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THERMAL ENCLOSURES FOR ELECTRONICALLY SCANNED PRESSURE MODULES OPERATING IN CRYOGENIC ENVIRONMENTS

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INTRODUCTION

Pressure measurements at the test section walls and the model surfaces in the National Transonic Facility (NTF) are being acquired using the Electronicaly Scanned Pressure (ESP) Measurement System (ref. 1). The Data Acquisition and Control Units (DACU) and the Pressure Calibration Units (PCU) for the ESP systems are located outside the tunnel while the ESP modules are maintained at a constant temperature in thermal enclosures mounted in the cryo-environment inside the tunnel and the models. This reduces pressure response lag due to long tubing lengths. The need to maintain the ESP modules at a temperature of 10 °C ±1 °C is dictated by the pressure module's thermal zero and sensitivity coefficients and the adverse effect of internally generated thermal energy on model boundary layers (ref. 2).

The operating temperature range of the ESP modules is 0 °C to 79 °C. The thermal zero coefficient is 0.04% F.S./°C and the thermal sensitivity coefficient is 0.02%/°C. These factors prompted the development of the thermal enclosures currently being used to house ESP modules. The enclosures are capable of maintaining a constant temperature to within ±1 °C at 10 °C and withstand the large pressures (931kPa (135 psia)) and low temperatures (-173 °C) associated with the tunnel operation (ref. 2). This paper describes the design requirements, construction, and testing procedures for these enclosures.

DESIGN REQUIREMENTS

The thermal enclosures used at NTF for model and tunnel pressure measurements must meet certain requirements to ensure high quality measurements. Temperature control to within ±1 °C is essential because of the thermal zero and sensitivity coefficients of the transducers. Also the use of on-line calibrations to correct for temperature induced errors is expensive. A ±207kPa (±30 psid) ESP module that experiences a 1 °C change in temperature also experiences a 0.04% F.S. change in zero output equal to 0.16kPa (0.024 psid) and a 0.02% change in sensitivity equal to 0.04kPa (0.006 psi) at full scale. The operating temperature (10 °C) of a package is determined by its effect on the boundary layer of the model or wall of the tunnel.

The enclosure heater controller used at NTF is a proportional voltage type which senses the internal temperature of the enclosure using a Resistance Temperature Device (RTD) mounted in the enclosure. The heater assembly used in the models must be compatible with these heater controllers. The temperature sensor location must be optimized and the thermal energy loss due to the tubing and wiring exiting the enclosure must be minimized to effectively maintain the internal temperature. The ESP module(s) as well as the tubing, associated electronics, wiring harness, and the heater assembly are required to fit inside the thermal enclosure. Table 1 shows the inside dimensions of thermal enclosures built according to these procedures. These dimensions plus a minimum 0.635 cm (0.25 in.) insulation wall thickness determine the overall dimensions of the enclosure which must fit into the allotted space in the tunnel or model.

The enclosure material currently being used is a closed-cell foam manufactured in accordance with the specifications listed in table 2. The material must be capable of withstanding the 931kPa (135 psia) tunnel pressure without deformation of shape or increase in thermal conductivity. The enclosure must be soundly constructed (structurally stable, snug-fitting parts, and overlapping joints) using a material that is equal to or better in thermal conductivity, strength, and performance than that of the foam insulation described in table 2.

CONSTRUCTION TECHNIQUES

Two methods of fabrication that have been successfully utilized are the milling method and the piece-wise assembly method. The milling method is accomplished by milling the inside and outside dimensions of the enclosure from a block of foam (fig. 1). The assembly method is accomplished by cutting out the sides with overlapping joints and bonding them together with an adhesive (e.g., Crest 391 Urethane Rubber adhesive) that will withstand the -173 °C to 60 °C thermal environment. An example of this method is shown in figure 2. To avoid heat loss, the use of adhesive should be minimized since its accumulation at joints will increase the total heat loss of the enclosure. In addition, care should be taken to eliminate leaks and cracks by fabricating snug-fitting mating parts and by extending the inside face of the tubing and wiring access wall into the enclosure cavity (fig. 1).

Provisions must be made for routing the electrical and pneumatic lines that are necessary for the operation of the ESP module(s) out of the enclosure. Table 3 shows the number and sizes of electrical wires routed through the enclosure wall for up to 12 modules housed in the enclosure. One calibration tube is used for each module pressure range in the enclosure. The C1, C2, and reference tubes can be shared among all modules regardless of their pressure range. The tubes should pass through the enclosure wall via individual holes, provided the enclosure is large enough to accommodate the necessary holes (no more than 64, 0.15 cm (0.06 in.) O.D. holes per square inch). If not, the tubes and wires should be grouped together and brought through using one large exit hole. For ease in installation, it is recommended that the tubes and wires exit through the wall of the enclosure that is used to access the ESP package (fig. 3).

The enclosure size is determined by the number and type of modules and the allotted space in the model or tunnel. An enclosure housing one 48-channel ESP module (48-SL) requires an inside dimension of 9.52 cm long x 6.1 cm wide x 6.35 cm high (3.75 in. x 2.4 in. x 2.5 in.). These dimensions take into account the space needed for the heater assembly, control lines and pressure data lines, and the 6.35 cm (0.25 in.) minimum wall thickness. If more than one module is used in an enclosure, an electrical distribution board is required. The distribution board is fabricated on a printed circuit board and is placed with the modules as a point of distribution for the supply voltages to the modules. The minimum dimension of a distribution board is 6.35 cm x 0.317 cm x 2.54 cm (2.5 in. x 0.125 in. x 1 in.). A wiring schematic of the distribution board is shown in figure 4. These minimum enclosure dimensions can be increased and/or the corners may be rounded slightly, as shown in figure 5, to fit the allotted space within the model as long as the thickness does not decrease to less than 6.35 cm (0.25 in.). Figure 6 shows a thermal enclosure that was constructed according to the above procedures.

THERMAL CONTROL

The enclosure heater controller used at NTF is a closed-loop, proportional voltage type which measures the internal temperature of the enclosure via a temperature sensor (RTD) mounted in the enclosure. It compares this temperature sensor output voltage to the user selected temperature set point (voltage) and outputs a proportional 0-90 Vdc to the heater assembly for temperature control. The heater assembly is a series of commercially available heater elements. Each element consists of thin, flexible etched-foil heating coils laminated between two insulating layers of 0.025 cm (0.01 in.) thick Kapton. A 0.08 cm (1/32 in.) aluminum shroud (fig. 3) must be fabricated to enclose the ESP module package and to provide a surface to mount the heater elements. Heaters should be attached to all outside surfaces areas. It is required that the pressure data tubes and control tubes be heated before they exit the enclosure, since this is a major source of heat loss. The tubes can be heated by interweaving the heater element(s) between the tubes or by flattening the tubing bundle and wrapping the bundle with the heater element(s) to insure that all the tubes are exposed to the heat. Care should be taken not to place the heater elements in direct contact with the tubes (e.g., fiberglass tape between the heater and the tubing) to prevent melting of the pressure tubes. When all of the shroud/tubing heater elements are wired together, the total resistance shall be between 60-75 ohms.

TESTING PROCEDURE

The thermal package is tested at ambient and cryogenic temperatures to determine its ability to maintain the set temperature. The package is placed in an environmental chamber that is capable of obtaining cryogenic temperatures (-180 °C) and is then connected electrically and pneumatically to the Data Acquisition and Control Unit and the Pressure Calibrate Unit. The following tests are required:

1. Perform a leak check of control pressure tubes and pressure data tubes by applying appropriate pressures to each tubes (repair or replace module or tubing if leak rate is more than 0.138kPa/min (0.02 psi/min)).

2. Perform ESP system calibration at ambient temperature.

3. Apply known pressures to module(s) and acquire pressure data at ambient temperature.

4. Analyze data for proper operation.

5. Turn on heater controller and set temperature set point to 10 °C.

6. Cool chamber to -180 °C.

7. Ensure enclosure thermal stability is maintained at 10° ±1 °C before proceeding. If the temperature is not stable, the RTD must be repositioned to provide a slightly underdamped temperature response resulting in an adequate heater duty cycle. After repositioning the RTD, return to step 2.

8. Perform ESP system calibration at -180 °C.

9. Apply known pressures to module(s) and acquire pressure data at -180 °C.

10. Warm chamber to ambient temperature.

11. Perform ESP system calibration.

12. Evaluate all data for acceptable performance according to instrumentation specifications.

The heater controller must be monitored during the cryogenic segment of the test. The heater voltage should seek a constant value in a slightly underdamped manner and remain steady to within ±5 volts. The enclosure temperature should then remain stable to ±1 °C.

CONCLUDING REMARKS

This paper presents specific guidelines to design, construct, and test ESP thermal enclosures for applications at cryogenic temperatures. The enclosures maintain the ESP modules at a constant temperature (10 °C ±1 °C) to minimize thermal zero and sensitivity shifts, to minimize the frequency of expensive on-line calibrations, and to avoid adverse effects on tunnel and model boundary layers. The enclosures are constructed of a rigid closed-cell foam and are capable of withstanding the stagnation pressures to 931kPa (135 psia) without reduction in thermal insulation properties. This construction procedure has been used to construct several thermal packages which have been successfully used in National Transonic Facility.

REFERENCES

1. Mitchell, M.: Pressure Measurement System for the National Transonic Facility, Proceedings of the 29th International Instrumentation Symposium--ISA, May 1983.

2. Macha, J. M., Pare, L. A., and Landrum, D.B.: A Theoretical Study of Non-Adiabatic Surface Effects for a Model in the NTF Cryogenic Wind Tunnel. NASA CR-3924, August 1985.

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RECOMMENDED MINIMUM SIZE REQUIREMENTS FOR ESP THERMAL CONTAINERS FOR NTF MODELS

	32 Channel				48 Channel[g]			
Number of Modules	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Package Height[a] Inside (in.)	2.25	2.75[a] (2.25)[b]	3.25[a] (2.75)[c] (2.25)[b]	3.75[a] (2.75)[d] (2.25)[b]	2.0	2.5[a] (2.0)[b]	3.0[a] (2.5)[c] (2.0)[b]	3.5[a] (2.5)[d] (2.0)[b]
Package Length Inside (in.)	3.0	5.5 (3.0)[b]	8.5 (5.5)[c]	10.75 (5.5)[d]	3.25	6.0 (3.0)[b]	9.0 (6.0)[c]	11.75 (6.0)[d]
Package Width Inside (in.)	1.7	1.7 (3.2)[b]	1.7 (4.3)[b] (3.2)[c]	1.7 (3.2)[d] (5.2)[b]	1.9	1.9 (3.5)[b]	1.9 (4.7)[b] (3.5)[c]	1.9 (5.8)[b] (3.5)[d]
Number of Distribution Boards 2.5L x 1.0W x 0.125H	-	1	1	1	-	1	1	1
Leads (22 AWG)	6(2)[e]	6(2)[e]	6(2)[e]	6(2)[e]	6(2)[e]	6(2)[e]	6(2)[e]	6(2)[e]
Leads (24 AWG)	6(3)[e]	7(3)[e]	8(3)[e]	9(3)[e]	7(3)[e]	8(3)[e]	9(3)[e]	10(3)[e]
Pneumatic Tubes (0.040")	4	4[f]	4[f]	4[f]	4	4[f]	4[f]	4[f]

a = Increases in height represent increases in tubing height requirements.
b = Side-by-side mounting.
c = One forward, two back.
d = Double row.
e = Heater wires for 1 heater.
f = Plus one tube per additional range.
g = ESP 48SL

Individual Package Dimensions Have Been Increased to Reflect Clearances Needed to Assemble and Troubleshoot Complete Package. (Does Not Include Shroud or Insulation).

Table 1. Recommended minimum size requirements for ESP thermal containers.

Specification for Thermal Enclosure Material

LAST-A-FOAM 9515 Closed-Cell Rigid Foam

- o Density - 224.26 kg/m^3 (14 lb./cu. ft.)
- o Thermal Conductivity - 0.064 w/m·k (0.44 BTU in/hour/ft^2/°F)
- o Liquid Nitrogen Compatibility - Material shall show no visible damage or degration when a room temperature material specimen is immersed in liquid nitrogen for 5 ±1 minutes.
- o Char Yield - The specimen weight remaining at 600 °C shall be not less than 35% of the initial weight of the specimen when subjected to a temperature change of ambient to 600 °C at a rise rate of 10 °C per minute in a nitrogen environment.
- o Compressive Strength - The material shall have a minimum compressive strength of 1.79 Pa (260 psi) at the proportional limit over the full temperature range of -196 °C to 21 °C.

Table 2. Specification for Thermal Enclosure Material

ESP STING CABLE WIRING

Number of 24 AWG Wires

Six (6) Address Lines
One (1) Per ESP Module

	Number of 22 AWG Wires				Total #22+#24
Modules	GND	+12V	-12V	+5V	
1	2	2	1	1	13
2	2	2	1	1	14
3	2	2	1	1	15
4	3	3	1	2	19
5	3	3	2	2	21
6	4	4	2	2	24
7	4	4	2	3	26
8	5	5	2	3	29
9	6	6	3	3	33
10	6	6	3	4	35
11	7	7	3	4	38
12	7	7	3	4	39

Table 3. ESP Sting Cable Wiring

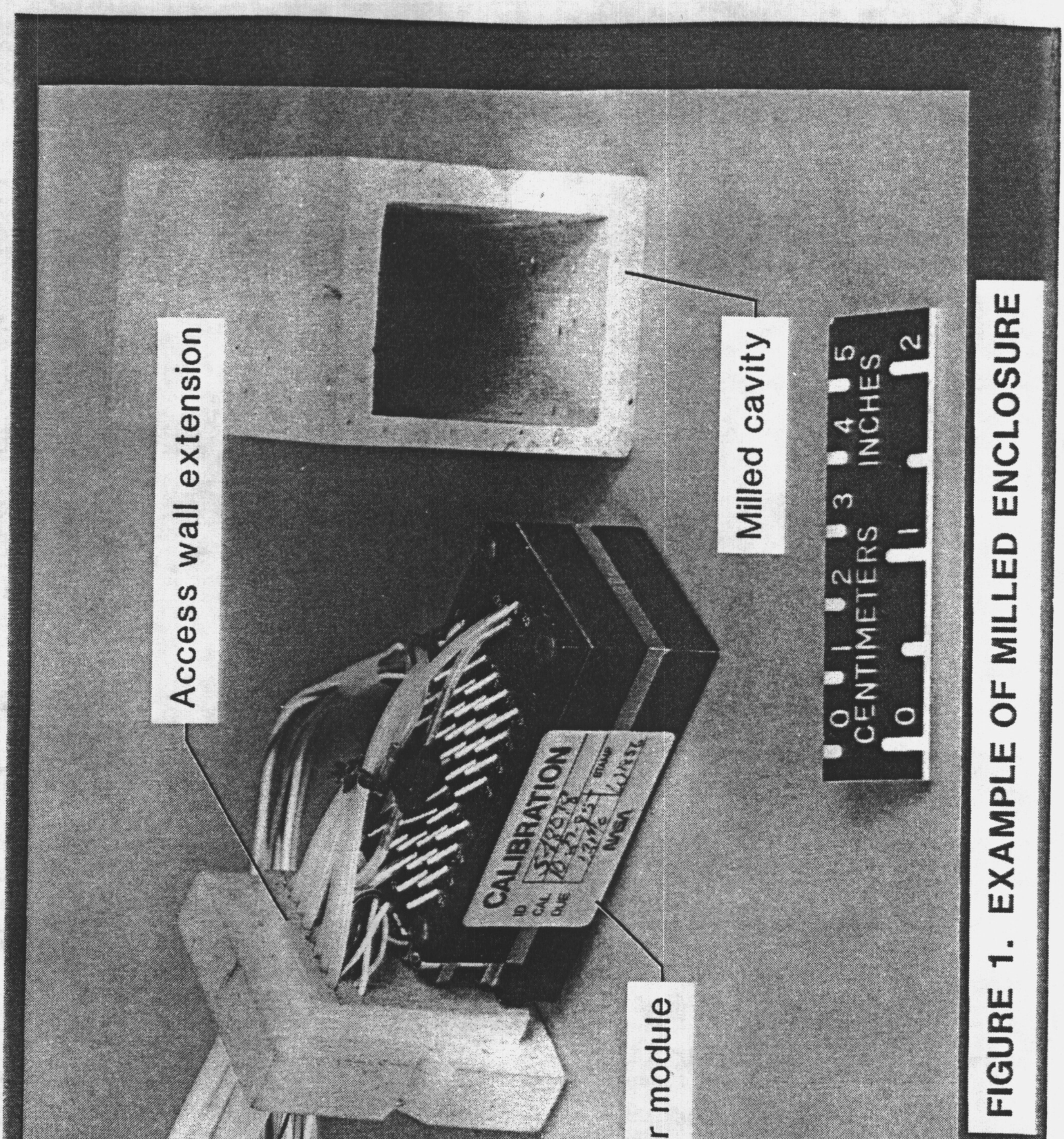

FIGURE 1. EXAMPLE OF MILLED ENCLOSURE

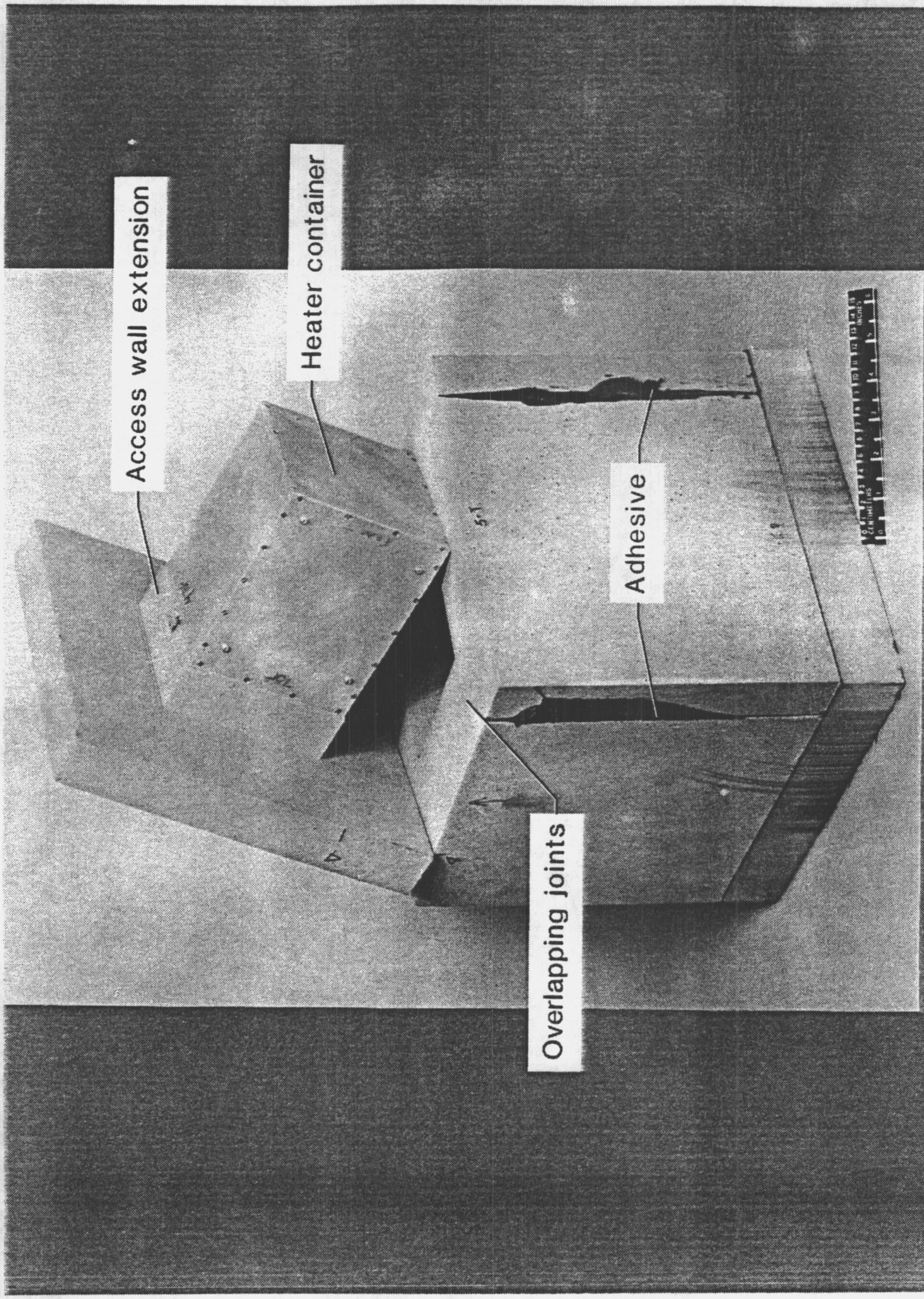

FIGURE 2. EXAMPLE OF PIECE WISE ASSEMBLEY ENCLOSURE (TUNNEL WALL PACKAGE)

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

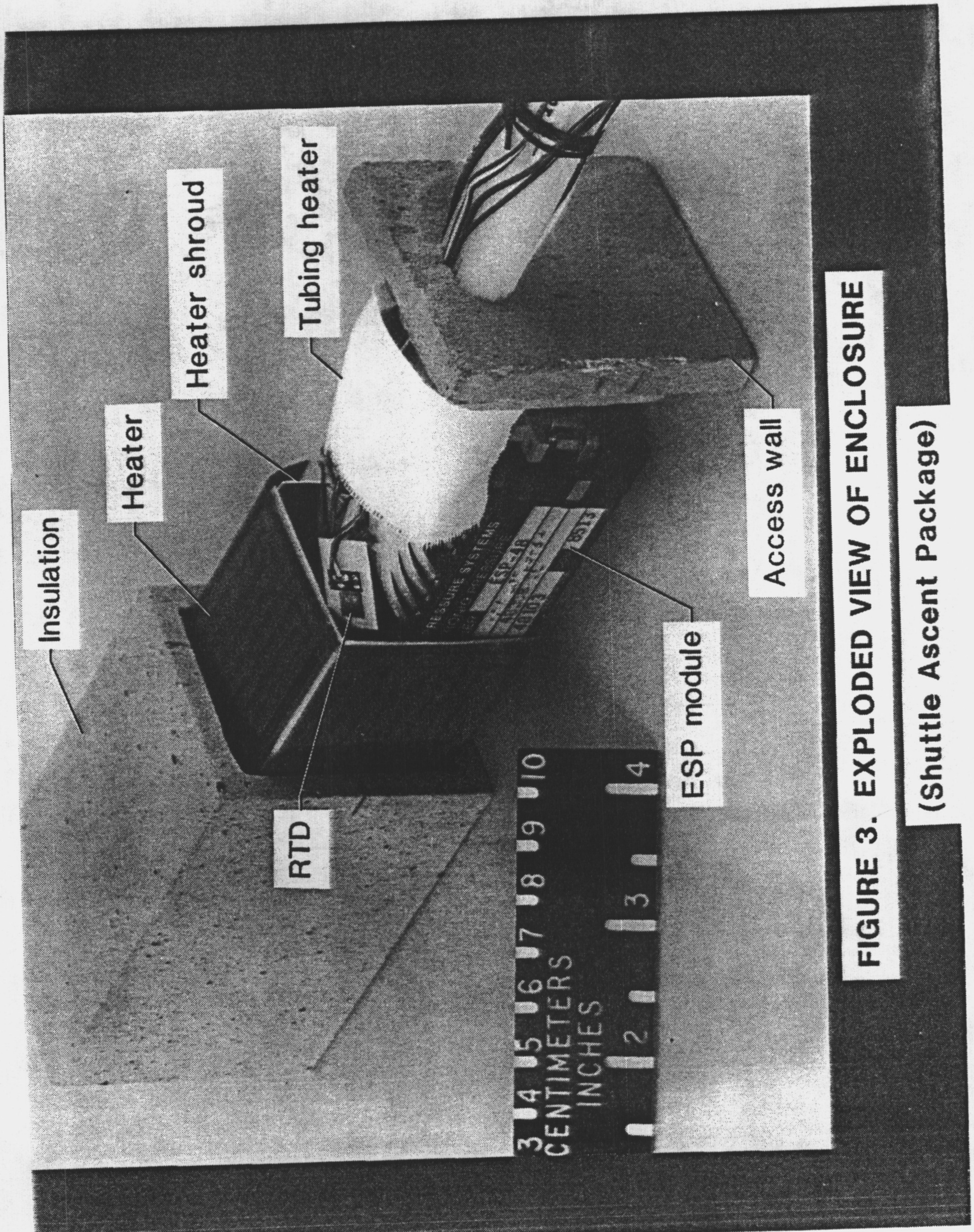

FIGURE 3. EXPLODED VIEW OF ENCLOSURE
(Shuttle Ascent Package)

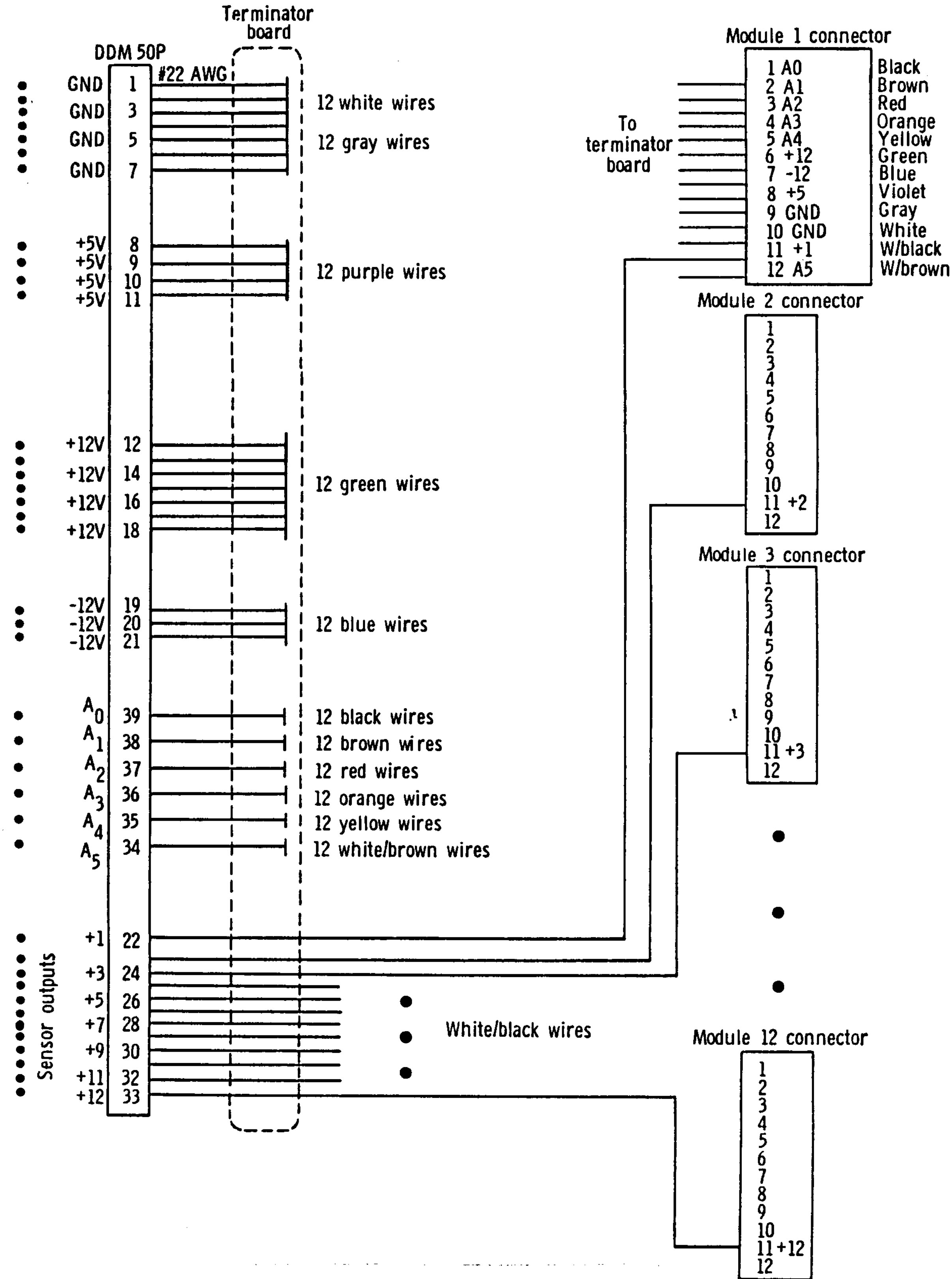

Figure 4. Distribution Board Circuitry

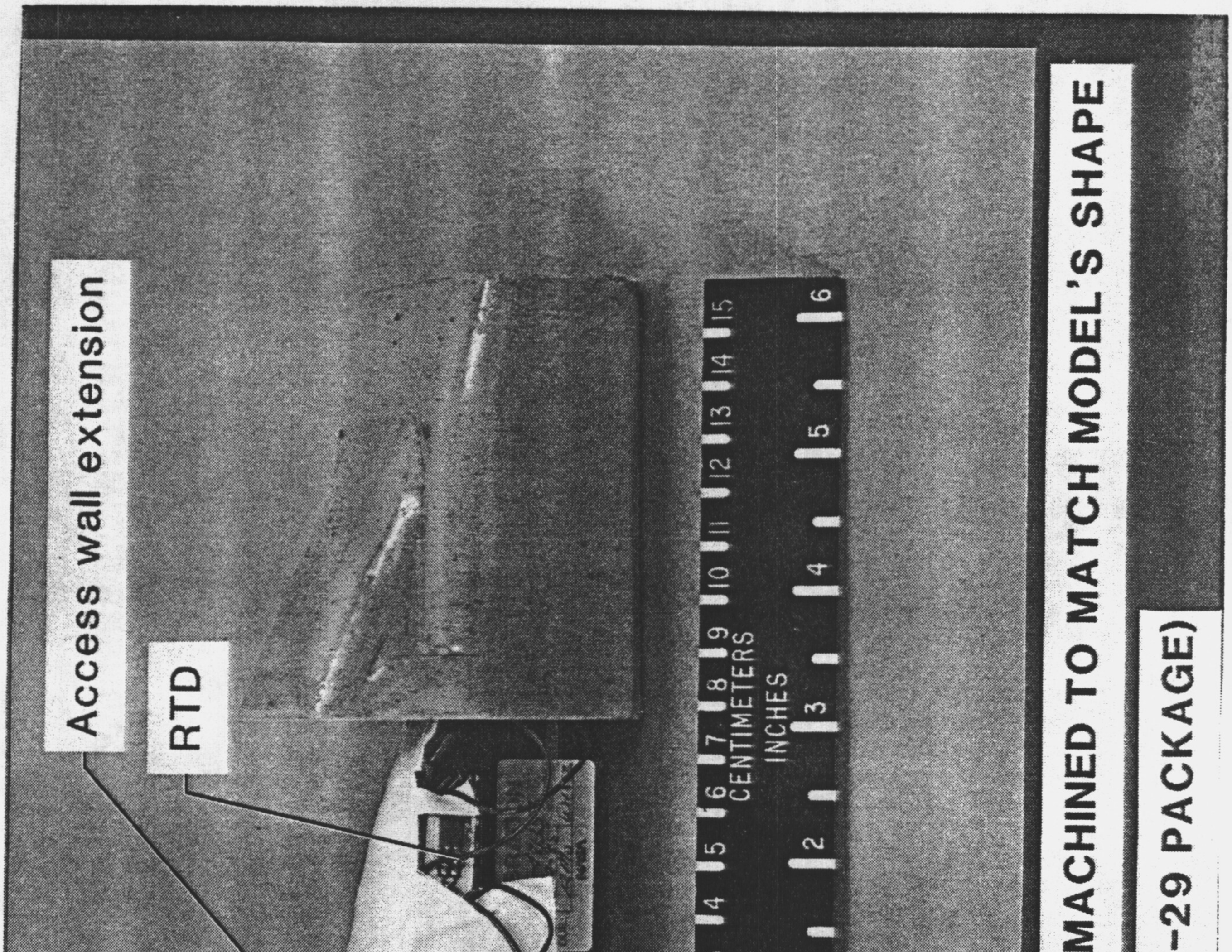

FIGURE 5. ENCLOSURE MACHINED TO MATCH MODEL'S SHAPE

(X-29 PACKAGE)

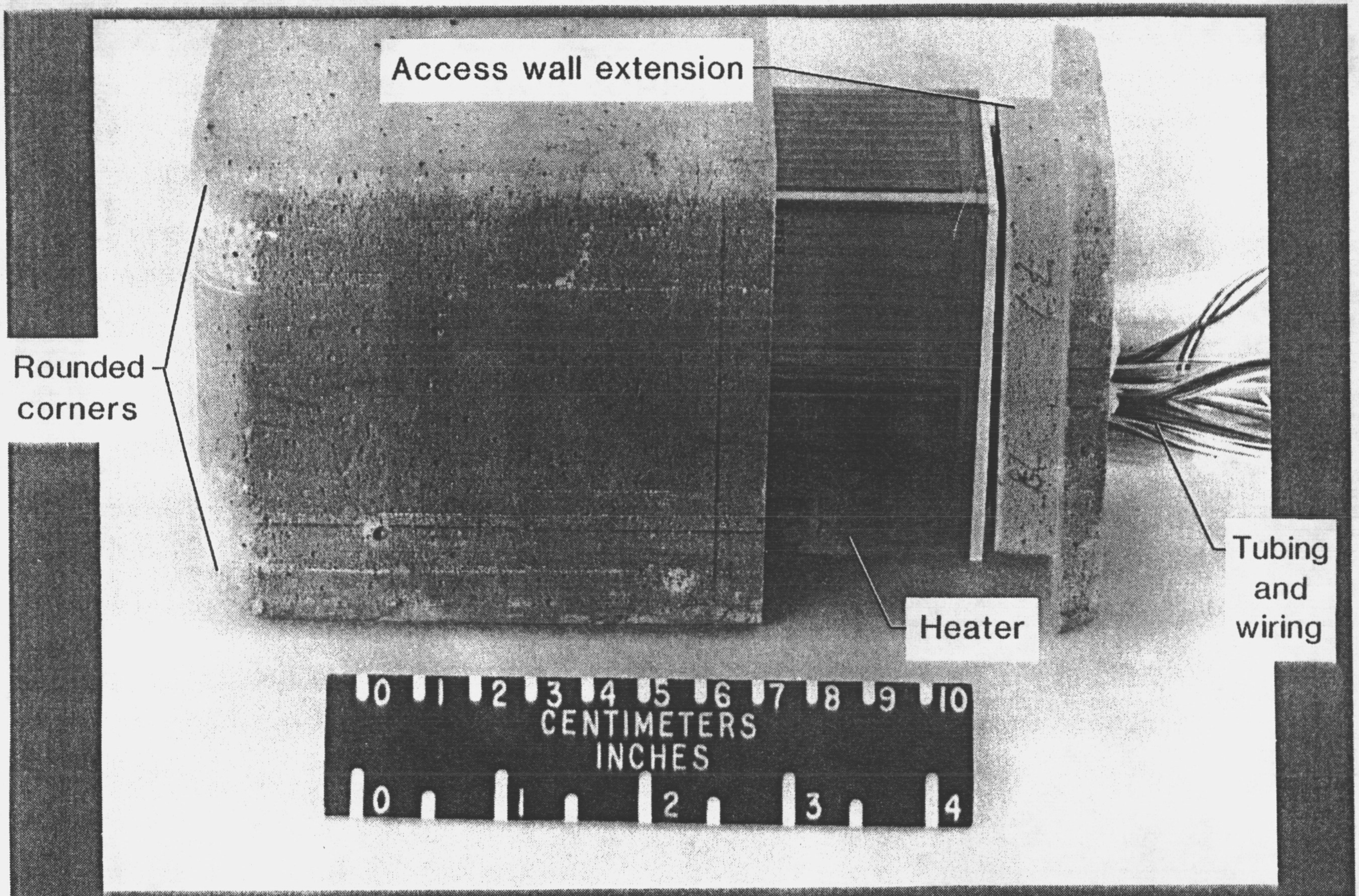

FIGURE 6. ENCLOSURE WITH ROUNDED CORNERS TO MATCH MODEL'S SHAPE

(SHUTTLE ASCENT PACKAGE)

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15. Supplementary Notes

16. Abstract

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