Bulletin 43
(Part 3 of 4 Parts)
(Part 4 of 4 Parts)

THE SHOCK AND VIBRATION BULLETIN

Part 3
Skylab, Vibration Testing and Analysis

Part 4
Prediction and Experimental Techniques, Isolation and Damping

JUNE 1973

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THE SHOCK AND VIBRATION INFORMATION CENTER
Naval Research Laboratory, Washington, D.C.

Office of
The Director of Defense
Research and Engineering

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The 43rd Symposium on Shock and Vibration was held at the Asilomar Conference Grounds, Pacific Grove, California. on 5-7 December 1972. The U.S. Army, Fort Ord, was host.

Office of
The Director of Defense
Research and Engineering

Shock Analysis

Shock Testing

PAPERS APPEARING IN PART 2

Structural Analysis

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SKYLAB VIBROACOUSTIC TESTING
AN OVERVIEW

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Skylab Orbital Workshop and Payload Assembly vibration and acoustic tests performed at Houston, Texas are discussed. Test article configurations, ground test objectives, testing constraints, tests systems, and the general program are described. Scope of additional papers to be presented in this series is discussed.

INTRODUCTION

The Skylab program is a manned orbital scientific space station to be launched in mid-1973 in a near-earth orbit up to 235 nautical miles. The 100-ton laboratory complex has multi-purpose scientific investigation capabilities. The three-man crew, brought to the orbiting laboratory by an Apollo spacecraft, will carry out more than fifty significant experiments in medicine, science, technology, earth resources, and operations. The first mission will last up to 28 days, and two subsequent missions will last up to 56 days each.

In support of the structural designs and qualifications of Skylab hardware, a ground test program was conducted at the Manned Spacecraft Center (MSC), Houston, Texas, Vibration and Acoustic Test Facility (VATF). These tests, from January 1971 to July 1972, were late enough in the design of Skylab to allow use of established structural configurations and was early enough in the program to precede most component qualifications.

A series of eight papers has been prepared covering the Skylab test program at Houston. This paper is first in the series and is structured to give an overview of the test program and will serve as an introduction to the remaining papers. Paper titles and authors are listed in Table I. These papers report work done under direction of NASA-Marshall Space Flight Center.

This paper discusses in the following paragraphs objectives of the ground tests, test configurations, testing constraints, the tests conducted, and the general scope of the other papers in the series.

OBJECTIVES OF GROUND TESTING

The Skylab major structural systems and components would require testing to verify structural integrity and satisfactory component functioning during the programmed life of the systems. This testing could be accomplished on an individual basis with a large number of small tests designed to impose predetermined environmental criteria on the specimens. A more efficient method of tests whereby all major structural systems and components are assembled as one unit and tested to prescribed environmental criteria could provide a less expensive method of achieving the desired goals. This latter method was chosen for the Skylab ground test program.

The test philosophy was to subject the Skylab system to a combined vibration and acoustic test environment that best simulated actual launch and flight conditions. The size of the available test facilities dictated the testing be accomplished in three major sections:

1. The orbital workshop
2. The payload assembly consisting of the airlock module, multiple docking adapter, apollo telescope mount, deployment assembly and shroud
3. The apollo service module.

The test objectives, as determined by the cognizant system contractor and NASA organizations, were to simulate the launch vehicle lift-off and boost, engine cut-off, vehicle separation environments and math model boundary conditions. These objectives were met during a related series of acoustic and vibration tests imposed on the major test articles.

Data acquired from these tests were used for verification of the orbital workshop, payload assembly and service module structural integrity and dynamic response characteristics. The data were also used to evaluate dynamic response criteria and for dynamic structural qualification of flight hardware components.

TEST CONFIGURATION

The test procedure followed in testing of the Orbital Workshop, Payload Assembly, and Service Module was to perform acoustic tests in the Manned Spacecraft Center Vibration and Acoustic Test Facility (MSC VATF) Spacecraft Acoustic Laboratory and then vibration tests in the MSC VATF Spacecraft Vibration Laboratory. The scope of this paper is limited to a description of the tests and test articles. Test details will be covered in other papers of this series as indicated in Table I.

A. Orbital Workshop

1. Acoustic Tests

The workshop was stacked in the Spacecraft Acoustic Laboratory with the S-IVB aft interstage and Instrument Unit SA-500D. Appropriate acoustic shields closed out both top and bottom of the stack. Figure 1 is a sketch depicting components in the stack and Figure 2 is a photograph of the stack in the Spacecraft Acoustic Laboratory.

2. Vibration Tests

For vibration testing the workshop was stacked in the Spacecraft Vibration Laboratory on a vibration test fixture. The S-IVB aft interstage and Instrument Unit SA-500D were not used in this test. Figure 3 is a photograph of the Orbital Workshop Spacecraft Vibration Laboratory stack.

B. Payload Assembly

1. Acoustic Tests

Acoustic test hardware for the launch configuration consisted of the S-IVB Forward Skirt with tank dome, Instrument Unit, Fixed Airlock Shroud, Airlock Module, Multiple Docking Adapter, Apollo Telescope Mount, ATM Deployment Assembly, and Payload Shroud. These components were stacked vertically in the Spacecraft Acoustic Laboratory reverberant chamber. The assembly rested on pneumatic casters and was acoustically sealed at the floor. Figures 4 and 5 are sketch and photograph depicting this configuration.

2. Vibration Tests

Stacking was identical for the Payload Assembly launch configuration vibration testing performed in the Spacecraft Vibration Laboratory. The assembly rested on a vibration test fixture used for suspension system attachment and for force input attach points. Figure 6 is a photograph of this configuration. For orbital configuration, the Payload Shroud was removed, the Apollo Telescope Mount was placed in the deployed position, and the Service Module was added to the stack. The Apollo Telescope Mount and Service Module were suspended on individual suspension systems. Figure 7 is a sketch depicting components in this stack. Figure 8 is a composite photograph of the stacked configuration.

C. Service Module

The Service Module was mated with a Command Module and subjected to both acoustic and vibration testing in the Spacecraft Vibration Laboratory (Figures 9 and 10). Since this testing was performed concurrently with installation of the reverberant chamber walls (the reverberant chamber was used for the first time to perform the Orbital Workshop test), the Service Module acoustic testing was conducted using special ducts to apply the acoustic energy using progressive wave mode of operation. A special fixture was used for supporting the Service Module during the acoustic testing, and a modified ground support ring mated to four air springs supported the Service Module for the vibration testing.

D. Component Tests

Component tests directly applicable to the Orbital Workshop/Payload Assembly Program were conducted in the MSC Spacecraft Acoustic Laboratory to resolve problems discovered during prior Payload Assembly acoustic testing:

1. The Instrument Unit-Flight Control Computer was installed in the Payload Assembly stacked in the reverberant chamber. Both mass simulated dummy and engineering models of the Flight Control Computer were tested to acoustical qualification criteria. A modal survey of the

Instrument Unit in the area of the Flight Control Computer was also made in this same configuration.

2. Apollo Telescope Mount/Control Moment Gyro acoustic tests were made to assist with Control Moment Gyro qualifications. A flight type Control Moment Gyro was mounted on the Apollo Telescope Mount which was stacked inside the Payload Shroud. The test article was subjected to adjusted acoustical qualification criteria for the prescribed time, after which it was to be functionally operated for its required life cycle time.

TEST SYSTEMS

A number of unique systems were assembled to meet the objectives and constraints of this program, the most significant of these systems are:

- Spacecraft Acoustic Laboratory (SAL)
- Automatic Acoustic Control System for the SAL
- Automatic Modal Tuning and Analysis System (AMTAS)
- Modal test air springs, ballast and isolation for high force shaker systems
- Transient Vibration Control System
- Acceleration exceedance detectors.

The Spacecraft Acoustic Laboratory reverberant room (47 ft, 4 in. wide, 45 ft, 4 in. deep and 75 ft high) has the capability to acoustically excite test vehicles up to 74 ft in height with high level energy over a wide frequency range. Approximately 250,000 watts of acoustic power can be provided by the 4500 horsepower laboratory compressor in conjunction with various horn combinations. Horns with 25, 50, 100, 250, and 630 Hz cut-off frequencies were used. High and low frequency WAS -3000 and EPT -200 air modulators were used to modulate the horns.

The automatic acoustic control system is a digital computer system that adjusts the acoustic levels seen by designated control microphones strategically spaced around the test article. The control computer displays this spectra along with the acceptable 1/3 octave band tolerances for immediate evaluation by test personnel.

The Automatic Modal Tuning and Analysis System (AMTAS) was specifically created for the Skylab modal testing program to give fast turn around to large quantities of structural data that otherwise could not be analyzed within the required time frame. This system performed highly interrelated control and data acquisition functions. A General Automation 18/30 digital computer was used for basic data acquisition and display.

AMTAS simultaneously controlled as many as twelve modal shakers each having a maximum sinusoidal force output of 150 lb. The data objective of the system was to provide normalized responses, mode shapes and orthogonality tabulation after each modal tuning run was completed. These data provided a high level of confidence in the validity and adequacy of the test results. AMTAS included a capability to protect the test vehicle from excessive force or motions. Additional details of the AMTAS and acoustic systems and other test systems are contained in additional papers in this series (See Table I).

TESTING CONSTRAINTS

A. Systems Limitations

Acoustics tests had no systems limitations. Tests were conducted with ample margin of power to obtain the required spectra.

Vibration testing high force sweeps were limited in force application due to reaching the limit of shaker capabilities. This resulted in lower instrumentation response levels and therefore resolution was not as good as would be desired.

Also, suspension system and shaker stinger characteristics combined in some cases to constrain testing. Where vibration sweep frequencies coincided with natural frequencies of shaker stingers and shaker suspension systems, the desired force levels for the sweeps could not be maintained for fear of failing some part of the system due to the large displacements encountered.

B. Structural Response and Loads

Flight type structural systems were included in the test articles and these systems were protected from overtest condition in both vibration and acoustic tests by automatic response and load limiting systems.

The vibration response limiting on certain components and structural systems was accomplished through use of properly calibrated accelerometers feeding a monitoring system that caused a shaker master control interrup when an established level was exceeded. The established level was usually 10 percent lower than the maximum do-no-exceed level. The load limiting system operated in much the same manner with strain gage devices feeding the monitoring system.

TEST PROGRAM

A chronology of the Skylab Vibro Acoustic Test Program is given to enable the reader to grasp somewhat the size of the program and the enormous amount of data collected. The Orbital Workshop was tested in the Spacecraft Acoustic Laboratory, in February 1971, to lift-off and boost condition acoustic levels of 151 dB and 149 dB overall sound pressure levels (OASPL), respectively. Vibration tests in three mutually perpendicular axes and modal survey testing were performed in the spacecraft vibration laboratory. Vibration exciters located strategically around the workshop were programmed to give proper loading for force controlled and motion controlled sine sweep tests. Frequencies of sweep tests were 5 to 60 Hz for longitudinal axis and 4 to 20 Hz for lateral axes. Modal dwell tests were run at 23 frequencies determined from the previous sweep tests. Mechanical impedance test data were acquired at selected locations for analytical purposes. Workshop test was completed in May 1971.

Payload Assembly testing began in the Spacecraft Acoustic Laboratory in August 1971. Lift-off and boost condition acoustic levels of 150 and 153 dB OASPL respectively, were imposed on the assembly. Launch configuration vibration tests in the longitudinal axis were performed in the Spacecraft Vibration Laboratory. Testing was performed in the same manner as workshop vibration tests. Modal dwell tests were run at 40 frequencies determined from previous sweep tests.

The Payload Assembly Orbital Configuration Vibration tests were completed in June 1972. Twelve sweep tests were made for the purpose of identifying frequencies of possible modes. Thirty-one separate modes were successfully acquired from the orbital configuration tests.

Two special component tests were run in the Spacecraft Acoustic Laboratory as a result of the previously conducted acoustic tests. The Instrument Unit/Flight Control Computer and the Apollo Telescope Mount/Control Moment Gyro received separate special acoustic qualification tests.

The Flight Control Computer tests were conducted in October 1971 at the Spacecraft Acoustic Laboratory in the Payload Assembly launch configuration. Engineering model and mass simulated Flight Control Computers were used to evaluate the proper specification levels for qualification testing of this component.

The Apollo Telescope Mount/Control Moment Gyro special qualification test was conducted April 1972 at the Spacecraft Acoustic Laboratory with the Apollo Telescope Mount, installed in the Payload Shroud including double angle nose cone. A live Control Moment Gyro was subjected to maximum flight acoustic environments to determine whether any bearing or operation problems would occur due to this environment.

Mechanical Impedance tests conducted on Payload Assembly components in July 1972 completed the Skylab Orbital Workshop/Payload Assembly testing at MSC.

OTHER PAPERS

A series of seven additional papers has been prepared to cover the details of development of unique testing equipment, facilities and computer software required for the extensive Skylab ground test program. Subjects discussed are:

- Skylab Vibration and Acoustic Structural Test Systems
- Orbital Workshop Vibroacoustic Test Program
- Skylab Payload Assembly Vibroacoustic Test Program
- Development of an Automatic Modal Tuning and Analysis System for Performing Skylab Modal Surveys
- Skylab Modal Survey Testing
- Use of Generalized Mass Contributions in Correlation of Test and Analytical Vibration Modes
- Vibration and Acoustic Tests of the Reconfigured Service Module Adapted for Skylab Missions.

Table I contains a list of the Skylab testing papers prepared for presentation to the

43rd Shock and Vibration Symposium. Also included in the table are author's names and company affiliations.

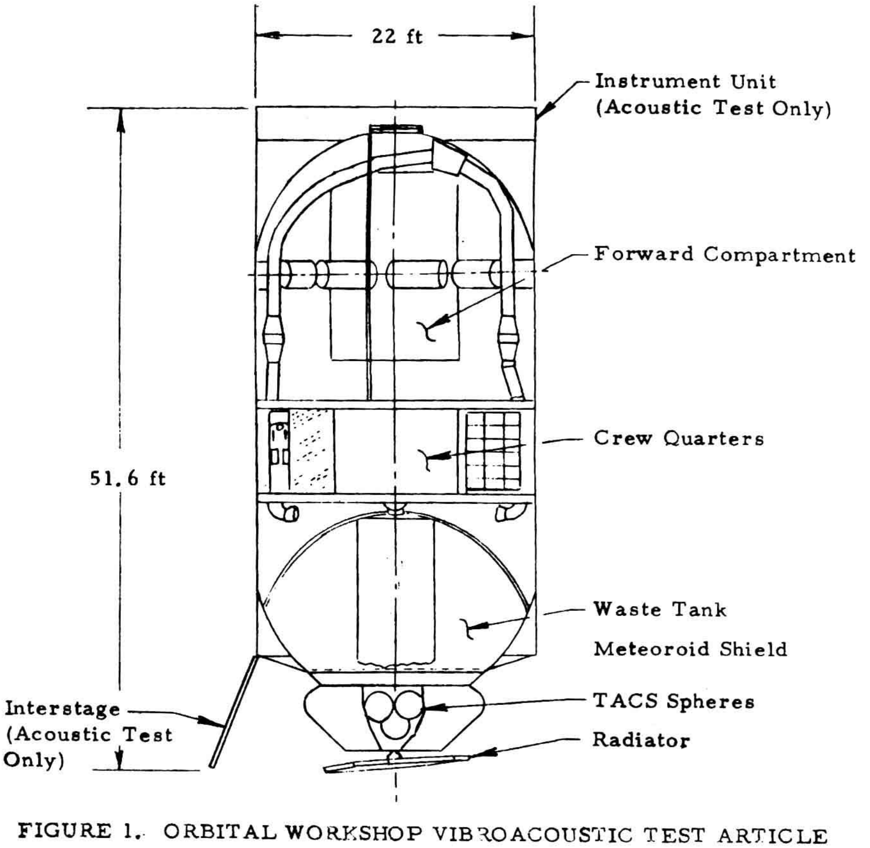

FIGURE 1. ORBITAL WORKSHOP VIBROACOUSTIC TEST ARTICLE

FIGURE 2. ORBITAL WORKSHOP STACK IN SPACECRAFT ACOUSTIC LABORATORY

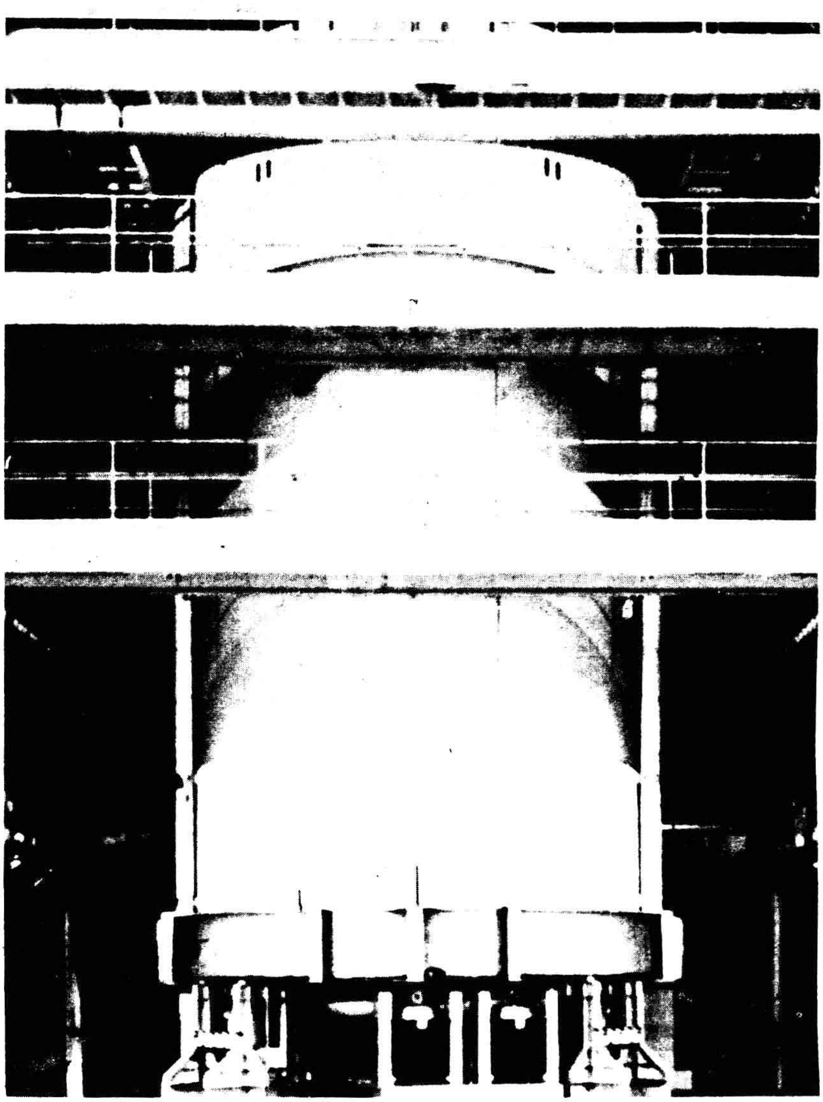

FIGURE 3. ORBITAL WORKSHOP STACK IN SPACECRAFT VIBRATION LABORATORY

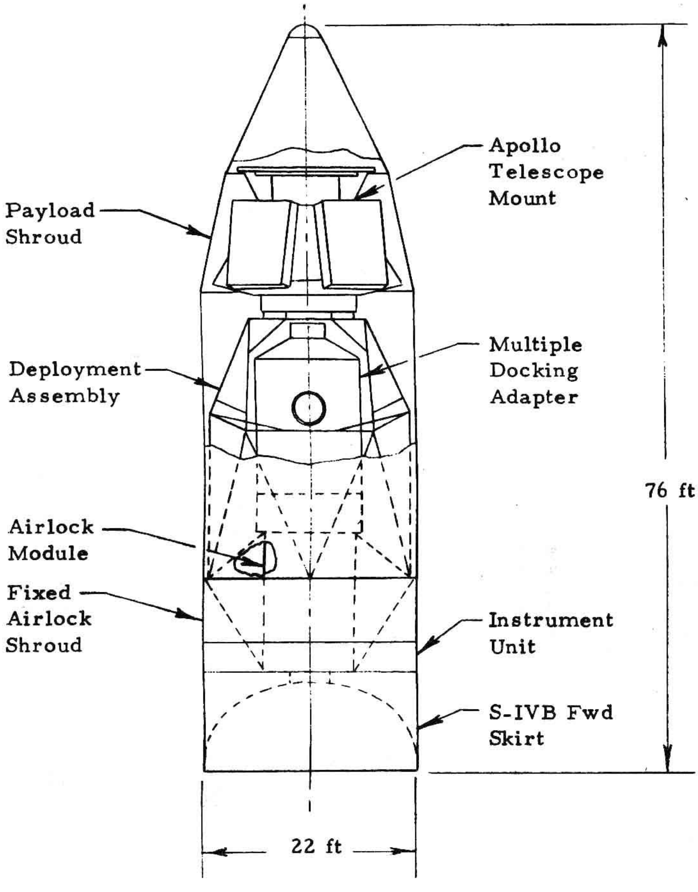

FIGURE 4. PAYLOAD ASSEMBLY LAUNCH CONFIGURATION IN SPACECRAFT ACOUSTIC LABORATORY