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THE USE OF RADIO-CONTROLLED MODELS TO EXPLORE NEW SURFACE CRAFT CONCEPTS

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ABSTRACT

Four radio-controlled models of semi-submerged surface craft have been developed and tested. Two are of a twin-hulled, four-strut version, and two are single-hulled with one strut. All are designed to provide low motion in high sea states and good speed capability. The radio-controlled models have provided valuable data on stability, drag, maneuvering, transients, controllability, motion and speed in waves and wind, anchoring and towing, and the effects of model variations.

Introduction

Radio-controlled (R/C) models are of interest because of the wide variety of experimental data they can provide at relatively low cost. Further, certain data can be obtained from tests with R/C models that is either impossible or very difficult to obtain from conventional towing tests. However, some tests are best conducted in the conventional manner, in which case, the R/C models can be used as standard towed models.

A basic feature of R/C models is that they can often be used in nearby bodies of water to obtain much of the data, thereby avoiding some of the cost, scheduling problems, and physical limitations imposed by conventional towing tanks.

The use of R/C models is becoming more popular not only because of the increased awareness of their potential, but also because of the development of low-cost, reliable, multichannel, commercially-available radio-controlled units. Six or more channels of proportional control are available at nominal cost.

A discussion of the types of tests suitable for R/C models will be presented together with a description and summary of test results of four different R/C models which were developed by the Naval Undersea Center (NUC).

Radio-Controlled Model Tests

The kinds of tests for which R/C models are most suitable are generally those in which motions or forces on unrestrained models are desired. Maneuvering and handling characteristics are ideally explored with R/C models. They are especially valuable in the early discovery of any of the more complex and unexpected dynamics problems which might be costly to solve on a prototype.

R/C models can also be used to explore the effects of wind, waves, anchoring, being towed, towing devices, beaching, etc. System failures can be explored, such as determining the effects of control surface malfunctions, the loss of one or more thrusters, simulated flooding or damage, etc.

Motions such as heave, pitch, roll, yaw, sway, and surge can be obtained in simulated waves, winds, and currents. Natural frequencies and damping coefficients are easily obtainable, and transient responses due to sudden deflections or control force changes can be recorded. Structural stresses and impact loads and pressures can be obtained. The effects of model changes can be readily obtained, such as new bow shapes, various appendage changes, modifications in length and beam or general geometry, and center of gravity and metacentric height changes.

Maneuverability can be explored under a wide variety of conditions. Data and practice in docking and other critical maneuvers can be obtained by both designers and future operators. Also of importance is the demonstration of the behavior of new types of surface craft, including permitting others such as prospective crew members to operate the R/C models to get a first-hand understanding of how the craft behaves.

Data can be recorded in various ways. Motion picture or TV coverage permits motions to be analyzed. Data can also be recorded on board or telemetered. In certain cases, an umbilical cable can be utilized which does not interfere with model motion. Still other valuable data can be obtained merely by observation.

Table I is a summary of the above discussion and shows the various simulations, test situations, model variables, measurements, methods of measurements, and test objectives. This table can be used as an aid in planning R/C model experiments; however, it is not meant to be comprehensive.

Table I. Types of Radio-Controlled Model Tests

1. Simulations: maneuvering, straight runs, drifting, station keeping, being towed, towing, anchoring, docking, beaching, flooding, damage, control surface deflections, control failures, sudden external deflections or forces, engine failure, light loading, overloading, resonance conditions, special operating situations, waves, wind, wind and waves, simulated sea states.
2. Model Variations: bow, appendages, general geometry, center of gravity, metacentric height, moment of inertia.
3. Measurements: motions, accelerations, forces and moments, attitudes, pressures, stresses, RPM, speed.
4. Methods of Measurements: photography, television, on-board instrumentation, telemetry, umbilical cables, direct observation.
5. Test Objectives: static and dynamic stability, maneuverability, motions in waves and winds, seaworthiness, natural frequencies and damping, handling characteristics, pressures and forces, stresses, automatic control systems.

R/C Models of Twin-Hulled, Four-Strut Semisubmerged Surface Craft

190-Ton SSP

The Stable Semisubmerged Platform (SSP) shown in Figures 1 and 2 is a new type of surface craft, which somewhat resembles the semisubmerged offshore oil rigs which have proven so successful in reducing motion, except designed for high speed and dynamically-stable operation. The SSP consists of twin, parallel, submerged, torpedo-like hulls. Each hull is attached to a pair of streamlined forward and aft surface-piercing struts. The four struts support an above-water cross structure. A stabilizing fin spans the gap between the aft hull tailcones. A controllable canard fin is attached to the inner side of each hull near the bow. The two canards, combined with two flaps in the aft stabilizer, provide excellent dynamic damping and offer the possibility of automatic control over heave, pitch and roll when underway.

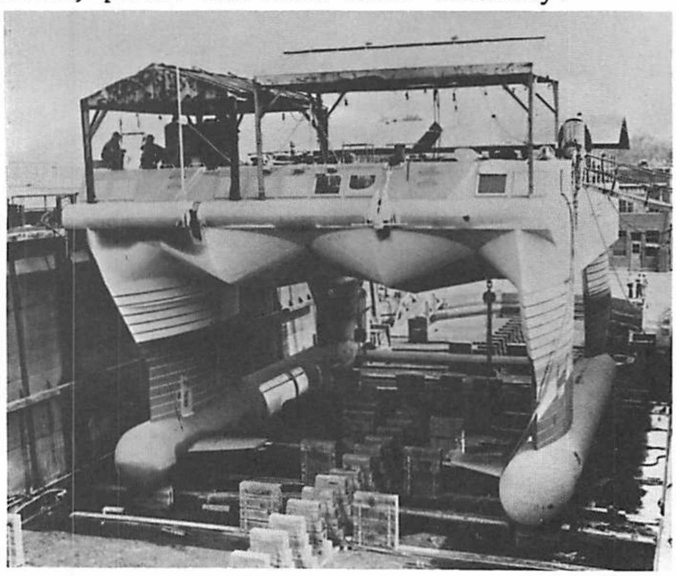

Figure 1. 190-Ton SSP in Dry Dock

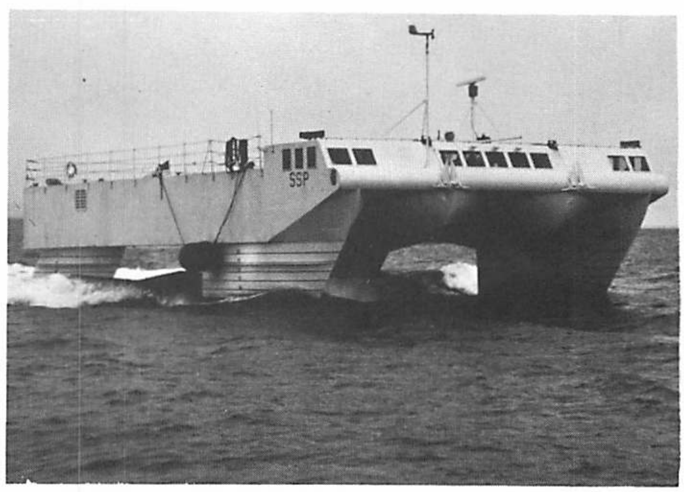

Figure 2. SSP Underway During Early Trials

The SSP was designed by NUC to serve as a work platform for its Hawaii-based facility and to demonstrate the new concept. The primary design objective was to provide an order-of-magnitude improvement in motion reduction relative to monohulls in large waves. The SSP is also predicted to have a considerable speed advantage in large waves relative to an equivalent monohull. It was operated for the first time in October 1973, and reached its design speed of 25 knots on the very second day of testing which took place in November 1973.

A further description of the SSP is presented in References 1 and 2, and a general description of the basic concept is presented in Reference 3. The Navy now calls this general type of concept a SWATH craft, meaning Small Waterplane Area Twin-Hulled craft.

A five-foot, radio-controlled model (Figure 3) of the SSP was constructed at the Lockheed Towing Tank in the fall of 1970. This model was used together with theory to help further evolve the SSP design, to obtain hydrodynamic data for further evaluation, and to help determine the full capabilities of this new concept.

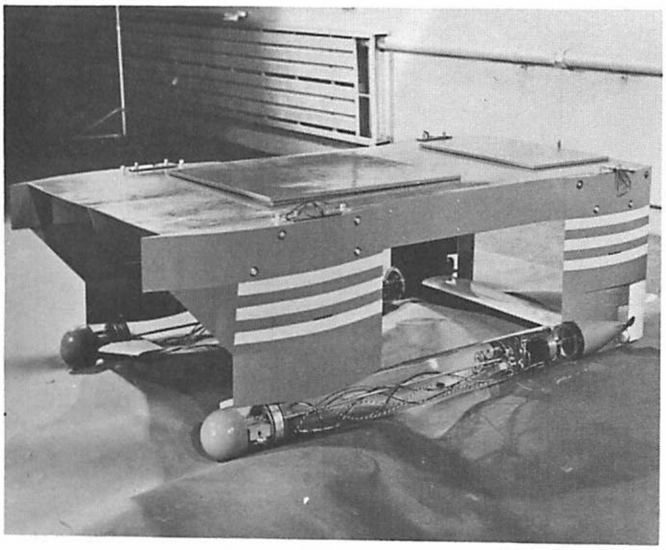

Figure 3. 5-Foot Radio-Controlled Model of the SSP

The model was constructed from wood, metal and plastic. Each major component is constructed as a separate unit which can be disassembled. The model is powered by two 28 volt dc motors providing 0.20 hp each. Rechargable batteries are located in the cross structure; these are sufficient for about 15 minutes of operation at its maximum speed of 10 feet per second.

The model is operated by means of a six-channel radio-control unit: Kraft model KP-6S. The rudders are paired together and controlled as a unit. The canards and reversible motors are individually controllable, and all controls are proportional throughout their operating range. A second radio-control unit was used for a few tests in which data on the effects of two flaps in the aft stabilizer were needed.

This model has been used for a wide variety of tests. Table II summarizes these tests and includes the basic conclusions resulting therefrom. In addition to these tests, the model has been used for over 50 demonstrations in San Diego Bay at NUC and has been flown twice to the Washington, D.C. area and once to Hawaii for other demonstrations and model tests.

3000-Ton SWATH Ship Model

In 1973, a 7 1/2 foot R/C model of a NUC-designed, 3,000-ton SWATH ship similar to the 190-ton SSP was fabricated by the Lockheed Towing Tank. This model is shown in Figure 4 and is relatively sophisticated since it has 6 channels of data telemetry from on-board instrumentation, in addition to 10 channels of radio control.

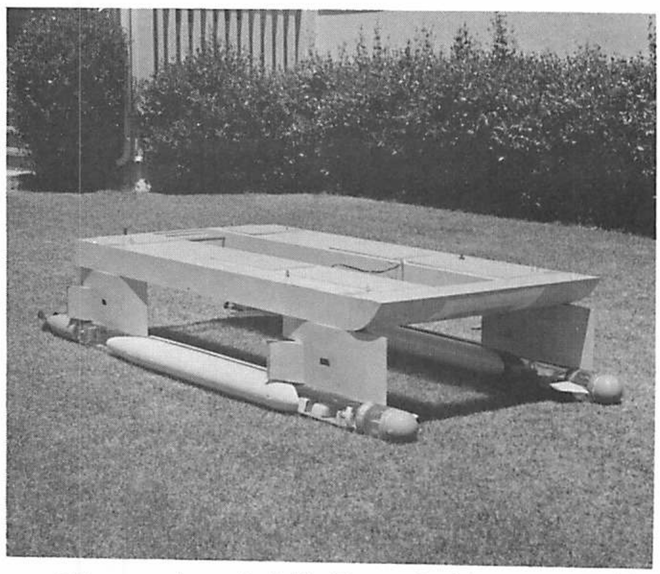

Figure 4. 7 1/2-Foot Radio-Controlled Model of a 3,000-ton SWATH

This 3,000-ton version was designed to be a small, selectively-outfittable, destroyer-sized Navy vessel with automatic control to permit near-level flight in high sea states at top speed. It has two cantilevered, all-movable stabilizing fins; two cantilevered, all-movable canards; and one rudder in each of the four struts. This is

Table II. Summary of Tests Conducted on the R/C Model of the SSP
(Note: All tests were conducted in the R/C mode unless otherwise specified.)

TEST	CONCLUSIONS
1. Straight runs, calm water (Lockheed Towing Tank)	The model was dynamically stable in all modes. Small canard and flap deflections trim out the pitch changes with speed. The SSP wave hump speed is about 10 knots. Spray sheets form on the struts around 15 knots.
2. Maneuvering, calm water (Transdec Facility at NUC, San Diego Bay and Lockheed Towing Tank)	The SSP has a natural bank into turns without roll control. Roll control can provide an increased inward bank or an outward bank. At rest, the model can rotate about its vertical center using differential propeller thrust. Differential propeller thrust also provides short turns at lower speeds and rudders provide good turn rates at moderate and high speeds. Response to rudders is fast. Single-engine tests showed no perceptible angle of yaw with only a 6 degree rudder angle needed for straight running.
3. Transients, calm water (Lockheed Towing Tank)	These tests provided some of the hydrodynamic coefficients both at rest and underway. The pitch and heave motions are tightly coupled. When underway, the roll, pitch and heave motions are nearly critically damped. Motions at rest are well damped, but less so than underway.
4. Tuft tests (Offshore Technology Seakeeping Basin)	Underwater motion pictures showed well-behaved flow around the hulls and struts, either with or without fairings. Fairings are not critical.
5. Line Towed (Lockheed Towing Tank. R/C used for trim only)	The SSP tows stably at all speeds, both in calm water and in large head waves. Towing in very large following waves can cause bow immersion if the tow speed exceeds the wave speed. Calm water runs with a calibrated tow line and radio-controlled for trim provided the drag coefficient as a function of speed.
6. Strut-towed (Lockheed Towing Tank. No R/C link.)	These tests were the only conventional towed model tests of the series, and provided many of the hydrodynamic coefficients.
7. Propellers (Transdec Facility at NUC)	Propellers were not modeled. However, tests showed that both propellers could rotate in the same direction without adverse effects, thereby reducing SSP costs.
8. Canard and stabilizing fin variations (San Diego Bay)	The SSP is unstable without the aft fin. Both damping and trim control are adversely affected by removal of the canards.
9. Controllability (San Diego Bay)	Strong dynamic control exists over heave, pitch and roll. Using dynamic control, the cross structure can be lowered to the water surface, or the model can be raised until the hulls begin to broach. Roll control is sufficiently strong to raise one hull partly out of water, while partly submerging the opposite side

Table II. Summary of Tests Conducted on the R/C Model of the SSP (Cont.)

TEST	CONCLUSIONS
	of the cross structure. The overall results indicate that an automatic control system can provide near-level flight in wave heights up to about the strut height.
10. Control surface failure (San Diego Bay)	Sudden control surface deflections at top speed produce no safety hazard to the SSP, although the resulting motions can be large and could be a problem for unalerted personnel.
11. Uniform waves (Lockheed Towing Rank)	At rest, motions are generally much smaller in waves than for an equivalent monohull, especially in roll; however, side sway might be equivalent or greater. In 45° bow waves, the model was slowly propelled forward by the waves. Motions underway in head and beam waves are much smaller than for monohulls. In large following waves at speeds less than the wave speed, motions are also smaller; however, at speeds greater than the wave speed, motions tend to be larger than for a monohull unless canard and flap control are used, in which case near-level flight should be possible.
12. Simulated sea states (Lockheed Towing Tank)	Motion was always less in simulated sea states than in equivalent uniform waves.
13. Wind and waves (Lockheed Towing Tank)	The model performed well at rest in all wave heights and angles tested, which ranged up to about 18 feet for the 190-ton SSP. At simulated winds above 100 knots, the hull bows emerged between waves due to wind lift on the cross structure, but there was no danger of overturning, although motions were large.
14. Simulated anchoring (Lockheed Towing Tank)	Anchoring in large waves was stable. Winds had the tendency to produce side-to-side swings when using a simple yoke attachment. Ballasting down in simulated 100-knot winds produced smaller vertical motions, but the topside was intermittently wetted by waves.
15. Station keeping (Lockheed Towing Tank)	In large waves and high winds, the model controlled well when station keeping. Above simulated winds of 100 knots the 12-foot wide tank was too narrow to permit the operator to control the random wind-produced yaws.
16. Bow shape variations (Offshore Technology Seakeeping Basin)	Seven different bow shapes for the cross structure were tested to determine which provided the least impact force and splash. A cross structure having two bow-shaped protuberances between the forward strut fairings was selected.
17. Bow impact pressures (Lockheed Towing Tank. Model was cable-controlled and self-propelled.)	Pressure gauges were mounted on the cross-structure bow. The data was transmitted via a cable to the carriage. Analysis indicated acceptable pressures for the SSP structure.

Table II. Summary of Tests Conducted on the R/C Model of the SSP (Cont.)

TEST	CONCLUSIONS
18. GM variations (Lockheed Towing Tank and San Diego Bay)	The metacentric height (GM) was varied by changing the center of gravity height. Results indicated that motions in waves reduced as the GM increased. Also, heel in beam waves and wind reduced as GM increased. The minimum design GM was selected as one-fourth of a hull diameter, while the desired design GM was three-fourths of a diameter.
19. Towing a submerged body (San Diego Bay and Lockheed Towing Tank)	One of several proposed future operations for the SSP is to tow a large fuel pod to extend its range. Model experiments were helpful in developing a stable tow system and pod.
20. Crew training and special operations	Part of the training for future SSP crew members consisted of operating the R/C model in a variety of situations including docking.

the only known version of a displacement ship which can provide full control over heave, pitch, roll, yaw, and sway.

Calculations indicate that the proposed ship design would have a structural fraction of around 0.40 if made of aluminum, which would provide good payload capability. Its draft is 28 feet which is acceptable for Navy harbors and most world ports. As designed, its beam exceeds the width of the Panama Canal; however, a 2,000-ton version would clear the canal. Alternatively, the beam of the 3,000-ton size could be reduced to clear the canal with but a small penalty in drag due to increased strut thickness and some penalty in reduced payload flexibility due to the reduced deck size. The hulls are bulged outward between fore and aft struts in order to help cancal strut wave drag.

The radio-controlled model has been utilized to obtain data on: (1) static and dynamic stability, (2) transients, (3) maneuverability, (4) controllability, (5) motions in waves, (6) drag, (7) hydrodynamic coefficients, and (8) forces on struts.

The strut force data was obtained through the use of strain gauges mounted near the top of each of two struts on one side to measure their bending moments in beam waves. The data was telemetered to a recorder. Some preliminary information was also obtained on the effect of filling the gap on each side between fore and aft struts to similate a one-strut-per-side SWATH.

Other data indicated that the model was both statically and dynamically stable. Transient results indicated good damping in all modes. Motions in waves were generally small, and controllability was good.

During early testing it was found that the turn rate was poor because the servos used to deflect the rudders were too weak. Subsequently, stronger servos were installed and tabs were added to the rudder trailing edges to reduce hinge moment. The turn rate is now good. Although the forward rudders contribute only a small amount of the turn rate, they would be of significant help in reducing yaw and sway when operating at angles to waves with an automatic control system.

R/C Models of Single-Hulled, One-Strut Semisubmerged Surface Craft

S^4 Model (operable at 10 ft/sec)

Figure 5 is a photograph of an R/C model of an S^4 (Single Strut Semi-Submerged Craft. The S^4 is a relatively simple configuration which may appear in a variety of shapes and resembles a snorkeling submarine with a greatly enlarged conning tower. It also resembles one of the many forms of the "shark" configuration invented by Boericke in NavShips in the late 1950's.

One feature of this type of surface craft is the possibility of providing greater seaworthiness and reduced motion for its size than any other known type of displacement craft. Another feature is that the S^4 can be made submersible more easily than most monohulls and SWATH-type craft. Its primary disadvantage is that it must be gravity stabilized in roll and pitch. This requirement greatly reduces its capability to carry topside load.

Some of the possible uses of an S^4 would include sonar and surveillance operations, firing missiles, towing objects, and supporting various kinds of oceanographic and research studies.

The R/C model shown in Figure 5 is a moderate speed (10 ft/sec) design, which has four channels of control. The rudder, individual canard fins, and motor are controllable. This model is always buoyant, but it can be fully submerged at higher speeds by deflecting the canards downward. When the model goes underwater, the motor is automatically turned off by means of a small top-mounted float and magnetic switch.

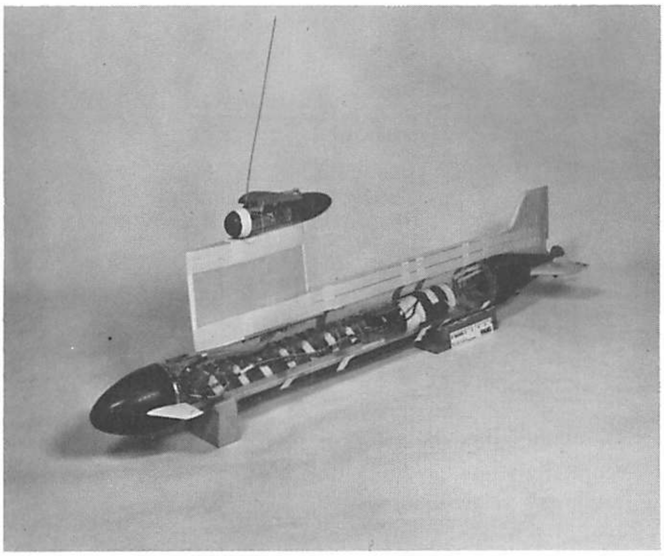

Figure 5. 4-Foot Radio-Controlled Model of an S^4

A variety of strut, canard, and tail fin designs were tested in order to obtain static and dynamic stability and to provide near-zero roll when turning without roll control. The stabilizing fins were found to be necessary for pitch stability, and the canards were needed to provide adequate pitch damping. Proper location and size of the strut were needed to provide adequate static heave and pitch characteristics. Theory was used in conjunction with model tests to achieve a balanced design.

Only limited model tests have been conducted in waves, and no quantitative data has been obtained. More testing is needed in both waves and wind, including more model variations, in order to better determine its basic characteristics.

S^4 Model (operable at 3 ft/sec)

A second R/C model of an S^4 is shown in Figure 6. This is a lower-speed version (3 ft/sec) and has one channel of telemetry in addition to two channels of control. The rudder and motor are controllable; the output from a hull-mounted fathometer is telemetered.

Sufficient tests have been conducted on this model to insure its static and dynamic stability, together with good turning performance. As in the case of the previous model, insufficient data have been obtained in waves to fully determine its characteristics.

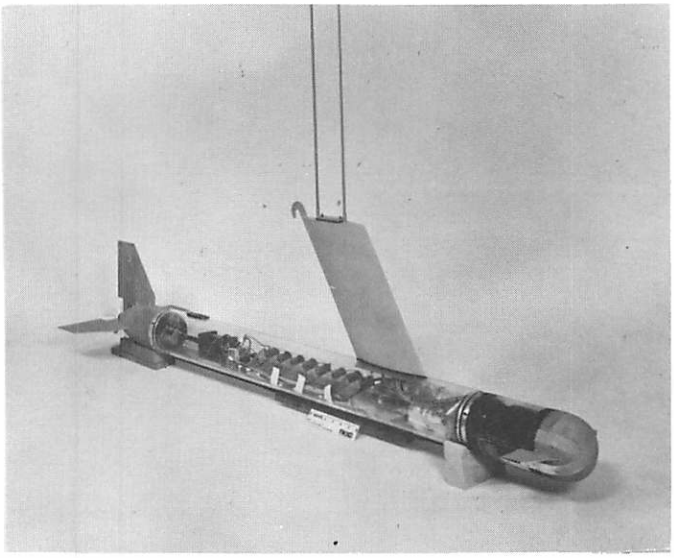

Figure 6. Lower-Speed, 4-Foot Radio-Controlled Model of an S^4

CONCLUSIONS

Four radio-controlled models have been constructed and tested. All four have provided valuable design data, some of which could not have been obtained in any other way. Of the four, the model of the 190-ton SSP has been tested the most extensively. Many design questions have been resolved and much data pertinent to operation of the SSP has been obtained. In general, the model and full-scale results are in good agreement, although testing of the SSP is still in the early stages.

ACKNOWLEDGEMENTS

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