NASA Technical Memorandum 104140

p 28

AN AUTOMATED THERMAL VACUUM TEST SYSTEM FOR USE IN ENVIRONMENTAL TESTING OF FLIGHT SYSTEMS AND COMPONENTS

Craig S. Cleckner
Jeffrey R. Knutson

November 1991

National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

TABLE OF CONTENTS

FIGURES

TABLE OF CONTENTS (continued)

FIGURES

Abstract

Unusual requirements for the PD/ADS transducer thermal vacuum testing led to the development of a conductively heated and cooled, fully automated, bell-jar test system. The system has proven to be easily adaptable for other tests, and offers the advantages of quick turn-around and low operational cost.

Introduction

The Aeroassist Flight Experiment (AFE) is an experimental blunt-body reentry vehicle designed to demonstrate the concept of aerobraking in orbital transfer maneuvers. The Pressure Distribution/Air Data System (PD/ADS) consists of an array of pressure ports and associated transducers in the AFE aerobrake for pressure data acquisition during the aeropass. The pressure data information will be used for Computational Fluid Dynamics (CFD) code validation.

Acceptance testing for space flight hardware at the NASA Langley Research Center is governed by the Langley General Environmental Verification Specification (GEVS) for National Space Transportation Payloads, Subsystems, and Components. As a part of the acceptance testing program for the pressure transducer (PT) flight units, each unit must undergo a thermal-vacuum test. As developed from the GEVS document, these thermal-vacuum tests subject the pressure transducers to six temperature cycles between the transducer operating extremes of 0 to 200 degrees F (See Figure 1). Each cycle includes a two hour dwell at each temperature extreme and activation of the transducer at the beginning of the dwell period. The dwell ensures that the temperatures of the internal components of the pressure transducers are allowed to equalize. The activation of the transducers at the beginning of each hot or cold dwell serves as a screen for weak transducers. In addition to the GEVS requirements, the PD/ADS test requirements also specify that the temperature ramp rates for the transducers be held to one degree F per minute in both heating and cooling modes.

Each cycle lasts approximately 11 hours from beginning to end. Although continuous (around-the-clock) operation could have been used to perform this test, it was decided that a staggered day shift could provide one cycle per day without compromising the test. Since the acceptance test program lasted about a year and involved approximately one test per month, day shift operation eliminated the personnel shortages that around-the-clock operation entails.

System Background

The logistics of the flight unit deliveries, acceptance schedule, and the long-term availability of test equipment within Langley's Systems Engineering Division necessitated the use of a Centorr bell-jar vacuum system for this test program. The Centorr bell-jar is capable of achieving vacuum levels as low as 5×10^{-7} torr. In routine operation the system achieves vacuum levels of 5×10^{-6} within two hours of activation. This vacuum system offered the advantages of quick turnaround, low operational cost, and ready availability. The major drawbacks to the system were its relatively small test chamber, and its lack of provisions for heating and cooling capability.

In general, heating and cooling capability in previous bell jar tests had been provided by radiative heat transfer using heat lamps and some type of liquid nitrogen cold shroud. A first-generation thermal-vacuum fixture of this type is shown in Figure 2. While appropriate for certain types of tests, radiative heat transfer has several inherent problems. First, the ability to heat radiatively far outstrips the ability to cool by radiation. Secondly, because of the relatively weak coupling between the heat source or sink and the test subject, tight control of the test subject's temperature is difficult to achieve. This is true of both the absolute temperature of the test subject and the temperature ramp rate applied. Figure 3 displays data taken from an early PD/ADS test in which the system relied on radiative heating and cooling. Finally, as seen in Figure 2, heating lamps and liquid nitrogen shrouds tend to be bulky and take up much of the usable space in a bell-jar.

Once installed in the AFE vehicle, the pressure transducers and their mounting brackets will be wrapped in Multi-Layer Insulation (MLI). This effectively isolates the transducers from the radiation environment of the aerobrake, so that essentially all of the external heating applied to the transducers comes from conduction through the vehicle structure. Since the transducers will be heated/cooled conductively in the aerobrake, the test system was designed for conductive heat transfer.

Earlier in the PD/ADS program, candidate pressure transducers had been run through an evaluation test program that included thermal-vacuum testing in a bell-jar. These earlier tests had initially employed radiative heating and cooling, although by their conclusion the system had been modified to provide conductive heat transfer (See Figure 4). The second-generation fixture shown in Figure 4, has a liquid nitrogen cooling coil clamped to the top surface which provides efficient conductive cooling. The heating capability of this fixture is still derived from radiant heat lamps. Although, since the test article is mounted on the underside of the plate away from the lamps, the heating provided to the test article is conductive in nature. This second-generation fixture proved to be extremely useful, and quite adequate for small test articles. In spite of these improvements, a new fixture with greater surface area had to be devised to handle the larger numbers of transducers to be tested under the acceptance test program. The new, third-generation, fixture had to be capable of accommodating up to eight pressure transducers at one time (a typical shipment), while providing for uniform conductive heating and cooling of the units.

Fixture Design

The third-generation fixture is comprised of a pair of parallel, rectangular aluminum plates placed upright (on edge) in the bell jar. Aluminum was chosen as the plate material because of its relatively high thermal conductivity which serves to minimize temperature gradients across the surface of the plates. The plates are each 13 inches wide, 12 inches tall, and 0.38 inches in thickness. The outer surfaces of both plates are drilled and tapped with a distribution of 10-32 UNF screws to provide easy mounting for up to eight pressure transducers at a time. This configuration provides a total of 312 square inches of fixture surface area, as compared with 113 square inches for the second-generation fixture mentioned previously. Front, side and top views of the fixture situated in the bell-jar are shown in Figures 5 through 7, respectively. The heating capability for the new fixture is provided by five contact strip heaters which are sandwiched between the two aluminum plates. The heater strips are OMEGA Model OT-1505/240. The strips are metal-sheathed with a solid phenolic core, and are 0.355 inches in total thickness. The strips are rated for 500 watts each, providing a total available heating power of 2500 watts. Cooling capability is provided by a liquid nitrogen cooling coil which is also sandwiched between the aluminum plates. The cooling coil is constructed of 3/8 inch OD copper tubing. Figure 8 shows a cut-away view of the third-generation fixture and details the heater strips and cooling coil routing.

One of the aluminum plates is drilled and tapped with a pattern of 22, 1/4-28 UNF Helicoil inserts. The other plate is drilled with a matching pattern of clearance holes and countersinks. During assembly, the aluminum plates are pulled together by the 22, 1/4-28 countersunk bolts. The bolts are tightened until firm contact is achieved between the aluminum plates and the heater strips. This requires that the cooling coil be crushed slightly out-of-round, which ensures good thermal contact between the cooling coil and the aluminum plates. Copies of the shop drawings for the plates, complete with bolt patterns, are shown in Figures 9 and 10.

Control System

Due to the high efficiency of conductive heat transfer, temperature changes can occur too rapidly for manual control. This required that the entire heating and cooling process be controlled by an automated feedback control system. This innovative combination of conductive heat transfer and automated control had never been previously utilized by Systems Engineering Division.

The control system hardware consists of a KEITHLEY series 500 Data Acquisition and Control system (DAC) coupled to an IBM compatible personal computer (PC). The DAC can accommodate a variety of different temperature sensors, such as thermocouples, Resistance Temperature Devices (RTDs), thermistors and solid state temperature sensors. In addition to reading sensors, the DAC can output analog or digital control signals to operate the liquid nitrogen solenoid valves or heater strip AC power controllers. The DAC can also control functions related to the items under test. For instance, the DAC was configured to activate the PD/ADS pressure transducers at the beginning of each dwell period. This system provided exceptional control of the test unit temperature, ramp rates, dwell period, and cyclical repeatibility.

Although the heat input of the heater strips may be easily varied by adjusting the electrical current, the cooling capacity is not so easily adjusted. An earlier configuration of the test system using a simple, single solenoid control of the liquid nitrogen flow showed a tendency to overshoot the desired setpoint. When it became evident that more precise control of the liquid nitrogen flow was necessary, a variable flow, digital LN_2 valving system was implemented. An advantage to this type of variable flow rate valve is it's ease of interfacing with the data acquisition and control system. The theory behind this valving concept consists of N number of on/off valves connected in parallel with each other. The flow rate of each valve is calibrated by means of different size orifices to obtain a binary relationship to one another. Each valve has a flow rate twice as large as the next smallest valve. This binary relationship allows easy calculation of the total flow rate for any given combination of open or closed valves. The number of discreet flow rates achievable is a function of N, the number of valves implemented. For the PD/ADS bell jar, a two valve combination was implemented, resulting in four discreet flow rates including off. This valving system greatly enhanced the control system's ability to accurately control the LN_2 flow through the cooling coil. Figures 11-13 dramatically illustrate the improvement in the control system LN_2 flow control resulting from the use of the two valve arrangement. Figure 11 shows the desired time-temperature response for the SUNLITE Reference Cavity Test. Figure 12 is a plot of the actual control thermocouple response with the original one-valve arrangement. Finally, Figure 13 is a plot of the control thermocouple response after the implementation of the two valve arrangement.

Control System Software

Software for the system is written in a format specific to the Keithley controller. Prior to the development of the current bell jar test facility, control software was written from scratch or old programs modified to accommodate various temperature profiles or parameters as needed. This approach proved to be difficult and time consuming as each piece of new or modified software had to be tested and verified prior to use for actual testing. With these and other shortcomings in mind, software was written which will accommodate a variety of differing tests without additional programming effort. This menu driven software is readily used by test technicians with little computer experience.

In function, the operator is prompted to enter the temperature profile that is desired. This is done by entering groups of three key parameters. They are the target temperature, the ramp rate, and the dwell. Target temperature is the temperature that you want to achieve. Ramp rate is the rate at which the temperature is to change and dwell is the period of time to stay at the target temperature. Concatenated groups of these three parameters can define the most complex or basic temperature profile. After data entry by the operator, this profile is automatically written to a floppy disk. When the control section of the program is run, these parameter groups are read from the disk and executed in sequence. To allow for flexibility, the previously defined profile can be interrupted during the test and new parameters entered manually in real time.

The section of the software that actually controls the temperature is rather basic and does not incorporate sophisticated proportional, integral and derivative functions. Yet, despite it's simplicity, the software provides excellent system control. Proportionality in the heating and cooling functions is included as follows. The percentage of available heat called for is a function of the error signal squared. The error signal is the difference between the desired temperature and the actual temperature. The proportional band is two degrees F. Therefore, when the error reaches two degrees the system is calling for 100% heat. When the system calls for cooling, the valving system provides three LN_2 flow rates to choose from. The lowest flow rate is called for at an error of .5 to 1 degree F. The second level of flow is called for between 1 degree and 2 degrees F. At an error of over two degrees F. the highest flow rate is called for.

The software saves data from up to 18 sensors on disk at user-defined intervals. This data is time-tagged and saved in ASCII format for direct importation to most plotting and analysis programs.

System Safety

Automated testing can be subject to failures which can cause loss of control of the process underway. Potentially damaging levels of heat/cold can be harmful to personnel, the items under test or the facility itself. Steps must be taken before hand to ensure that there are no catastrophic results in the event of failure. Associated with this bell jar test system are three safety devices. The first of these is simply a backup battery power supply which protects the system from voltage surges and spikes, and provides up to 20 minutes of power in the event of a line power failure. The second device is an independent safety setpoint unit adjusted to detect temperature out-of-bound conditions. If these conditions are detected the test is aborted and a system safing procedure occurs. The third device is a DAC monitor unit. This unit monitors normal system operation and has the ability to interrupt the heat or cold sources. The computer must send a signal to this unit periodically and also read back a return signal. If this protocol is not repeated within a set period of time, the DAC monitor assumes a failure has occurred and interrupts the test. The computer program is written to interrupt the protocol upon detection of abnormal conditions such as too rapid temperature change or the actual temperature of the process not agreeing with the desired temperature. This protocol will, of course, also be interrupted by any hardware failures or stoppage of the computer. An aborted test must be manually reinitiated. A flowchart schematic of the system and all its components is shown in Figure 14.

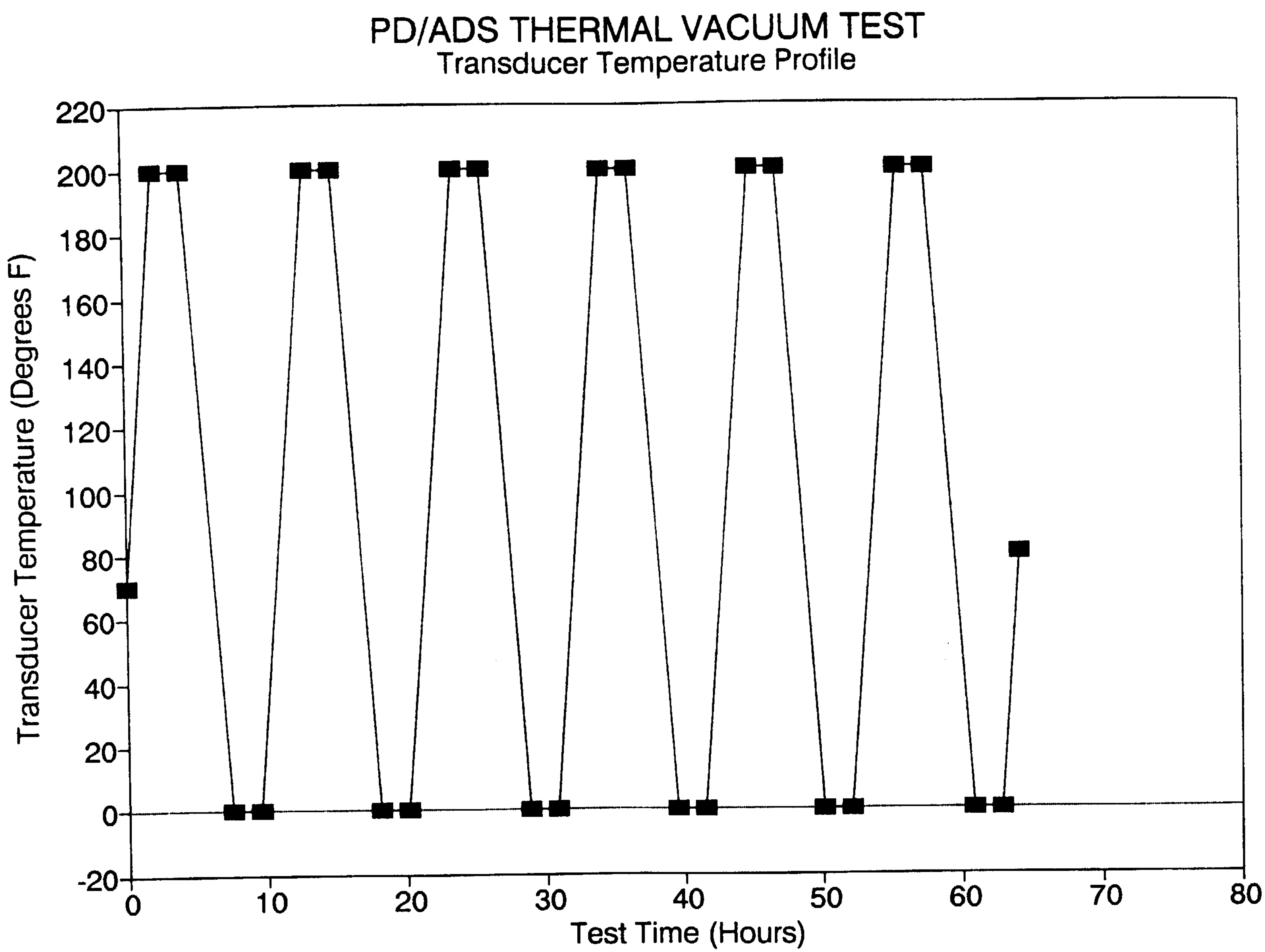
Conclusions

The test system has proven to be extremely flexible for providing temperature cycling of small payloads. The system provides a fully automated, conductive heating and cooling capability, which is adaptable to virtually any test scenario using an easy-to-use software program. This system provides exceptional control of the test article temperature, ramp rates, dwell period, and cyclical repeatibility.

The versatility of the test system is enhanced by the large surface area of the aluminum plates and the distribution of 10-32 UNF threaded holes over the surface. It is a simple matter to machine adaptor plates to allow other tests to be performed with the PD/ADS fixture.

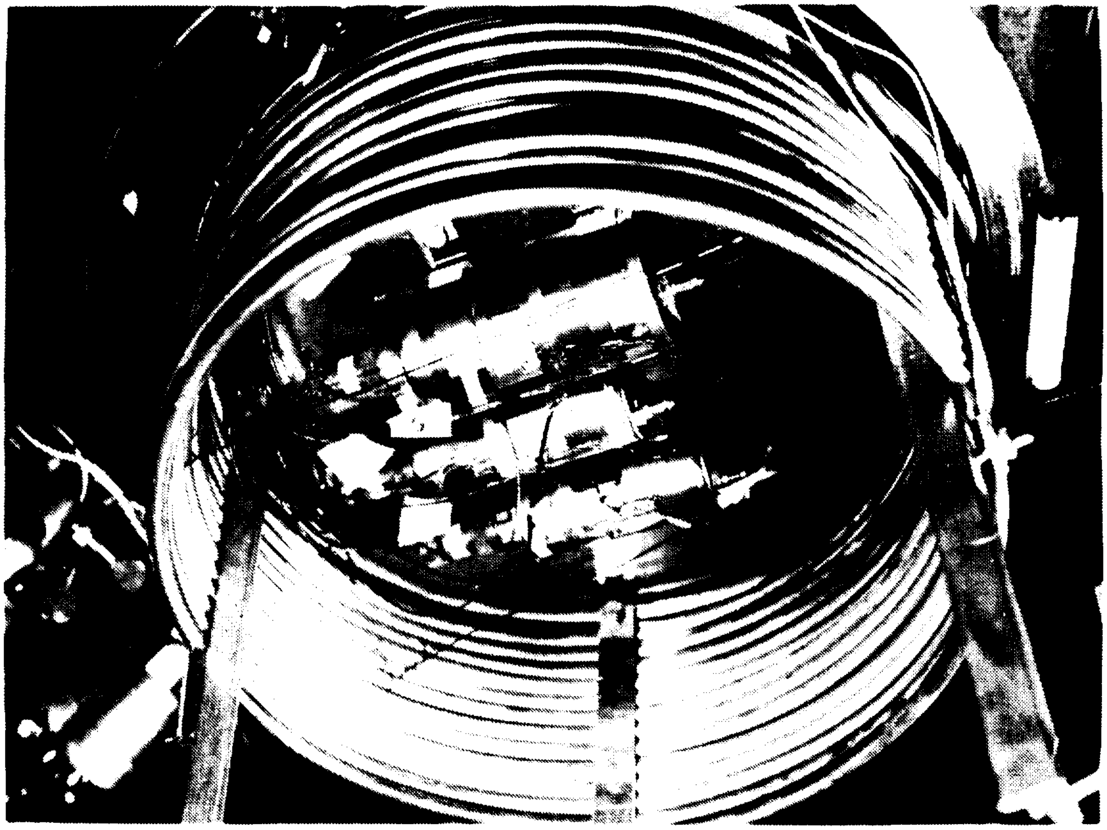
In its earlier, evaluation version, the system was used to test the PD/ADS evaluation transducers, and the Stanford University-Nasa Laser In-space Technology Experiment (SUNLITE) reference cavity mount. In addition to the PD/ADS acceptance test program, the final system has also been used to test the triaxial accelerometer mounting for the Rarefied-flow Aerodynamic Measurement Experiment (RAME), another AFE experiment; the Lidar In-space Technology Experiment (LITE) boresight prism assembly; and the SUNLITE mass storage disc drive. Photographs of several of these tests are included in Figures 15 thru 17.

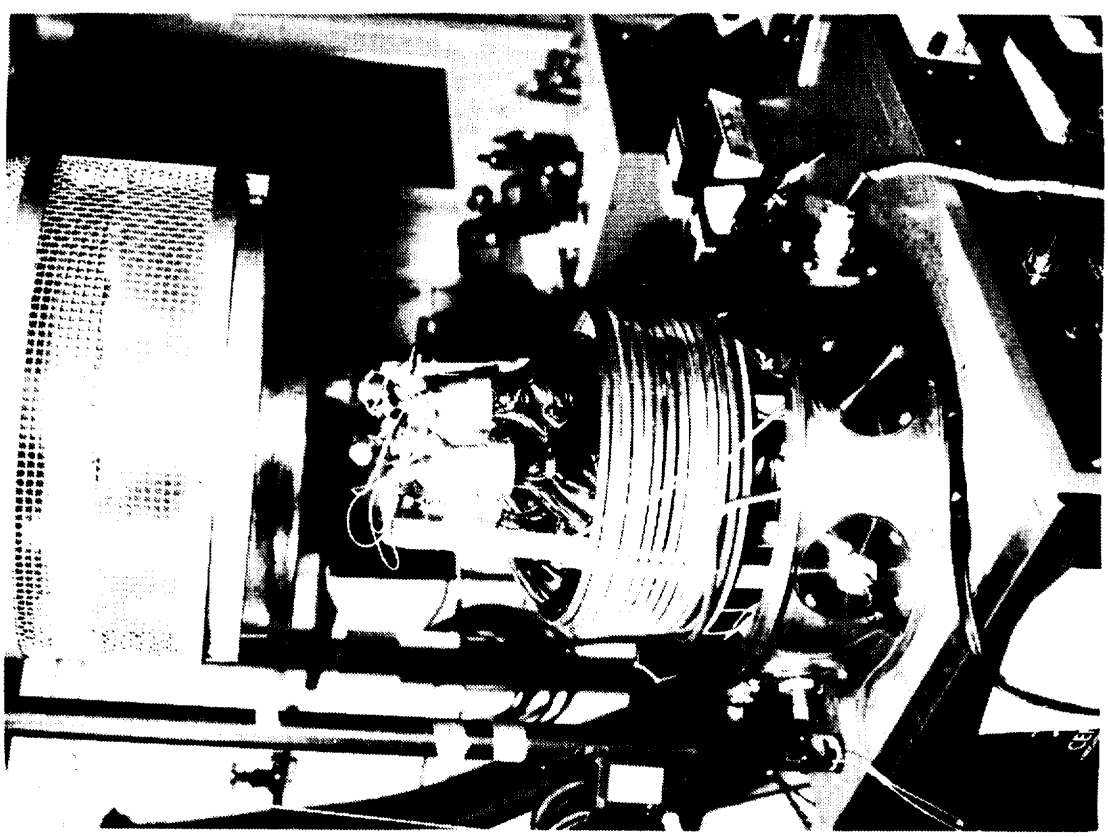
For the PD/ADS tests, the maximum and minimum temperatures achieved were 0 degrees and 200 degrees F, respectively. The heating and cooling ramp rates were one degree F per minute. On the RAME test, the fixture was only taken to a maximum of 150 degrees F. However, the ramp rates applied were the maximum rates achievable by the system. The maximum heating ramp rate was about 5.5 degrees F per minute, while the maximum cooling ramp rate was about 6.5 degrees F per minute.



Desired Temperature Profile for PD/ADS Pressure Transducers

Figure 1

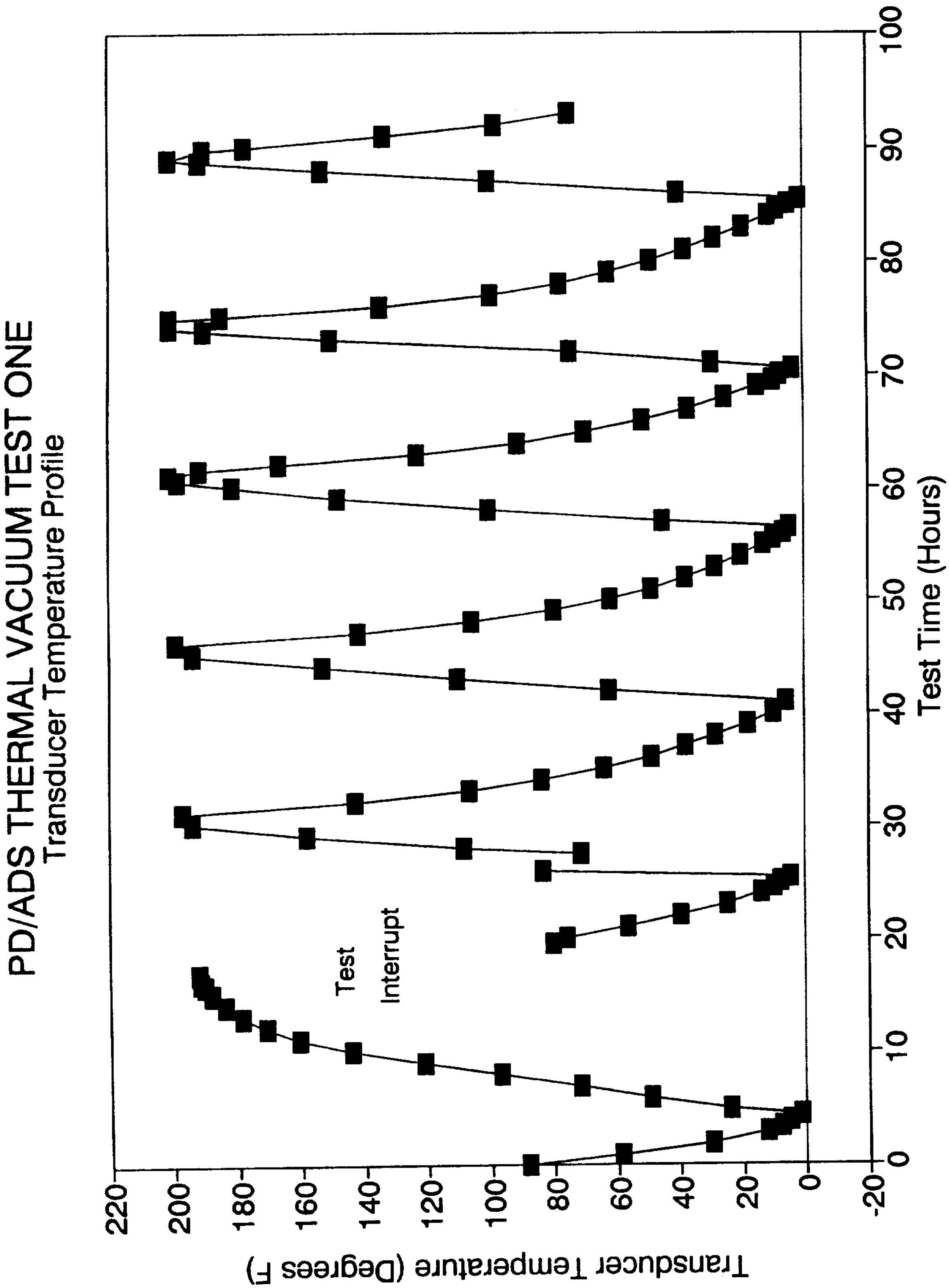




ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

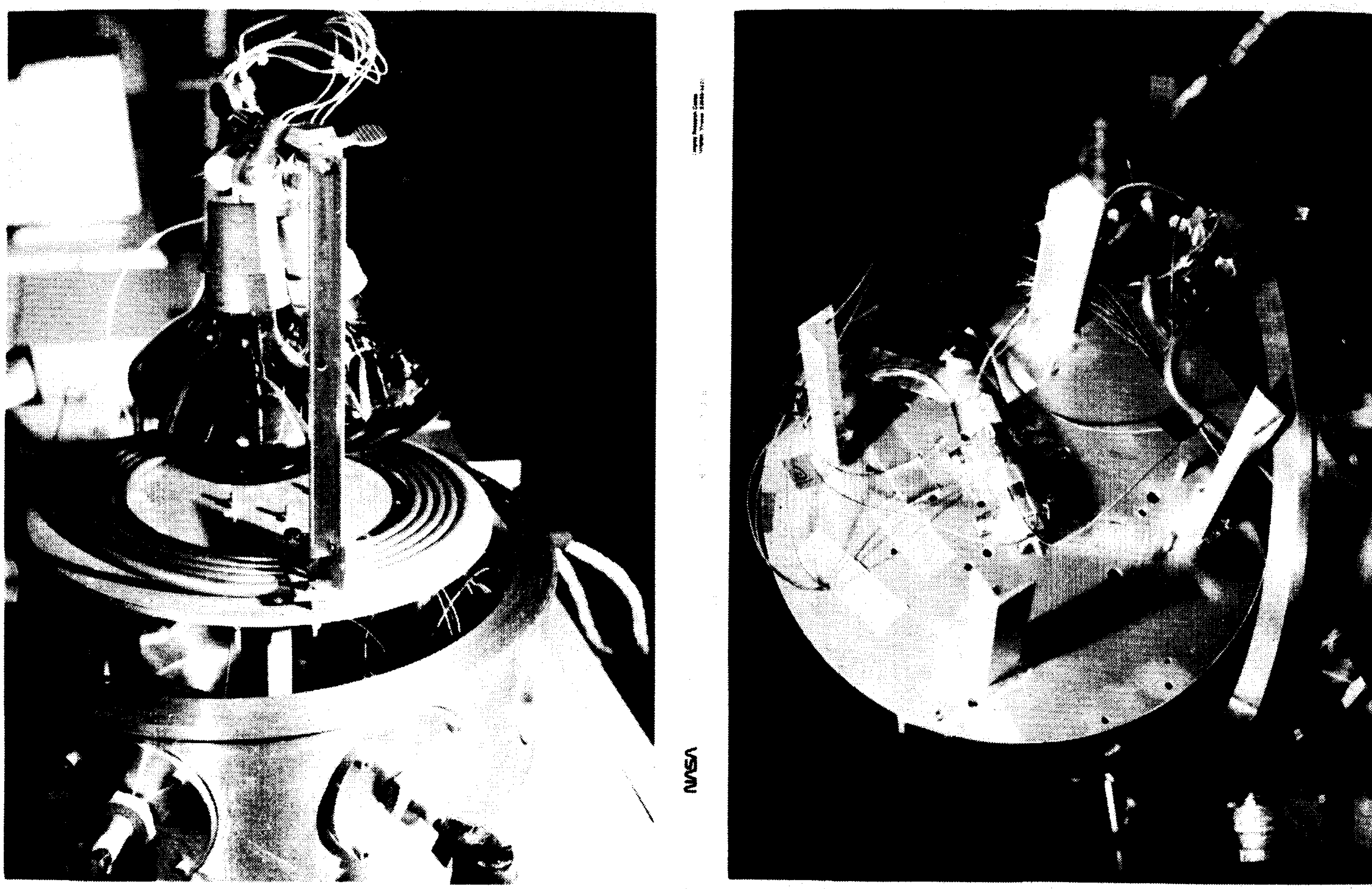
Early, First Generation Thermal Vacuum Test Fixture
Employing Radiative Heating and Cooling

Figure 2



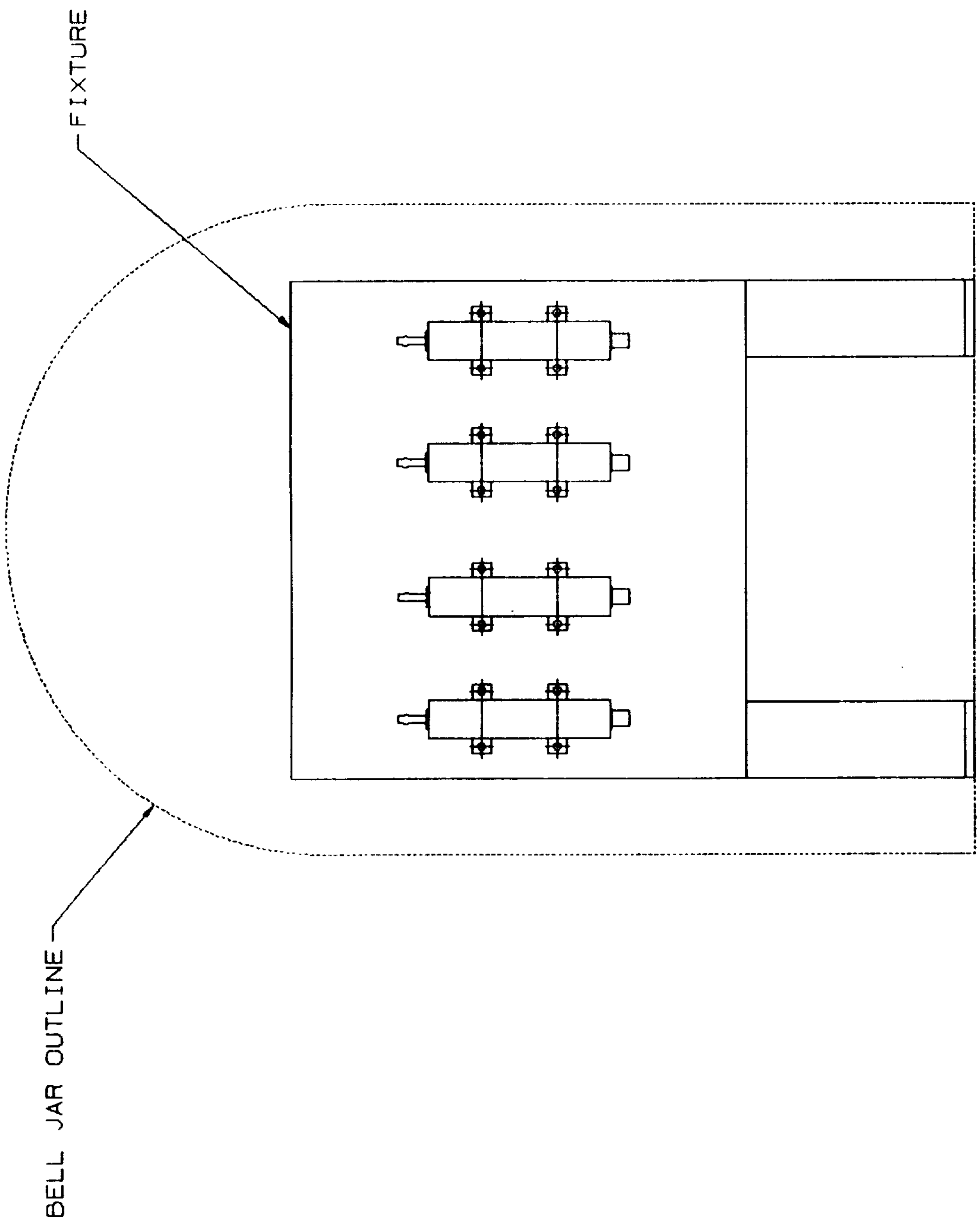
Actual Test Profile Obtained Using First
Generation Fixture (Radiative Heating and Cooling)

Figure 3



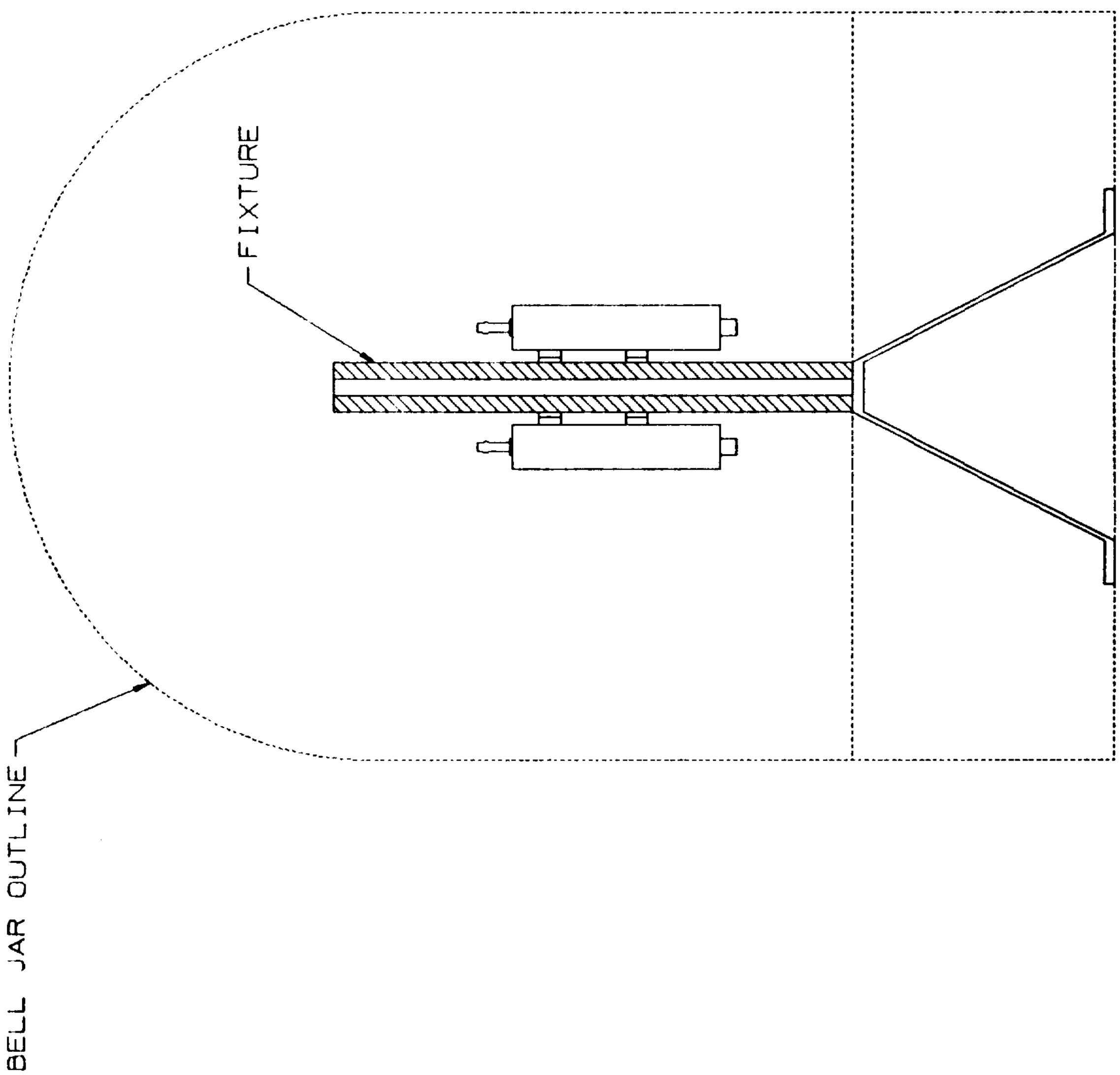
Second Generation Thermal Vacuum Test Fixture Employing Conductive Heating and Cooling. (Note small mounting area available on underside of fixture.)

Figure 4



AFE PD/ADS THERMAL VACUUM TEST FIXTURE - FRONT VIEW
WITH PIA PRESSURE TRANSDUCERS

Figure 5



AFE PD/ADS THERMAL VACUUM TEST FIXTURE - SIDE VIEW

WITH PIA PRESSURE TRANSDUCERS

Figure 6

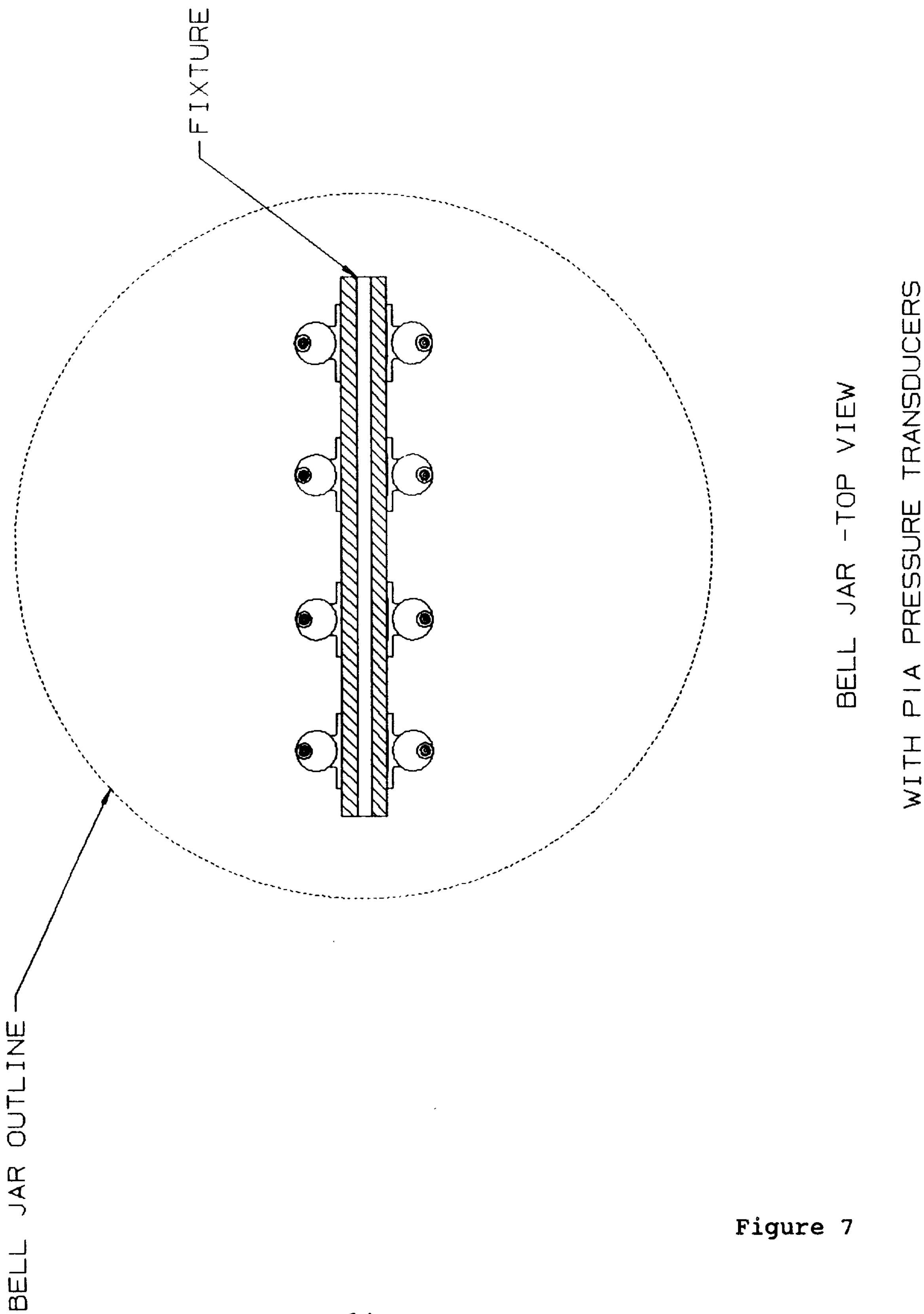
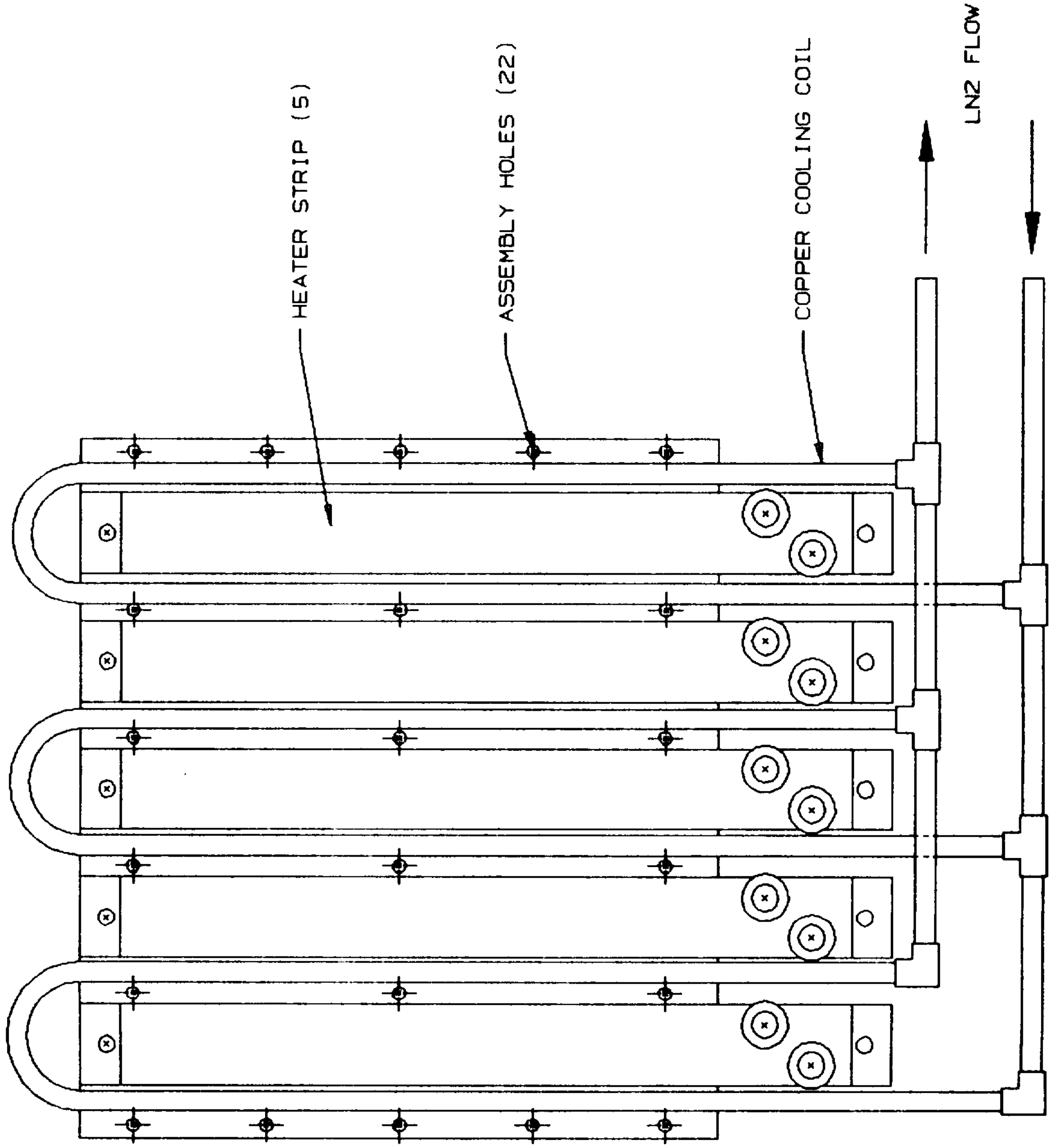

FIXTURE
BELL JAR OUTLINE
BELL JAR -TOP VIEW
WITH PIA PRESSURE TRANSDUCERS

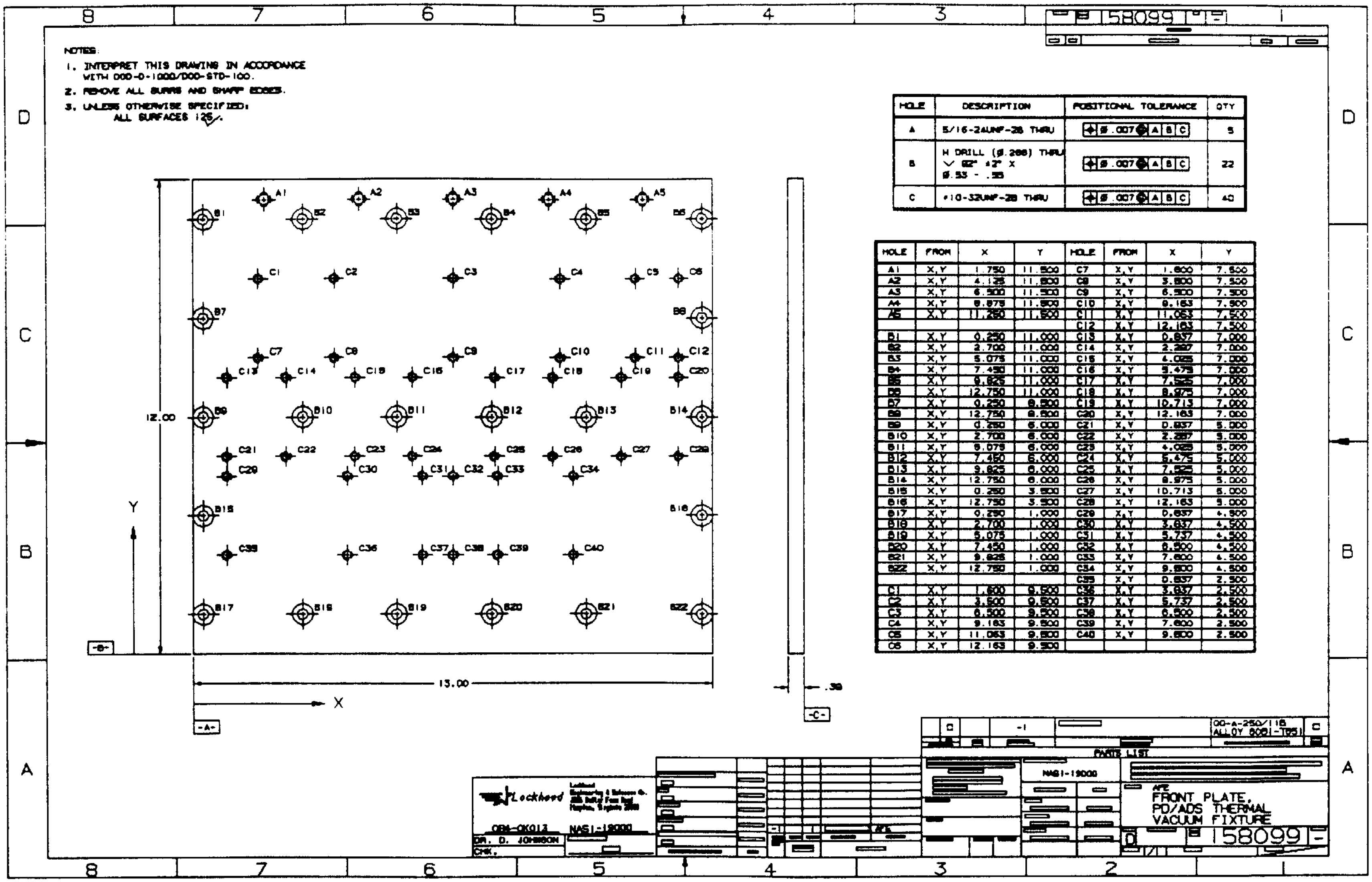
Figure 7



AFE PD/ADS THERMAL VACUUM FIXTURE

CUT-AWAY VIEW SHOWING HEATER STRIPS AND COOLING COIL

Figure 8



HOLE	DESCRIPTION	POSITIONAL TOLERANCE	QTY
A	5/16-24UNF-2B THRU	⌖ Ø .007 Ⓜ A B C	5
B	H DRILL (Ø.266) THRU ⌵ 82° ±2° X Ø.53 - .55	⌖ Ø .007 Ⓜ A B C	22
C	#10-32UNF-2B THRU	⌖ Ø .007 Ⓜ A B C	40

HOLE	FROM	X	Y	HOLE	FROM	X	Y
A1	X,Y	1.750	11.500	C7	X,Y	1.600	7.500
A2	X,Y	4.125	11.500	C8	X,Y	3.600	7.500
A3	X,Y	6.500	11.500	C9	X,Y	6.500	7.500
A4	X,Y	8.875	11.500	C10	X,Y	9.163	7.500
A5	X,Y	11.250	11.500	C11	X,Y	11.063	7.500
				C12	X,Y	12.163	7.500
B1	X,Y	0.250	11.000	C13	X,Y	0.837	7.000
B2	X,Y	2.700	11.000	C14	X,Y	2.287	7.000
B3	X,Y	5.075	11.000	C15	X,Y	4.025	7.000
B4	X,Y	7.450	11.000	C16	X,Y	5.475	7.000
B5	X,Y	9.825	11.000	C17	X,Y	7.525	7.000
B6	X,Y	12.750	11.000	C18	X,Y	8.975	7.000
B7	X,Y	0.250	8.500	C19	X,Y	10.713	7.000
B8	X,Y	12.750	8.500	C20	X,Y	12.163	7.000
B9	X,Y	0.250	6.000	C21	X,Y	0.837	5.000
B10	X,Y	2.700	6.000	C22	X,Y	2.287	5.000
B11	X,Y	5.075	6.000	C23	X,Y	4.025	5.000
B12	X,Y	7.450	6.000	C24	X,Y	5.475	5.000
B13	X,Y	9.825	6.000	C25	X,Y	7.525	5.000
B14	X,Y	12.750	6.000	C26	X,Y	8.975	5.000
B15	X,Y	0.250	3.500	C27	X,Y	10.713	5.000
B16	X,Y	12.750	3.500	C28	X,Y	12.163	5.000
B17	X,Y	0.250	1.000	C29	X,Y	0.837	4.500
B18	X,Y	2.700	1.000	C30	X,Y	3.637	4.500
B19	X,Y	5.075	1.000	C31	X,Y	5.737	4.500
B20	X,Y	7.450	1.000	C32	X,Y	6.500	4.500
B21	X,Y	9.825	1.000	C33	X,Y	7.600	4.500
B22	X,Y	12.750	1.000	C34	X,Y	9.600	4.500
				C35	X,Y	0.837	2.500
C1	X,Y	1.600	9.500	C36	X,Y	3.637	2.500
C2	X,Y	3.600	9.500	C37	X,Y	5.737	2.500
C3	X,Y	6.500	9.500	C38	X,Y	6.500	2.500
C4	X,Y	9.163	9.500	C39	X,Y	7.600	2.500
C5	X,Y	11.063	9.500	C40	X,Y	9.600	2.500
C6	X,Y	12.163	9.500				

Figure 9

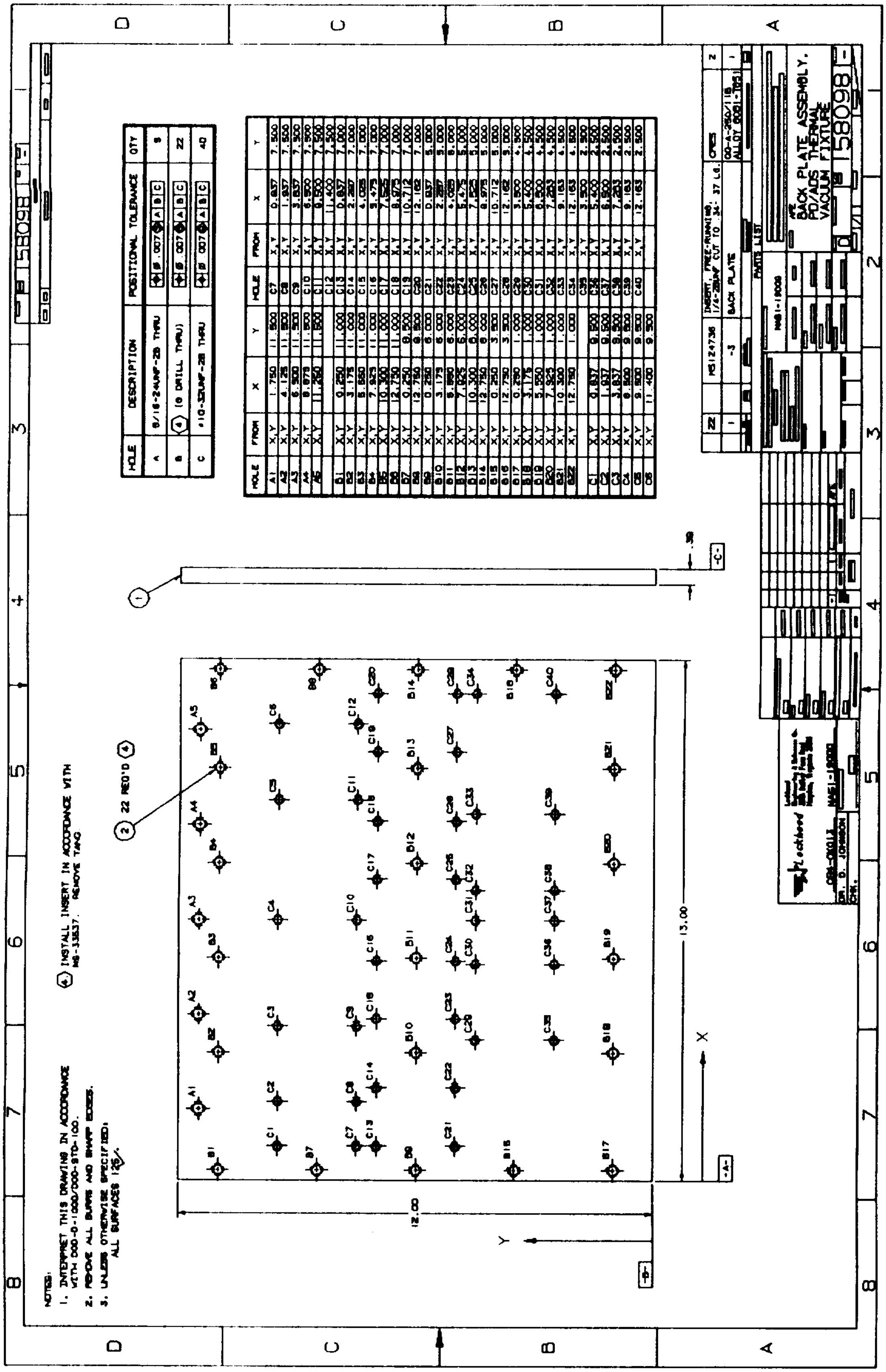
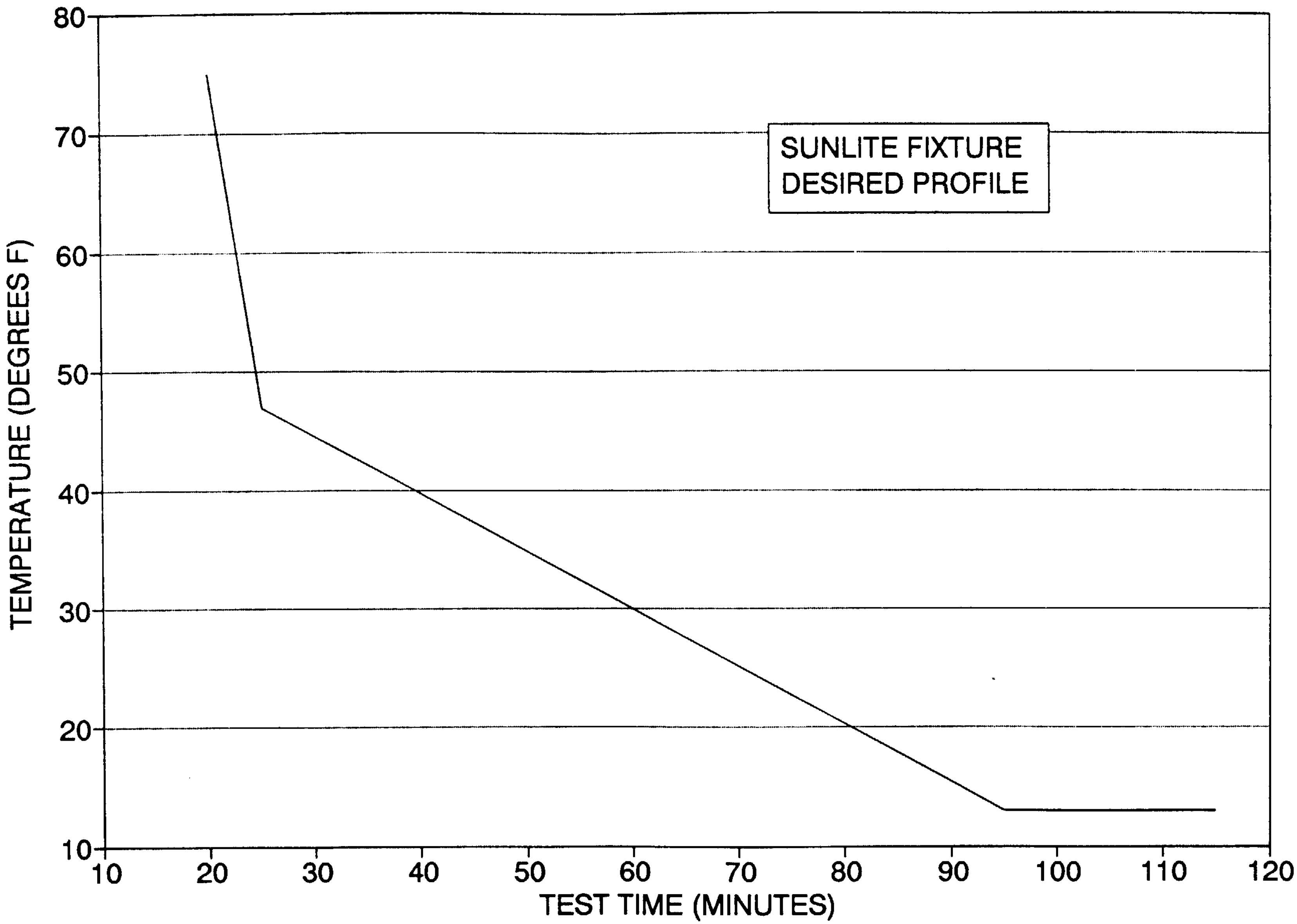
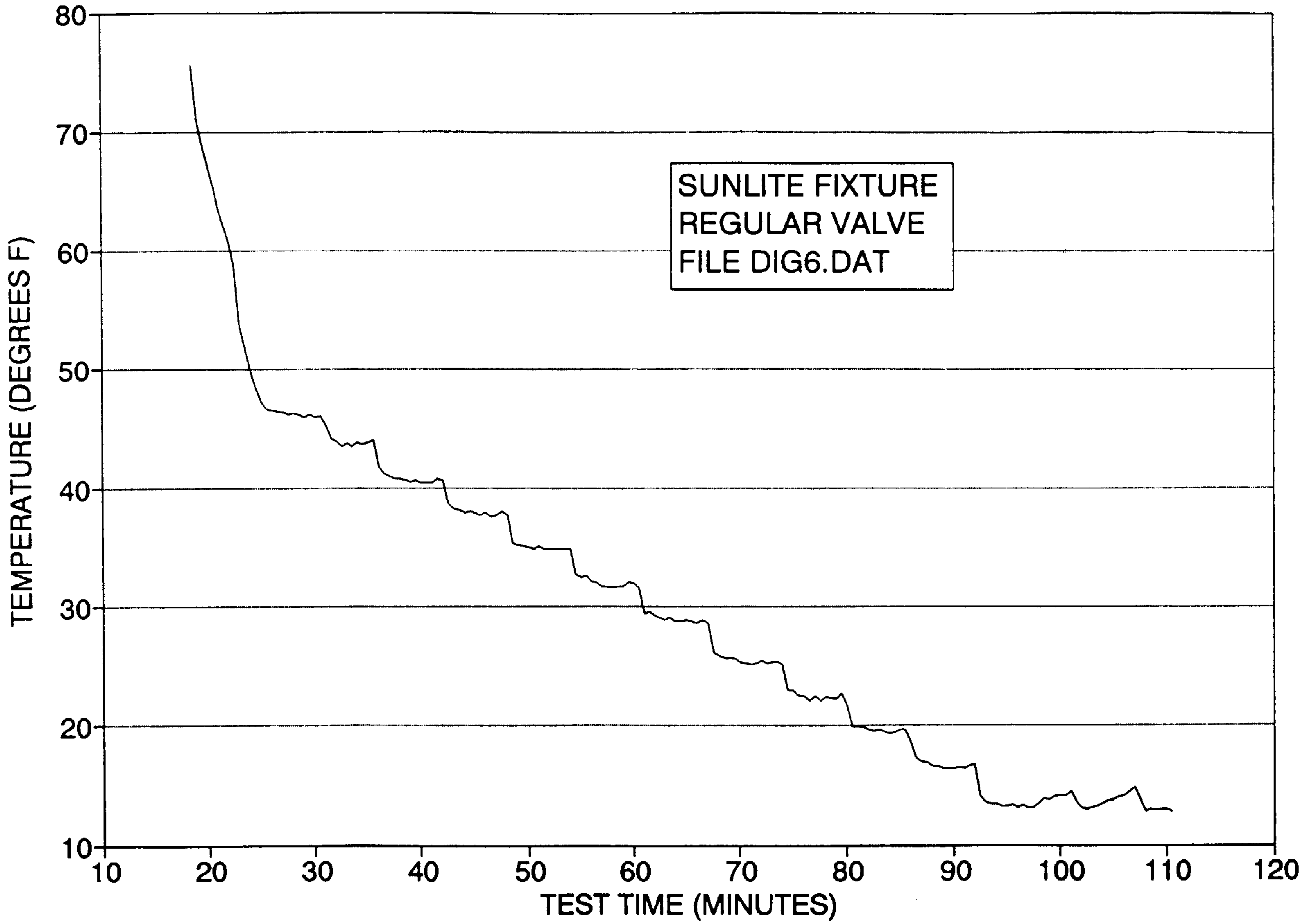

NOTES:
1. INTERPRET THIS DRAWING IN ACCORDANCE WITH DOD-D-1000/DOD-STD-100.
2. REMOVE ALL BURRS AND SHARP EDGES.
3. UNLESS OTHERWISE SPECIFIED: ALL SURFACES 125
4 INSTALL INSERT IN ACCORDANCE WITH MS-33537. REMOVE TANG
22 REQ'D
13.00
12.00
BACK PLATE ASSEMBLY, PD/ADS THERMAL VACUUM FIXTURE
158098

Figure 10



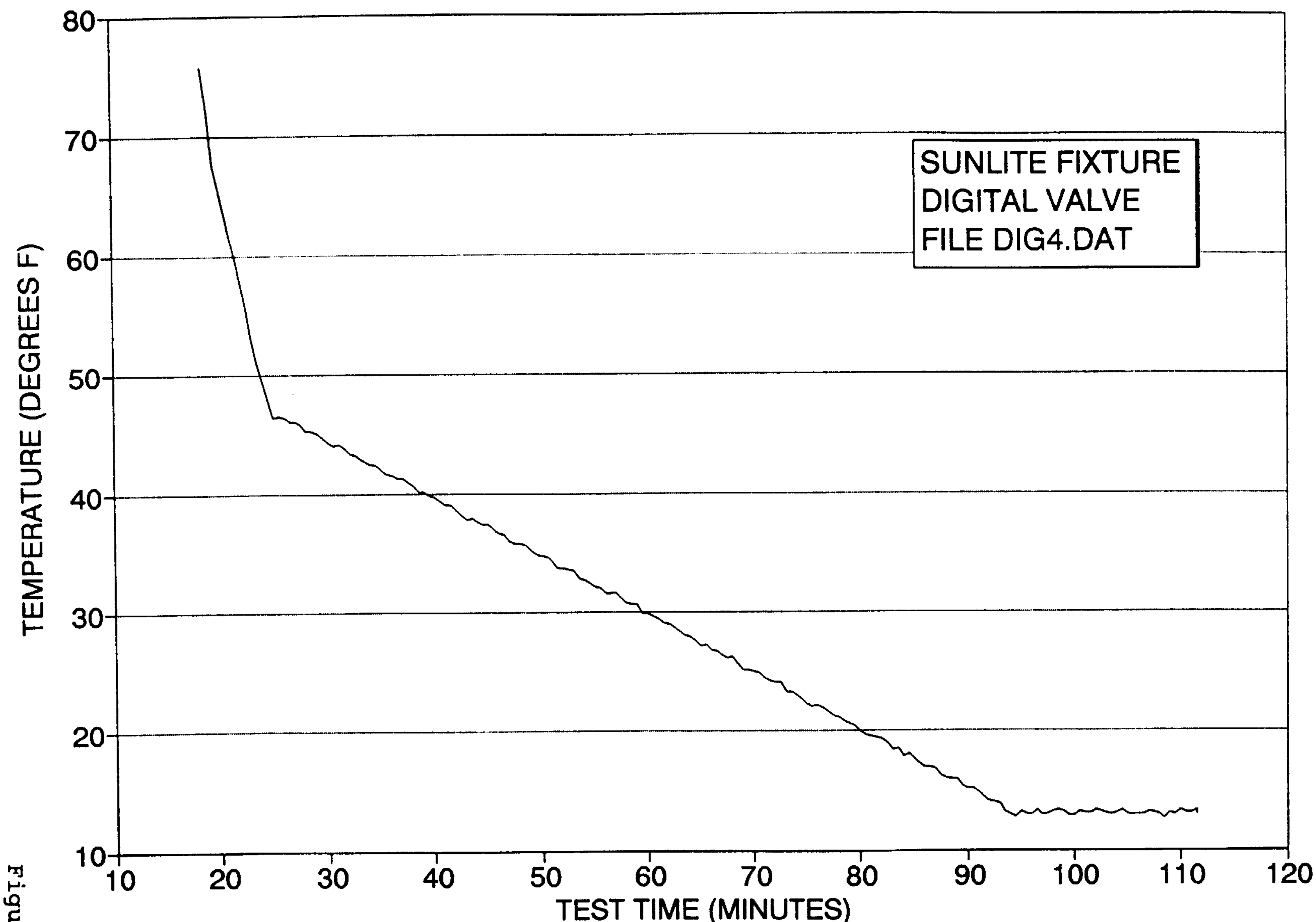
Desired Temperature Profile for
SUNLITE Reference Cavity Test

Figure 11



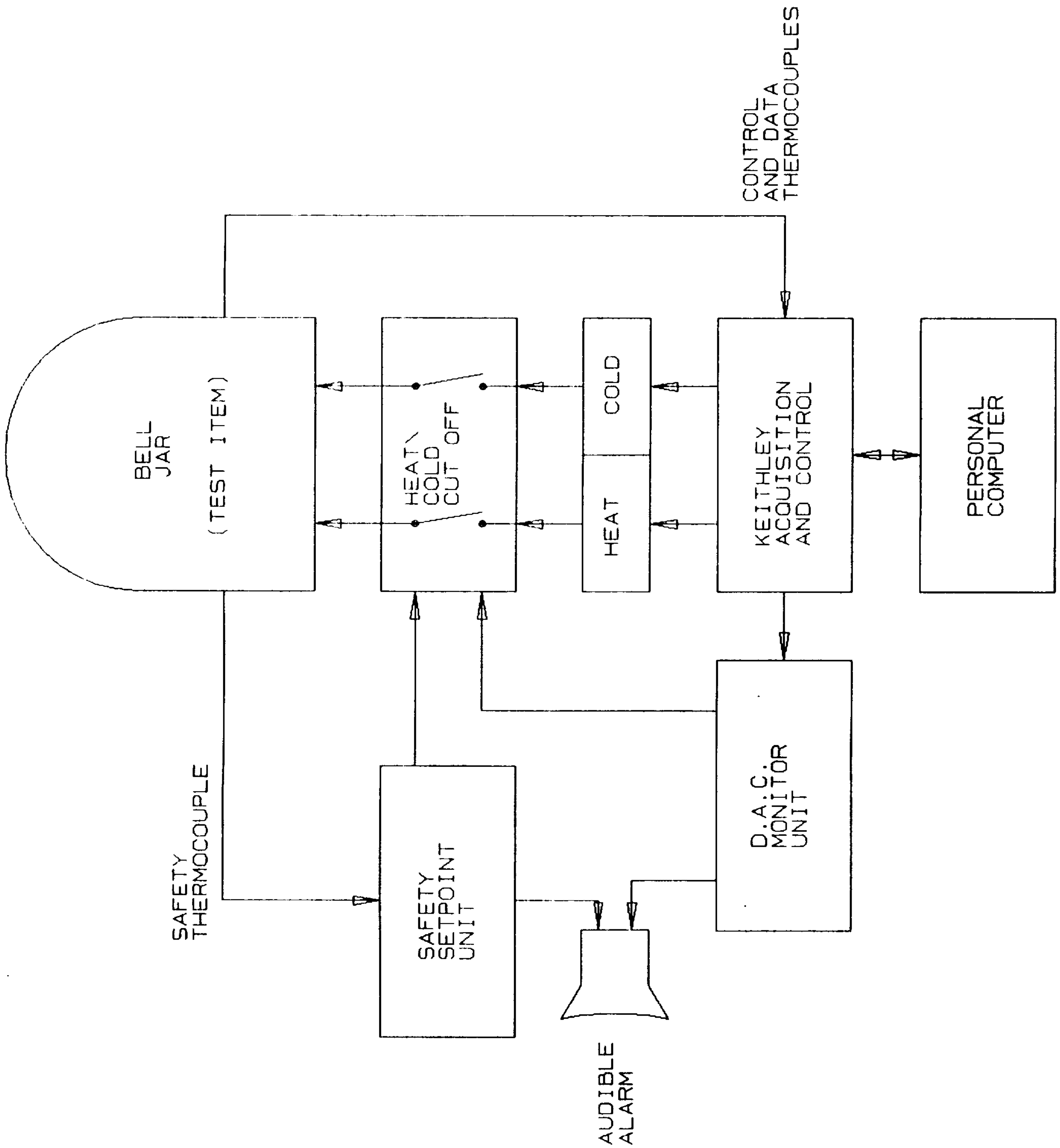
Actual Test Results from the SUNLITE
Reference Cavity Test **Without** the
Digital Liquid Nitrogen Valve in Place

Figure 12



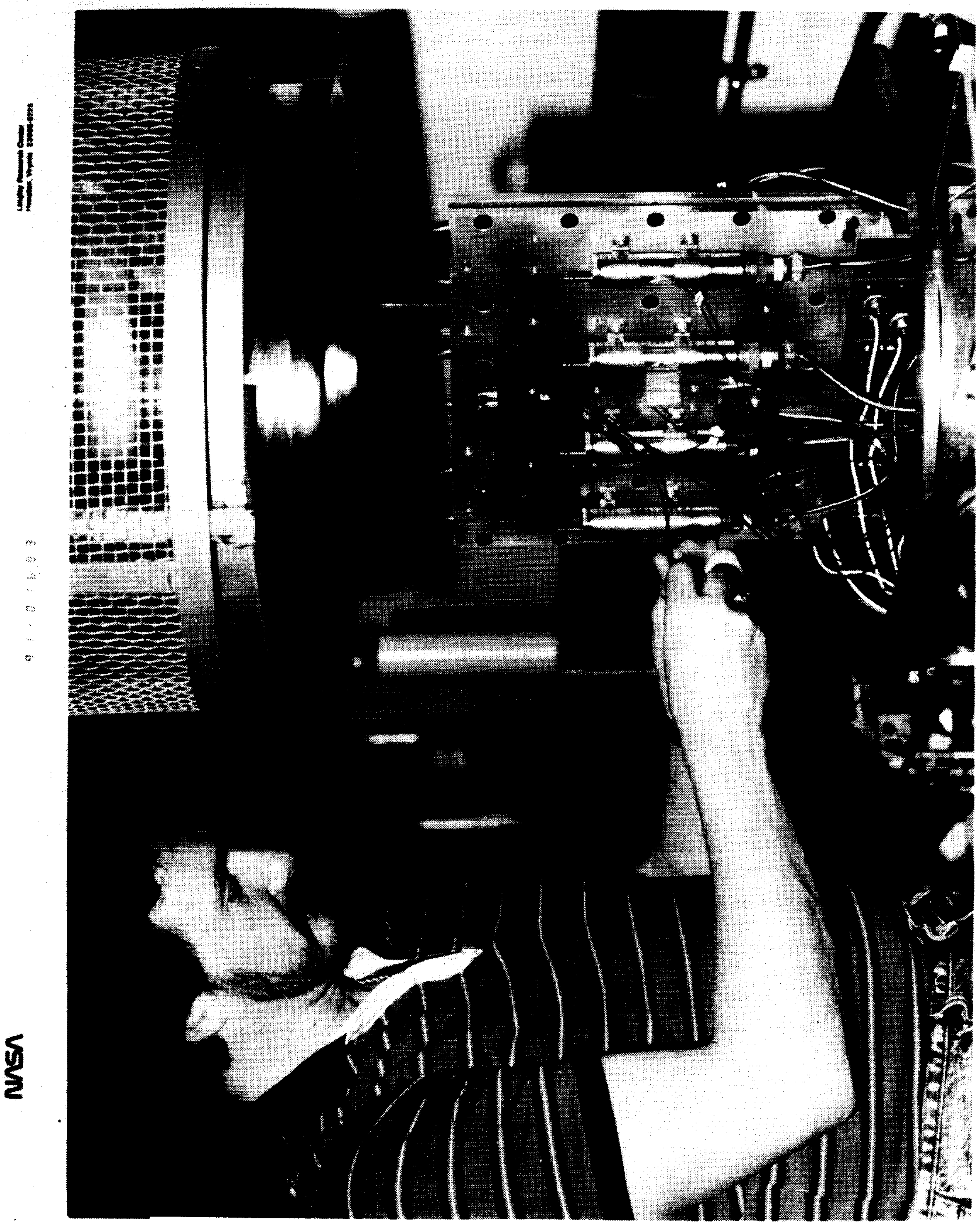
Actual Test Results from the SUNLITE Reference Cavity Test **With** the Digital Liquid Nitrogen Valve in Use

Figure 13



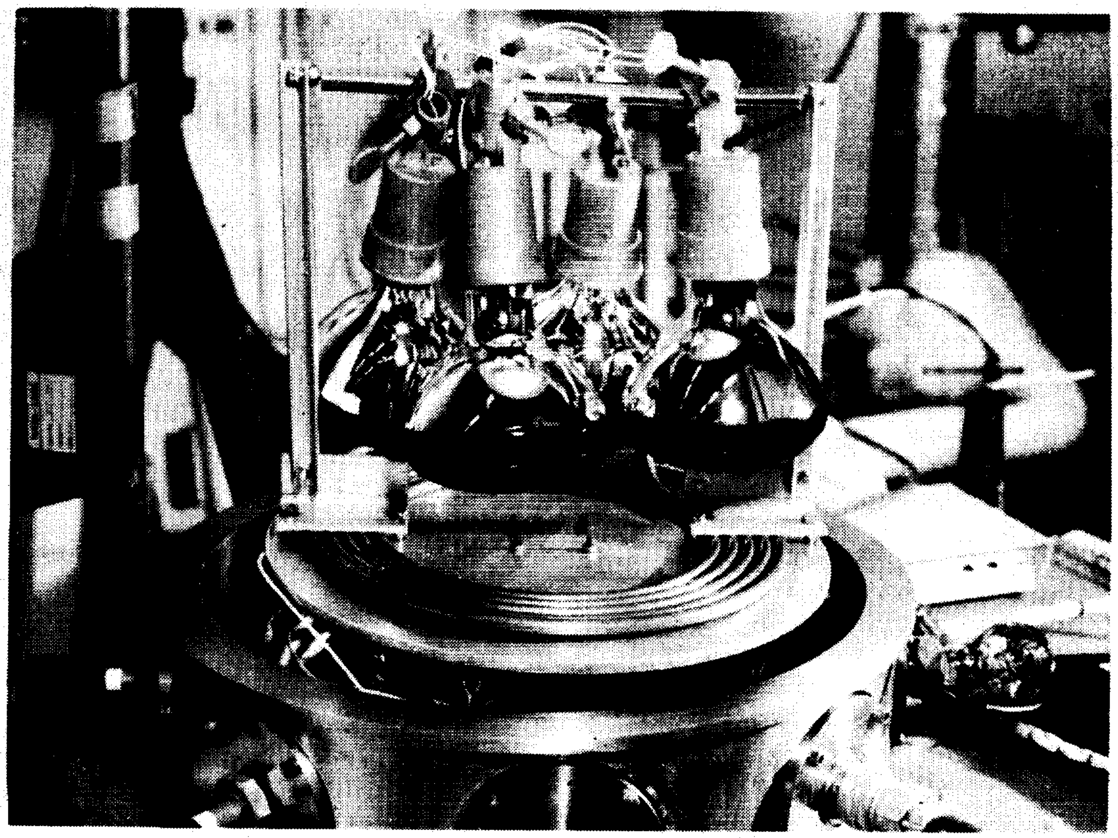
Thermal Vacuum Test System Schematic

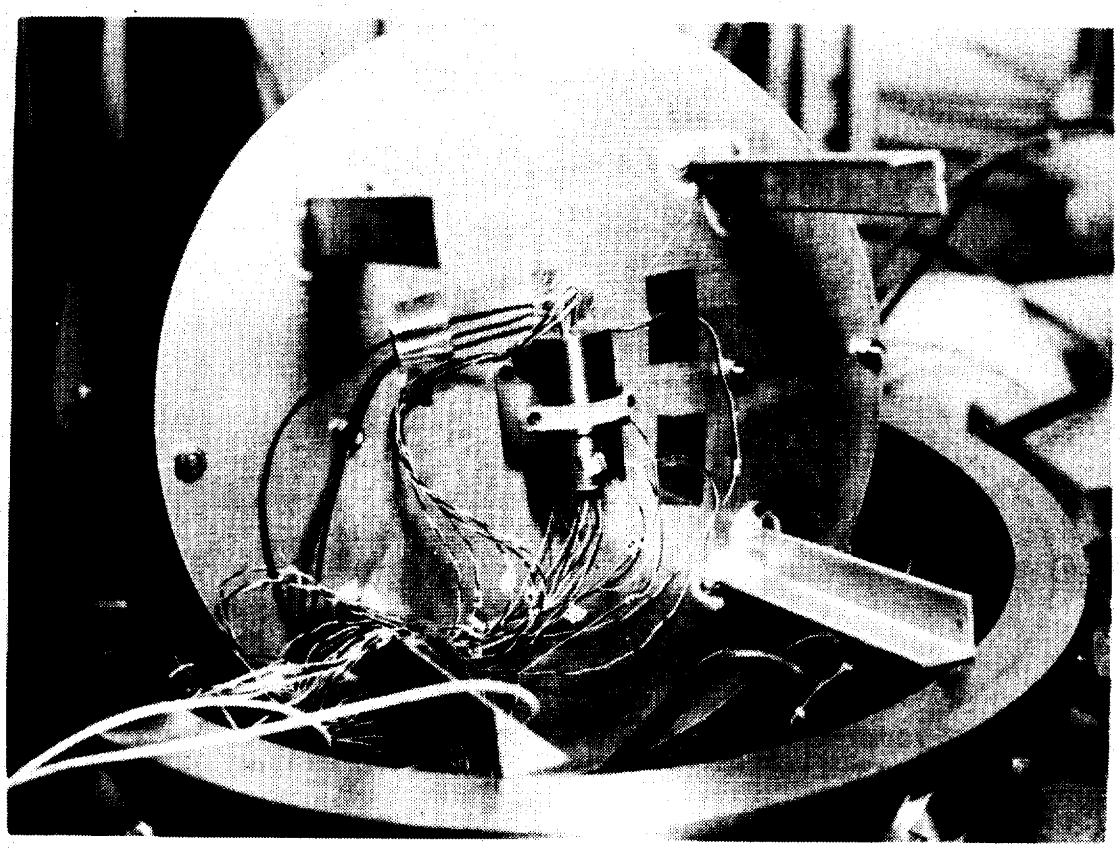
Figure 14



Thermal Vacuum Test System Configured to Test
PD/ADS Model P1A Pressure Transducers

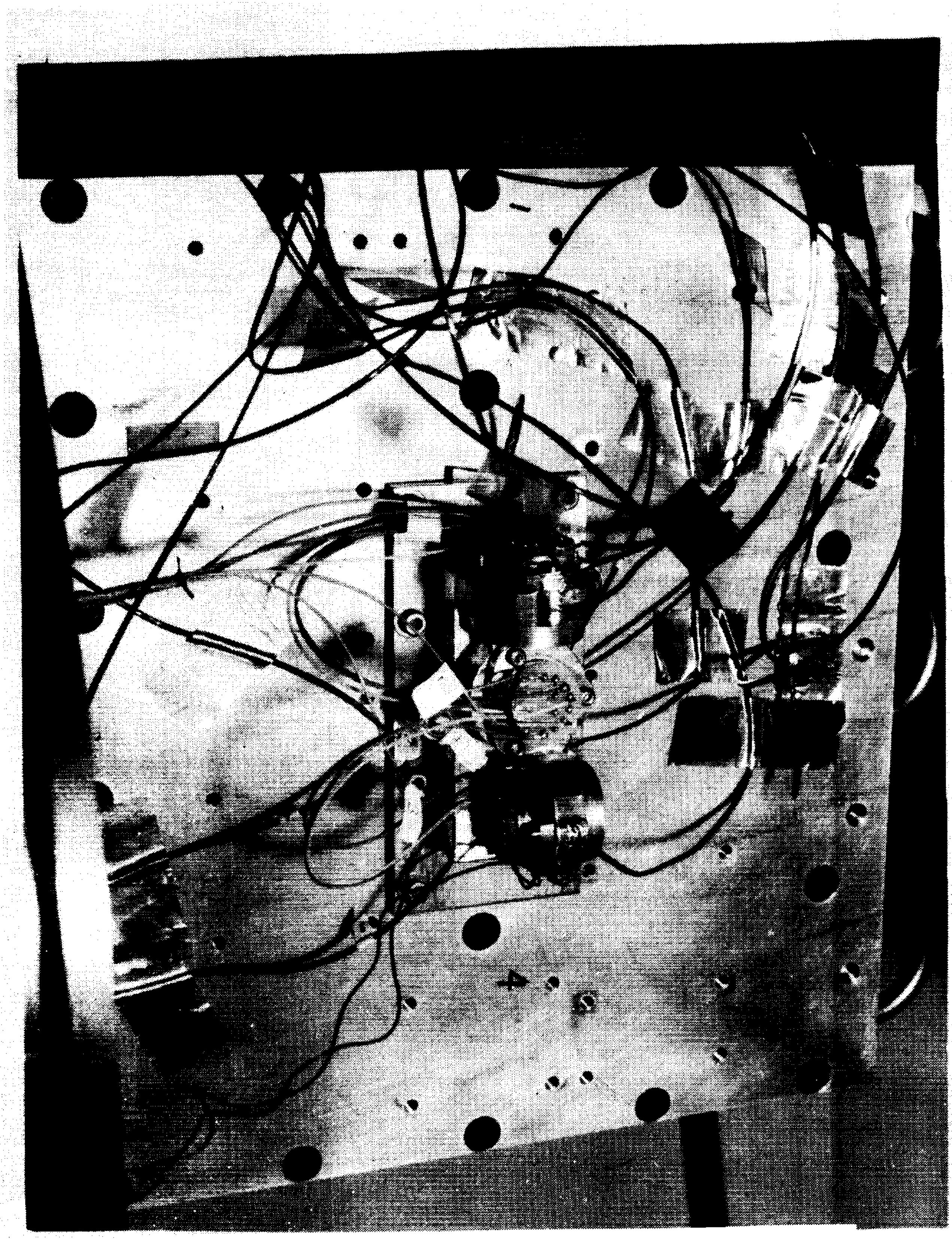
Figure 15





Second Generation Test Fixture Configured to Test SUNLITE Reference Cavity

Figure 16



L-91-5747

Thermal Vacuum Test System Configured to Test
RAME Tri-axial Accelerometer Mounting Plate

Figure 17

Report Documentation Page

NASA — National Aeronautics and Space Administration

1. Report No. NASA TM-104140	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle An Automated Thermal Vacuum Test System for Use in Environmental Testing of Flight Systems and Components		5. Report Date November 1991
		6. Performing Organization Code
7. Author(s) Craig S. Cleckner, Jeffrey R. Knutson		8. Performing Organization Report No.
		10. Work Unit No. 592-01-11-04
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665-5225		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546-0001		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Unusual requirements for the Pressure Distribution/Air Data System (PD/ADS) transducer thermal vacuum testing led to the development of a conductively heated and cooled, fully automated, bell-jar test system. The system has proven to be easily adaptable for other tests, and offers the advantages of quick turn-around and low operational cost.

17. Key Words (Suggested by Author(s)) Thermal Vacuum Testing, Conductive Heat Transfer	18. Distribution Statement Unclassified - Unlimited. Subject Category 38

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	28	A03

NASA FORM 1626 OCT 86