B.Bishop (Commanding Officer of NOSC), who was very enthusiastic about the program, sent an official letter to NAVMAT suggesting that DNL act as the SSP Program Manager in the joint DNL/NAVAIR/NAVSEA program.

On 7/1/70 funding was received directly from DNL under a new task assignment which listed H.O.Porter (NOSC Hawaii), Hightower, and me as Co-Principal Investigators for the SSP.

On 11/1/71, a little over a year later, when the SSP design was essentially completed, the task assignment from DNL was revised to cover the construction phase wherein Hightower was then listed as the Principal Investigator and I was listed as the Associate Investigator. As it turned out, the bulk of the SSP funding was provided by DNL.

SSP Technical Plan

We were clearly at the leading edge of SWATH technology since there was no previous technical literature on SWATH to draw upon. We were planning a large step in going from 5-ft towed model tests to an 80-ft operational vessel. The SWATH effort had been only a 1-man program for a year, augmented by several other people at NOSC for an additional half year. Seldom has a major Navy development proceeded so quickly.

Early focus was placed on the critical issues of drag, static stability, dynamic stability, structure, and propulsion. To minimize risk, the aid of the specialists already working on the SWATH Naval Feasibility Study was enlisted. Also, even though the SSP was designed to be inherently stable, an automatic control system was planned to not only further reduce the already low motions, but to reduce risk in the case of unanticipated dynamic problems. A radio-controlled model was unorthodox at that time, but I felt that its use would serve to explore certain types of dynamic behavior that could not be investigated with towed models.

JDH wisely chose later in 1970 to contract for a group of naval architects at the Pearl Harbor Naval Shipyard to conduct the majority of the structural and mechanical design, and to prepare all of the SSP contract drawings.

SSP KAIMALINO DESIGN, FIRST HALF OF 1970

Program Management

It was agreed that I would manage all SWATH-related aspects of the SSP program, and manage the general San Diego effort; and that JDH would manage the NOSC Hawaii work in addition to acting as the overall program manager and integrate the two efforts into a single program. Also, I was to approve the final SSP design prior to construction. At NOSC Hawaii, A.T.Strickland would join the team in late April and be the assistant to Hightower, G.A.Wilkins would be a consultant, and Porter would assist in program management.

LCDR Kreitner at the Pearl Harbor Naval Shipyard (PHNS) and his naval architect team would join the SSP team later to conduct the detailed structural design, general arrangement, weight breakdown, mechanical design, detailed static and damaged stability, and provide the final drawings.

Prior to starting their detailed design task, the PHNS team requested on 5/4/70 that we first prepare a full conceptual design. For the San Diego part of the task, I would conduct the hydrodynamic design, specify the SSP configuration, plan the model test programs and analyses, and manage the San Diego effort; Higdon would conduct the dynamics analysis and automatic control design, determine hydrodynamic loads, and assist with model tests; Karig would work on the main and auxiliary propulsion systems; Warnshuis would concentrate on future uses of the SSP and their impact on the SSP design with the assistance of Sturgeon; Wham would assist on planning sonar installations; L.E.McKinley would work on the design of plexiglass domes; and Burke would provide the general SSP structural design. Most of these people were in my Group, and all but one of them were already on the Naval Feasibility Study, so their work on the SSP design was easily arranged.

First San Diego/Hawaii SSP Group Meeting

To integrate the SSP work between NOSC San Diego and Hawaii, Hightower called the first of several meetings at San Diego on 4/10/70. It was agreed that the current San Diego SSP design and plans were on target, namely: 150 tons, 80 ft length, 40 ft (12m) beam, 15 ft x 25 ft (5 x 8m) center well, removable plexiglass and sonar bow domes, Solar turbines located in the lower hulls, CRP propellers, 30-ton payload, automatic control, 20 kts, and 5 ft radio-controlled model tests in a tank at San Diego with later tests planned on a 12 ft model at DTNSRDC. NOSC Hawaii proposed to build the SSP on their grounds with the help of contractors, and planned that the SSP be used to support: (1) RUWS, (2) various experimental sonar systems, (3) submersibles, (4) the marine mammal program, (5) general oceanography, and (6) demonstration of the technology. Technology demonstrations would include SWATH dynamics and motions, its use with helicopters, etc.

NOSC San Diego Design Work

On 4/6/70 I completed the analysis of the towed model tests [4, Part II] which was of great help in designing the SSP configuration. To stimulate outside interest, I gave the first paper (unpublished) on SWATH on 5/5/70 at an AIAA/NAVY meeting at Newport, RI. On 5/22/70 I updated the SSP configuration after reestimating the vertical center of gravity (VCG). Following another update in VCG on 6/16/70, I increased the forward strut chordlength to 25.0 ft (7.6m), increased the hull centerline spacing to 40 ft (12.2m), moved the cross structure bow forward, moved the propellers and rudders aft, selected 7'9" (2.4m) for the aft fin chordlength (same proportions as in the original 1969 5-ft towed model), changed the overall length to 88 ft (27m), and raised the pilot house about 2.5 ft (0.8m) above the weather deck for better visibility aft. Most of these changes became final values. The displacement remained at 150 tons, and I estimated the speed at 23 knots (12m/sec) with 2,000 SHP.

On 6/20-23/70 I made some initial tests on strut spray in the free-surface water tunnel at Caltech; as a result, I swept the leading edge of forward struts forward about 40 degrees to reduce spray.

Burke made good progress on structural ideas for his portion of the SWATH Feasibility Study, and estimated the structural weight of all-steel and all-aluminum SWATHs as a function of vessel displacement [4, Part IV]. Dr.McLean recommended the use of ferro-concrete for the SSP lower hulls; however, Burke reported that there were many structural unknowns, and urged caution. He also laid out early structural designs for the SSP, which were of help later to the Pearl Harbor team. On 6/16/70 I contributed the idea of a triangular structural arrangement at the top of the forward struts to transfer the strut bending moment into the upper and lower decks of the cross structure; this idea carried through to the final design.

Higdon analyzed the loads and motions in waves for general SWATH ships, including the effects of automatic control [4, Part III]. He showed that very little motion would result in waves, and that automatic control, if used, would reduce motion by a factor of two or more. His estimate of SSP side loads on 6/8/70 was later found to correlate reasonably well with model test results, and was very useful to the structural designers at Pearl Harbor. He also verified that the dynamic stability in yaw was acceptable, and verified the sizes of the canards and the stabilizing fin.

Karig developed generalized propulsion system weights for SWATH ships as a function of power level and type of system; he included the use of diesels, turbines, and combinations thereof [4, Part V]. He also treated such problems as air supply, exhaust, cooling, noise, and reduction gears. This early analysis aided in his selection of turbines for the SSP which were to be located in the lower hulls at that time.

Warnshuis [4, Part VII] developed a generalized mathematical model for determining SWATH ship performance, based upon drag, power, and weight information developed in other parts of [4]. He also included the idea of optionally towing a fuel pod to extend range. The result was an interesting set of graphs showing SWATH ship displacement as a function of various performance requirements. This result assisted him in selecting the different types of naval applications recommended for SWATH ships. These results were also useful in planning future demonstrations of the SSP.

Wham and Anderson covered the sonar potential of SWATH ships [4, Part VI]. This study was useful in developing later proposals for testing sonar systems on the SSP, and also led to the idea of replaceable bow domes for the SSP.

Radio-Controlled Model

I designed an early version of the 5-ft radio controlled model, and made calculations of its drag and power on 4/7/70. Meetings were held with Barkley at the Convair Towing Tank on 4/9/70 to discuss model details and the possibility of building the model in their model shop.

On 6/25/70 I made a drawing of the final radio-controlled SSP model with a length of 56.82 inches (144cm), and the next day a contract was awarded by NOSC to Convair to build and test the radio-controlled model.

NOSC Hawaii Contributions

During May and June 1970 Strickland determined the auxiliary power requirements, made some initial calculations on strut stress, based upon Higdon's loads, updated the vessel component weights and centers, and made some independent calculations on the required waterplane area. He also summarized the major SSP tasks needed based on inputs from NOSC San Diego.

SSP KAIMALINO DESIGN, LAST HALF OF 1970

Management

The naval architects at PHNS began work around 7/1/70 on the structural design. On 8/24/70 at DNL's suggestion, NAVSEA officially requested DTNSRDC to support the NOSC SSP program by constructing and testing a 12-ft model of the final SSP design. In Hawaii, the intended construction site for the SSP was changed from NOSC Hawaii to Pearl Harbor, and on 11/12/70, the Pearl Harbor Naval Shipyard officially agreed to build the SSP. Throughout the program, we were fortunate to have had the management assistance of many people, especially Dr.McLean, Dr.Lawson, Admiral Langille, and Captain Bishop.

San Diego Design Work

The radio-controlled model was completed by Convair in August 1970. C.R.Nisewanger joined our Advanced Concepts Group to aid in the model tests, to maintain and modify the model, and to help in the SSP design. We conducted several days of testing at Convair through October 1970. The SSP model performed well, and exhibited no dynamic problems. It responded nicely to flap, canard, rudder, and motor commands; banked into turns without roll control; and maintained a straight course with only one propeller operating with only a small rudder deflection. The drag was measured using a towline attached to a force transducer. Following tank tests, we operated the model in San Diego Bay to further explore its dynamic characteristics (Fig.9).

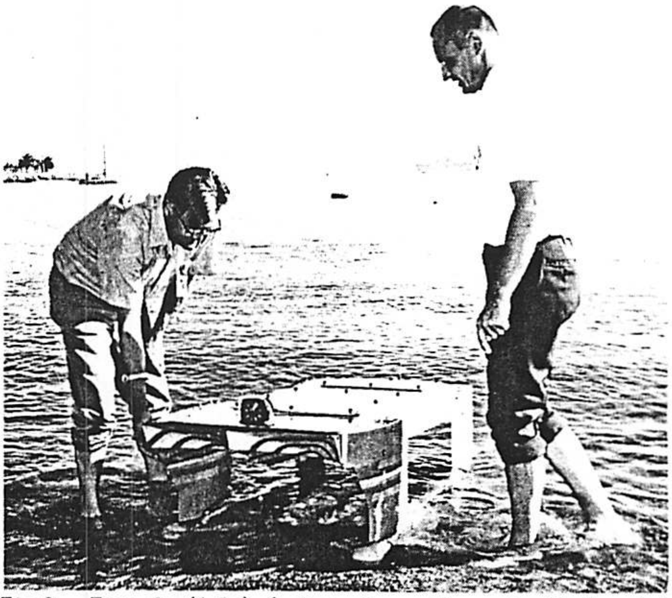

Fig.9. Five-ft (1.5m) 6-channel, radio-controlled model of the SSP KAIMALINO being prepared for tests in San Diego Bay by C.R.Nisewanger (left) and D.T.Higdon (right). (U.S. Navy photograph)

On 7/3/70 Karig recommended CRP propellers for the SSP, and suggested the Wilkenson Marine Propulsion Engineering (MPE) type. He also recommended either Solar or Avco Lycoming gas turbines in the lower hulls, and stated a preference for the latter as being the more completely marinized.

In August I conducted an analysis of canard effectiveness which further verified the selected fin size, and predicted the roll, heave, and pitch natural periods of the SSP. On 8/21/70 in a memo to Hightower, I suggested that aluminum be used for the cross structure and struts, and that the lower hulls be made of steel rather than ferro concrete; the latter resulted from an input from Burke, together with a very strong recommendation by Dr.J.D.Stachiw (a mechanical engineer at NOSC San Diego) to not use ferro concrete. In the same memo, I recommended that the stern of the cross structure of the SSP be moved forward, and that the upper region of the aft strut be swept forward, in order to solve certain design problems. After studying the cost and weight of different alternatives, I jointly made the decision with NOSC Hawaii on 9/18/70 to use steel struts and hulls, and an aluminum cross structure.

On 10/5/70 I specified a 15 percent thickness ratio for the forward struts, and a 12 percent ratio for the aft struts; and two weeks later, after consulting with Stachiw, recommended that acrylic underwater windows be placed in each strut.

On 10/18/70 I laid out a new drawing of the SSP scaled to the 12-ft model size to be used in tests at DTNSRDC. This drawing was very close to the final SSP configuration, and I delivered it to DTNSRDC on 10/22/70. On the same trip, I distributed the final reports to the sponsors of our 7-part SWATH Naval Feasibility Study; this report was distributed widely throughout the Navy, universities, and industry.

By 11/15/70 the displacement of the SSP had grown to 160 tons, and I reestimated the drag, power, and propeller characteristics, and settled on a 6-ft (1.8m) propeller diameter. This new information, together with some additional details on the configuration, were sent to DTNSRDC for incorporation in the 12-ft SSP model.

On 10/29/70 we used the radio-controlled model in the Convair tank to test some new cross structure bow shapes to minimize impacts. One was a four-prong bow designed by Nisewanger. On 11/12/70 we tested the model at the Offshore Technology Tank (OTC) at Escondido, CA, to determine its response when operating at various angles to waves, and when maneuvering in waves.

On 12/11/70 Higdon completed his calculations on control surface hinge moments and loads, and specified their maximum deflections. Also, he completed numerous computer analyses on SSP motion and motion reduction using various control system logics.

Hawaii Design Work

Strickland continued to technically coordinate the work at PHNS and NOSC Hawaii with our work at NOSC San Diego. He also continued to update the component weights and centers of gravity as the design changed or became more detailed. On 9/21/70 the SSP displacement reached 167 tons.

The Pearl Harbor team continued to keep up with the many configuration changes, to detail the various structural and mechanical aspects of the design, and to make some of the final SSP drawings.

SSP KAIMALINO DESIGN, 1971

NOSC San Diego

On 1/16/71 we again tested the radio-controlled model in waves at OTC; the objective was to explore five new bow shapes to reduce impact. Following analysis of the tests, I drew the final SSP bow design on 1/19/71 which consisted of twin impact alleviators located between the forward struts and attached to the under side of a flat surface at the bow canted at 20 degrees.

On 1/28/71 I specified more details and made further changes to the SSP configuration; these were transmitted to NOSC Hawaii, and to DTNSRDC for incorporation in the 12-ft model. The changes included the new bow shape, and an increase in the lower hull diameters to 6.5 ft in order to increase the displacement to the final 190 tons requested by NOSC Hawaii. I accordingly increased the propeller diameters to 6.5 ft. DTNSRDC began construction of the 12-ft model on 2/18/71.

By 3/12/71 Higdon, Nisewanger, Karig, and I had completed the detailed design of the final SSP configuration. This included design of the hulls, struts, fins, control surfaces, propellers, prop guards, bow shape, and cross structure. In addition, we had specified the control actuator requirements, hydrodynamic loads, power plant type and power requirements, shaft speed, metacentric heights, and provided NOSC Hawaii with assistance on the structural design, propulsion system, and internal ship systems. Also, we had planned, conducted, and analyzed tests on the 5-ft towed and radio-controlled model, and helped plan and coordinate the design confirmation tests to be conducted on the 12-ft SSP model at DTNSRDC. We published a variety of reports during this period [5 through 12]. Ref. [9] was the first technical paper on SWATH to be presented at a professional meeting and published in a technical journal. Coincidentally, the American Society of Mechanical Engineers (ASME) sponsored not only that paper, but Reference [1], Reference [34], and this current paper, all on SWATH.

Tests on the 12-ft model began at DTNSRDC on 3/22/71, and were run around the clock. J.Haines and R.Dilts were our contacts in NAVSEA as the sponsor, and J.Feldman was our contact at DTNSRDC, together with J.Hadler and R.Stevens; J.A.Fein and C.Pritchett were in charge of the testing, and were very helpful. The late Dr.R.B.Chapman (who joined our Group after graduating from Caltech), Higdon, and I attended the tests, sometimes separately, and sometimes together. Several reports were issued by DTNSRDC on the model tests [13-18]. The resulting drag coefficients were close to the results from our 5-ft SSP model. Tests in waves (with fixed controls) showed good motion behavior at all speeds in both head and following waves throughout the design sea state of 4. Even throughout sea state 5, there were no cross-structure impacts except at the higher speeds in following waves. After the tests, I inspected the 12-ft model and made a detailed analysis of the drag. I found several imperfections on the model that would increase the drag. On 3/28/71 I updated the drag and power estimates for the SSP based on the corrected test results. It was predicted that the SSP would require 1175 SHP per side to provide 20 knots for the 190 ton displacement. On 5/3/71 I extended the calculations to 25.3 knots where the power was estimated at 2120 SHP per side.

On 6/2/71 Chapman and I completed a very detailed analysis of the 12-ft model drag results which included corrections for model anomalies and a change made in the SSP aft struts. The result was an estimate of 2,050 SHP per side at 25 knots with a propulsive efficiency of 0.75. On 6/4/71 I specified the final SSP propeller characteristics after obtaining hull wake calculations from D.Nelson at NOSC San Diego. The new propulsive efficiency was estimated to be 0.77. With the newly-proposed General Electric T64-GE-6B gas turbines, I predicted a speed of 25.5 knots with a power output of 2,150 SHP per side. Also, I specified that each propeller should rotate in the same direction, contrary to normal marine practice, in order to reduce cost and spare parts. Shortly thereafter, I checked and approved the resulting SSP wake-adapted propeller design conducted by MPE based on our inputs. On 10/22/71 I requested that additional underwater viewports be placed in the struts above the propellers.

Hawaii

Work on the detailed design of the SSP proceeded rapidly at PHNS where the design team had been increased to 10 personnel working 10 hours a day, 6 days a week. Their goal was to complete all SSP drawings by 6/15/71.

NOSC Hawaii continued to integrate the efforts of the different design teams, report to the sponsors on overall progress, assist in various aspects of the structural and mechanical design, keep track of the overall weight and center of gravity, help obtain the necessary funding to complete the SSP design, and arrange for construction at Pearl Harbor.

SSP Trials Plan

Early in 1971 work started on a joint NOSC San Diego/Hawaii trails plan for the SSP. NOSC San Diego planned the powering and motion trials, and NOSC Hawaii planned the structural and ship systems tests. In November 1971 Porter and I visited DTNSRDC and NAVSEA to obtain their comments on the completed plans.

NAVAIR

Around March 1971 NAVAIR offered to design and supply the main propulsion system for the SSP; NOSC readily agreed, and so did DNL. The NAVAIR work was to be led by W.E.Simmons, and the propulsion system was to be constructed at the Naval Air Engineering Center (NAEC).

By 5/5/71 it was clear that engines larger than the Avco Lycoming TF14 turbines would be needed if the SSP was to reach a speed of 22 knots or more. Simmons recommended the use of General Electric T64-GE-6B turbo shaft helicopter gas turbines rated at 2,150 HP. Due to their larger size, he also recommended that the engines be placed in the cross structure, and to drive the propellers through a 4-tier chain drive. He completed the design specifications for this new propulsion system on 5/28/71. Detailed drawings of the propulsion system were completed around August 1971.

Presentations and Publicity

Dr.McLean asked me to give all SSP and SWATH presentations to official visitors at NOSC headquarters. Generally, I would present slides and movies, then take the visitors down to the adjacent beach in San Diego Bay where they would operate the radio-controlled model.

I gave 12 presentations in 1970 to official visitors, who were mostly Navy Admirals and Captains from Washington, D.C.. I gave 24 presentations during 1971, and 48 presentations in 1972. During 1973 I gave only 20 presentations, and only 7 in 1974. The primary reason for the decrease in presentations was that NAVSEA and DTNSRDC felt responsible for marketing the SWATH in the Navy, and requested that NOSC reduce its marketing efforts on this new concept.

During the years following 1970, a large number of news releases were made by NOSC on the SSP. Many articles appeared in magazines and newspapers, such as [19-22]. The public appeared to be very interested in the new SWATH concept. After several years, however, the question was asked more frequently of why the Navy had never built a second SWATH, and why Mitsui in Japan had became the world leader in SWATH construction. Our answer was that the Navy had become very interested in building a variety of types of new SWATH ships many times, but no funding was ever made available from Congress.

3,000 Ton SWATH Proposal

In regard to future Navy ships, a team of eleven of us at San Diego completed the conceptual design on 9/27/71 of a 3,000 ton SWATH with the outside help of Litton, Boeing, Alcoa, and Budd Engineering. This was to be an all-aluminum, 315-ft, 35 kt ship capable of normal operation through sea state 6, and modularly outfitted for a variety of missions [23]. A model of the ship is shown in Figure 10, together with members of the Advanced Concepts Group and NOSC management. Unfortunately, nothing came of the proposal which was submitted to NAVSEA and other Navy offices, except possibly for increased interest in SWATH.

SSP CONSTRUCTION

Contractual Arrangements

The first draft of the SSP specifications was completed by PHNS personnel on 12/16/71. The final draft was completed on 3/10/72. For reasons to be discussed later, construction would take place at the U.S. Coast Guard (USCG) Yard at Curtis Bay, MD, rather than at Pearl Harbor. The NAEC would construct the complete modularized propulsion system under the sponsorship of NAVAIR and the technical direction of Simmons. The USCG yard would determine the final weight and center of gravity of the SSP, and conduct the builder's trials.

Construction

Construction of the SSP began at the USCG Yard in June 1972. Porter was held responsible by NOSC for the SSP construction. Strickland was stationed at the Yard to monitor most of the construction, and was relieved near the end by W.Mazzoni of NOSC.

Shortly after construction began, P.V.H.Serrell (a NOSC San Diego contractor) was asked to review all of the structural drawings. He found several regions where changes were needed; these changes were incorporated in the drawings prior to their fabrication.

SSP construction proceeded quickly, and on schedule; all visitors to the USCG Yard were impressed by their staff, planning, and workmanship. The SSP was launched on 3/7/73, and first operated in Chesapeake Bay in October 1973. The SSP reached its design operating speed of 25 knots the following month.

Fig.10. Advanced Concepts Division and NOSC management with a model of a 3,000-ton SWATH (From left to right: Nisewanger, Chapman, Baldwin, Karig, Bishop, Clifton, Lang, McLean, Warnshuis, Sturgeon), 1972. (U.S. Navy photograph)

NOSC SAN DIEGO SSP CONTRIBUTIONS, 1972 AND BEYOND

SSP Technical Work, 1972 - 1973

Chapman and I continued to update the SSP drag and power predictions; however, the changes were minor. On 3/4/72 Higdon completed calculations on the SSP trim attitude as a function of speed, based upon the 12 ft model test results. In October 1972 Serrell designed a loading device that could be used to simulate the hydrodynamic spreading loads acting on the SSP. Also in 1972, Sturgeon assisted in the furnishing and outfitting plan for the SSP. D.L.Endicott (trainee in the Group) assisted in the control fin analysis [24]. In 1973 a series of wave impact pressure tests was conducted by R.L.Bedore (Group member) and Chapman on the 5-ft radio-controlled model [25]; also, Higdon and I completed a paper on the SSP hydrodynamics [26].

In addition to specific work on the SSP, we conducted a variety of research studies on basic SWATH questions, many of which were applicable to the SSP. These studies were sponsored by NAVSEA, NAVAIR, DTNSRDC, and IED. They included dynamics by Higdon and me [27-29], general hydrodynamics [30], control surfaces by M.G.Harris (trainee in the Group) [31], sinkage and trim by Chapman [32], drag of SWATH model components by Chapman [33], and a very basic and useful theory on SWATH drag developed by Chapman [34] that incorporated my earlier methodology on viscous drag. R.L.Wernli (trainee in the Group) later assisted Chapman in documenting and improving the SWATH computer drag program [35].

SSP Trials Plan

Beginning in January 1972 our Group developed various detailed trials plans. In addition to hydrodynamic trials, we included test plans on the propulsion system by Simmons, a structural test plan by Serrell, and an acoustic test plan by A.G.Fabula (NOSC San Diego employee). The final SSP test plan [36] was issued on 12/12/72. This work was sponsored by NAVSEA and DTNSRDC. On 3/26/73 DTNSRDC issued an outline of a new sea trials test plan based upon [36].

On 2/13/74 S.Hawkins (SWATH Program Manager at DTNSRDC selected by NAVSEA) agreed with Dr.McLean that all final reports on the SSP tests by DTNSRDC or NOSC would be approved by both NOSC and DTNSRDC prior to issuance. Also, the raw data would be shared. I was asked by Dr.McLean to act for NOSC to approve all such test reports.

SSP Mapping Trials

These trials were successfully completed by NOSC on 2/19-20/74 in Chesapeake Bay near Annapolis, MD. The purpose was to obtain sufficient data to map the SSP propeller pitch and control surface settings as a function of speed, power output, and other variables so the SSP could begin sea trials with the proper settings. As the test director, I wrote an internal memo on 5/15/74 which enclosed analyses by Chapman and Higdon that provided the information needed to set the propeller pitch and control surface deflections. During the Eastern trials period, A.J.Schlosser (NOSC) was responsible for the operation and maintenance of the SSP, and J.Berkley was his assistant in charge of trials instrumentation.

Chain Drive Problems

On 2/28/74, in the initial stages of the DTNSRDC sea trial program, a shaft in the upper part of one chain drive failed due to a sharp-edged keyway. DTNSRDC was very helpful in exploring the cause. Hightower was asked by NOSC on 4/15/74 to resume responsibility for the SSP operation and maintenance, and to solve the chain drive problems. Serrell assisted Strickland and others in the redesign to provide the SSP with full power capability with a safety factor of two. Following modifications, the SSP was transported to NOSC Hawaii in February 1975.

Auxiliary Propulsion System

In November 1974 J.F.McCartney, with the assistance of R.A.Wiley (Advanced Concepts Group members) and Nisewanger, completed the design of the SSP auxiliary propulsion system [37]. NOSC Hawaii installed the system in the SSP following its arrival in Hawaii. The system satisfied requirements and worked well for several years. It has recently been modified by NOSC Hawaii.

Buoyancy Adders

In May 1974 our Group was asked by NOSC Hawaii to increase the SSP displacement to provide more payload. On 6/10/74 I wrote a memo showing how blisters added to the lower-hull midsections would not only provide 20 to 40 tons more displacement, but would reduce drag at certain speeds up to 16 knots. Wernli used Chapman's theory [34] to predict the drag. On 12/31/74 Bedore completed the design of two 15-ton blisters, and later verified the drag predictions by testing the radio-controlled model in a towing tank with blisters attached. The blisters were constructed under a contract in Hawaii and added to the SSP; they increased SSP displacement to 217 LT. Several years later these blisters were replaced by NOSC Hawaii with larger ones that increased the displacement to the current 227 LT.

SSP Trials

On 7/15/75 DTNSRDC initiated sea trials on the SSP in Hawaii. Our San Diego Group assisted in test planning, participated in the trials, analyzed the results, and compared the results with model tests. My review of the DTNSRDC reports was coordinated with G.Elmer (new SWATH program manager at DTNSRDC). A number of reports resulted, and the findings correlated reasonably well with model tests and predictions [38 - 47].

Automatic Control System

Our primary sponsor, Dr.Lawson, requested that the automatic control system not be installed on the SSP for about a year. His reason was to demonstrate that the vessel was inherently stable, and had low motion characteristics, even without motion control. Accordingly, Higdon finished the automatic control system design, and constructed and installed it on the SSP in September 1975 [48]. The new system operated well, and further reduced the already-small SSP motions when underway. In a recent discussion with the SSP crew, I discovered that they now turn on the automatic system only when sea conditions are unusually rough.

Acrylic Dome

An acrylic dome was installed on the port bow late in April 1976. This hemispherical dome was designed by Stachiw [49]; it is 6-in thick, 6.5-ft in diameter and weights 5,000 lbs. At the time, it was the world's largest acrylic casting. Several of us participated in an impact analysis to ensure that the dome would be at least as safe as the previous steel dome. This dome permits two or three observers to look out underwater with the SSP underway; the resulting view is spectacular.

Propeller Photographs

On 5/26/77 I obtained high-speed motion pictures (200 frames/sec) using a Millikan camera mounted in the viewport above one propeller to document propeller operation up to 22 knots. Dr.L.A.Parnell (Group member) obtained additional pictures in July and August. The results showed some tip vortex cavitation at normal operating conditions, but not enough to significantly reduce efficiency. Additional pictures were taken through a viewport from the opposite strut, but were not as clear because of the distance and of entrained air flowing past the viewport; however, they provided additional useful information.

PROGRAM HURDLES

Sponsorship

When developing a new concept, the most difficult hurdle is to find a sponsor. This is so because sponsors typically desire high-tech results but with low-risk, and want all major technical problems to be solved in the proposal; also, they typically want a detailed plan complete with specific target dates and costs. In the case of the SSP, we were fortunate to find sponsors who were more realistic, and who appreciated the value of taking risks and quickly turning an idea into hardware with a minimum of paper work.

Alternative SWATH Design at DTNSRDC

A major hurdle arose on 6/17/71. Dr.McLean, the Technical Director of NOSC, received a graph generated by someone at DTNSRDC which compared the SSP curve of power versus speed with a curve for a new SWATH shape designed at DTNSRDC. This graph incorrectly showed that the SSP had three times the power requirement of the DTNSRDC SWATH, called the Pien Cat. Such a situation is the kind of hurdle that, if true, can immediately halt a program like the SSP.

As it turned out, Chapman and I were able to show in a memo on 6/25/71 that the SSP was the best design for the purpose; that the SSP curve had been plotted too high, and covered only the speed region where its wave-making drag was highest rather than the higher speed region for which the SSP was actually designed and where its wavemaking drag was low. Also, the curve for the Pien Cat (a good design for a large ship) had been extrapolated in speed well beyond its data limit, and into its wavemaking drag hump region, but without showing any increase in drag due to wavemaking. As a result, we convinced DNL to continue sponsorship of the SSP.

It is interesting to note that none of the SWATH models tested at DTNSRDC until the fall of 1973 had stabilizing fins. I was told that the reason was that they believed a SWATH did not require such fins, and that the fuel and ballast could be transferred fore and aft to correct for any undesired trim changes caused by variations in speed.

SSP Safety Review

On 5/12/71 NAVSEA directed that a safety review be conducted on the SSP prior to permitting its construction at their Pearl Harbor Naval Shipyard. The primary concern was the seaworthiness and survival capability of the SSP. T.Sarchin, R.Dilts, J.Sejd and S.Caldwell of NAVSEA conducted the review under the direction of S.Hersh and R.Johnson. Both NOSC Hawaii and San Diego participated in preparing information for the review in their respective areas of SSP responsibility.

The 5-ft radio-controlled model was of great help in the safety review. We used the model in San Diego Bay to demonstrate that the SSP was inherently safe under all conditions of large wave encounter, control surface failure [6], off-design conditions, and simulated lower hull and strut flooding. All critical loading conditions were rechecked by Higdon [5]. Chapman conducted a hydroelastic stability analysis of strut deflection which was reported in Appendix A of [8]. Also, motion pictures of the SSP model tests were shown under various simulated sea state conditions.

NOSC Hawaii and Pearl Harbor covered the safety aspects of the structure, ship systems, and machinery, and conducted the static and damaged stability analyses.

On 9/27/71 NAVSEA cleared the SSP for safety as long as their recommendations with respect to watertight doors and a backup CO_2 fire extinguishing system were followed. As a by-product of the review, the NAVSEA reviewers were a great help and provided a list of 72 recommendations to improve the detailed design of the various internal ship systems and certain minor structural aspects. No hydrodynamic changes were suggested or needed. On 3/15/71 Porter responded to NAVSEA by thanking them for the review and listing the corrective measures taken.

Recommended Halt by DTNSRDC

In Febrry 1972 our primary sponsor, DNL, informed us that DTNSRDC had another new SWATH design which they claimed to be superior to the SSP, and that DTNSRDC recommended that the SSP not be built. As a result, DNL asked Professor P.Mandel (Massachusetts Institute of Technology) to independently investigate the situation. I was asked by NOSC to provide the necessary information to Mandel, and enlisted the aid of Chapman and Higdon. We agreed that the DTNSRDC configuration was a good one for large ships, but believed that we had designed an equally good one [23] for future ships; however, for a small range support craft, we showed that the SSP design was still the best design of all. After considerable information exchange, the three of us apparently convinced Mandel that the SSP was indeed the best design for the intended purpose because the problem disappeared and sponsorship continued.

Pearl Harbor Cost Escalation

On 12/27/71, the cost estimate for SSP construction was suddenly doubled by the Pearl Harbor Naval Shipyard. Alternative building sites were explored in Hawaii and on the mainland. Dr. J.Lawson, our sponsor, discussed the problem wih Dr.R.A.Frosch (Assistant Secretary of the Navy for R and D) who suggested that the SSP be built at the USCG Yard at Curtis Bay, MD. This suggestion may have saved the SSP program. Captain D.Keach (who had replaced Admiral Langille in DNL's office) assisted DNL in making arrangements with the USCG. On 3/2/72 Captain Bishop signed an official letter from NOSC to the USCG requesting that they build the SSP.

G.A.O. Investigation

On 2/11/74 NOSC was informed by the General Accounting Office (GAO) that some of their personnel would visit the Center for one to three weeks to investigate the funding of the SSP as the result of a request by the Senate Armed Forces Committee. It is not known who originated the request for the investigation. The conclusions of the resulting GAO investigation clearly stated that the funding sources used for developing the SSP were in accordance with DOD and Navy guidelines. Also, because of its cost, the GAO stated that it would have been better if the Navy had brought the SSP proposal to the attention of Congress so that Congress could weigh the relative need for the SSP against other demands for funding. In summary, the GAO investigation cleared SSP of any funding disorder.

Everyone I have talked to, both in and out of the Navy, doubts that the SSP would have ever been built had it proceeded any differently.

Design Review

On 11/18/75 I asked DTNSRDC if they would assess the strength of the SSP to withstand impacts in large waves in view of their SSP trial data, 12-ft model data, and recent tests conducted on an all-plastic structural model of the SSP [50]. On 12/1/75 DTNSRDC stated that a preliminary analysis indicated that the structure was safe in the design sea state 4, but that data in sea state 5 at 18 kts indicated that several members in the cross structure would begin to yield. In sea state 6, significant bottom damage was predicted. It was recommended that SSP speed be reduced to 5 knots in sea state 5. As a result, Captain R.B.Gilchrist (new Commanding Officer at NOSC) established temporary operating constraints on the SSP until more data was obtained. Also, NOSC initiated an internal design review to explore the problem and check the DTNSRDC predictions.

On 1/27/76 Parnell analyzed model wave impact tests and studied earlier structural analyses conducted by both NOSC and DTNSRDC. His results indicated no predictable damage at normal speed through the middle of sea state 5, even without automatic control. With automatic control, another sea state would be gained. This latter result was verified by Higdon.

Following further corroborative information, the operational limits for the SSP were broadened. Actual experience gathered to date from the SSP shows no damage to the primary structure, at any speed and in any waves up to the maximum 25 to 30 ft waves that have been encountered. Once, however, when overloaded at rest in waves, some secondary structural damage was found in one of the two bow impact alleviators, although it was not noticeable from outside.

SUCCESS

Operational Experiences

Hightower and R.L.Seiple [51] described the operational experiences of the SSP KAIMALINO in supporting a wide variety of tasks in the ocean off Hawaii. In the first three years of operation in Hawaii, the SSP had already logged 2,000 hours of operation at sea as a range support craft. The authors stated that the SSP had far surpassed expectations, and performed operations in waves that monohull ships twenty times her displacement had been unable to accomplish. The SSP has served her objective so well as a range support vessel, and with such good reliability, that it is hard to believe that she was ever considered by some to be an experimental craft.

USCG Motion Tests

During April and May 1978 the USCG, with Navy assistance, conducted comparative side-by-side motion tests on the 89-ft SSP, a 95-ft USCG patrol boat, and a 378-ft USCG cutter in the Molokai Channel off Oahu. The results showed that the SSP had the least motion in waves of the three [52]. All of the 18 USCG test personnel got seasick when aboard the patrol boat, while there was almost no incidence of sea sickness when they were aboard the SSP or the large cutter [53,54]. The difference in displacement between the SSP and the cutter was a factor of around 15.

Buoy Tending Tests

On 3/7-11/83 tests were conducted by a joint USCG/Navy team to explore the SSP's buoy-tending capabilities. The 89-ft SSP was compared in side-by-side tests with a 180-ft USCG buoy tender. Both vessels were very maneuverable, but the SSP was found to have a far superior seakeeping ability [55]. For example, the average roll of the USCG tender was 16 times that of the SSP in beam seas.

Dr.William B.McLean's Report

In a memo on 6/21/76 Dr.McLean reported that he had the opportunity to participate in the use of the SSP during the past week to photograph porpoises underway and to study sharks while at anchor. He stated that anyone who had the chance to operate for a period of time aboard the SSP would be spoiled for operation aboard any other type of hull form. Even at rest in large waves and 35 knot winds, the SSP rode for hours at anchor with little perceptible motion; also, the hunting effect of conventional hulls at anchor was not apparent. He was highly enthusiastic about both Navy and commercial uses of SWATH when scaled either up or down from the SSP.

Helicopter Tests

In September 1976 the Naval Air Test Center and the USCG explored the helicopter-handling characteristics of the SSP during a series of over 80 landings and takeoffs (Fig.11). A cover was placed over the SSP well. The results were dramatic [56,57]. Pilots called the SSP stability characteristics "unprecedented".

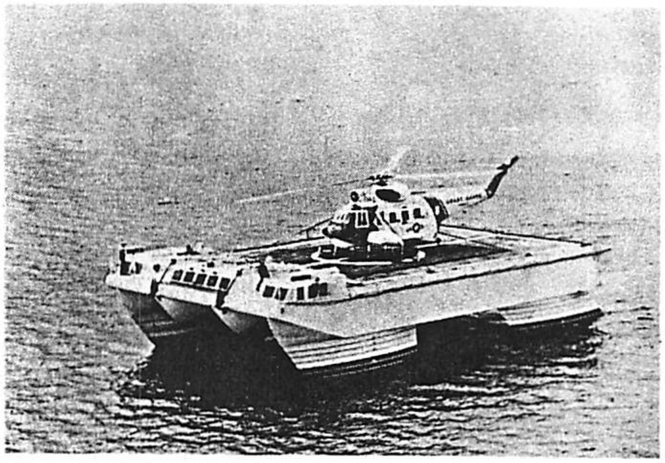

Fig.11. SSP with a cover over the center well undergoing trials with a USCG helicopter, an extension of similar trials with Navy helicopters. (U.S.Navy photograph)

University Test Cruises

In February 1985 the National Science Foundation and the Office of Naval Research sponsored four test cruises aboard the SSP. Sixteen participants from three universities conducted nine scientific projects, each an extension of their current work [58]. Captain R.P.Dinsmore, (Woods Hole Oceanographic Institution) made the arrangements for the test cruises. During one storm, participants that usually got seasick did not. Beakers, portable computer terminals, coffee cups, etc., placed on smooth tables did not shift or spill. Instrument deployments and recoveries were made over the side and through the center well with greater ease than on a monohull. Without exception, the participants were enthusiastic about the SWATH concept.

Mitsui

The Mitsui Company in Japan, with the help of the Japanese government, has been the world leader in the development of SWATH vessels; these vessels have performed exceptionally well [59]. Dr.H.Narita (manager of R and D) was the initiator of the Mitsui work. He drew heavily on the SSP development as evidenced by the similarity between his first vessel, the MARINE ACE, and the SSP. Figure 12 shows him meeting me at NOSC in 1970 when he first learned about SWATH.

Fig.12. Author meeting Dr. Narita of Mitsui in 1970 after being introduced by Dr. William B. McLean (right), the Technical Director of NOSC. Dr. Narita visited NOSC to obtain information of the SSP; he later initiated the SWATH program at Mitsui. (U.S. Navy photograph)

MTS Award

I was surprised and gratified to receive in 1976 the Lockheed-Sponsored Eighth Annual Marine Technology Society's Award for Ocean Science and Engineering. The award was based upon my contributions to the SSP KAIMALINO (Fig.13). As shown herein, many people contributed to the success of the SSP; they deserve to share the credit.

CITATION

The Marine Technology Society takes great pleasure in presenting the eighth Lockheed Award for Ocean Science and Engineering to Doctor Thomas G. Lang for his contributions to the design, development, construction and testing of an experimental prototype of a 190-ton SWATH-type ship, the Stable Semi-submerged Platform (SSP).

This revolutionary ship has demonstrated unprecedented stability characteristics in sea state 4 and 5 conditions, thus permitting normal work functions to be routinely performed on deck.

Dr. Lang contributed to the development of the semi-submerged ship, with a series of five patents issued over the last four years, supplemented with the articulation of his theoretical and design concepts in numerous technical papers. The experimental phase progressed from a free-running, radio controlled model tested in San Diego Bay to a series of towing-tank tests. Dr. Lang then personally solved many of the technical and administrative problems connected with the construction of the first experimental 190-ton SSP, which entered service as a workboat at the NUC Hawaii Laboratory in 1975.

Dr. Lang has been deeply involved in all phases of the project, from specification to design to construction and to sea trial verification. His dedication to the concept has been matched by his technical, innovative skills and his personal commitment.

This award is given in recognition of these accomplishments and their importance to the growing ship design technology requirements for our Navy of the future.

Fig.13. Eighth Annual Marine Technology Society Award for Ocean Science and Engineering, presented to the author in Septebmer 1976 for his contributions to the SSP KAIMALINO.

THE FUTURE

Comparison With Other Vessels

In predicting the future prospects of SWATH, it is useful to make technical comparisons with other types of vessels. One such comparison [60] indicates that the SWATH niche lies in the speed range between where displacement monohulls and planing monohulls are most efficient. This SWATH niche broadens considerably in rough water, and may cover any feasible vessel speed range for situations where other types of craft are unable to carry out their missions due to excessive motion in waves.

SWATH Applications

SWATH appears to be most applicable when people, air vehicles, and low-density payloads are to be carried, or when vessel motion is otherwise a problem. Possible Naval and commercial applications are presented in [60-62]. Figure 14 is an artist's illustration of a 64-ft (20m) multipurpose SWATH designed for sportfishing

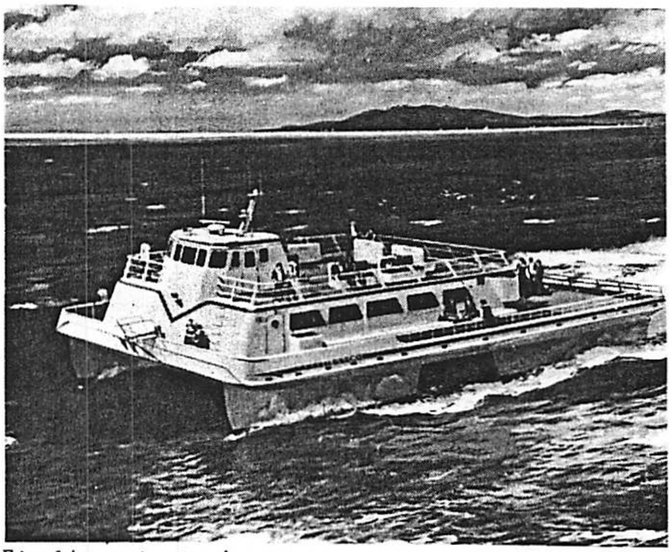

Fig.14. Artist's impression of a 64-foot (20m) multipurpose vessel contract design by the Semi-Submerged Ship Corporation (SSSCO).

or day cruising, but which can be outfitted for many other uses such as range support, surveying, and ferrying people. Another use of a larger SWATH is oceanographic research [63]. Figure 15 is an artist's conception of a 2500 ton SWATH oceanographic research vessel designed for use by universities [64]; this particular version is a conceptual design recently completed by the Semi-Submerged Ship Corporation, and sponsored by the Woods Hole Oceanographic Institution; the task was coordinated for them by Dinsmore. Similar versions would be useful for the Navy T-AGOS mission, commercial seismic surveys, and diving support.

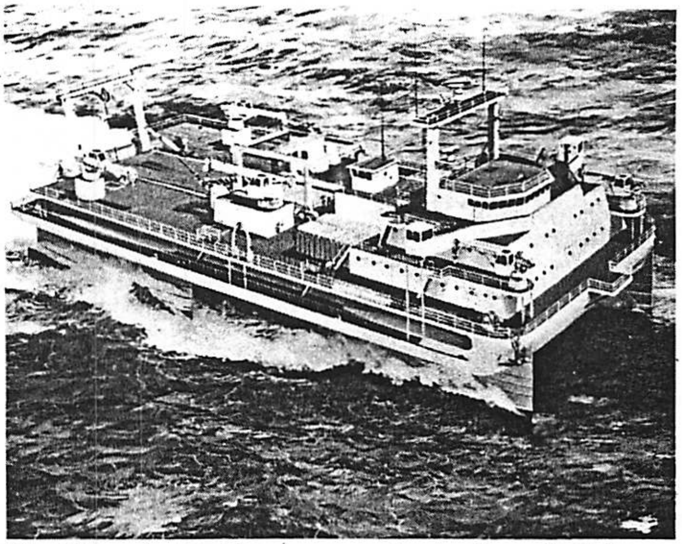

Fig.15. Artist's impression of a 2,500-ton Oceanographic Ship conceptual design by SSSCO for the Woods Hole Oceanographic Institution.

CONCLUSIONS

The SSP KAIMALINO resulted from a combination of design, research and invention made possible by the efforts of a combination of people, talents, facilities, and circumstances. The path to success was far from direct since many hurdles and changes were encountered, both technical and otherwise. Also, the SSP was at the leading edge of technology since there was no technical literature on the subject to draw upon.

The SSP program proceeded quickly relative to most ship development programs. The actual design work started after one year as a one-man project, and a half year as a several-man program at the Naval Ocean Systems Center. The design and construction of the SSP took about 3.5 years, which included almost a year spent in selecting a shipyard and letting a contract.

The SSP has not only been successful as a range support craft for the Navy, its intended purpose, but it has directly lead the way to many other SWATH developments around the world. A very large number of reports on SWATH research, design, and development have been published following the initiation of work on SWATH at NOSC.

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