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PROPOSED MANNED DYNAMIC TESTING OF SPACE STRUCTURES

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ABSTRACT

Dynamics problems likely to be encountered in orbital structures and some possible investigations to study these problems are outlined. The items proposed are dynamic measurements at each step in space station development, inclusion of failure analysis capability with space rescue mission, and an orbiting structures laboratory. Role of manned participation is emphasized.

A more detailed outline of one possible vibration test experiment is included as an appendix. The prime objective of this experiment to evaluate test equipment and procedures in orbit.

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PROPOSED MANNED DYNAMIC TESTING OF SPACE STRUCTURES

SUMMARY

Dynamics problems likely to be encountered in orbital structures and some possible investigations to study these problems are outlined. The items proposed are dynamic measurements at each step in space station development, inclusion of failure analysis capability with space rescue mission, and an orbiting structures laboratory. Role of manned participation is emphasized.

A more detailed outline of one possible vibration test experiment is included as an appendix. The prime objective of this experiment is to evaluate test equipment and procedures in orbit.

I. INTRODUCTION

As structures are designed for lighter weights, dynamic loads and deflections become more and more important considerations. The ultimate in lightweight structure would have thin sections, large spans, and would be deployed or perhaps even manufactured in space. Most structures require controlled orientation, thus introducing the problem of coupled structural control-system dynamics. Since these structures would not be capable of resisting gravity and air loads, they could not be evaluated on the earth. Also, any change in material properties due to the space environment must be evaluated. Testing during each step of the space flight program is proposed. This testing philosophy allows data from each spacecraft to be used for design verification for succeeding spacecraft. Maximum use would be made of on-board equipment and crew capability to provide versatility with a minimum of payload weight.

II. SITUATIONS

Three basic situations exist where testing is to be done:

(1) Testing of early manned space stations.

(2) Investigating dynamic problems of manned and unmanned space stations and space rescue.

(3) A structures and materials orbital laboratory where manufacturing, fabrication, and dynamics investigations would be conducted.

The first of these would be integrated into existing planned Apollo and AAP flights. The second is seen as an additional requirement for a capability in the same time period. The third would be planned for a later date.

III. TESTING IN EARLY MANNED SPACECRAFT AND SPACE STATIONS

Objectives for early flights would be to determine dynamic properties of "heavy" structures in space environment, to evaluate materials, and to develop test equipment and procedures. Later flights would investigate dynamics of "light" structures. Of the twenty flights now planned for AAP, eleven call for "orbital assembly of large structures" and thirteen call for "observatories and space science laboratories." These should provide a large variety of configurations and dynamic problems for investigation. Unmanned spacecraft might be placed in matching orbits with instrumented manned spacecraft so that deployment and operational dynamics can be monitored and measured. A "construction zone" might be established in space. Equipment from experiments would be stored in orbit for possible use in later experiments. Testing of scale models, typical segments of large structures, and deployment mechanisms to accurately determine operational forces and motions should do much to improve present devices. Deployment mechanisms are at present probably the most unreliable of all spacecraft components. An interplanetary spacecraft, assembled in orbit, could possibly be developed within the next few years. Dynamic testing may be very useful for verifying structural integrity, checking control system performance, and providing a qualification test. An example of the spacecraft available for experimentation is the proposed artificial gravity satellite shown in figure 1.

<u>Summary - Early Manned Station Testing</u>

a. Objectives

(1) To determine dynamic properties of an orbiting manned spacecraft.

(2) To determine dynamic properties of a spinning spacecraft.

(3) To develop and evaluate vibration test equipment and procedures for use in space.

(4) Evaluate space rescue techniques and equipment.

(5) Measure dynamic properties of deployed spacecraft during deployment and operation.

(6) To evaluate attitude control system effectiveness and parameter changes.

(7) To provide a capability to measure and evaluate dynamics problems due to equipment failure or those encountered during operation.

(8) To measure changes in the elastic properties of materials due to space environment.

(9) To measure the dynamic properties of interplanetary craft assembled in orbit.

b. Objectives

(1) S-IVB - Apollo Vehicle: Multiplex, analog-to-digital, digital computer, telemetering equipment, control thrusters and power sources would be useful. The principal modification is the provision for connections and possibly alternate modes of operation.

(2) Sensors: Accelerometers and gyros. Methods of attachment need investigation. Non-contact sensors would be very useful. Present models should be adapted to withstand space environment. This equipment could also be useful for flatness measurements.

(3) Shakers: Electrodynamic or electromechanical shakers could be adapted to environment for small forces. Rocket thrusters might be useful for large forces. Attachment could be a problem. Electrostatic excitation should be evaluated for exciting large thin members.

(4) Display instruments and control console.

(5) Cabling and connecting equipment.

(6) Test specimens.

c. Duties of Crew

(1) Deploy payload or test specimen.

(2) Place instrumentation.

(3) Connect test equipment to spacecraft.

(4) Check out equipment.

(5) Monitor test.

(6) Replace or repair equipment.

(7) Set up alternate configurations.

(8) Conduct simulated rescue operations.

The manned orbital vibration measurement experiment listed in Appendix A is an example of the type of work to be done. This experiment would achieve objectives 1 and 3 and possibly several of the other objectives depending on options chosen.

IV. INVESTIGATION AND SPACE RESCUE

At some time, a space rescue capability will be established. Besides the moral, psychological, and propaganda (such as rescue of cosmonauts) values of this mission, much useful engineering and scientific information could be retrieved from the failed vehicle. The equipment developed for this mission could alternately be used for investigation of failures of unmanned vehicles when economically feasible and when no other methods exist. Analysis of failure is often the most direct means of engineering improvement. Since a large number of the possible failure modes involve dynamics, much of the equipment discussed previously should be very useful during investigations. A proven device which can attach to and stop the tumbling of an arbitrarily shaped spacecraft is the principal item which needs to be developed. The rescue craft must be large enough to carry all equipment into matching orbit.

A typical combination of activities during a mission is shown in figure 2.

<u>Summary - Space Rescue and Investigations</u>

a. Objectives

(1) Capability of retrieving personnel from orbiting spacecraft.

(2) Capability of investigating failures of spacecraft.

b. Equipment

(1) Reentry spacecraft with positions for extra personnel.

(2) Maneuvering spacecraft capable of matching orbits while carrying all other equipment.

(3) Proven device for stopping tumbling of an arbitrarily shaped spacecraft.

(4) Test Equipment: Typical composition might include cutting and disassembly tools, X-ray and optical cameras, vibration pickup, strain gauges and oscilloscope.

(5) Additional propellants, batteries, or other supplies which may be needed for operational tests with object spacecraft.

(6) Repair equipment for structure, heat shield, lines, etc.

(7) Spare parts.

c. Duties of Crew

(1) Match orbit with objective spacecraft.

(2) Stop spinning or tumbling of object spacecraft where desired.

(3) Remove personnel to rescue spacecraft as required.

(4) Perform desired operational tests on object spacecraft.

(5) Measure and photograph damaged areas.

(6) Remove damaged or failed parts for engineering and scientific analysis on earth.

(7) Make repairs.

Structures and Materials Orbiting Laboratory

A complete structures and materials laboratory and fabrication facility with specially designed equipment would be placed in orbit. The following areas would be investigated.

(1) Dynamics of lightweight structures.

(2) Dynamics of large spinning structures.

(3) Effects of environment on structural properties.

(4) Effects of environment on material properties.

(5) Fabrication of thin-film structures and structural models.

(6) Manufacture of large thin-film surfaces.

(7) Test methods research.

(8) Control methods and control dynamics.

(9) Construction and deployment dynamics.

A survey of the equipment needed for such a laboratory should be made so that development can be started. A typical simple experiment is demonstrated in figure 3.

a. Objective: To conduct investigations in the fields of materials, structures, manufacturing methods and dynamics.

b. Equipment: A specially designed laboratory space station.

c. Duties of Crew: Station would be manned by engineers and specialists in their fields.

V. CONCLUSIONS

Man is an integral part of each testing situation. Where man is already present, investigations can be conducted without large amounts of specialized extra equipment. The versatility, adaptability, and judgment of the man cannot be duplicated.

The investigation and space rescue mission practically requires manned participation. Development of an unmanned vehicle which could meet all of the possible requirements is probably impossible, and development of a special vehicle for each mission would not be practical because of time considerations. A manned vehicle seems to be the only solution. Also, the investigating (rescue) crew could possibly make corrections or repairs. No unmanned alternative exists for the orbiting structures and materials laboratory.

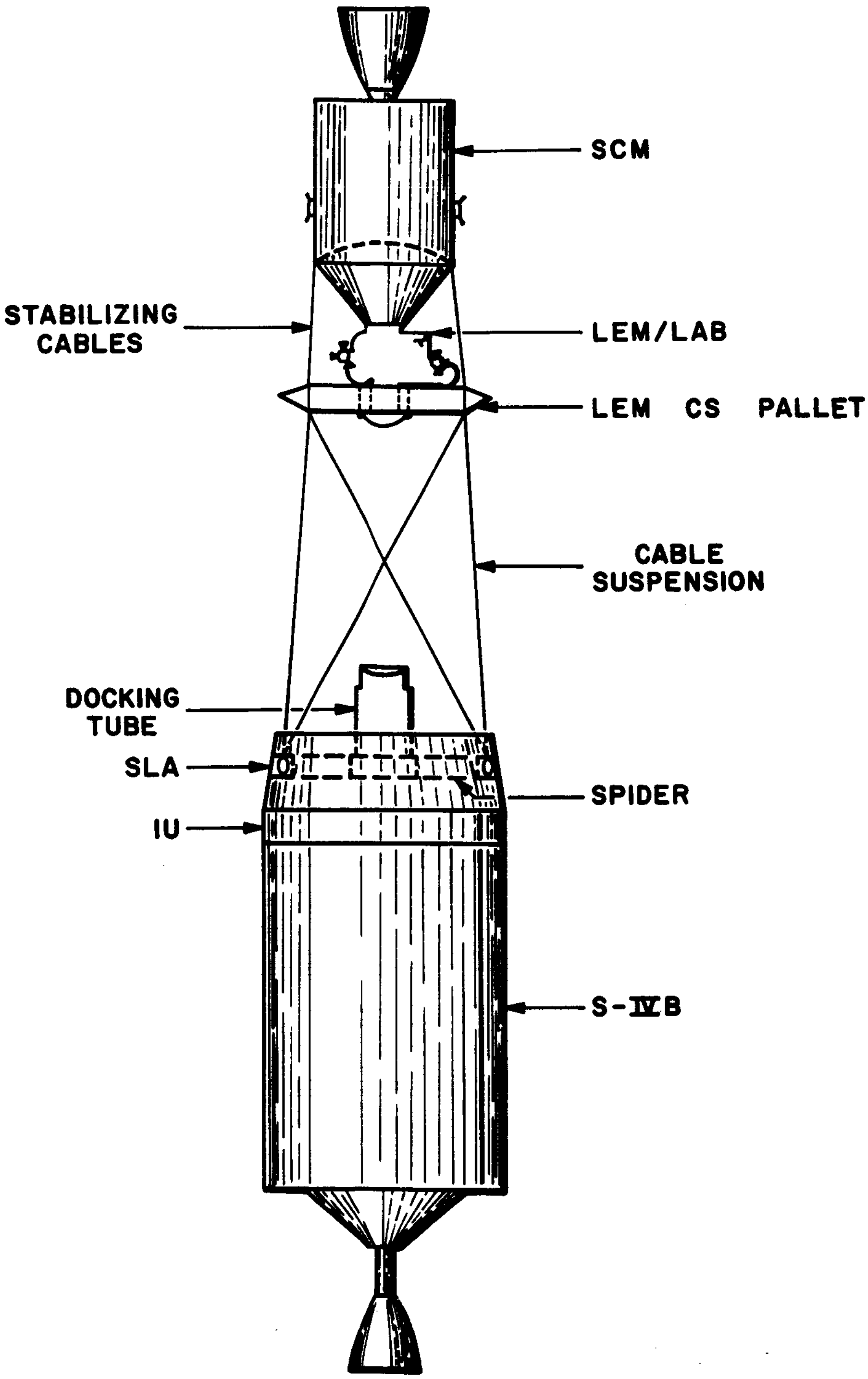

FIGURE 1. PROPOSED ARTIFICIAL GRAVITY SPACECRAFT

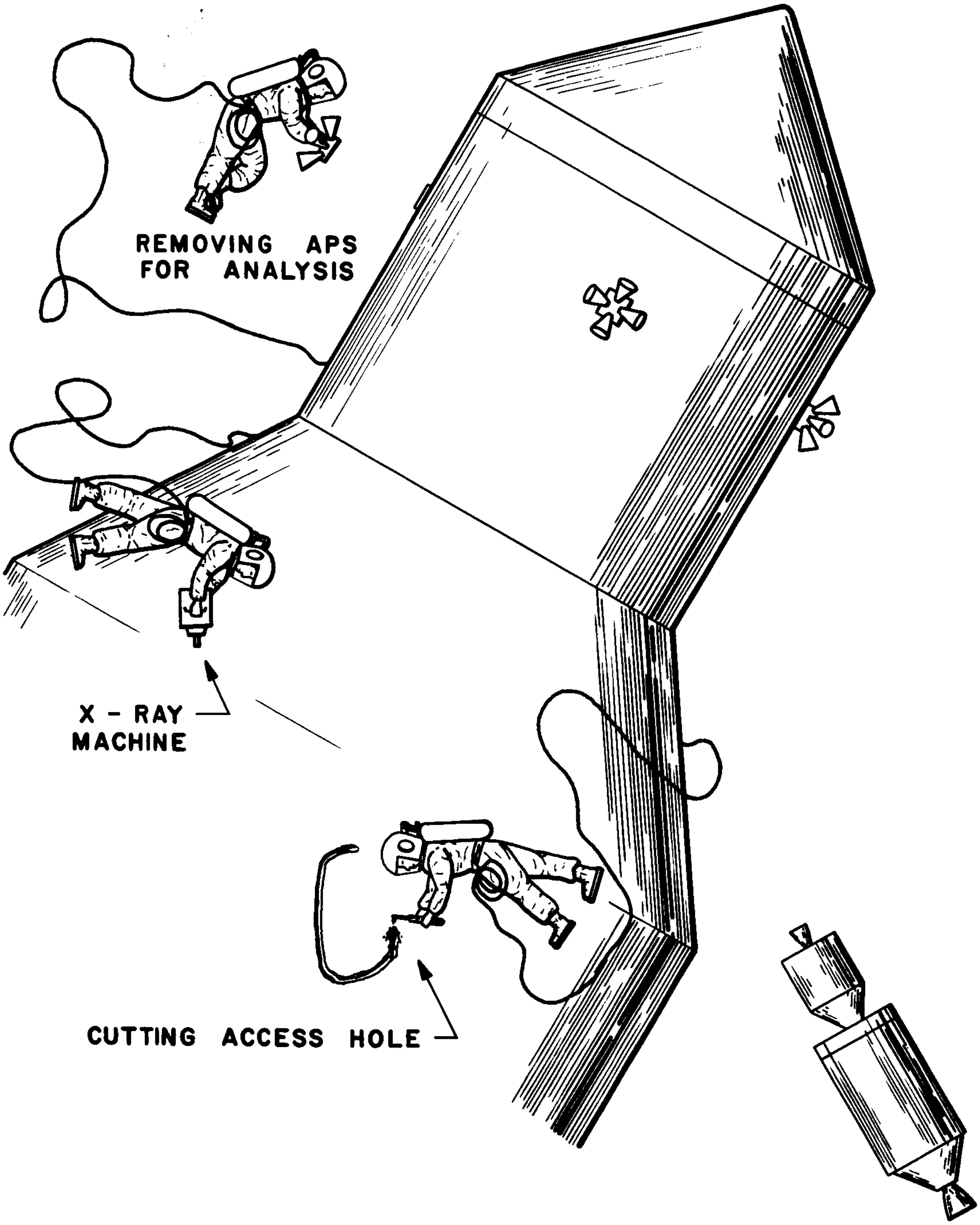

FIGURE 2. SPACE RESCUE FAILURE ANALYSIS ACTIVITIES

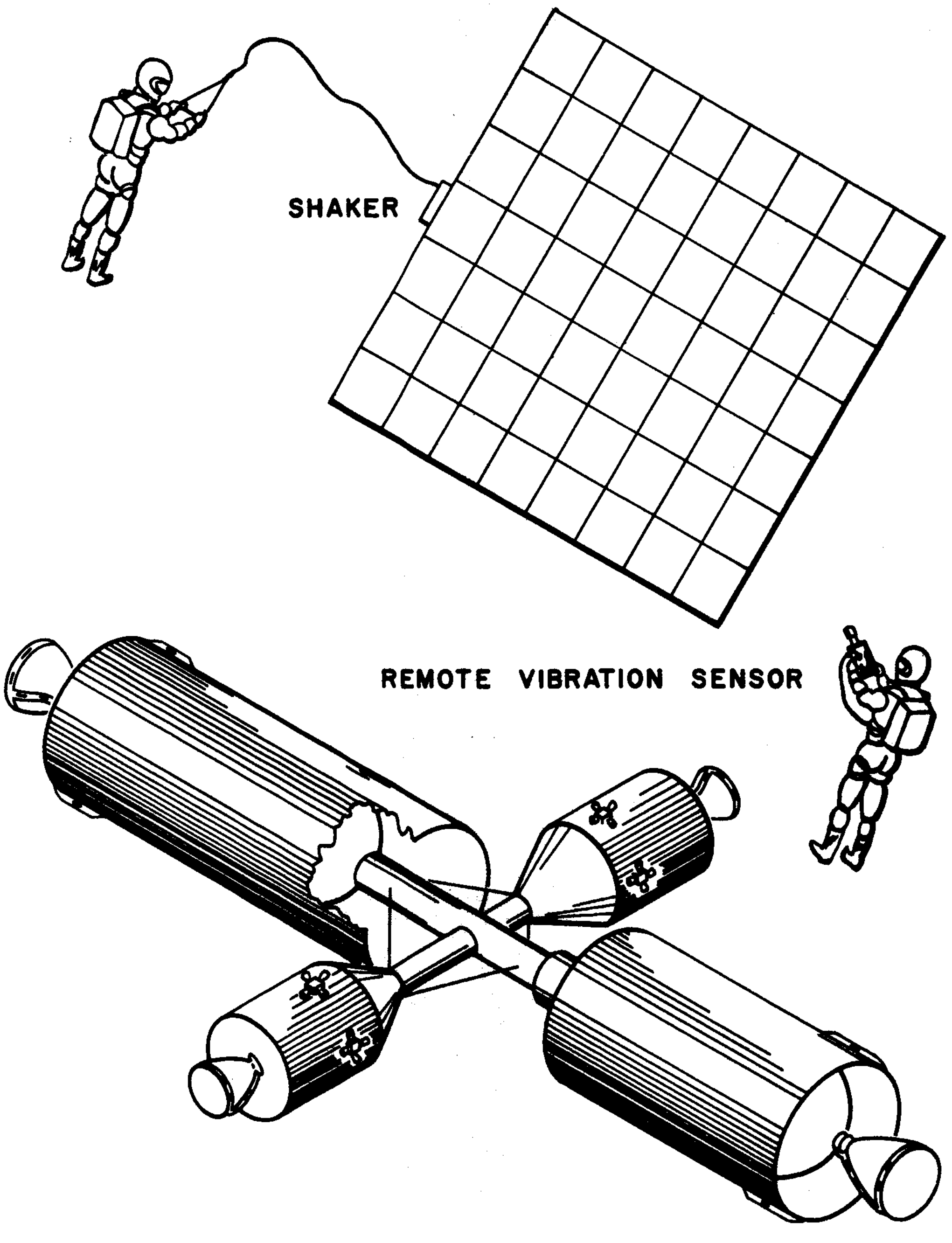

FIGURE 3. DETERMINING THE DYNAMIC PROPERTIES OF A TEST STRUCTURE

APPENDIX A

Orbital Vibration Measurement Experiment

Dynamics and control problems will probably exist for the lightweight structures now being planned for orbital use. Experimental data are needed to verify vibration analysis where parameters are vastly different from those of present structures. Gravitational and air loads prevent ground testing of many of the configurations. The only alternative is testing in orbit.

An S-IVB Apollo spacecraft would be vibration-tested using an internally mounted electrodynamic or electromechanical shaker. Approximately six accelerometers would be mounted internally on the spacecraft. These would provide frequency, mode shape, and damping data for the spacecraft and a standard for external measurements. Accelerometers would be attached to unprepared surfaces on the exterior of the vehicle using the most promising method(s) developed during ground tests in simulated space environment. The non-contact vibration sensor would be positioned and controlled by an astronaut during the test.

Additional measurements of environmental vibration levels could be made if desired. The non-contact sensor would also be used to measure deployment and operating vibrations of any payload structures.

A. Purpose and Objective

1. To evaluate equipment performance and vibration test procedures in the orbital space environment.

2. To measure the vibration characteristics of a spacecraft in orbit.

B. State of Present Development

All equipment being used for ground tests would need to be adapted to space environment.

C. Parameters to be Measured

Frequency, amplitude, and phase of structural vibrations. Comparison of data provided by various sensors.

D. Analysis of Performance of Experiment

The first item would be to establish the practicability of attaching sensors to an unprepared surface. Methods used would be the ones found most promising during laboratory tests. Results would be in form of the astronaut's recorded voice comments, time records, and quality of recorded data. Photographs could be used to evaluate accuracy of placement at premarked and unmarked locations.

The non-contact sensor would be hand-held or unrestrained during testing. One astronaut would be required for its operation. Value of a passive gyro stability package mounted with the sensor should be evaluated. A second astronaut would operate the control console, varying frequencies and force amplitudes and observing displacement amplitudes.

All measurements should be sampled, digitized, and telemetered to earth on a real-time basis where possible. If possible, two selected channels of analog data should also be telemetered, probably the ones which are selected for console display. In any case, the digital data should be stored on tape.

Environmental and operational vibration characteristics could be measured at any time if desired. Use of the non-contact displacement measuring equipment moving in free translation to measure surface flatness should also be investigated.

E. Methods of Analyzing and Interpreting Data

Data would be analyzed by conventional methods now in use.

F. Description of Experiment

A vibration analysis would be made on a manned spacecraft in orbit to determine the effect of the space environment on structural and material properties, especially damping. Two different methods of measuring vibrations from a point outside the body would be evaluated. One would require attaching a sensor to the body; the other would not require contact.

G. Astronaut Timeline Analysis

Operation	Men	Time (hr)
Attach sensors	1	1
Deploy non-contact sensor	1	1
Connect, warm-up and checkout console	1	1/2
Conduct test	2	2
Store equipment	2	1/2

H. Preflight and Recovery Facilities Required and Data Handling Procedures

No special preflight is needed. Up to three channels of telemeter data for some parts of the experiment would be desirable. Storage of data on magnetic tape to be returned with crew is required.

I. Equipment Description

(1) Internally mounted accelerometer system.

(2) Accelerometer for external mounting with installation materials.

(3) Non-contact vibration sensor system.

(4) Electrodynamic shaker (100 lb vector).

(5) Test control console.

J. Spacecraft Modification

(1) Mounting of internal accelerometer system.

(2) Shaker mount.

(3) Equipment storage.

(4) Electrical connections and wiring.

(5) Weight and Volume.

Item	Weight (lb)	Volume (ft^3)
Internal accelerometer system	10	.15
External accelerometer	5	.15
Non-contact sensor system		
amplifier	20	.5
antenna	10	1.0
Shaker	100	1.0
Console	20	.5
TOTAL	165	3.3

M. Envelope

None of the items listed has an irregular shape. The control console must, of course, be mounted in an accessible location during operation.

N. Power Requirements

500 watts - 20 minutes.

200 watts - 40 minutes.

O. Thermal Constraints

Most of power dissipation would be inside the spacecraft.

P. Other Environmental Constraints

Electromagnetic radiation from shaker would need to be reduced to compatible levels considering other spacecraft equipment. All deployed equipment would be adapted to space environment.

Q. Telemetry

Not absolutely essential. Experiment can be adapted to whatever is available.

R. Development Program

All equipment would need to be redesigned to adapt to environment and reduce weight. Primary problems are heat dissipation, material compatibility for deployed items, and attaching methods for external accelerometers.

S. Cost can vary considerably, depending mostly on the effort made to reduce weight.

	Item	Deployment Cost
	Non-contact sensor	$20,000.
	Shaker	25,000.
	External accelerometer mounting	15,000.
	Console	10,000.
	Other equipment	2,000.
	System studies	20,000.
	TOTAL	$92,000.

APPROVAL NASA TM X-53545

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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