AIAA'86

AIAA-86-2312
Zero-G Simulation Verifies EVA Servicing of Space Station Modules

B. N. Griffin, Boeing Aerospace Co.,
Huntsville, AL

AIAA Space Station in the Twenty-First Century

September 3-5, 1986/Reno, Nevada

ZERO-G SIMULATION VERIFIES EVA SERVICING OF SPACE STATION MODULES

Brand N. Griffin*
Boeing Aerospace Company
Hunstville, Alabama

Abstract

The Space Station accommodations required for on-orbit zero-g maintenance and repair were evaluated during two months of neutral buoyancy testing. Boeing, in a joint effort with NASA, used Shuttle-type pressure suits and the simulated weightlessness provided by neutral buoyancy to assess four areas of hardware and operations. These included: 1) Space Station System Architecture; 2) Common Module Exterior; 3) Common Module Interior; and 4) Voice-Activated Systems. Specifically, the tests focused on servicing debris shield/body-mounted radiator panels, replacement of thermal blankets or Multi-Layer Insulation and repair techniques for debris damage. Design engineers and astronauts participated as pressure-suited test subjects in evaluation of a broad range of concept options. The significant findings from these tests are: 1) the astronaut positioning arm is one of the most useful tools for Space Station EVA operations; 2) the minimum separation between modules should be 78 inches; 3) axial debris panels were preferred over circumferential; 4) on-orbit repair techniques for debris-damaged modules were effective; and 5) voice-activated systems are ideal for EVA. Improved suit communications, however, are required for implementation.

Neutral Buoyancy Testing of Space Station Hardware

Extravehicular Activity (EVA) will be required for Space Station assembly, maintenance and repair. Boeing and NASA's Marshall Space Flight Center (MSFC) have taken steps to define the station accommodations required for on-orbit EVA operations. Two series of tests were conducted in the MSFC Neutral Buoyancy Simulator. In November, 1985, techniques for removing and replacing the module's debris shield/body-mounted radiator panels were performed and, on this basis, procedures for the repair of a damaged module pressure shell were conducted in March of 1986. The purpose of these tests was to provide the program with formative design data used for developing requirements and concepts of the habitable modules.

Neutral buoyancy has proven to be an accessible approximation of weightlessness. Hardware and procedures evolve with confidence knowing the neutral buoyancy operations are a credible representation of on-orbit activities. For these tests, the space-like environment was contained within the MSFC 75-foot diameter by a 40-foot-deep test facility. EVA operations were performed in Shuttle-type pressure suits which operated at 3.1 psi above ambient pressure. Before each test, subjects were carefully weighted to neutralize the buoyancy of their pressure suits. This form of testing has played a major role in manned space flight from its early days to the recent EASE/ACCESS truss tests performed on Shuttle Mission 61B.

*Lead Engineer, Configuration
Member AIAA

Test Hardware

It is widely accepted that the module construction will be a two-wall design. The outer skin serves as protection from meteoroids and debris while the inner shell retains the atmosphere. Sandwiched between the two skins are approximately 30 layers of Multi-Layer Insulation (MLI). Test hardware was conceived to drive out EVA operational discriminators for various design configurations.

The study area of the module was represented by an aluminum half-cycle with provisions to evaluate internal and external pressure suit operations (see Figure 1).

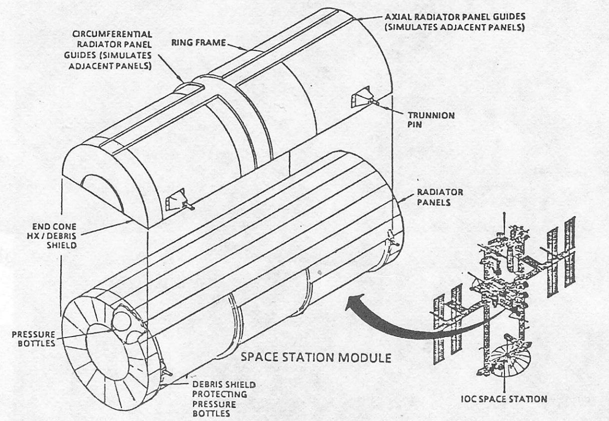
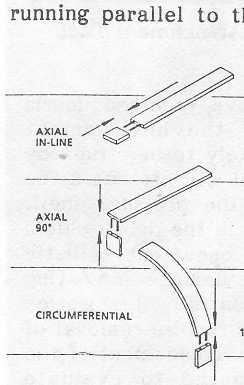


Figure 1 Space Station Module Configured for Neutral Buoyancy Testing

Color was used to code certain structural features of the module. One end was painted blue indicating the debris shield over external pressure bottles and red lines portrayed the potential attach points along protruding ring frames. In order to assess alignment and interference, the edge of adjacent panels was represented by aluminum channels positioned on either side of the test panel. Three configurations and two lengths for each panel were analyzed. A matrix comparing hardware to operations is shown in Figure 2. Two straight panels running parallel to the module's axis explored different



		PFR		MFR		RMS	
		WITHOUT RRAT	WITH RRAT	WITHOUT RRAT	WITH RRAT	WITHOUT RRAT	WITH RRAT
AXIAL IN-LINE	10'	TEST 1	TEST 1				
	20'	TEST 1 TEST 4	TEST 1 TEST 4	TEST 3	TEST 3 TEST 5		
AXIAL 90°	10'	TEST 2	TEST 2				
	20'	TEST 2 TEST 4	TEST 2 TEST 4	TEST 3 TEST 5	TEST 3 TEST 5		
CIRCUMFERENTIAL	90°	TEST 6	TEST 7	TEST 10 TEST 8	TEST 10		
	180°	TEST 4 TEST 6	TEST 4 TEST 7	TEST 3 TEST 10	TEST 3 TEST 8 TEST 10	TEST 9	TEST 9

Figure 2 Test Matrix Comparing Hardware to Procedural Options

removal/replacement envelopes and a third curved panel evaluated 90° and 180° circumferential arrangements. Since the panels may also double as radiators, removal requires disconnecting fluid couplings. Three valve assemblies and one heat pipe/heat exchanger mechanism were evaluated. In the case of the heat pipe design, two 18" tubes extended from one end of each panel configuration. A Radiator Replacement/Attachment Tool (RRAT) was built in anticipation of potential binding and alignment difficulty (see Figure 3). The RRAT provided precise movement and alignment of heat pipes, allowed positive handling about a pivot point and served to guard the exposed heat pipes during translation.

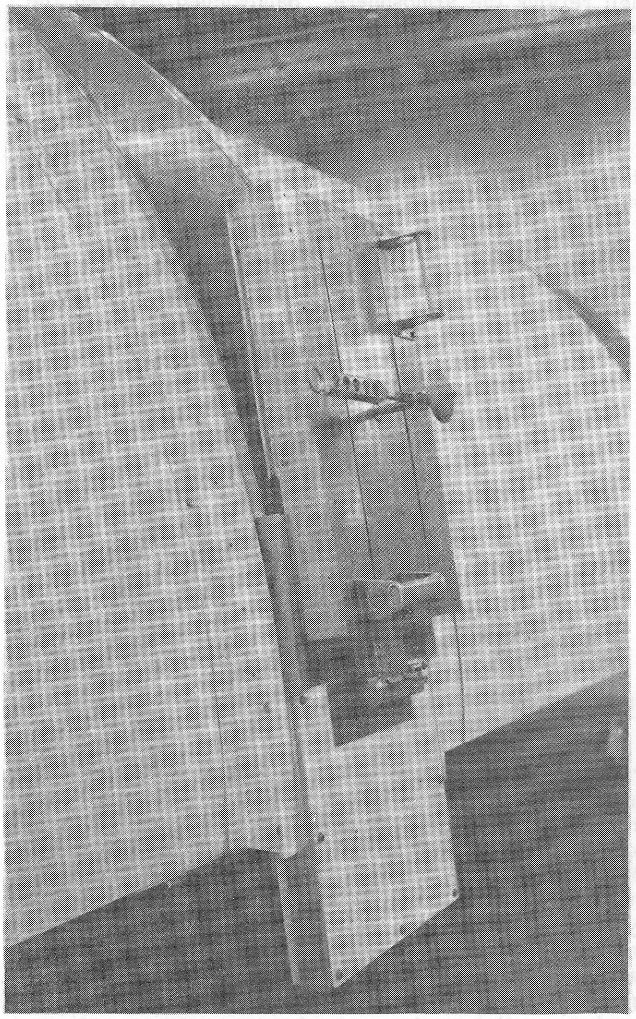


Figure 3 Radiator Replacement/Attachment Tool

Shuttle and Soviet spacecraft have received debris impacts. Statistical modeling of the environment indicates the space station is also likely to be struck by debris. In most cases, the outer panel will attenuate the impact and prevent penetration of the pressure shell. The price of this protection is a hole in the debris shield and damaged thermal insulation. Concurrent ballistic tests have produced significant MLI damage indicating the potential for impaired thermal control. Restoration of thermal integrity, therefore, would require removal of the debris shield then either repair or replacement of the damaged MLI. Tests were conducted to evaluate techniques and tools for repairing various sizes of MLI panels.

In the unlikely event of a pressure shell penetration and loss of atmosphere, an on orbit repair would avoid a costly, time-consuming and disruptive ground fix. A portion of the module's interior was constructed to the assess pressure suit repair techniques. In order to get to the damaged wall, equipment racks have to be removed (see Figure 4). Neutrally buoyant racks, therefore, were positioned in front of the test hole. Before removing the racks, utilities must be disconnected. The test racks were constructed with different utility hook-up locations which allowed comparison of automatic removal operations. The surrounding rack faces of the module interior were represented by aluminum and plexiglas panels. These panels established the physical boundaries yet allowed for observation and documentation through the transparent plexiglas.

Figure 4 Test Subject Removes Equipment Rack to Provide Access to Damaged Shell

Additional test hardware was comprised of equipment necessary for repairing the pressure shell damage. Procedures, tools and patches patterned after concepts developed under NASA contract NAS8-36462, "Space Station Wall Design and Protection Damage Control" for MSFC, were used. The tools used for repair are displayed in Figure 5.

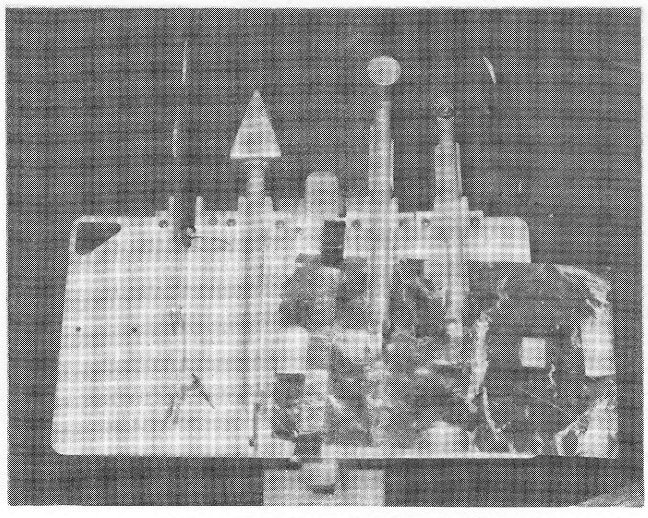


Figure 5 Tools Designed to Repair a Hole in the Pressure Shell

Test Operations

Consistent with the concept development phase of the Space Station Program, test procedures and hardware options were intentionally comprehensive. Since alternative methods of using the same hardware often produced a different impact on accommodations, procedures were rehearsed on a computer graphic system prior to getting into the water. Figure 6 shows an example of a computer simulation image. These synthetic dry runs were used to select and depict a particular test operation. When bound together, the images formed a kind of story board procedures document used by test engineers in the control room. Tests were designed to compare various methods of performing the same task. The operations that were compared include: (1) procedures using one and two test subjects; (2) single and two hand operations; (3) restraint options including tether and handholds only and alternative foot restraint locations; and (4) use of the Remote Manipulator System (RMS) as an astronaut positioning arm, (see Figure 7) and use of the RMS as a handling aid for debris panel operations and use of the Manned Maneuvering Unit (MMU) for operational envelope analysis (see Figure 8).

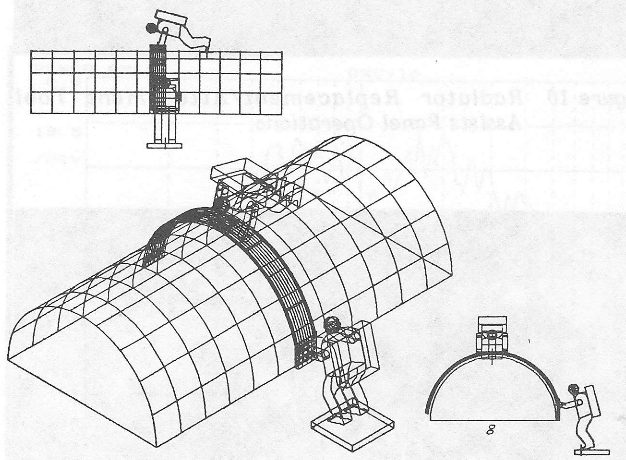


Figure 6 Computer Simulations Helped Refine Procedures Before Testing

An important element of test operations was evaluation of a voice-activated check list. This feature allows the astronaut to perform routine or infrequent tasks without depending on total recall or turning checklist pages. The arrangement used EMU communications system coupled with a micro VAX II, DECtalk PTC-01 and Verbex Series 4000 located in the control room.

Evaluation

Evaluation of test hardware and procedures was a team effort. Contributions were made by Boeing, Marshall and subcontractor designers, test subjects and participating astronauts. According to plan, test operations were directed by communications from the control room. This link served as a record of comments and an opportunity for real-time procedural modifications. Furthermore, there were five fixed cameras and one swim camera providing continuous video coverage. Briefings before and after the tests, combined with control room records, virtually guaranteed critical assessment of test performance, value, application and improvements.

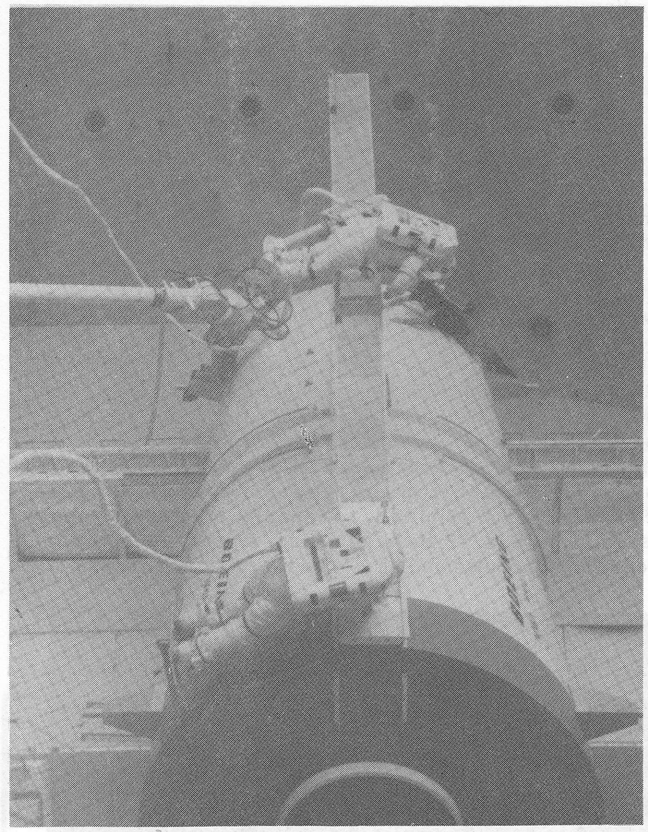


Figure 7 The Remote Manipulator System is Used as the Space Station's Astronaut Positioning Arm

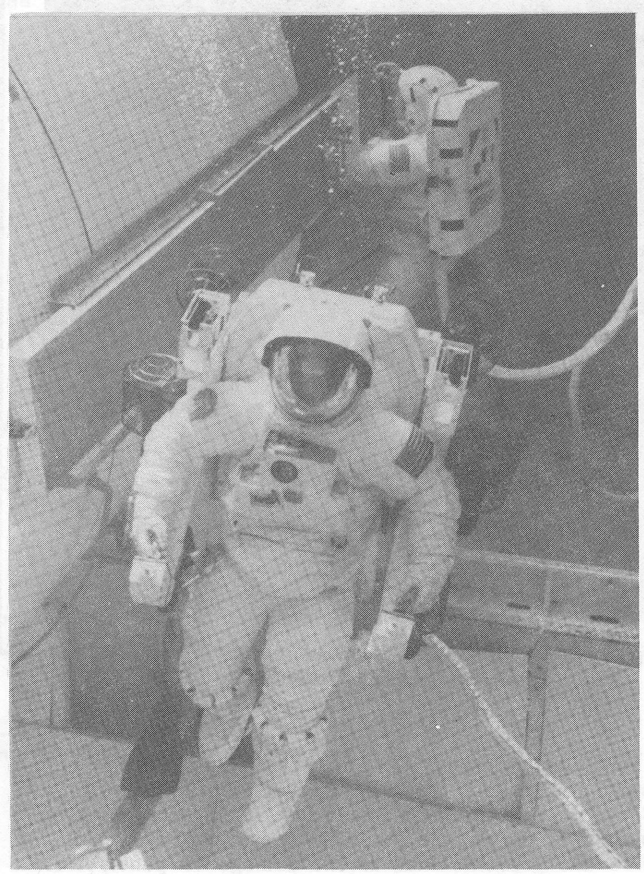


Figure 8 The Manned Maneuvering Unit Simulator Provides Data on Access Envelopes

Findings

The significant findings from the neutral buoyancy test can be classified in four areas: 1) space station system architecture; 2) module exterior; 3) module interior; and 4) voice activated system.

Space Station System Architecture. 1) The single most useful tool was the remote manipulator system. When used as an astronaut position device, the RMS with a manipulator foot restraint was an excellent worksite affording positive restraint, positioning flexibility and two free hands. 2) Furthermore, RMS-based servicing freed the module from additional weight and complexity for foot restraint, as well as handhold accommodations. When debris panels were fitted with a grapple fixture, the RMS performed well as a third arm for panel restraint and translation. An example is shown in Figure 9. 3) The manned maneuvering unit worked best as a means for astronaut inspection of the module. 4) The accommodations required to enable adequate panel inspection are a 78-inch minimum separation between pressurized modules and an RMS with sufficient reach.

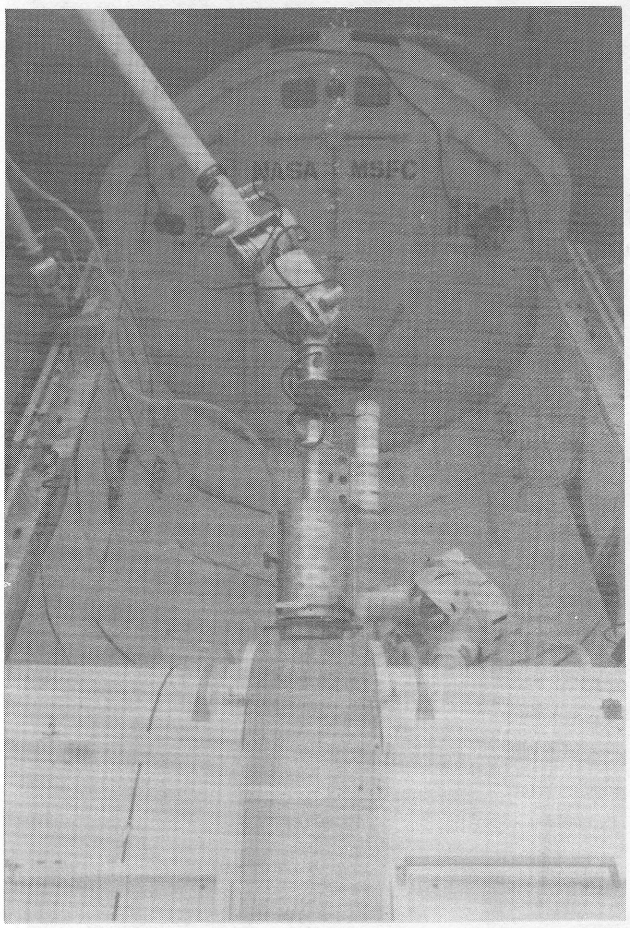


Figure 9 The Remote Manipulator System Grapples a Panel to Assist in Removal

Module Exterior. 1) The axial debris panels were more manageable than the circumferential panels. 2) Concentrating the mechanical and fluid interconnects at one end of the module simplifies operations, reduces EVA time and prevents inadvertent damage to panels from crew translation and handling. 3) The panel continuity and commonality are affected by window, trunnion, keel and umbilical intrusions. 4) When the panels are used as radiators with exposed heat pipes, alignment and handling tools are necessary. Figure 10 shows the RRAT in use. 5) The trunnions used to support the module in the Shuttle cargo bay can be used on-orbit as support fixtures for EVA scaffolding. 6) Careful restraint positioning is essential for reach with large MLI panels, whereas smaller panels are less sensitive to astronaut positioning (see Figure 11). 7) Line-of-sight operations between crew members is an important factor in EVA productivity.

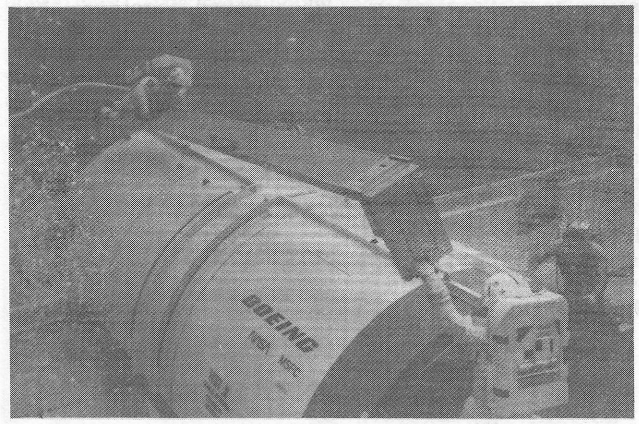


Figure 10 Radiator Replacement/Attachment Tool Assists Panel Operations

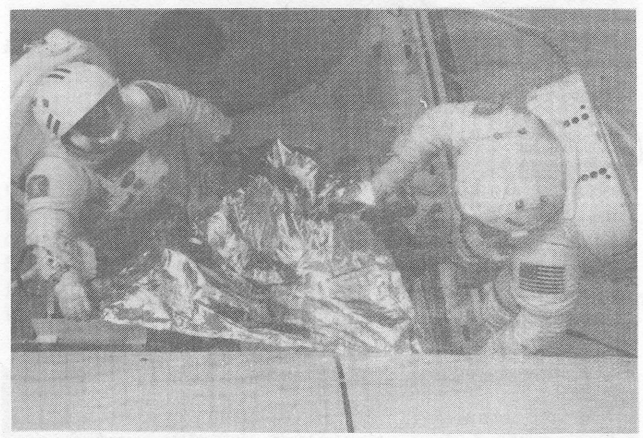


Figure 11 Multi-Layer Insulation is Being Prepared for Attachment to the Module

Module Interior. 1) Due to the size of the pressure suit, at least two single racks (42 inches) must be removed for access to the wall. 2) Disconnecting the equipment rack utilities was easiest from the front. 3) down the aisles. 4) Pressure shell repair procedures and tools are adequate but could be refined. See Figure 12.

Voice-Activated System. The voice activated system has considerable applications for EVA operations. 1) It eliminates cumbersome check lists and 2) allows for both hands to be in the job. 3) The system is ideal for Space Station operations since rotating crews will be most likely be unfamiliar with rarely used procedures; 4) The voice-activated computer offers an opportunity for artificial intelligence applications.

Neutral buoyancy testing revealed an unexpected technical problem. Voice recognition in the laboratory and in a pressured EMU on the surface operated as planned. There was little or no recognition, however, under water. Test time did not allow complete resolution of this issue, but improved microphones in the suit are expected to eliminate the problem. A comparison of signal-to-noise for the voice communications in the Neutral Buoyancy Simulator and the Shuttle Mission STS-6 displayed a close similarity (see Figure 13). A successful neutral buoyancy test, therefore, is presumed to be applicable to space operations.

These initial Space Station neutral buoyancy tests are the first steps along the evolutionary path to design maturity. As with any tests, some active concerns have been put to rest while other issues requiring additional testing have surfaced. Boeing has plans to continue neutral buoyancy testing in support of NASA's Space Station Program.

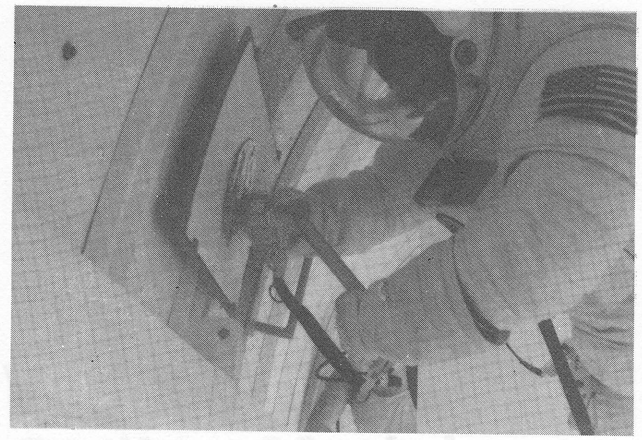


Figure 12 Test Subject Positions Patch Over Simulated Hole in Pressure Shell

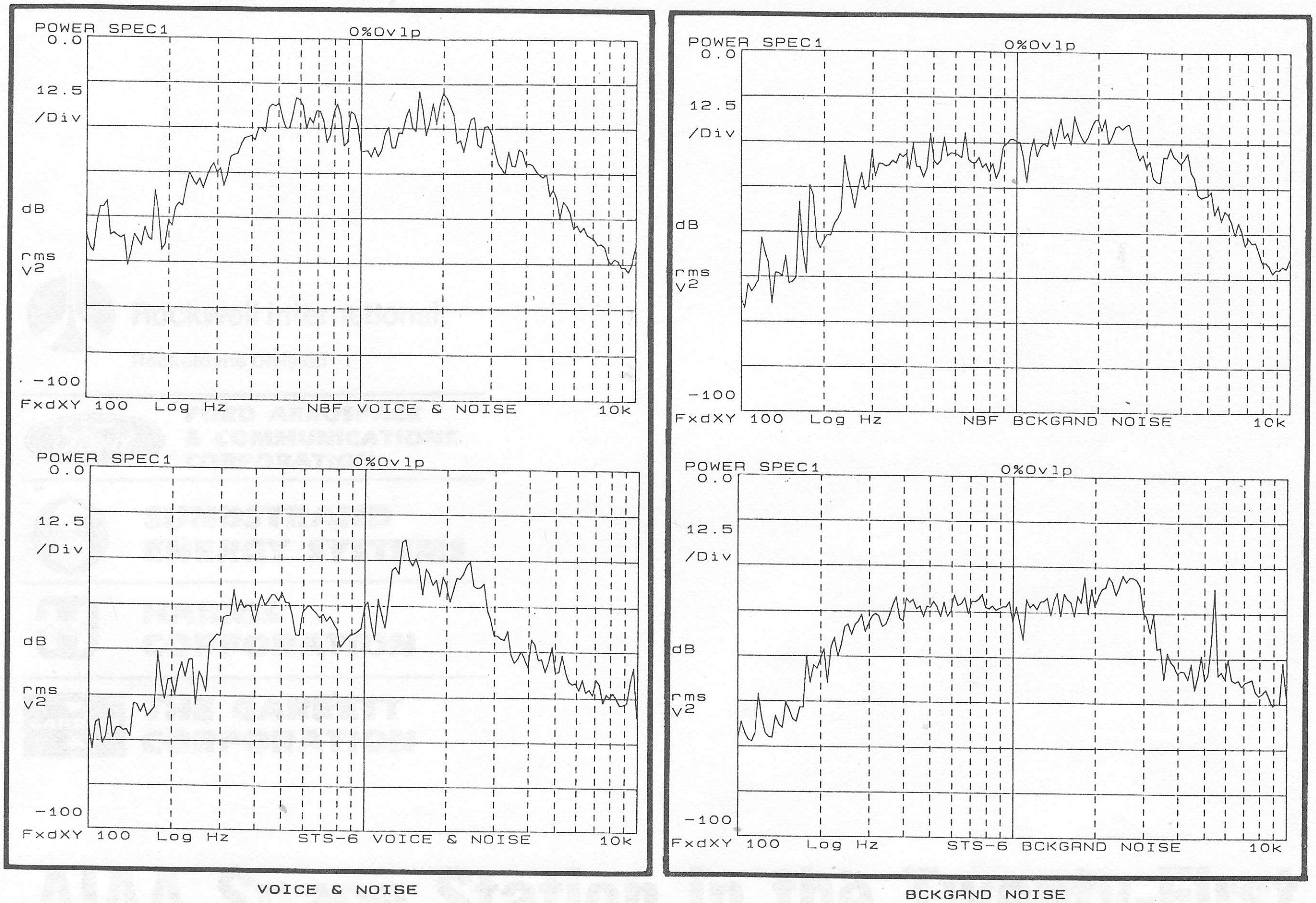


Figure 13 Voice and Noise Comparison Between the Neutral Buoyancy Facility and EVA on Mission STS-6

ACKNOWLEDGEMENT

NASA Photos by Dennis Keim