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REMOTE-CONTROL MODELS AS SUBMERSIBLE SIMULATORS

by

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Engineering Department

ABSTRACT. The remotely controlled operations of one-tenth scale models of a submersible under construction at the Naval Ordnance Test Station are described. A description of the control system and the resulting maneuverability of the model is given, and potential uses for the low-cost simulator are suggested.

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FOREWORD

This publication describes the development and operation of an inexpensive remote-control one-tenth scale model submersible. The model was built at the Naval Ordnance Test Station to simulate the Deep View vehicle, a submersible work boat presently in the early stages of development. The model simulator presents meaningful advantages in projecting the operational characteristics of the full-scale vehicle and in the training of submersible pilots. Interest in the model setup has been gratifying, especially among those involved in submersible programs. It is hoped that the information given here may suggest other simple, inexpensive, yet effective simulators for other submersible programs.

The work was done during 1966 and 1967 and was supported by Independent Exploratory Development funds.

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INTRODUCTION

The remote-control model submersibles discussed in this publication were designed to provide simple, inexpensive, yet realistic submersible simulators for use in the development of the Naval Ordnance Test Station's Deep View project.

Project Deep View (Fig. 1) is a NOTS submersible currently in the early stages of development. It is intended for operation at depths to 5,000 feet (Fig. 2).



FIG. 1. Artist's Conception of the Deep View Submersible.



FIG. 2. Deep View Is Designed for Operations to 5,000 Feet. Shown here are potential test areas off the Southern California coast.

Its planning began as a result of (1) successful completion of the NOTS Deep Jeep submersible and the operational need indicated through experience by its use at sea, (2) the need for an oceanographic research submersible designed around the requirements of the ocean scientists who will use it, and (3) the Navy's need for experience with glass, as used in submersible vehicles, to aid in designing future very deep submersibles.

The Deep View submersible is expected to be designed as a steel hull with a glass-hemisphere bow; it will be 44 inches in diameter and 15 feet in length. The two occupants will usually assume a prone position; however, sitting will be possible. The small size of the craft should facilitate transporting and handling at sea and make it especially effective as the work boat it is intended to be (Fig. 3).

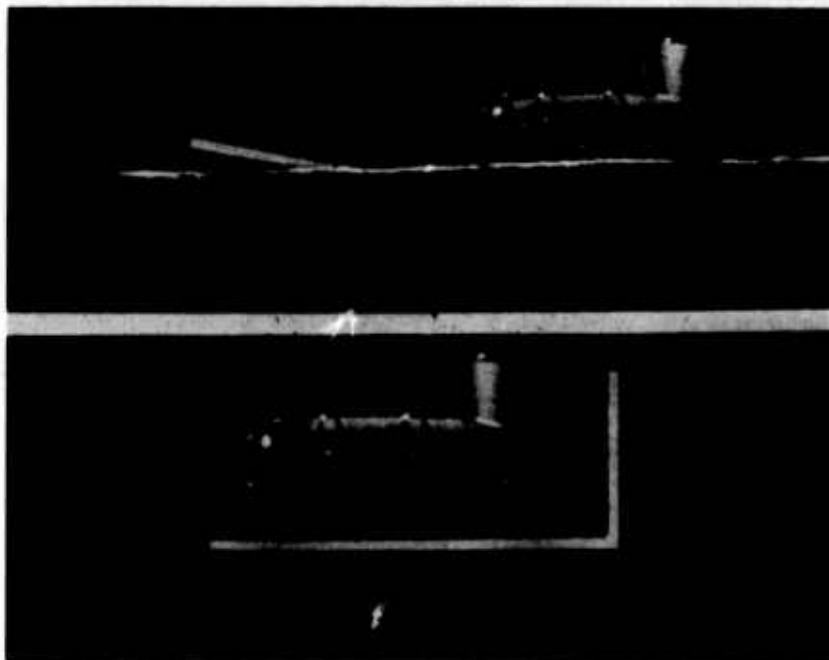


FIG. 3. Deep View Will Have Its Own Trailer for Transport, Launch, and Recovery Like a Sports Boat.

Early in the Deep View program there became evident a severe need for a low-cost simulator and pilot trainer to make possible test evaluations of candidate controls and propulsion systems. Elaborate simulators such as those in use in the bathyscaphe Trieste project and in the Apollo program and the aerospace television-type simulator systems were not within the budget of the Deep View project. To meet the need for a simulator that would make possible the necessary testing program and also give piloting experience to project members, a remote-control submersible system seemed to be indicated. With such a scale-model craft designed to be operated in a tank filled with water, and with the appropriate remote controls, it was felt that the

effectiveness in meeting the human-engineering requirements of the full-scale system could be evaluated.

Therefore, experimentation with simple designs and materials was begun in an attempt to construct a one-tenth scale model that could be made to perform typical submersible maneuvers by remote control. Actually, several models were made, each incorporating some new feature, as experience, imagination, and discussion among project personnel indicated possible improvements. The models discussed in the following pages represent the latest versions to date. These models and a movie made to demonstrate the concept and system feasibility have been the object of much interest as they have been on display at NOTS, both to the general visitor to the Station and to those scientists particularly interested in oceanographic studies.

BACKGROUND

The Deep Jeep submersible, a developmental work boat on which construction was begun at NOTS in 1960, was to become the first American-built deep submersible. The project had employed a model that could be operated by remote control by means of loosely connected wires forming an umbilical cable. By the use of this system, the test pilot was able to practice various controlling techniques and maneuvering procedures, with the result that by the time actual ocean tests of Deep Jeep were made, the pilot was fairly well trained and prepared to handle the craft on the first dive.

The Deep Jeep model was operated from a control box containing switches, rheostats, and the battery supply (Fig. 4). Two motor pods



FIG. 4. Deep Jeep Model and Control Box.

pivoted simultaneously from straight up through horizontal to downward. Two reversible propellers could be proportionately controlled either simultaneously or individually. This model served as a fairly adequate, extremely inexpensive simulator for Deep Jeep (Fig. 5).



FIG. 5. Deep Jeep Model in Water-Filled Tank.

The experience gained during the design, construction, and testing of Deep Jeep (Fig. 6), and especially during its actual operation, culminating in April 1966 with attempts to retrieve the hydrogen bomb



FIG. 6. Deep Jeep at Sea.

lost off the coast of Spain, indicated the need for improvement in several of the operational characteristics. Of primary importance was the need for improvement of control of the maneuverability and of the control-propulsion loop. Many managers of submersible projects might agree that while some submersibles have adequate propulsion systems, and some have adequately designed control systems, there is still a great need for a combined control/propulsion system that will permit the pilot to obtain high performance and completely controlled maneuverability with ease.

The Deep View project is a second-generation vehicle designed to take advantage of the information gained in the course of work with Deep Jeep and to incorporate as many of the necessary improvements as possible. The primary purpose of the design and construction of Deep View is to provide a useful submersible work boat that will meet the needs of those engaged in oceanographic research and other underwater tasks.

In much the same way that the development of Deep View depends upon the experience gained with the parent full-scale Deep Jeep, the remote-control scale model designed to simulate the operation of Deep View borrows from the experience gained with the earlier remote-control model of Deep Jeep. The current model simulator of Deep View, however, is operated by the same type of controls that will be used in the full-scale boat. These more sophisticated controls have replaced the battery pack and control box originally employed in the scale model.

MATERIAL AND EQUIPMENT

Model Vehicle

The first Deep View Model was constructed at home; household equipment and materials were used. A 2-pound coffee can became the hull of the model, and papier-mâché made from toilet paper and wheat flour formed the ogive afterbody. A plexiglass dome hemisphere approximately 5 inches in diameter was attached to provide the forebody of the model. The propulsion motors were DC reversible slot-car motors that originally cost \$2.50 each. Since the first model was built, however, motors of that size have ceased to be used extensively in the slot-car sport, with the result that the same motors are now available as surplus items at a cost of 50 cents apiece.

Control System

Remote control of the model is accomplished by means of a control system mounted on both arms of a swivel chair in which the operator sits. The controller, mounted on the right arm of the chair, is a three-axis isometric unit sold by Measurement Systems, Inc., Norwalk, Conn. In response to pressure by the hand, the control handle and grip provide proportional control of the lateral, longitudinal, and yaw motions

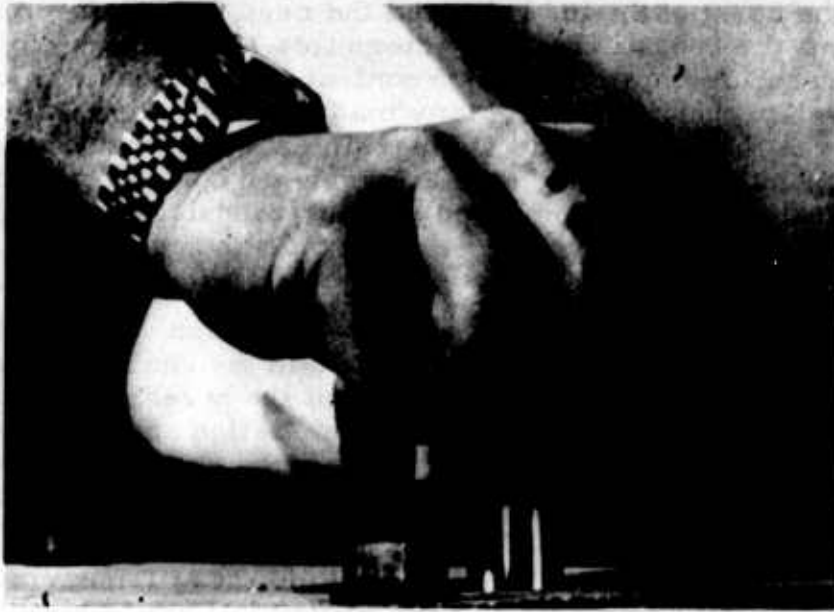


FIG. 7. Three-Axis Controller for Deep View Model Simulator.

of the model (Fig. 7). Since the control handle is isometric, it does not move significantly, but extremely sensitive sensors inside the base of the control handle detect control pressures (0 to 10 pounds) and the direction from which they originate. These signals are then translated into electrical signals of from 0 to 10 volts, which are used to vary the power to the model motors. Since the same type of control system will be used on the full-sized submersible, the electrical signal from the controller is proportional to the signal that will control the much larger motors of the full-scale boat in the same way.



FIG. 8. Potentiometer Vertical-Axis Control.

Potentiometers are used at present to control the vertical motion (Fig. 8). They are mounted on the left arm of the operator's chair. Several control systems are being experimented with for control of this motion.

Twenty-eight-gauge enamel-coated solid wires go from the controller to the model where they connect to the propulsion motors. The wire umbilical system is only one of many which could be used. A radio-controlled version could be used under water if the transmission distance were kept small.

Model Tank

The tank in which the model is operated is made of aluminum sheets welded together. A plexiglass plate is installed along most of one wall so that movies and still photographs can be taken of the model under water. The tank is pallet size and is approximately 4 by 4 feet in plan view and approximately 3 feet deep (Fig. 9). Ionized water is



FIG. 9. Control Setup and Simulator Model in Tank.

used as the operating fluid in which the model is submerged. The use of ionized water reduces brush wear and commutation damage to the DC motors that operate in the modified tap water. In this environment, highly reliable operations are possible for about 20 minutes, after which time the motors are run for about 30 seconds in kerosene. The kerosene has the effect of "rejuvenating" the motors for another 20 minutes of operation. The 20-minute actual motor-operating time has posed very little serious limitation on the operations. In fact, it has been found to be a more than adequate length of time for most experiments.

In the tank are four large rocks (Fig. 10), placed there to simulate a canyon for maneuvering operations. Nicknamed "Scripps Canyon"

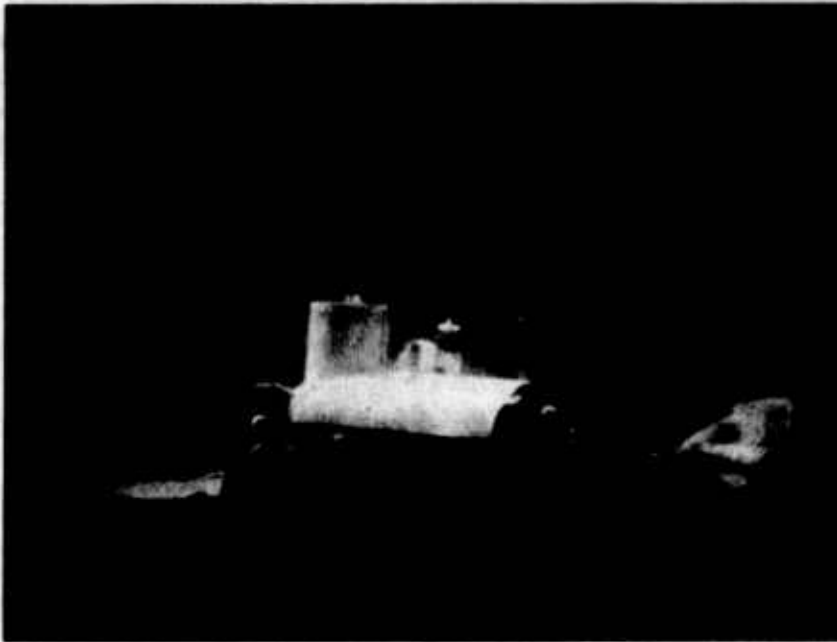


FIG. 10. Deep View Model in "Scripps Canyon." Note vertical motor amidship and fore and aft motors far astern.

in reference to Cousteau's Soucoupe dives off La Jolla, Calif., the rocks are coated with a polyester resin to prevent contamination of the water.

Other equipment in the tank includes a tube of aluminum with a section cut out of it as shown in Fig. 11. This is used as a mock-up for



FIG. 11. Deep View Model Entering Simulated Entrance Chamber of Undersea Installation.

maneuvering trials to test the pilot's skill in entering, navigating up to, and emerging from a submerged tunnel. The tube can also be used to simulate the entrance chamber of an undersea installation, a feature that is planned to meet expected program requirements of some future submersible operations at NOTS.

CONTROL PROCEDURES

The operator, sitting in the swivel chair (see Fig. 9) with controls on both the left and the right side of his "cockpit," is free to turn his body to orient himself fairly realistically with the maneuvering model. By hand pressure on the controller and the potentiometer he can put the model through a variety of maneuvers in the tank and thus simulate the control possibilities of the full-scale Deep View vehicle.

He can gain practice in causing the model to perform vertical motion simultaneously with limited lateral and longitudinal motion as he dives the boat in a hovering mode into the hole of the rock canyon, seeking to maneuver the model in and out of the canyon without bumping the rock walls.

In a similar manner, he can produce longitudinal motion simultaneously with limited lateral and vertical motion by practicing inserting the model into the aluminum tube in the tank.

A lateral motion while simultaneously limiting longitudinal and vertical motion can be practiced by "docking" sideways at a given depth against a wall. Hovering without motion in a cross current is also a proficiency test and training exercise. Thus, the pilot is able to practice various combinations of twisting and turning, dock-side maneuvering, and bottom contouring close to the rocks.

ADDITIONAL EXPERIMENTS

Vertical Control

Several locations for the vertical control handle have been experimented with as well as different means of controlling the vertical motion. The vertical control handle has been placed on the left side of the cockpit in some trials and on the right side in others. A potentiometer that can be set at any vertical thrust setting has been used as has a potentiometer that is spring-loaded to return to off when released.

Model Design

Some models have been constructed with an entrance tube and fairing (sail) and some have been designed without these elements. The effect

on the accuracy and ease of control with and without the sail has been tested in the tank with no cross current, and also when a cross current is present. A model without a sail is much easier to control in a cross current.

The motor that produces the vertical motion has been moved fore and aft on the model to establish the benefit of different motor positions for this vector. The aft motors that control the fore and aft speed as well as the turning rate have been set at various angles of from 0 to about 20 degrees with respect to the fore and aft line (Fig. 12). Extreme differences in performance were noted. Maneuverability at the 7-degree setting is very good, with little reduction in the fore and aft speed of the submersible.

An interesting element of serendipity occurred with the making of the second model. In the course of its construction it became obvious that the fairing of the entrance tube could be made in such a way as to



FIG. 12. Model With Vertical Motor in Forward Position.

serve as one of the stabilization fins. Therefore, a three-fin model was made on which the tube fairing was used as a stabilization fin.

The interior of one model was prepared as a mock-up of the interior of the full-scale vehicle, to show the seating position that would be possible (Fig. 13).

Another model was designed to drop a weight when the craft was bumped against a wall, a device designed to demonstrate an emergency buoyancy mode.

Still another vehicle is a barge that, to date, has been operated only at the surface. On top of the barge is a gyrocompass and a rate-of-turn

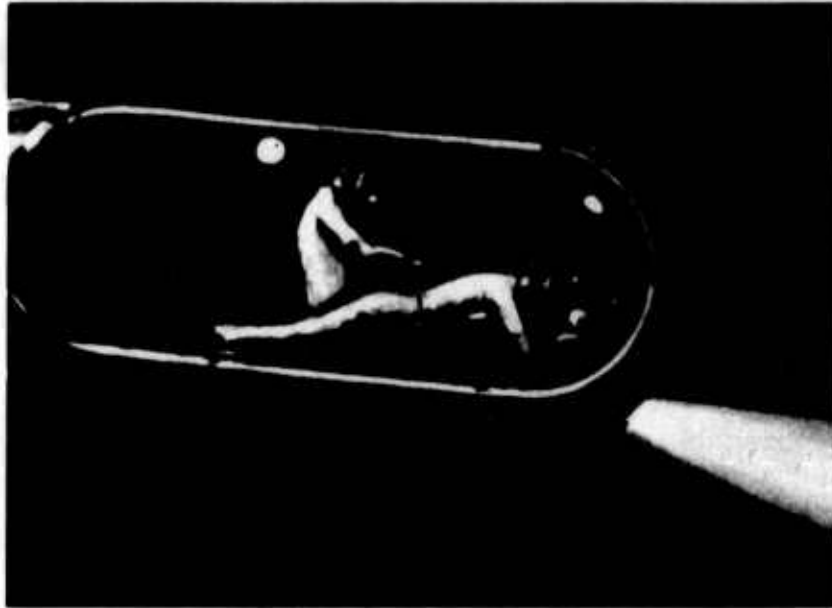


FIG. 13. Artist's Conception of Possible Crew Positions in Deep View Vehicle.

sensor. Two propulsion motors located abaft and submerged provide the thrust for constant heading or constant-rate turning experiments.

Search problems and navigational runs of even short duration suggest the need for an automatic heading instrument. These model experiments have helped to indicate the degree of sensitivity required to hold a heading and to perform constant-rate turning.

Simulated Operational Trials

Near bottom effects caused by turbulence from the propellers have been studied. These studies were indicated as critical after the experience with Deep Jeep in Spain, where the muddy sea bottom was easily disturbed, making bottom operations almost impossible as visibility became negligible in the area that had been disturbed.

Reversing, turning, and hovering characteristics have also received extensive experimentation by the use of the model.

FUTURE PLANS

Plans for the future call for certain modifications to the submersible model, the introduction of new training drills, and the use of a full-scale boilerplate mock-up to evaluate the control system and the environmental, operational, and human-engineering factors that will be involved in the final Deep View system. The following is a list of such changes as they are currently planned:

1. Installation of bumpers to reduce damage to the model and to provide a means of estimating bumper requirements for the final boat.

2. Introduction of pitch control into the system by installing a motor inside the model that will move a weight fore and aft. This type of control feature is similar to one planned for the full-scale vehicle. On the present scale model, pitch is controlled by external weights in a static mode.

3. Dragging a lead rope between the model and the bottom of the tank to experiment with this type of near-bottom contouring technique.

4. Conducting wave-action studies in approximate scale with the heading being held while the model is subjected to the effect of waves. These studies should help to determine the necessary sensitivity of control necessary under such conditions.

5. Experiments in constant-depth holding by means of an electrical signal from a depth sensor. These experiments can easily be done in a manner similar to the constant-heading experiments now being conducted. Similarly, lateral motion can be controlled or prevented.

6. Investigation of launching and recovery operations to determine by use of the model the optimum technique for the adjustment of surface buoyancy. (Such a model study proved very useful in the Deep Jeep program.)

7. Simulation of initial operations with the full-scale boat by the use of the model of the submersible and handling cranes and trucks. (This "walk through" on a model scale was very useful in the Deep Jeep program in helping to predict program needs.)

8. Encapsulation of a test pilot in a full-size boilerplate mock-up of Deep View from which he will operate the scale model positioned directly in front of him. While evaluating the environmental systems, the pilot will perform the work routine from his capsule. This procedure should give a worthwhile evaluation of the interior equipment and its relationship to control as it will be experienced in the full-scale vehicle.

REMARKS

The remote-control model submersible simulator has proved extremely useful in evaluating the control system, maneuvering procedures, and human-engineering problems that can be expected with the full-scale vehicle.

Control of the model in and out of the canyon and the tube and the various reversing problems have clearly shown the different aspects of the control problem. In 15 minutes (average), most strangers to the setup acquire a sufficient degree of skill to do all the drill and maneuvers which have been established as a standard. One lady was able to do all the drill after only 5 minutes of experience. We believe that these fairly brief training periods indicate that the general human-engineering approach is at least adequate.

The maneuverable model system provides a tremendous amount of experience while the main project is still in a changeable stage. We believe this is an economically significant factor.

Many times we have been glad that our models are inexpensive, because we have continually come up with ideas for different experiments that often require another small model. Such models have in every case shown us almost instantly the effect of the new ideas and the degree of success or failure of our experiments. We have found far more answers than we had really looked for or thought we would find, and we have gained many ideas for even additional systems.

The dynamic models have helped both the submersible pilots and designers to visualize and comprehend operational problems before they occurred.

We hope that designers and operators of other submersibles will seriously consider the benefits to be gained by the use of this modeling technique. The experience we have had with this tool has repeatedly indicated to us its advantages.

The stimulation of imagination which results from modeling is well known. The effect is even greater when the modeling process is dynamic.

ACKNOWLEDGMENT

The author wishes to acknowledge the great amount of work done by Allyn Berryman, electronics technician, who not only designed and constructed all the electronics for the Deep View simulator, but suggested and put into practice many of the better ideas used on it.

The dependable services and continued loyalty of John W. Ball, project machinist, for his help on both the Deep Jeep scale model in 1960 and the Deep View model simulators in 1967 are also gratefully acknowledged.

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