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RESEARCH AND DEVELOPMENT AT THE MARSHALL SPACE FLIGHT CENTER NEUTRAL BUOYANCY SIMULATOR

Vygantas P. Kulpa
Neutral Buoyancy Simulator
Marshall Space Flight Center

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INTRODUCTION

The Neutral Buoyancy Simulator (NBS), a facility designed to imitate zero-gravity conditions, is located at the National Aeronautics and Space Administration's (NASA) Marshall Space Flight Center (MSFC) in Huntsville, Alabama. In the facility's million-gallon water tank, weightlessness is simulated by placing weights or floats on the test subjects and test articles so that they are neutrally buoyant.

Flight experience indicates excellent correlations between neutral buoyancy simulations and weightlessness. In addition, simulating space operations by this technique allows an entire set of procedures to be evaluated without interruption. Two space construction experiments flown aboard a recent NASA mission relied heavily on research done at the Neutral Buoyancy Simulator. During the two years prior to flight, extensive testing was done for the Experimental Assembly of Structures in Extravehicular Activity (EASE) and the Assembly Concept for Construction of Erectable Space Structures (ACCESS).

MSFC NEUTRAL BUOYANCY SIMULATOR APPLICATIONS

The first neutral buoyancy simulator, which had a 7.6 meter (25 foot) deep water tank, opened at MSFC in the 1960's when little was known about space, especially about Extravehicular Activity (EVA) or space walks outside a spacecraft. Thus, it served as a laboratory for studying how neutral buoyancy simulations could be used to mimic space operations.

The current 12 meter (40 foot) deep, 23 meter (75 foot) wide water tank opened in 1968 to support the growth occurring in the space program. Early research in this facility centered on investigating how neutral buoyancy could be applied to space operations and to the development of equipment and techniques for conducting underwater simulations. General research was conducted by the NBS staff to examine spacesuit capabilities and demonstrate hardware concepts and procedures for diverse activities such as astronaut transportation systems, spacecraft repair, and large space structure assembly.

Today, research at the NBS falls into two categories: maintaining the facility to support researchers from NASA and outside the agency and conducting in-house research to advance the state of the art in zero-gravity simulation. The simulator is used primarily to select concepts, verify preliminary hardware designs, develop EVA procedures, train personnel, and support missions real time.

The facility has been vital to the success of a variety of NASA missions. In 1985, the NBS was designated a National Monument because of the role it played in developing the repair procedures for Skylab in 1973 when the spacecraft's sunshield was damaged during launch and its solar arrays failed to deploy. The simulator continues to be used for developing EVA procedures for servicing and repairing spacecraft. Tests are in progress to ensure that the Hubble Space Telescope and the Space Station are designed for long-term operations in space.

In the Shuttle era, the Neutral Buoyancy Simulator is a research laboratory used by NASA and the aerospace community for engineering studies of hardware. In 1985, the first structures (EASE and ACCESS) were built in space after many hours spent in the MSFC tank, selecting the structural concepts, developing assembly techniques, verifying EVA procedures, and training the crew. As we enter the Space Station era, NASA and aerospace contractors are testing concepts for station components in the Neutral Buoyancy Simulator. The facility provides an environment where they can evaluate such complex operations as patching a habitable module in the event that it is punctured in orbit. In addition, concepts can be developed for the station's framework.

NASA and aerospace contractor research activities are escalating, and therefore, the NBS is used primarily to support this research. However, the simulator staff continues to conduct in-house research to improve simulation quality. This in-house research often results in benefits for NASA and other customers. For instance, the facility staff designed and installed an underwater version of the Remote Manipulator System (RMS). It is the only functional RMS available for neutral buoyancy training, and it has been valuable in practicing procedures that cannot be simulated elsewhere. This underwater system allowed the EASE/ACCESS crew to practice complex procedures in which astronauts assembled the structures while being moved and positioned by the RMS.

The NBS record over the past 18 years shows that the staff has devised innovative solutions to challenging problems. This has given NASA and its contractors the assurance that hardware and procedures that work in neutral buoyancy simulations will work successfully in space.

NEUTRAL BUOYANCY SIMULATOR OPERATIONS

The MSFC NBS has many other unique features besides the manipulator arm. It is the largest NASA facility of its kind. This enables the tank to accommodate large space structures like the 12 meter (40 foot) tall ACCESS tower or other very large satellites like the Hubble Space Telescope. The tank is equipped with a full-size mockup of the Shuttle payload bay where mockups of flight hardware can be mounted for tests. Pressurized spacesuits and an underwater Manned Maneuvering Unit (MMU) are available for use in simulations.

A control room adjacent to the water tank provides a work place for customers during tests. The control room is equipped with consoles and television monitors showing five views inside the tank, communications equipment, and an audio/video taping facility.

The experience of the NBS staff is a valuable asset in determining potential uses for the facility. For tests, which are joint endeavors between government and private industry, the NBS staff works with the user, with leadership taken by one or the other as the situation demands. By working together as a team, the test benefits from both the expertise of the NBS staff and the user.

In the most successful efforts, such as the EASE/ACCESS program, the user works closely with MSFC personnel from the beginning of a project. For example, to ensure safety, a NASA engineer inspects user hardware prior to delivery. This inspection not only guarantees that the hardware meets safety standards but helps the user resolve other problems before the hardware is shipped. Working together early in the project's development establishes close ties between the user and NASA personnel and gives the NBS staff the opportunity to inform the user of lessons learned from previous neutral buoyancy tests. Requirements for using the facility are outlined in the MSFC Neutral Buoyancy Information and Requirements document (1).

The MSFC team also helps the user by filling critical positions required for tests. The NBS provides test subjects who are scuba and pressure suit qualified; they are trained to evaluate space equipment designs objectively and develop operations procedures. MSFC also supplies other support personnel, including utility divers, safety divers, underwater photographers, systems engineers, timekeepers, recompression chamber engineers, lock engineers, inside diving attendants, and medical officers.

Prior to a test, the NASA team prepares the facility for the test by performing final safety checks and suiting up the test subjects in Shuttle Extravehicular Mobility Units (EMUs) or spacesuits. Once a test subject has been neutralized, the test begins. The test conductor, usually a member of the user's team, supervises test activity from the control room. The test conductor is in charge until the test is completed, except during any emergency situations when the NASA test director automatically assumes control. Under the test conductor's leadership, preplanned procedures are followed to complete specific test objectives.

At the conclusion of the test, the NASA test director resumes control as the test subjects are depressurized and unsuited and equipment is removed, secured, or stowed. After each simulation, key test personnel participate in a debriefing; this is the primary opportunity for the user to record the test subjects' observations which often result in changes to the hardware design. For example, as the EASE/ACCESS test progressed, the design of the structures, such as the size of the struts and beams, was influenced by ease of handling during NBS tests. The debriefing also provides a forum for identifying any facility, pressure suit, hardware, or procedural problems to be corrected before the next simulation.

The NBS staff worked closely with the EASE/ACCESS investigators to conduct several series of neutral buoyancy simulations which started with the development of experiment concepts and continued through personnel training. The neutral buoyancy tests conducted for both the EASE and ACCESS experiments are excellent examples for others considering NBS simulations to support space construction projects.

EARLY NBS LARGE SPACE STRUCTURE RESEARCH

Five years before the mission, researchers from the Massachusetts Institute of Technology (MIT) began early concept studies of large space structures. MIT graduate and undergraduate students were trained to work as test subjects in the Neutral Buoyancy Simulator, and development tests were conducted using a number of test subjects, both suited and unsuited. For early tests, the students used the Apollo A7LB series spacesuits to explore spacesuit capabilities and limitations for assembly tasks.

Preliminary space structure designs were investigated in a series of tests which took place during MIT school breaks. During the first tests conducted in 1980, MIT studied how rapidly people learned and how productive they were in assembling structures underwater. For these experiments, a tetrahedron almost identical to EASE and a truss structure were assembled repeatedly. The students found that their performance was better than expected and test subjects could assemble structures while floating unrestrained. This influenced the concept for the EASE flight experiment.

In 1981, MIT used a series of tests in the MSFC/NBS to build structures with different configurations that filled the water tank and to integrate other hardware with the structures. Figure 1 shows MIT students building a large space structure in the MSFC/NBS.

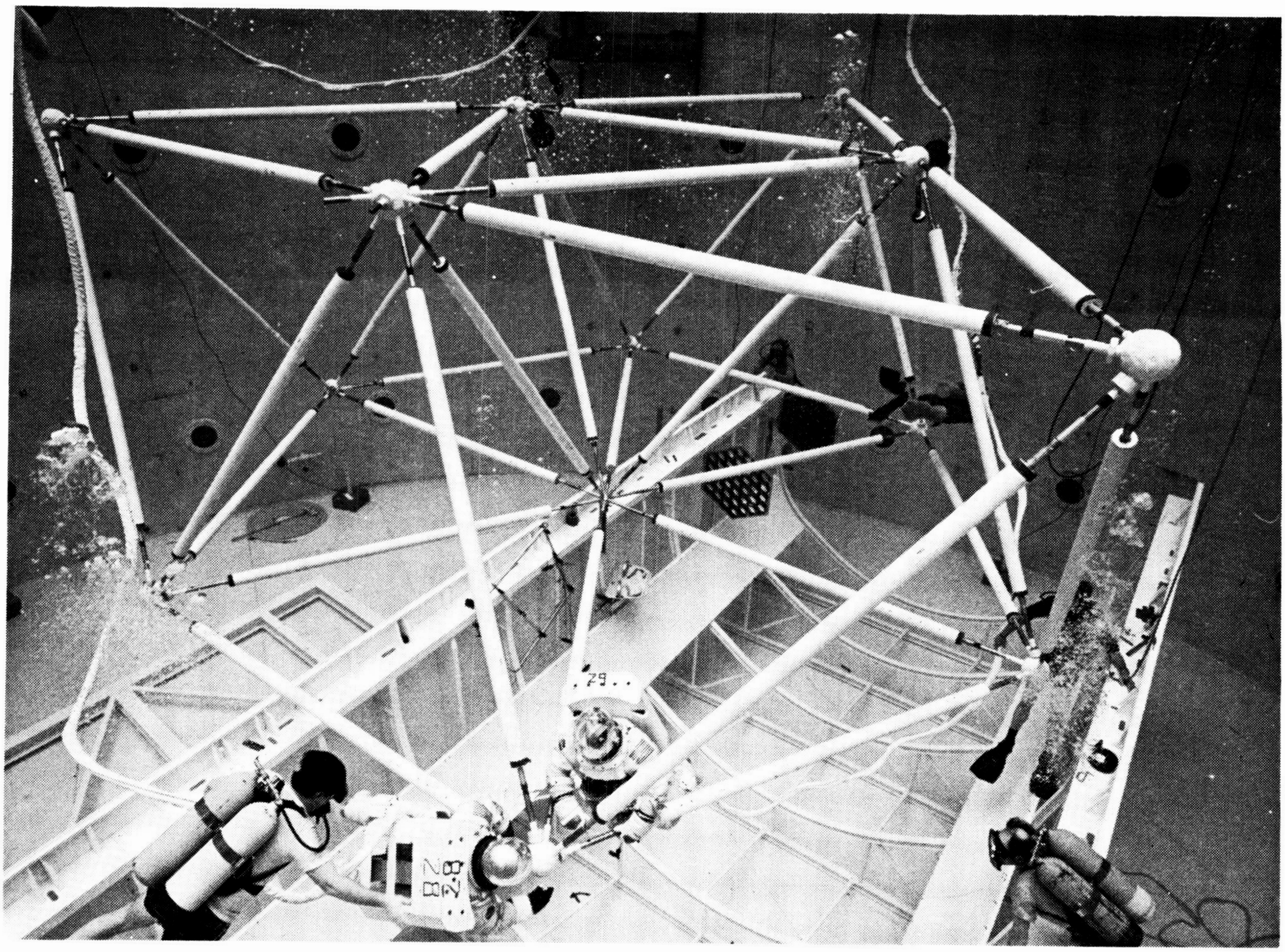

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FIGURE 1

In 1982, additional tests were conducted to examine how the different sizes and shapes of beams and other structural members affected human performance. These tests confirmed that the diameter of the EASE beams could be handled by a suited astronaut underwater and, therefore, could probably be handled in weightlessness. Also, various assembly aids such as a mobile work station similar to the Manipulator Foot Restraint (MFR) work station and the harpoon used to help restrain the large EASE beams were tested. The MIT team also participated in tests for another MSFC project, the Solar Array Flight Experiment (SAFE), a 30.9 meter (100 foot) high solar array which was flown and deployed on Shuttle mission 41-D. Through these tests they learned how to design large space structures for stowage and prepare hardware for flight.

During the same time frame, the ACCESS investigators from the NASA Langley Research Center in Hampton, Virginia conducted a series of neutral buoyancy tests. Langley researchers received suit familiarization training and served as suited test subjects in a variety of NBS large space structure experiments. They assembled various structures using different techniques with subjects restrained, unrestrained, and working from mobile platforms. While some of the structural members were as long as 5.5 meters (18 feet), one structure was composed of struts and nodes similar to those used for ACCESS.

These neutral buoyancy tests led Langley investigators to conclude that the short 23-centimeter (9-inch) struts were easy to handle. The investigators also concluded that the NBS tests showed subjects wasted time moving between work sites. Therefore, by using a technique where the subjects remained at fixed work stations, the Langley investigators decided that they could measure human productivity in assembling large space structures without confounding assembly times with time required for moving building materials to and from the work sites. These tests influenced the decision to use an assembly technique with the astronaut remaining stationary in fixed foot restraints as the ACCESS truss tower was assembled bay by bay and moved up along an assembly fixture.

DEVELOPING THE EASE/ACCESS EXPERIMENTS

Neutral buoyancy tests were a vital part of the EASE/ACCESS experiments. Since EASE and ACCESS were the first large space structures assembled in orbit as a part of a carefully controlled experiment, one of the main goals was to measure the ability of humans to assemble large structures in space. One way to measure this performance was to compare the times required for underwater assembly with the times required for on-orbit assembly. Therefore, investigators carefully recorded the NBS task times for repetitious correlation with on-orbit times.

Both the EASE and ACCESS flight hardware was designed to be as similar as possible to the neutral buoyancy hardware so that accurate correlations between flight and underwater neutral buoyancy assemblies could be made. As is usually the case, the final hardware design for both experiments was refined during neutral buoyancy simulations.

In June 1984 during separate tests, mockups of EASE and ACCESS were mounted on a mockup of the Mission Peculiar Equipment Support Structure (MPESS), a lightweight carrier that bridges the Shuttle payload bay, for the first time and placed in the water tank. During these tests EASE experimenters verified interfaces with the carrier and made decisions about where to mount the beams on the MPESS and where to locate foot restraints for ease of assembly. The EASE assembly technique was also modified so that two people were used to build the structure; one person had done the assemblies during early NBS tests. As a result of these tests, EASE investigators collected the data needed to begin final hardware design of beam latches and other intricate interfaces. Figure 2 shows the EASE payload development tests in the MSFC/NBS.

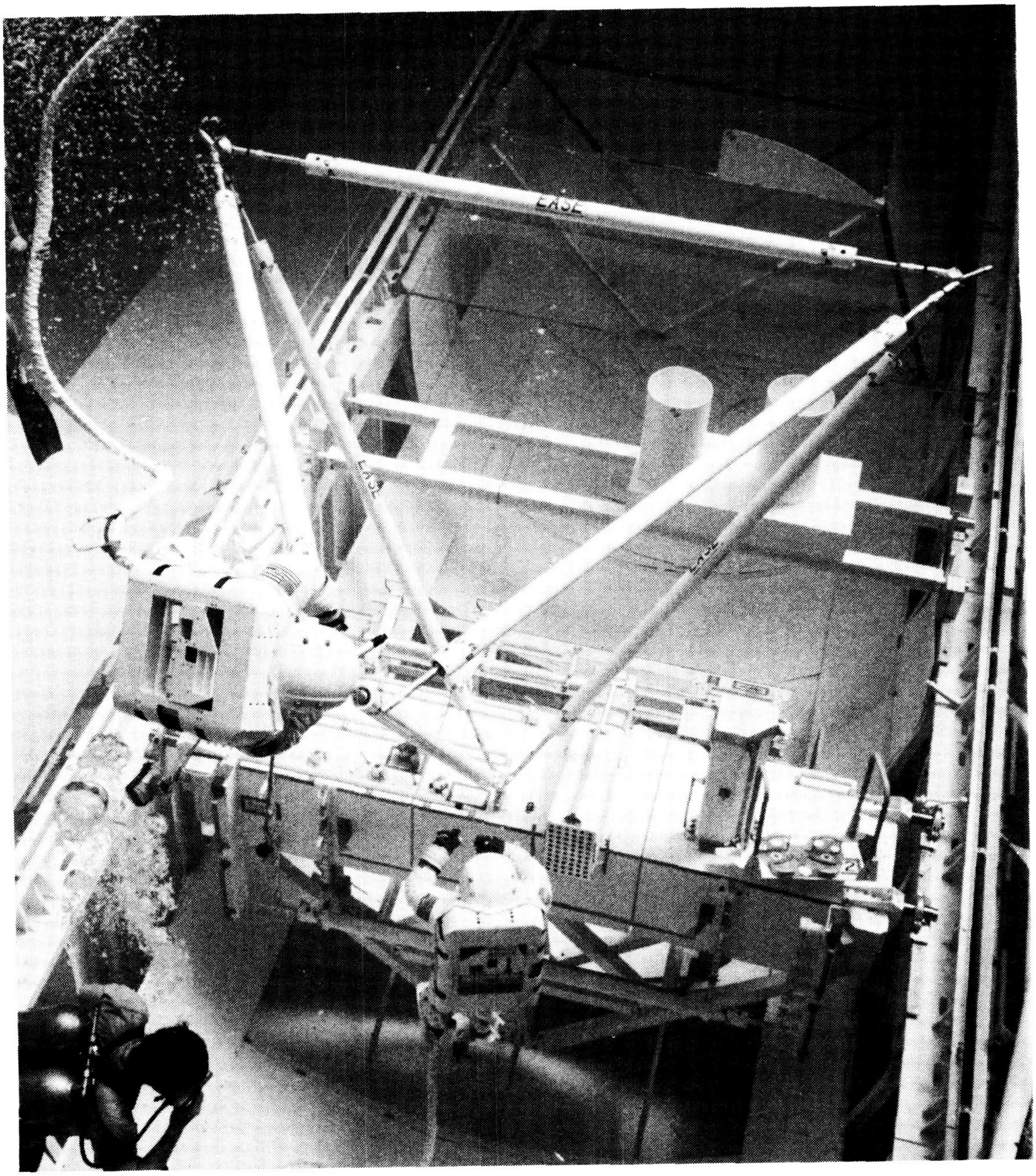

FIGURE 2

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ACCESS investigators also made some hardware modifications, such as changing the latches on the strut and node canisters and modifying some procedures. For example, investigators had planned to tether every strut and node. Neutral buoyancy tests proved that this would quickly fatigue the hands of the suited astronaut. Since the ACCESS components were small, it was decided that they could be handled safely without tethers, and investigators received approval not to tether the ACCESS components. Figure 3 shows ACCESS being assembled in the MSFC/NBS.

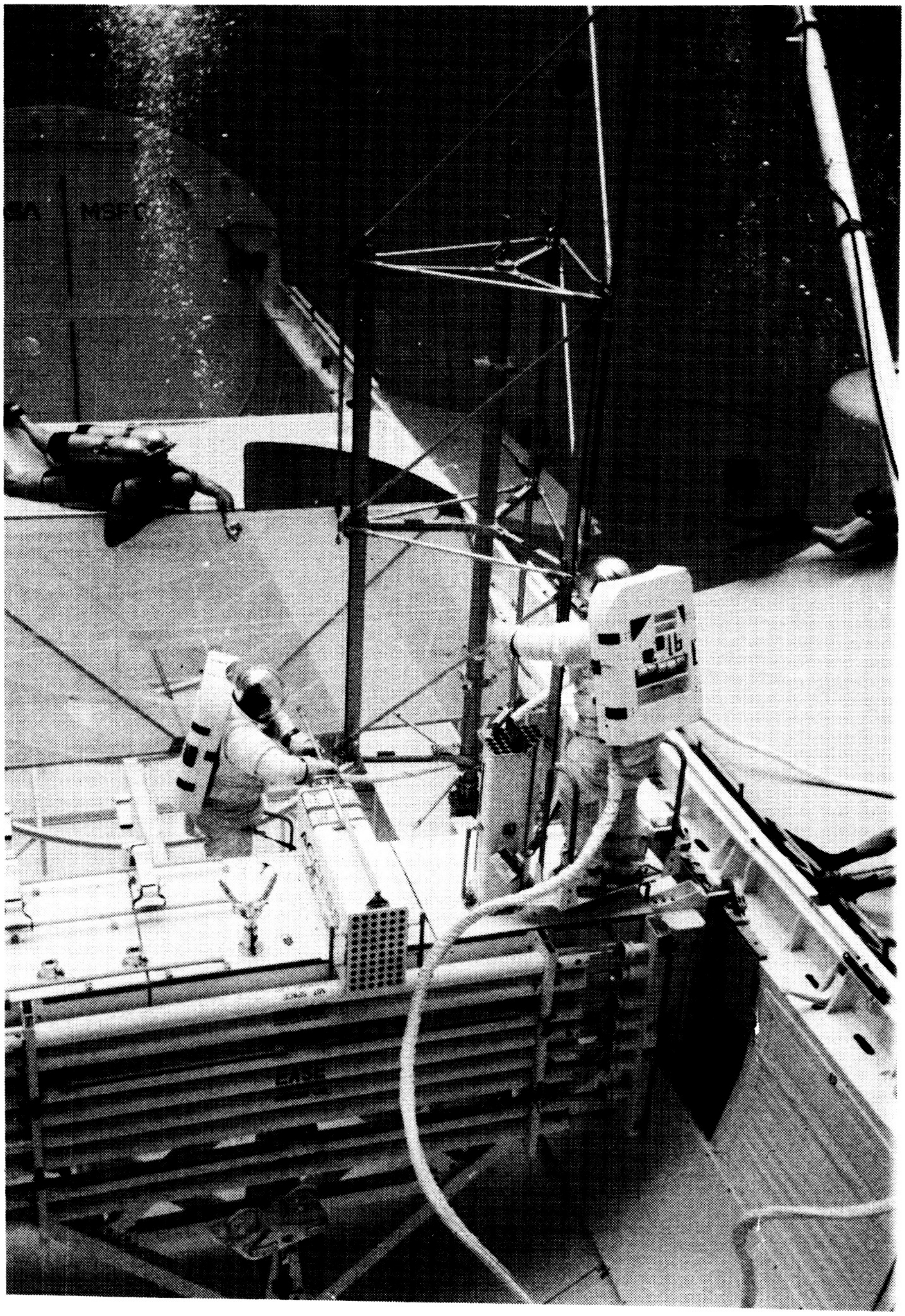

FIGURE 3

From the fall of 1984 until the spring of 1985, MIT and Langley research teams worked together in an unique joint test series. The MSFC/NBS staff prepared the facility for these tests and worked with researchers to complete them. Special underwater cameras were purchased and optics were modified in order to simulate the Shuttle payload bay flight video cameras. It was important to simulate this aspect of the EASE/ACCESS experiments because the cameras had to be placed in the appropriate positions to record construction activities; the cameras were the main data collection devices.

Astronauts Jerry Ross and Sherwood Spring, the two mission specialists assigned to build the structures in space, participated in procedures development and verification tests in the MSFC Neutral Buoyancy Simulator. Design changes continually surfaced, even in the last set of tests a few months before the mission. As a result of the last test series, foot restraints were modified to accommodate the crew. It was critical that the suited astronauts be able to reach specific areas of the structures from the fixed foot restraint work stations.

Contingency procedures and devices were also verified in the NBS. For example, the astronauts practiced contingency procedures for jettisoning the structures in space should the assembled structures get stuck and prevent the payload bay doors from closing. These simulations went smoothly and helped verify that the structures were safe for flight.

Some flight training also was accomplished in the MSFC/NBS because it was the only neutral buoyancy facility equipped with a RMS and deep enough to accommodate the large ACCESS truss tower. The crew trained in the NBS for the detailed test objectives which were planned by the Johnson Space Center to demonstrate the uses of the Space Transportation System as a work platform for space construction activities. The NBS was used to train the astronauts and develop procedures for these tasks: assembling and disassembling EASE and ACCESS from the MFR/RMS; attaching a simulated electrical cable to the ACCESS truss tower; removing and replacing a strut and node from the tower to practice a repair operation; manipulating two connected EASE beams; and manipulating the assembled EASE and ACCESS structures. These tasks were also refined as the astronauts practiced them in the NBS. For example, the crew found that it was easy to maneuver two or three bays of the ACCESS tower; based on this neutral buoyancy test, the task was changed and the entire 10-bay structure was successfully removed and manipulated in flight.

After the hardware and procedures had been refined in the MSFC/NBS, the EASE/ACCESS neutral buoyancy mockups were moved to the Johnson Space Center Weightless Environment Training Facility (WETF) where the astronauts finished training for the mission.

IMPROVING NBS SIMULATIONS

The Neutral Buoyancy Simulator staff not only engages in research and development projects conducted by users of the facility but also supports applied research. New techniques for zero-gravity simulation are being investigated as time permits. Concepts under study include computer data collection and display, robotics, and heads-up displays for spacesuit helmets. Over the last few years, new microcomputer equipment has been purchased for the purpose of investigating computerized test instrumentation and data recording.

In these times of budgetary constraints, the NBS is not able to acquire all of desired facility items. The staff uses ingenuity to continue testing with available equipment by reconditioning or modifying equipment not originally intended for underwater use. For example, video cameras have been fitted into special cases so that they can be used underwater to record tests.

The challenge "it cannot be done" invokes the NBS team to prove that "it can be done." An excellent example of this is the underwater Remote Manipulator System, an electrically powered six-degree-of-freedom robot arm. The neutral buoyancy manipulator arm first was developed as a robotics experiment when NASA announced that the Shuttle would be equipped with a manipulator system. At the time, some people said that it would be impossible to develop electronics for the RMS that would operate underwater. However, the NBS staff developed waterproof connectors and a pressurized system to keep water out of the delicate electrical components. Figure 4 shows the underwater RMS being used to practice removing and manipulating part of the ACCESS truss tower.

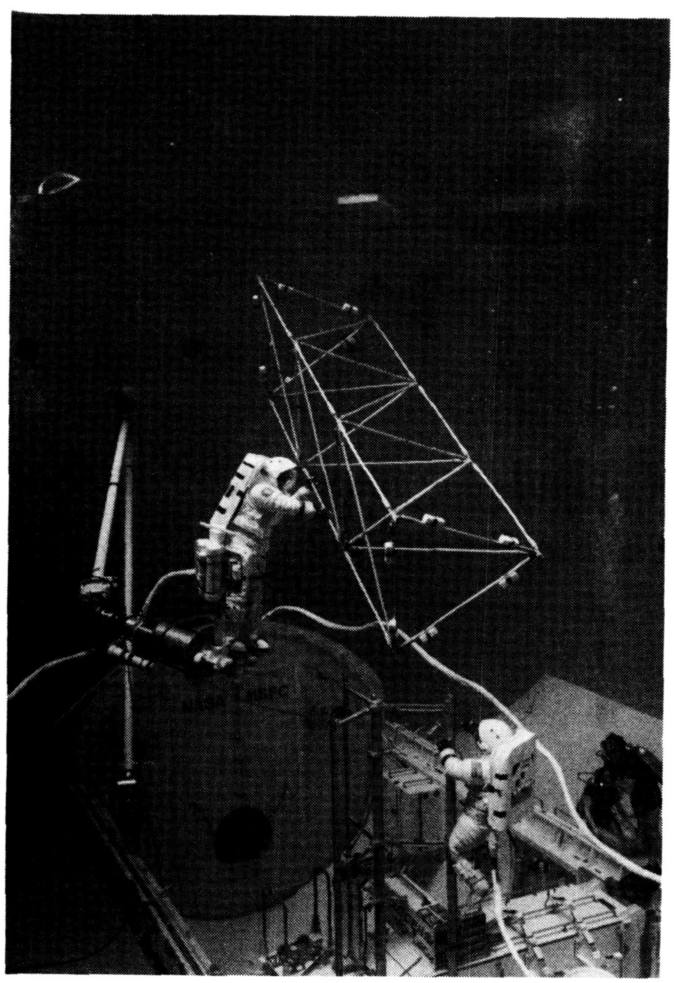

FIGURE 4

The MSFC/NBS manipulator arm is the only one available for neutral buoyancy tests requiring functional simulation of the Shuttle RMS. Presently, the NBS staff is working on techniques to make the underwater RMS operate more like the Shuttle RMS. Recently, toggle switches were replaced with rotational and translational hand controllers to match the Shuttle RMS. Now, the staff is developing a computer program to make the operation of the neutral buoyancy RMS even more similar to the operation of the Shuttle RMS.

The neutral buoyancy RMS was useful during the development of the detailed technical objectives accomplished during the second EVA of the EASE/ACCESS mission. The Marshall Center NBS was the only place were procedures could be developed for activities with one astronaut working on the Manipulator Foot Restraint work station attached to the end of the RMS.

CONCLUSION

The number of neutral buoyancy simulations conducted each year is increasing as NASA's activities in space increase. The goals at the Neutral Buoyancy Simulator are clearly in line with NASA's objectives for aerospace research.

The MSFC/NBS team supports many NASA projects. Current tests are focused on developing concepts for components of the planned Space Station. The success of the EASE/ACCESS mission has proven the value of developing and testing hardware and procedures for assembling large space structures in orbit. The Space Station and other space construction projects can benefit from using the Marshall Space Flight Center Neutral Buoyancy Simulator.

REFERENCE

1. MSFC Neutral Buoyancy Information and Requirements. National Aeronautics and Space Administration/Marshall Space Flight Center. November 1, 1985. (Available as MSFC-RQMT-623)