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The Test Facility Requirements For The Thermal Vacuum Thermal Balance Test of the Cosmic Background Explorer Observatory

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ABSTRACT

The Cosmic Background Explorer Observatory (COBE) underwent a thermal vacuum/thermal balance test in the Space Environment Simulator (SES) at the Space Simulation Test Laboratory, Goddard Space Flight Center. This was the largest and most complex test ever accomplished at this facility. The 4 meter X 4 meter (13 feet X 13 feet) spacecraft weighed approximately 2223 kilograms (4900 pounds) for the test. The test set-up included simulator panels for the inboard solar array panels, simulator panels for the flight cowlings, Sun and Earth Sensor stimuli, Thermal/Radio Frequency Shield heater stimuli and a cryopanel for thermal control in the Attitude Control System/Shunt Dissipator area. The fixturing also included a unique 4.3 meter (14 feet) diameter Gaseous Helium Cryopanel which provided a 20 Kelvin environment for the calibration of one of the spacecraft's instruments, the Differential Microwave Radiometer. This cryogenic panel caused extra contamination concerns and a special method was developed and written into the test procedure to prevent the high buildup of condensibles on the panel which could have led to backstreaming of the thermal vacuum chamber. The test was completed successfully with a high quality simulated space environment provided to the spacecraft. This paper describes the test requirements, test set-up, special fixturing requirements, the related contamination concerns and a general discussion of the test and test results.

INTRODUCTION

The Cosmic Background Explorer (COBE) Observatory, (Figure 1) launched in November 1989 aboard a Delta launch vehicle into a sun synchronous polar orbit, was built and tested at the NASA/Goddard Space Flight Center, Greenbelt, MD. The mission objective of the Observatory was built to explore and study the 3 Kelvin Cosmic Background Radiation measuring light in wavelengths from 1 micrometer to 1 centimeter. The Observatory carries three instruments. The Differential Microwave Radiometer and the two cryogenically cooled instruments, the Far Infrared Absolute Spectrophotometer (FIRAS) and the Diffuse Infrared Background Experiment (DIRBE)

The COBE Observatory underwent a combined thermal vacuum, thermal balance and mission simulation test. The 24 day test was completed in June, 1989. The test took place in the

8.5 meter x 12.2 (28 feet X 40 feet) Space Environment Simulator (SES) in the NASA Goddard Space Flight Center Space Simulation Test Engineering Environmental Test Laboratory.

SPACECRAFT TEST CONFIGURATION

The COBE Observatory is approximately 4 meters (13 feet) tall and approximately 4 meters (13 feet) wide at its widest diameter (Figure 2). The spacecraft weighed approximately 2223 kilograms (4900 pounds) for the test. The major changes to the flight configuration which affected the test set-up (ref. 1) were as follows:

- o The Wallops Flight Facility (WFF) and the Tracking Data Relay Satellite (TDRS) Omni Antenna and the support boom was not installed.
- o The flight Solar Arrays and Cowlings were not installed.
- o The DMR horns had temperature controlled targets inside them and the flight contamination covers were removed.
- o Two spacecraft power cables were routed through an external diode box.
- o Helium was not flowed through the flight dewar aperture cover.
- o The flight dewar ejectable cover remained in place. The DIRBE and FIRAS instruments were not exposed to the chamber environment.
- o A test multilayer insulation thermal blanket was used instead of the flight Thermal/Radio Frequency Shield thermal blanket.
- o Plumbing lines were used to vent the flight dewar.
- o Test-only temperature controlled survival heaters were installed on the Thermal/RF Shield panels.

TEST REQUIREMENTS

As in any thermal vacuum test, this highly complex test set-up was designed to meet the test objectives of the COBE Observatory and to provide the Observatory with the best possible space simulation. The following are the major test objectives of the COBE Observatory and some of the specific test objectives which influenced the test set-up (ref. 1) are also listed.

- o Provide the assurance that specified mission objectives will be met.
- o Verify the functional operation of the flight components at elevated and lower than expected flight temperatures thereby proving that there is design margin at the system level.
- o Provide confidence that the Observatory will survive the thermal environments imposed upon COBE during launch and mission sequence.
- o Determine operating and performance characteristics of COBE during a simulated orbital environment.
- o To obtain a pumpdown curve and contamination measurements that will allow for a formulation of an estimate of the potential of COBE to self-contaminate its instruments.

- o Verify the flight worthiness of COBE.
- o Validate the data flow paths for nominal and contingency mission operating procedures between the COBE spacecraft systems and the Payload Operating Control Center (POCC) under simulated mission conditions.
- o Perform tests to demonstrate compatibility with Ground and Space Networks.

Specific Thermal Objectives

- o Verify that the thermal mathematical model used to thermally design COBE and which will be used to support the mission, sufficiently represents COBE.
- o Verify the thermal performance of the thermal/RF shield.
- o Thermally cycle the COBE electronics at least four times between their qualification temperatures

Specific DMR Objectives

- o To simulate early mission conditions, in which the instruments rely on survival heaters to prevent extremely cold temperatures.
- o Establish thermal balance temperatures for the DMR heads with a variety of heater combinations.
- o Measure offset while viewing equal temperature cold targets with all radiometers at operational temperatures.
- o Measure stability of instruments at operational temperatures, while viewing cold targets.
- o Attempt calibration by differentially warming targets with heaters.

Specific Power Objectives

- o Demonstrate the ability of the shunts to dissipate the maximum load imposed upon then under hot conditions.

Specific Attitude Control Objectives

- o Stimulate the Coarse Sun Sensors to demonstrate that they operate properly.

TEST SET-UP

The same test set-up was used for all three phases of the test, thermal vacuum, thermal balance and mission simulation (Figure 3).

Fixturing

The Observatory was mounted to a aluminum Payload Attach Fitting (PAF) which is the interface to the Delta rocket. The PAF was mounted onto a cylindrical aluminum support structure which was bolted to the chamber's 2.7 meters (9 foot) payload table. Mounted inside the support structure was a temperature controlled Diode Box through which one of the

Observatory's power cables were installed (Figure 5). Inside of the PAF, a cryopanel was mounted which was used for the Attitude Control/Shunt Dissipator. A Zero-Q interface provided temperature equilibrium between the PAF and the Observatory. The flight cowlings were replaced by 6 flux temperature controlled heaters panels. Three flux temperature controlled panels were mounted to simulate the in-board flight solar array panels. A large aluminum structure was built and hung in the chamber which provided radiant heat to approximately 25 percent of the Thermal/RF Shield. Six heater plates mounted on poles which resembled STOP signs, were mounted in the appropriate places to provide radiant heat to the Observatory's sun and earth sensors (Figure 6). Lights mounted in special fixtures were used as stimuli for the sensor. A 453.6 Kilograms (1000 pound) 4.3 meter (14 foot) gaseous Helium cryopanel was mounted in a support frame and hung over the Observatory to provide a 20 Kelvin environment for the DMR heads. A multilayer insulation blanket was mounted around the periphery of the cryopanel so that the entire area within the thermal shield would not be influenced by the chamber walls. A copper strap was clamped to the cryopanel and mounted on the 31 gigahertz (GHz) radiometer head to provide a conductive heat sink. Vent lines for the flight LHe Dewar was brought out through chamber penetrations.

Contamination Control Measuring Devices

Also a major part of the test requirements and which added complexity to the test set-up, were the contamination measuring devices. Three temperature controlled 10 megahertz (MHz) Quartz Crystal Microbalances were used to measure the real time quantitative outgassing of contaminants from the Observatory. The QCMs were spaced radially from the DMR heads. Each device was placed .6 meters (2 feet) from the Observatory at heights of 74, 142 and 224 cm (29, 56 and 88 inches) measured from the spacecraft support structure. The QCM's were operated at -40°C and -60°C. A Residual Gas Analyzer was used to provide a real time analysis of gases and chemical elements in the chamber. A Coldfinger, which is a cylindrical device was used to provide a quantitative and qualitative idea of the amount of outgassing occurring when the device is activated at LN2 temperature during the last eight hours of the test. A Scavenger Plate, with the same purpose as the Coldfinger was also used, but this device is activated for the entire test. Six COBE project provided Witness Mirrors were installed in strategic locations on the Observatory and were used to detect molecular and particulate contamination.

Test Instrumentation

A large and diverse amount of test instrumentation was used on the Observatory and the fixturing. A significant amount of ground support equipment was required for operating the test instrumentation as well as the flight instrumentation. For thermal temperature measurements, 160 copper-constantan thermocouples were mounted on the Observatory. Approximately 200 copper-constantan thermocouples were mounted on the various fixtures. Twelve silicon diodes were mounted on the 20K cryopanel. Twenty Eight heaters circuits were mounted on the Observatory in various places including the Thermal/RF Shield. Seventy heater circuits controlled the fixturing. Also, there were 13 strain gauges and 3 accelerometers mounted on the flight dewar.

DISCUSSION

Major Test Preparations

The most difficult preparation task in terms of dollars and hours was the refurbishment of the SES Helium Skid. The original purpose of the Helium Skid was to operate the chamber 20K Helium Cryopanel. In the test, the Helium Skid was used to cool the 20 K Helium Cryopanel which was mounted over the spacecraft. After the Helium Skid was refurbished, the plumbing had to be rerouted to accommodate the lines to the test Helium Cryopanel. All total the task took two years to complete. The 28 year old Helium Skid was a major concern because its reliability was in question up to the week before the test and it was critical to the success of the test. The Helium Skid performed flawlessly throughout the duration of the test. Several chamber shroud and gimbal leaks developed prior to the test, all were repaired except for a gimbal leak which only occurred during LN2 operations.

The 453.6 kilograms (1000 pound) 4.3 meters (14 foot) 20K GHe cryopanel was made in two pieces and required a massive support structure which was mounted onto the chamber gimbal. The cryopanel was mounted 6 meters (20 feet) above the payload table and a minimum of 15 centimeters (6 inches) above the Observatory with one end of the panel raised higher than the other to prevent contamination from dripping onto the spacecraft.

The Thermal/RF Shield stimulus panel which backed 25 percent of the Thermal/RF Shield was also hung from the chamber gimbal and was difficult to install because of its height above the chamber floor and its ten separate panels.

Caution was used for handling and mounting the cowling panels and the solar array simulators because they mounted directly to the flight spacecraft.

A bakeout and test verification run was completed prior to the flight test to bakeout the chamber and fixturing and to verify the proper operation of the Helium Skid and the 20K cryopanel, the ACS/Shunt dissipator cryopanel, 5 temperature conditioning units, all test heater circuits and thermocouples, to thermally map the SES chamber for test thermal analysis purposes and to determine the temperature gradients across a test cowling. Stainless Steel wire was strung across the chamber to provide strain relief for the test cabling.

This test was the first test to be completed using the new Space Simulation Laboratory data acquisition system. Another unusual aspect of the test set-up was the use of an air conditioning system which cooled the spacecraft during ambient testing. The air conditioner was kept outside the chamber and lines made of cleanroom bagging material was routed through special holes in the test cowlings. Another first was in using the new data system to control the 70 flux controlled heater circuits, which greatly simplified the task.

Certainly not the least challenging part of the test set-up was installing the spacecraft around the fixturing, removing the protective cleanroom bagging (and then reinstalling the bag post test), building enough scaffolding to sufficient height to allow access to critical portions of the Observatory, hooking up the cryogenic lines, the instrumentation, and properly positioning the fixturing.

All of the pretest and post test chamber activities were accomplished under Class 110,000 cleanroom conditions with all personnel wearing full cleanroom garments.

Test Description

THE COBE Observatory underwent a 4-cycle thermal vacuum test and a hot and cold case thermal balance test with a mission simulation test simulating several orbits of the spacecraft (ref. 2) (Figure 4).

The chamber shrouds remained at LN2 temperature, -191°C, for the duration of the test. The 133 flight and test heater circuits provided the necessary heated environment for the spacecraft. The test started with a long hot soak, during which time the experimenters hoped that most of the outgassing of the Observatory would occur. The Mission Simulation tests were run during the hot and cold thermal balance phases so a kind of cyclic stabilization was established (ref 3.). The test duration was 24 days.

Special Concerns

The major concern of the test was the buildup of gas condensibles on the 20K GHe cryopanel which averaged between 18K and 20K during the test. Prior verification testing of the panel had shown that if enough gas condensed on the panel and the panel warmed up, the chamber pressure would rise rapidly above 3 x 10^{-3} Torr which would cause backstreaming of the diffusion pumps (the pumps do not have main valves) which would be a catastrophic event. To prevent this problem, the test procedure was written to warm up the cryopanel to 40K, a sufficient temperature to release the gas condensibles, every 2 or 3 days. This procedure was accomplished during temperature transition periods to not interfere with the hardware testing.

Another concern was the "cold leak" in the chamber gimbal. The gimbal was not flooded with LN2 except for critical Attitude Control testing and only when the 20K cryopanel was warm.

Safety was always a concern. A test run and a critical lift procedure was written for the raising and lowering of the 20K cryopanel. This massive panel was hinged on one side and was raised in a nearly 90 degree vertical position for the installation of the spacecraft and was then lowered via an electric winch to its supports for the test configuration.

The COBE LHe Dewar was brought into the chamber at superfluid conditions (less than 2.8K) and the dewar had to be properly vented throughout the test. Also the dewar Aperture Cover Bandclamp was heated during the test to the prevent possible release of the cover which would have exposed the 2K FIRAS and DIRBE instruments to a much warmer environment resulting in a catastrophic ice build-up. The Observatory pyrotechnic devices were safed to prevent accidental firing.

Stringent cleanroom rules were strictly enforced to prevent molecular or particulate contamination.

Test Results

The detailed test results are beyond the scope of this paper, however, an overview of the results and some test problems which affected the facility will be discussed. The first problem which occurred caused the thermal system and the diffusion pumps to be secured. An o-ring froze causing the dewar vent line to leak helium. The vent line was pumped on with the chamber at 3 x 10^{-3} Torr and the test was able to continue (ref. 2). Later on in the test, the same leak caused the chamber shrouds to be secured again. The chamber pressure remained on the 10^{-8} Torr range for the majority of the test. For the last two days of the test, the pressure rose to the 10^{-7} Torr range and stayed there. Leakchecks were performed as a precaution but no explanation was found. One of the 17 chamber diffusion pumps failed, but the test was not affected.

The procedure for warming the 20K panel was very successful. The chamber pressure rose no more than one decade. Due to the cold leak, the gimbal was not flooded with LN2 for the majority of the test. This caused the Earth Sensors to be "noisy" and only two of the three sensors were operated for most of the test (ref. 3). The gimbal was flooded several times with LN2, with the 20K cryopanel warm, to allow all three of the Earth Sensors to be operated.

Chamber vibration and RF interference did not interfere with FIRAS functional testing as had been expected. While there were a few anomalies which occurred with the DMR instrument, the test was very successful because the 20K cryopanel provided the necessary environment for the radiometer heads to be tested at their operating temperatures.

All contamination criteria was successfully passed. Overall the COBE Observatory test objectives were met.

SUMMARY

This was by far the largest most complex test ever accomplished at the Goddard Space Simulation Test Laboratory. The many different unique fixtures and multitude of instrumentation caused the test preparations to be spanned over a period of several years. All of the man-hours and dollars spent for hardware culminated into an overall successful test in which the COBE Observatory test objectives were met. The Observatory is now making astronomical history as it orbits the Earth making a Skymap which scientists will use to attempt to find the origins of our great Universe.

ACKNOWLEDGEMENTS

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2. "Goddard Space Flight Center Environmental Test Report," Space Simulation Test Engineering Section Procedure 37544-4-89R, August 1989.

3. "Test Report for the Thermal Balance/Thermal Vacuum/Mission Simulation Test of the Cosmic Background Explorer (COBE)," COBE-TR-750-1113-3200-01D, November 1989.

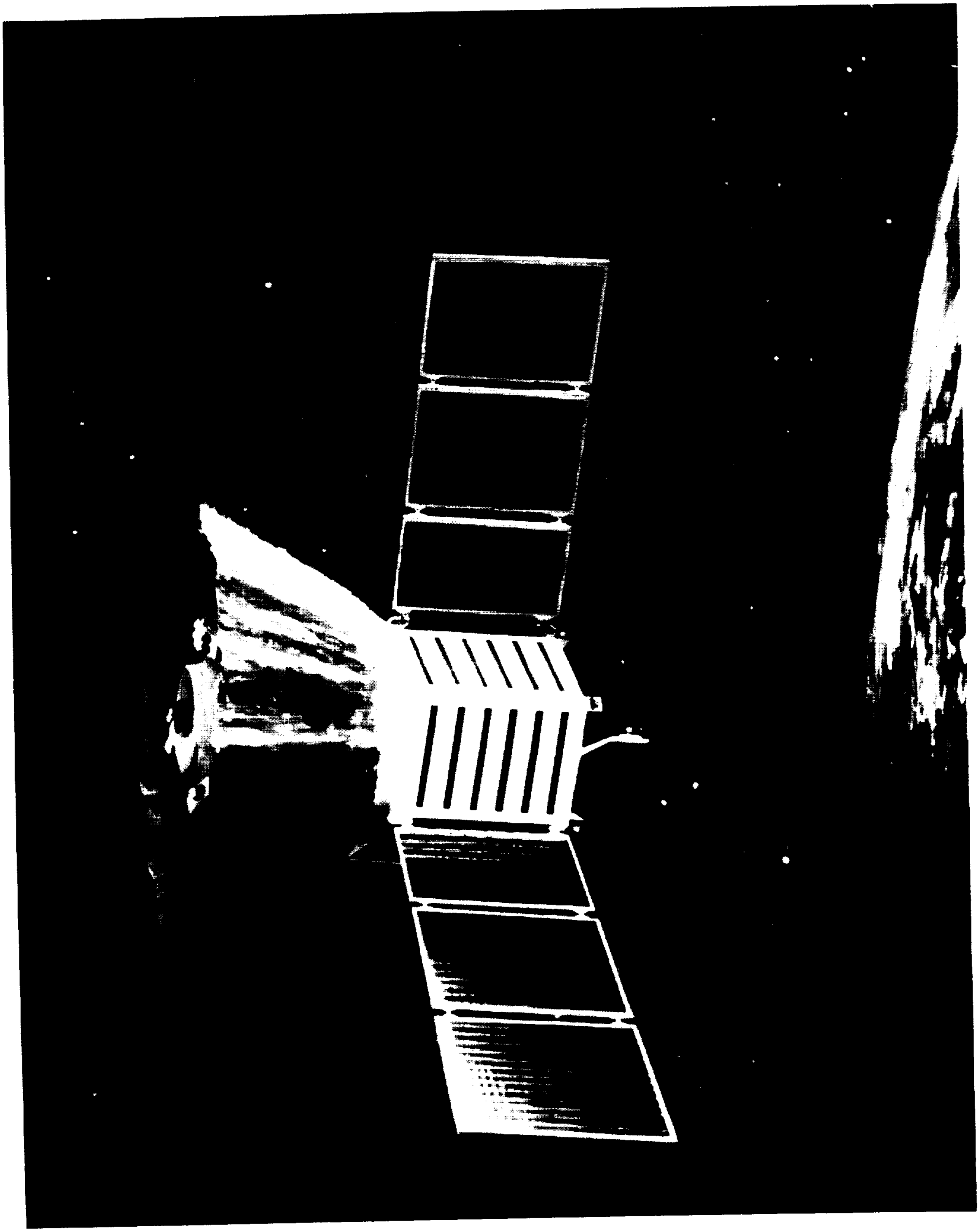

Figure 1. The Cosmic Background Explorer Observatory

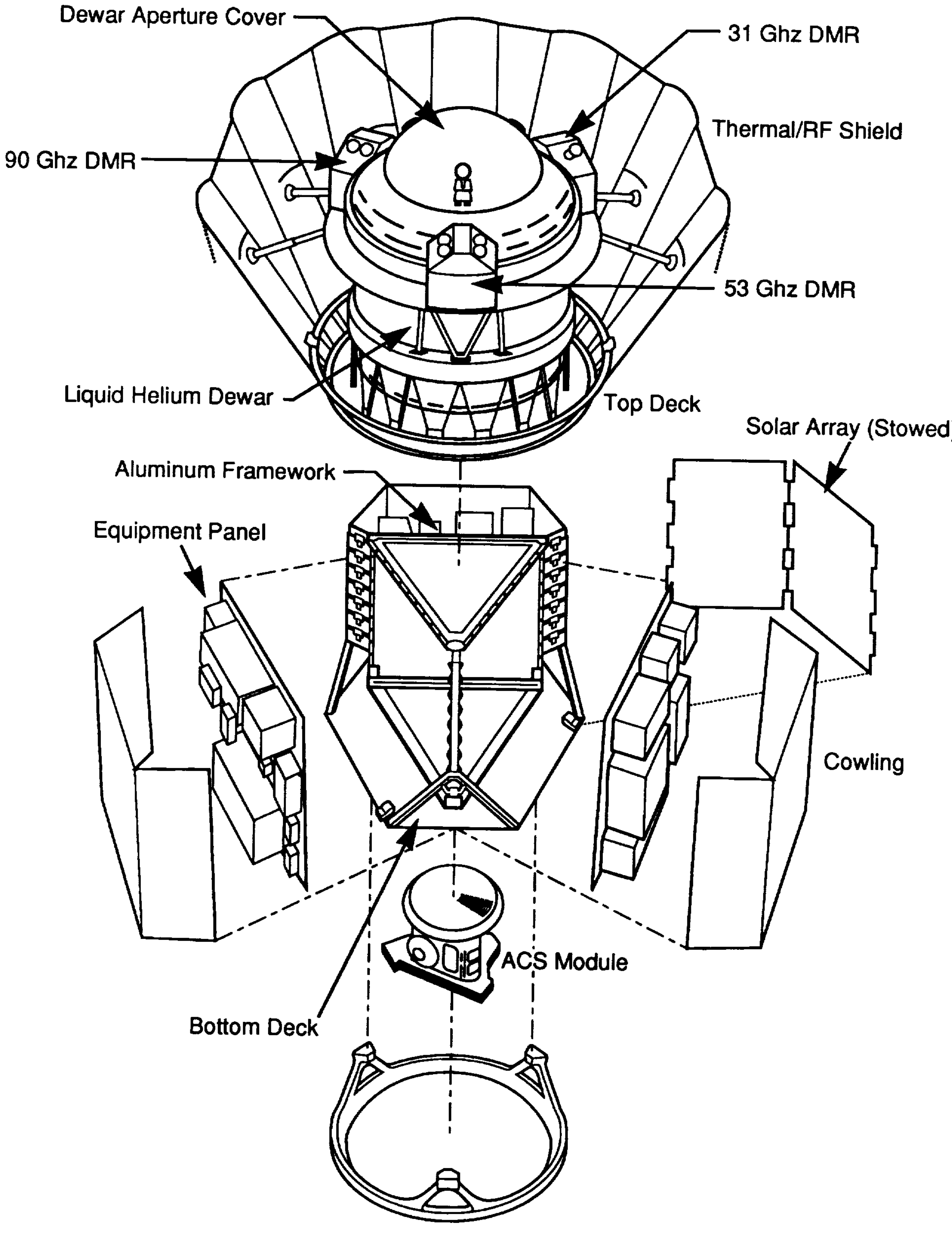

Figure 2. COBE Observatory (Exploded View)

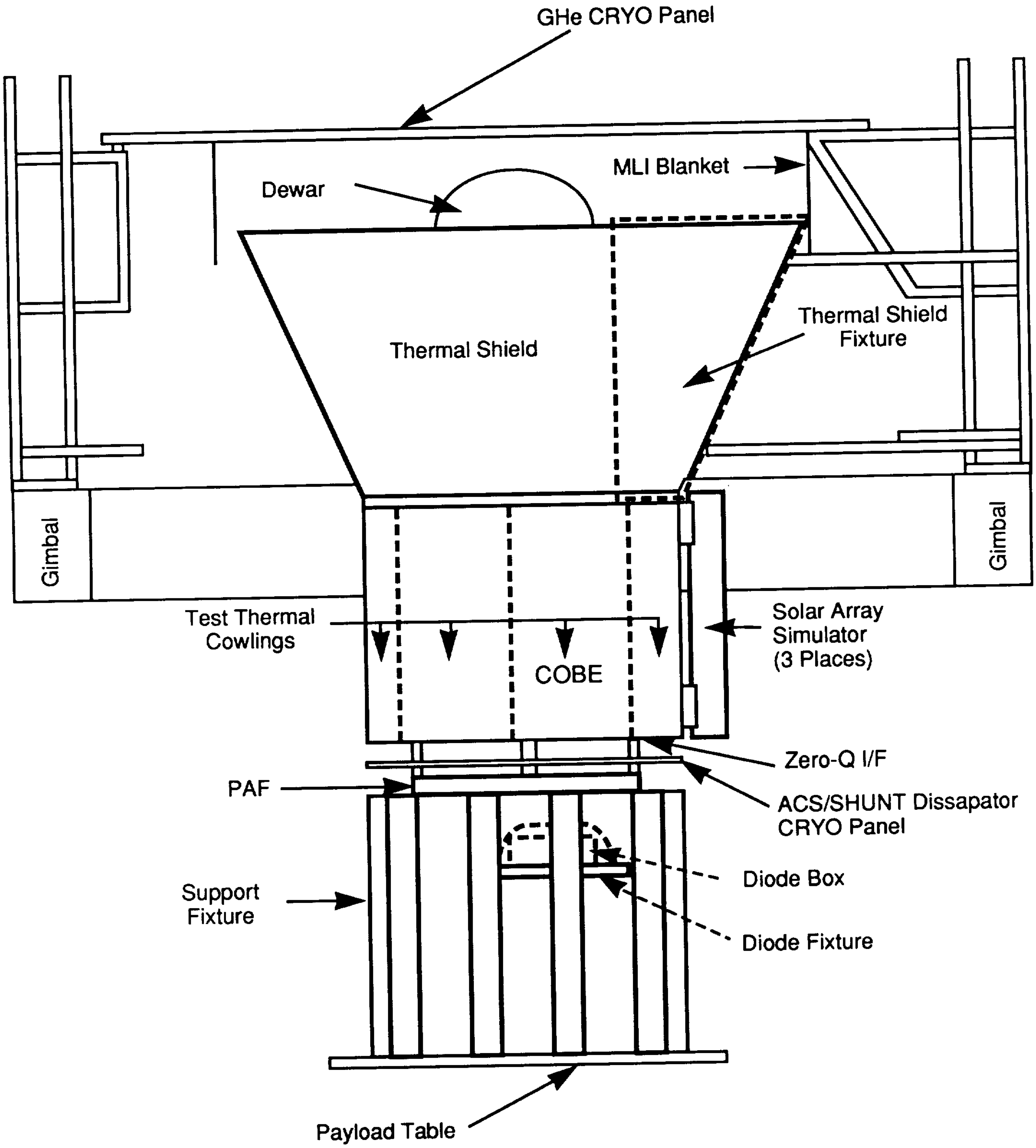

Figure 3. COBE SES Test Setup

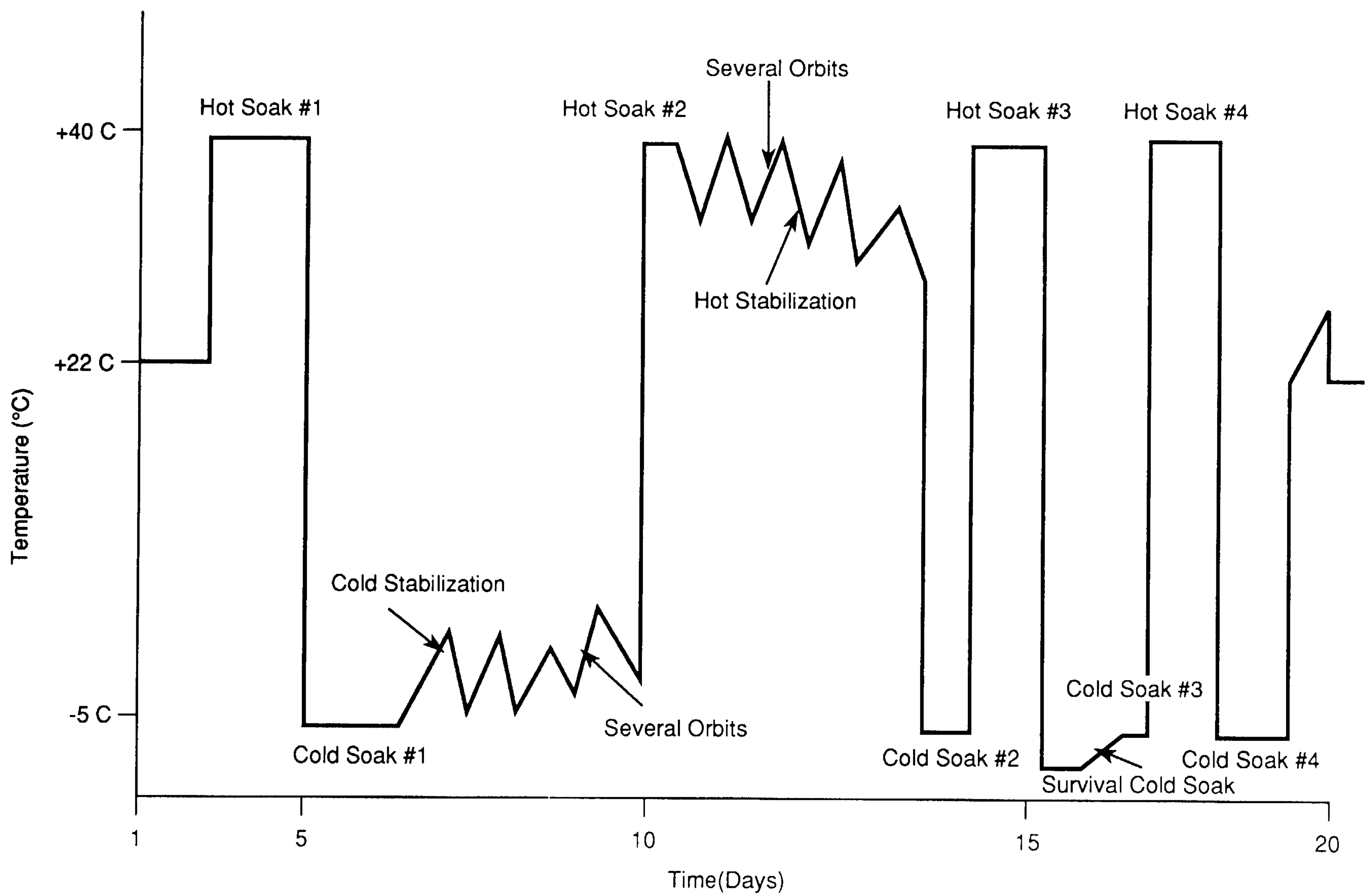

Figure 4. COBE TV/TB Mission Simulation Test Profile

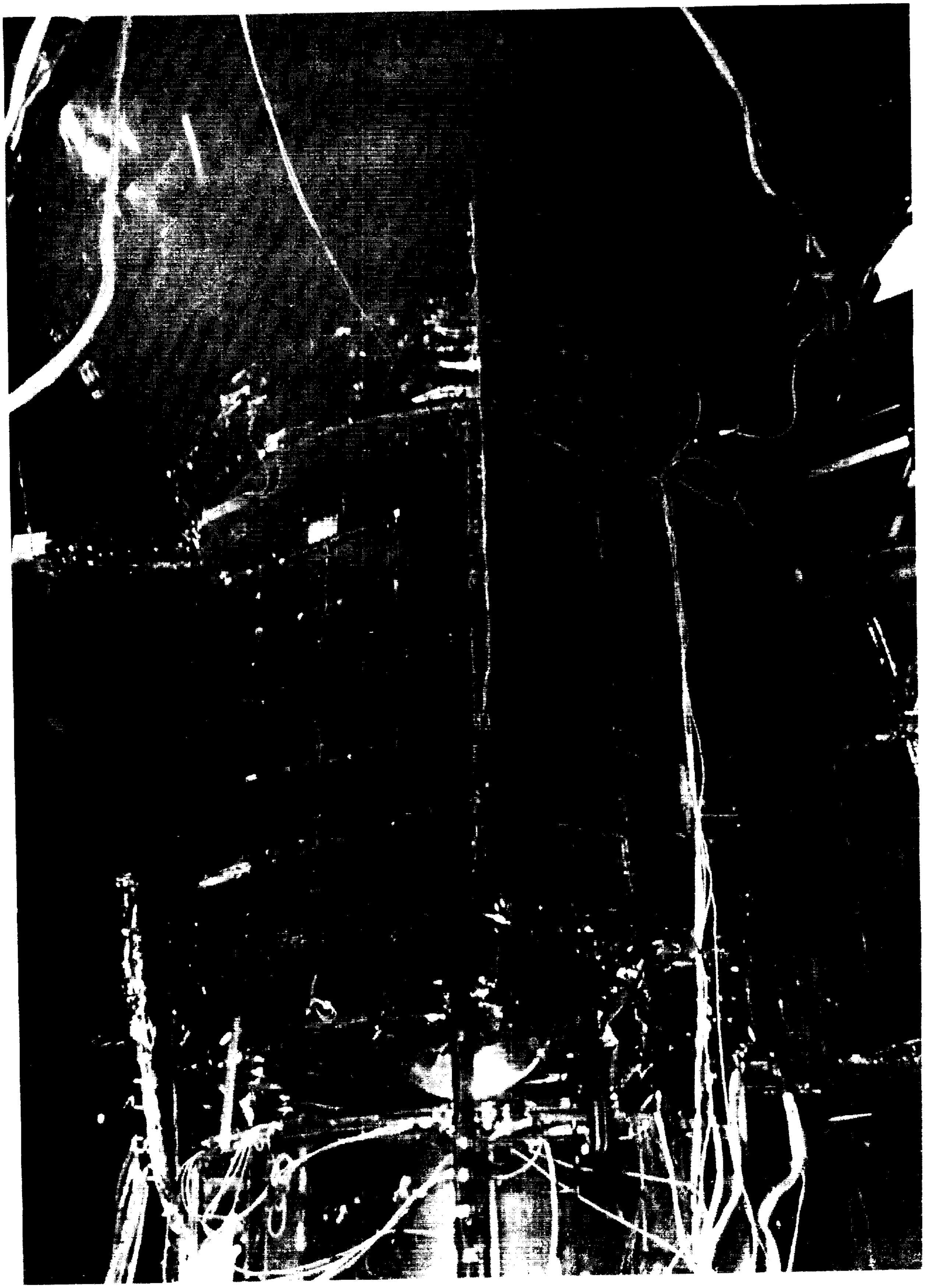

Figure 6. COBE In SES

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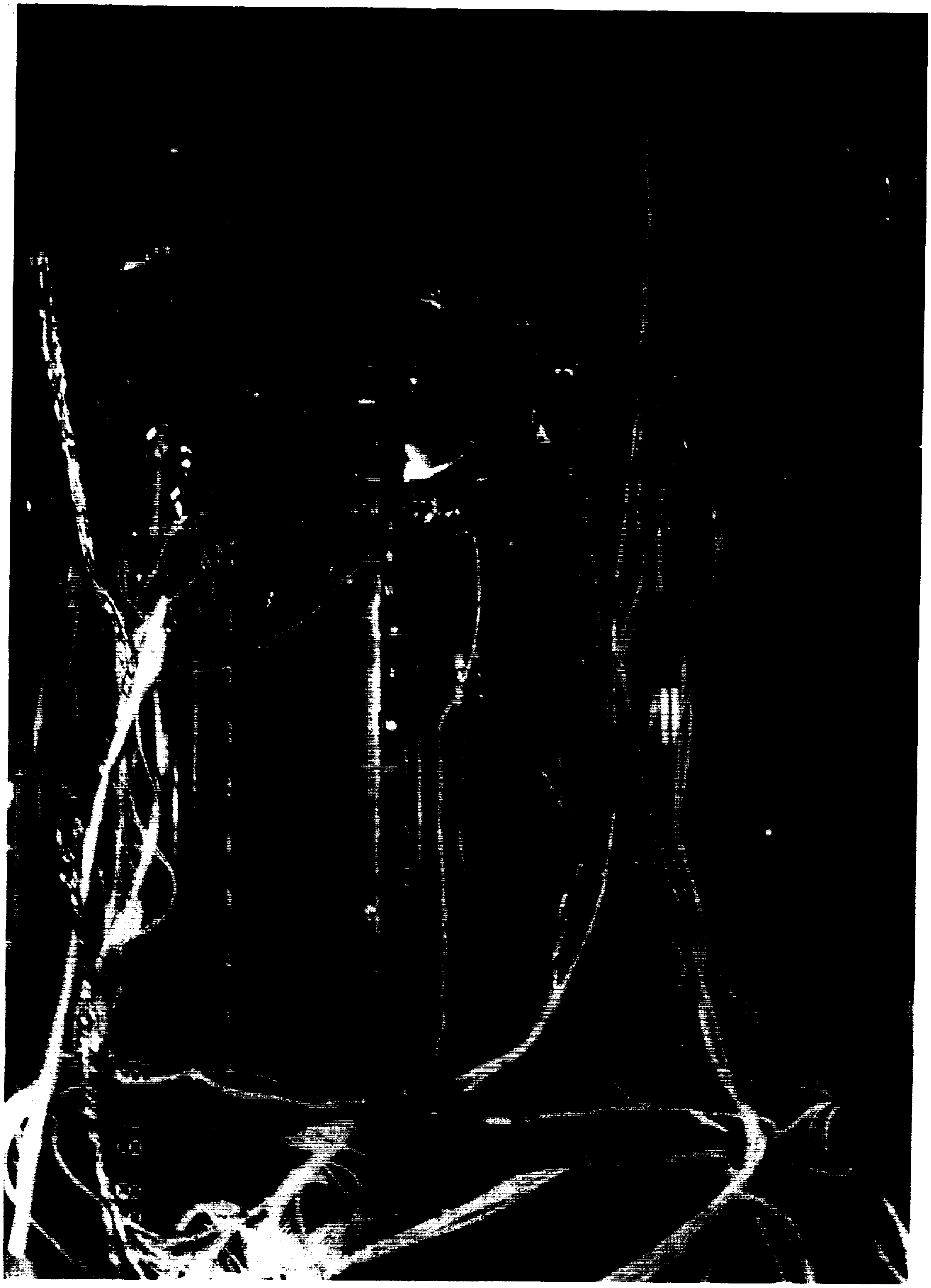

Figure 5. Instrumentation and Test Harnesses