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AFFDL-TR-66-76

20070917071

THERMANTIC STRUCTURE TEST PROGRAM

Radiant heaters from 4 infra
achieved 3000 F with Pyro-metric heater

THOMAS F. HUGHES

TECHNICAL REPORT AFFDL-TR-66-76

JUNE, 1966

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FOREWORD

This report was prepared by the Structures Test Branch, Structures Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. This report describes test technique development and actual tests of the Aeronca Thermantic Structure performed during the period from December 1964 to October 1965. The tests were performed under Project 1368, Task 136804 and directed by Mr. T. F. Hughes, project engineer. Messrs E. M. Candler and J. E. Pappas were responsible for instrumentation and data reduction.

Results of the tests and analysis of the test data will be found in Technical Documentary Report No. ML-TDR-64-267, Part II, Volume 1.

This technical report has been reviewed and is approved.

Robert L. Bondurant

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Acting Chief, Structures Test Branch
Structures Division

ABSTRACT

A re-entry vehicle section built of Aeronca's thermantic construction was tested to demonstrate the performance of the structure at the design conditions. The design point for the structure is the peak loading and temperature portion of the first re-entry cycle with equilibrium temperatures overall. Three conditions were tested. Static Test I and Static Test II were room temperature, load only tests. There was no damage to the structure from these tests. Static Test III was a combined elevated temperature and load test. The elevated temperature portion of this test was started and aborted five times because of various equipment failures. Each elevated temperature run caused the coating to crack. The highest temperatures were recorded during the last run. Temperatures on the lower surface ranged from 2800° to 3195°F. The temperatures on the upper surface ranged from 2824° to 3176°F. An infrared heating system was developed for this program, capable of heating large structures to temperatures in excess of 3000°F.

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SECTION I

INTRODUCTION

The Aeronca Manufacturing Corporation Thermantic Structure was subjected to a static test program to demonstrate the performance of the structure at the design conditions. Included in this program were room temperature, load only tests and elevated temperature tests.

The thermantic structure had the largest area, heated to the highest temperature of any structure that had been tested up to that time. This required the development of an infrared heating system capable of heating a large ceramic coated structure (70 sq. ft.) to temperatures in excess of 3000°F.

SECTION II

TESTING TECHNIQUES DEVELOPMENT

The major problem associated with the Thermantic Structure Test Program was the development of a heater capable of heating the structure to the desired test temperatures.

Two methods were considered, flame heating and infrared heating lamps. The contractor recommended that a flame heat source be used to heat the exterior surface of the test specimen since this type of heating would more nearly simulate the re-entry environment than infrared heating methods. The flame heating method was discarded in favor of an infrared system because of poor temperature control and the high noise level associated with flame heating methods.

Several factors were considered in selecting an infrared heating system that would give the required specimen temperature (3400°F) for the required length of time (15 min.). The temperature and time requirements dictated a heater that had provisions for cooling the quartz envelope of the heating lamps. The quantity of coolant (water or air) required was limited by the supply available in the test facility. Tests indicated that the optimum maximum operating voltage for the 1500 watt T3 heating lamps was 425 volts. Therefore, the heater had to be capable of producing the required specimen temperature at this lamp voltage.

Table I shows the different heaters that were investigated and their operating parameters.

Item 1 was a Research, Inc. water-cooled, aluminum reflector. Holes were drilled in the

TABLE I

INFRARED HEATER OPERATING PARAMETERS

ITEM		Air Req'd SCFM/Ft^2	Water Req'd GPM/Ft^2	Power Density KW/Ft^2
1	Research, Inc. Modified	98	1	96
2	Martin	——	5	125(Note 1)
3	Lunar 1"	——	16	48
4	Lunar 1/2"	21	32	96
5	Pyro-Metric Original	46	——	100
6	Pyro-Metric Modified	14	——	100

NOTE:

1. Power density of the Martin heater is based on using 2000W T3 lamps at 400 volts. All other figures are based on using 1500W T3 lamps at 425 volts.

reflector and a plenum chamber was welded to the back of the reflector. Air was blown directly down on the lamps. Temperatures exceeding 3000°F were indicated on an 8 x 12 in. panel using this heater. The airflow requirements were 98 SCFM per square foot of heater. The airflow requirements for the full size test structure would have exceeded the capacity of the test facility.

Item 2 was an infrared heat reflector unit designed by the Martin Company. The lamps were recessed into semi-circular grooves in a water cooled, gold plated, copper reflector. The lamps were cooled by conduction from the quartz envelope to the reflector. Provisions for supplemental air cooling of the lamps was built into the reflector. The unit was evaluated using 2000 watt T3 lamps and graphite blocks as the test specimen. The data indicated that temperatures of approximately 3200°F could be attained on the thermantic structure using this heater with 2000 watt T3 lamps. Because of its size (10-1/2 x 11 in.), this reflector would not give a good match to the contour of the specimen. Also, these units were the most expensive heaters evaluated. They would have cost approximately 50 percent more than the heaters that were finally selected.

Items 3 and 4 were water cooled reflectors designed by Lunar Infrared Systems. These reflectors required a separate unit for each lamp. Using these individual units, different size and shape heaters could be assembled. The 1 in. units gave a lamp density of 12 lamps per square foot, and the 1/2 in. units a lamp density of 24 lamps per square foot. Each reflector assembly required 1-1/3 gallons of water per minute for cooling. The water requirements for the thermantic structure test would have exceeded the capacity of the facility. The 1 in. units did not provide sufficient lamp density to reach the required temperature. The 1/2 in. units required supplemental air cooling at high lamp voltages. Since individual reflectors were required for each lamp, the set-up time for these heaters was greater than for any of the other heaters evaluated.

Items 5 and 6 were designed by Pyro-Metric, Incorporated. The reflector body was cast from a refractory oxide which has a melting temperature above 3000°F. All metal parts exposed to high temperatures were fabricated from stainless steel. Each individual reflector held five lamps. Lamp densities of 25 lamps per square foot were possible with these units. The original heater that was evaluated had a single 3/16 in. OD line to blow air down the center of the lamp array. An FDTT designed modification was then incorporated with the basic heater. This modification replaced the single air tube with seven small tubes (.039 in. ID) to direct the air jets underneath and between the lamps for more effective cooling. This arrangement reduced the volume of air required and minimized the effect of the air on the specimen. With 425 volts applied to the lamps, specimen temperatures of 3200°F were attained. This modified heater was the one selected for use on the thermantic structure.

SECTION III

TEST ARTICLE AND LOAD APPLICATION METHOD

The test article was a 90-inch long section based on a superorbital re-entry vehicle forebody. It was built of Aeronca's thermantic construction (see Section VII for construction details). In addition, there were metal transition sections attached to the forward and aft ends of the structure to insure that the test parameters could be properly applied and that the structures response to these parameters would more nearly simulate the response of a re-entry prototype. The test article is shown in Figure 1.

All tests were conducted using a floating test set-up. In this procedure the entire vehicle is tested as one integral unit with the dead weight of the structure and all attached test fixtures relieved by lead weights suspended from pulleys and attached to the test article. This, in effect, puts the vehicle in a zero "g" condition. All test loads were required to be uniformly applied and perfectly balanced in translation, roll, pitch, and yaw.

The vehicle was loaded through metal tension plates bonded to the interior of the test vehicle with General Electric RTV Silastic. Figure 2 shows the tension plate layout for the upper half of the vehicle. The layout of the lower half is similar to this. These loading points were interconnected to produce particular loading distributions by aluminum "whiffle trees." The nose cap loads were applied through straps bolted to the forward transition section. The equipment loads were applied to the equipment mounting lugs attached to each of the frames. All loads were applied by hydraulic rams or struts. An emergency "fail safe" system was designed into the loading hardware. This consisted of placing tension links, with known failing loads, between each hydraulic loading strut and the load point of the vehicle. In the event of a structural failure occurring during a test condition, in which all applied loads are "dumped" to zero, the tension links would prevent any local overload of the structure by failing at a load level below the damage level of the vehicle.

The load control was accomplished with the Air Force Flight Dynamics Laboratory, Structures Test Facility 50-Channel Controlled Loading System. The 50-Channel system is a closed loop servo system with automatic programming of load levels. The loads are applied by hydraulic cylinders with pressure supplied from electro-hydraulic servovalves. These valves are controlled by electronic controller channels which, by means of load cells, measure the applied loads and send the necessary correction signals to the servovalves until the correct load is achieved. The loads desired are generated by programmers which supply electronic signals to the controllers. The controllers treat the signals for transmission to the servovalves. The resulting loads are directly proportional to the signal level generated by the programmers and equal to those specified by each controller. A detailed description of the 50-Channel Controlled Loading System is on file at the AFFDL Structures Test Branch (FDTT).

SECTION IV

ELEVATED TEMPERATURE TEST METHODS

Since the elevated temperature condition tested was to demonstrate a design point, no attempt was made to conduct transient heat conditions during the test program. The test condition required that the back face of the structural honeycomb be cooled to 100°F and that the surface of the test article be heated to 3200°F and held for 2 minutes.

Radiant heating techniques were utilized for the elevated temperature conditions. The basic heating elements used were General Electric 1500T3/CL infrared heating lamps. These lamps were mounted on Pyro-Metric PM 500M ceramic reflector assemblies (Figure 3). The reflector assemblies were then mounted on an air manifold and support frame which were contoured to match the shape of the test article (Figure 4).

The test article was divided into 24 control zones (Figure 5) with a thermocouple in each zone for temperature control and monitoring purposes. The first three elevated temperature runs used the General Electric Heat Control Computer No. 2 (HCC No. 2) for temperature control. The last two runs were controlled manually.

The heat control computer is a special purpose digital function generator with a time shared analog computer for control of power regulating equipment. The computer can program and control radiant energy. For this test program the computer was used to control the surface temperature of the test article. The function generator produces a voltage that varies as a function of time. The system is a closed loop operation utilizing a thermocouple feedback and/or power feedback for computing the degree of compliance with the desired test program. The computer generates an error signal proportional to the power required to balance the system. A detailed description of the heat control computer and the other equipment used for the elevated temperature tests is on file at the AFFDL Structures Test Branch.

SECTION V

INSTRUMENTATION

Instrumentation of the thermantic structure included strain gages, thermocouples, deflection potentiometers, and load cells. All the strain gages and thermocouples were originally installed by Aeronca Manufacturing Co. The deflection potentiometers and load cells were calibrated and installed by FDTT. The transducer outputs were acquired and processed by the AFFDL Structures Test Facility High Speed Data Acquisition and Processing System (DAPS).

Rosette type strain gages were used on the back face of the structural honeycomb and axial type gages on the frames. Both types used foil sensing elements on a bakelite carrier and were temperature compensated for A-286 steel. Each leg of a rosette gage was treated as an individual gage. Each gage was wired to a single active arm Wheatstone bridge network. This bridge network was in turn completed within the DAPS where the strain gage outputs were modified by the apparent strain, temperature compensation values, moduli of elasticity, and strain rosette equations, through computer programming. This was to obtain axial and principal stresses.

Three types of thermocouples were used. Iridium vs. Iridium-40% Rhodium and Platinum vs. Platinum-10% Rhodium thermocouples were used to measure the surface temperatures. Platinum vs. Platinum-10% Rhodium thermocouples were used to measure the subsurface temperatures. Chromel vs. Alumel thermocouples were used to measure the temperature at the braze line and on the back face (Figure 6). The thermocouple outputs were converted to temperature data by computer programming.

The system displacement transducers measured the deflection of the test article by measuring the displacement of a spring-loaded steel cable attached to the test article. The cable was directly coupled to a precision potentiometer. The cable displacement resulted in an output voltage change. This output voltage change was recorded and converted to a displacement data by the DAPS.

The load measurement system consisted of double bridge load cells at each load point. One bridge of the load cells was used for data and the other bridge for load control purposes.

A detailed description of the DAPS, transducer characteristics, methods of installation, electrical wiring circuits, type of output information, and transducer locations on the test article are on file at the AFFDL Structures Test Branch (FDTT).

SECTION VI

TEST PROGRAM

The test plan for the thermantic structure was developed by Aeronca with the concurrence of FDTT and FDTS. The test program is presented in Aeronca Report ER-602 and Reference 1.

Static Test I

Static Test I was a room temperature, load only condition. The loads were those loads associated with the +10 g point of the first re-entry cycle (Reference 2, Page 21). The loads were controlled automatically by the 50-Channel Controlled Loading System. The loads followed the time-load program shown in Figure 7. All data was read and recorded at a rate of one sample per second for the first 105 seconds of the load program. There was no damage to the structure from this test.

Static Test II

Static Test II was similar to Static Test I with the exception that the loads were those loads associated with the -4 g point of the first re-entry cycle (Reference 2, Page 21). There was no damage to the structure from this test.

Static Test III

Static Test III was an elevated temperature and loads test. The outside surface of the test article was to be heated to 3400°F and after this temperature had stabilized, the +10 g loads were to be applied. However, because of the limitations of the infrared heating lamps, the required surface temperature was reduced to 3200°F. Also, various equipment failures during the elevated temperature portion of the test caused the tests to be stopped before the load was applied. Following is a list of the five elevated temperature runs that were made:

Run No. 1

This run used the AFFDL Structures Test Facility Heat Control Computer No. 2 (HCC No. 2) for temperature control. The computer was programmed to follow the time-temperature curve shown in Figure 8. The program was held on the 400° and 1000°F plateaus to check the operation of HCC No. 2. The test was stopped when pieces of the ceramic coating fell into the lamps and caused several lamp failures. The surface temperatures recorded just prior to the end of the test ranged from 2500° to 2800°F.

Run No. 1A

Because of the coating and lamp failures in the previous run, it was decided to heat only the upper surface and control zones 16A and 16B of the lower surface. The test procedure was the same as for Run No. 1. The test was stopped when the large power demands for zones 16A and 16B caused lamp failures in these zones. The excessive power requirements for these zones was the result of being adjacent to the unheated area. The maximum temperatures recorded on the upper surface were all approximately 2600°F.

Run No. 2

Prior to this test the cracked ceramic coating was removed and the specimen was recoated with a thinner coating. The test procedure was the same as for Run No. 1 and the entire specimen was heated. The test was stopped when a malfunction in the temperature control circuitry caused large power surges to the heat lamps. The maximum temperatures recorded before the malfunction were all approximately 1800°F.

Run No. 3

In an attempt to isolate some of the problems in the temperature control system, the heat lamp input power was manually controlled for this run. This test was stopped when a hydraulic hose in the test area caught fire. The maximum temperatures recorded ranged from 2300° to 2900°F.

Run No. 4

The lamp input power was controlled manually for this test. This test was stopped when the honeycomb core at one spot on the lower surface started to melt and was causing lamp failures. Also, two of the tension links failed from high temperature effects. This precluded the application of the test loads to the specimen. The maximum temperatures recorded ranged from 2800° to 3195°F. This run ended the test program.

The ceramic surface coating cracked during each elevated temperature run. The test article was recoated before Runs No. 2, 3, and 4 with a thin wash coat. This thin coating had less blistering and cracking than the original coating. A discussion of coating failures is contained in Reference 1.

SECTION VII

DISCUSSION

DESCRIPTION OF STRUCTURE

The primary structure consisted of load bearing honeycomb sandwich panels welded and/or mechanically joined together. The panels used A-286 for the face sheets and Hastelloy C for the core. Edge members of N-155 were brazed to the panel face sheets to provide suitable material for welding at the longitudinal and transverse joints. The structure was stabilized by conventional ring frames located at Stations 35, 65, 95, and 125. The rings and webs were machined in two halves, upper and lower, from N-155 multimet plate.

The primary structure was protected from the environmental heat flux by a ceramic heat shield. The heat shield was reinforced by an open face Inconel honeycomb core. This core was brazed to the outer face of the structural panels at the same time as the panel brazement was made. The reinforcing core was flame sprayed to provide oxidation protection to the core and to assist in the adhesion of the foamed ceramic material. There were two coats applied, one nickel-chrome undercoat and a final coat of zirconia flame spray. Fiberfrax fibrous insulation was installed to a depth of .50-inch into the bottom of the reinforcing core. The use of the fibrous insulation improves the structures insulation characteristics and reduces the total weight. Foamed alumina was then added to finish filling the honeycomb core. The alumina foam was the primary heat rejection component of the heat shield. The alumina reradiated a high percentage of the incident heat flux and its low thermal conductivity minimized the heat transfer through the structure. The heat shield was completed with the application of a zirconia base, high emittance coating. This final coating was used to increase the thermal capability through higher emittance, protect the heat shield reinforcing honeycomb core, provide increased erosion resistance, and to maintain an aerodynamic surface. A molded RTV rubber heat exchanger was bonded to the back face of the structural honeycomb. Water was circulated through the heat exchanger to maintain a back face temperature of 100°F.

Details of the structure are shown in Figure 9. A discussion of the design, fabrication, and properties of the thermantic structure is contained in References 2 and 3.

THERMOCOUPLE INSTALLATION

During the checkout of the infrared heating system, it was noted that the response of the contractor-installed control thermocouples was very slow. A subsequent inspection of these thermocouples showed that they were not flush with the surface as had been planned. In some cases, the junction was simply not at the surface. In other cases, the thermocouple wires were touching for some distance into the structure. This, in effect, put the measuring junction at some point below the surface. The sub-surface thermocouples were found to be in the same condition. Surface thermocouples were then installed by FDTT for temperature control (Figure 6). The originally installed thermocouples were monitored during each test, but the data was not used for the thermal analysis of the structure.

The thermocouples mounted on the surface posed a different problem. When the ceramic coating in the area of a thermocouple separated from the structure, the thermocouple was lifted from the surface and would give a false temperature indication. This problem was partially eliminated by using a thin wash coat of ceramic for the last three elevated temperature runs. The thin coating showed less cracking and better adhesion than the original thick coating.

TEMPERATURE CONTROL

For the automatically controlled elevated temperature tests, the time-temperature mode of the heat control computer was used. In this mode of operation the output of a thermocouple mounted on the test specimen is compared, by the computer, to the

programmed temperature. The computer then generates an error signal which activates the ignitron power regulators. The ignitron power regulators regulate the power to the radiant heat lamps.

During Run No. 2, after approximately 760 seconds of controlled operation, there were large power surges to the heating lamps. A subsequent evaluation of the data showed that there had been a small surge of power to the heating lamps even though there had been no demand for power by the computer. There was a lag in time between when the power was applied to the lamps and when the structure and control system reacted to the power increase. The result was that as the temperature was increasing, the power was decreasing and vice versa. The computer kept calling for more power to maintain the programmed temperature. These excessive power requirements caused lamp failures. The total time involved from the initial power surge until the test was stopped was approximately 20 seconds.

In an attempt to isolate the problem and to complete the test program, the computer was bypassed and the ignitron regulators were operated manually for Runs 3 and 4.

There were no problems encountered in controlling the power for Runs 3 and 4. The test program was ended with Run No. 4. The checkout of the heat control computer is being continued on other test programs.

SECTION VIII

CONCLUSIONS AND RESULTS

The Thermantic Structure Test Program was unique in several respects. First, the thermantic structure had the largest heated area (approx. 70 sq. ft.) and the highest temperature requirement (3200°F) of any high temperature test that had been conducted at FDTT. Second, this test program was the first to require multi-channel (24) operation of the FDTT full scale elevated temperature system. Third, the ceramic coating required different thermocouple mounting techniques than used with metallic materials.

The high temperature of the specimen required the development of a heater with a higher capability and more reliability than any available at the time. The heater used was a commercially available heater incorporating an FDTT designed modification which greatly increased its overall capability. The development of this heater gave the AFFDL Structures Test Branch the capability of testing large size structures to temperatures in excess of 3000°F.

The multi-channel operation of the full scale elevated temperature system brought to light several problems associated with multi-channel operation. These problems were either solved or work is continuing on their solution for other test programs.

Further work is required to optimize the attachment of thermocouples to this type of material. FDTT is experimenting with flame spraying as a thermocouple attachment method. Preliminary test results indicate that this method gives good results on a ceramic surface.

SECTION IX

REFERENCES

1. W. R. Niehaus, J. E. Shrout, R. G. Anderson, "Final Report on Hypersonic Lift Vehicles - Test Evaluation," ML-TDR-64-267, Part II, Volume 1, November 1965.

2. C. J. Giemza, W. B. Hunter, et al, "Final Report on Structural Heat Shield for Re-entry and Hypersonic Lift Vehicles," ML-TDR-64-267, Part I, Volume 1, January 1965.

3. C. J. Giemza, W. B. Hunter, et al, "Final Report on Hypersonic Lift Vehicles," ML-TDR-64-267, Part I, Volume 2, January 1965.

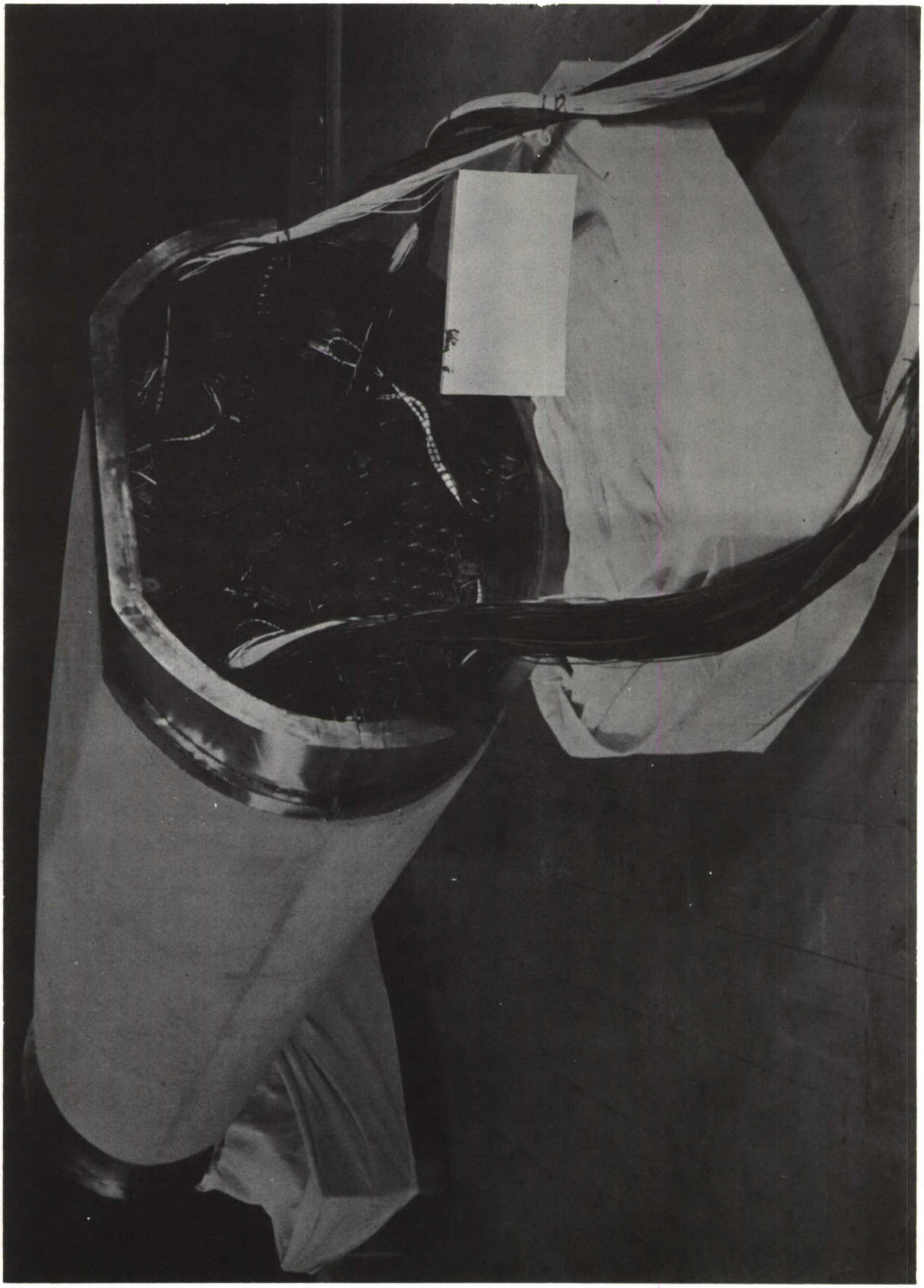


Figure 1. Thermantic Structure Test Article

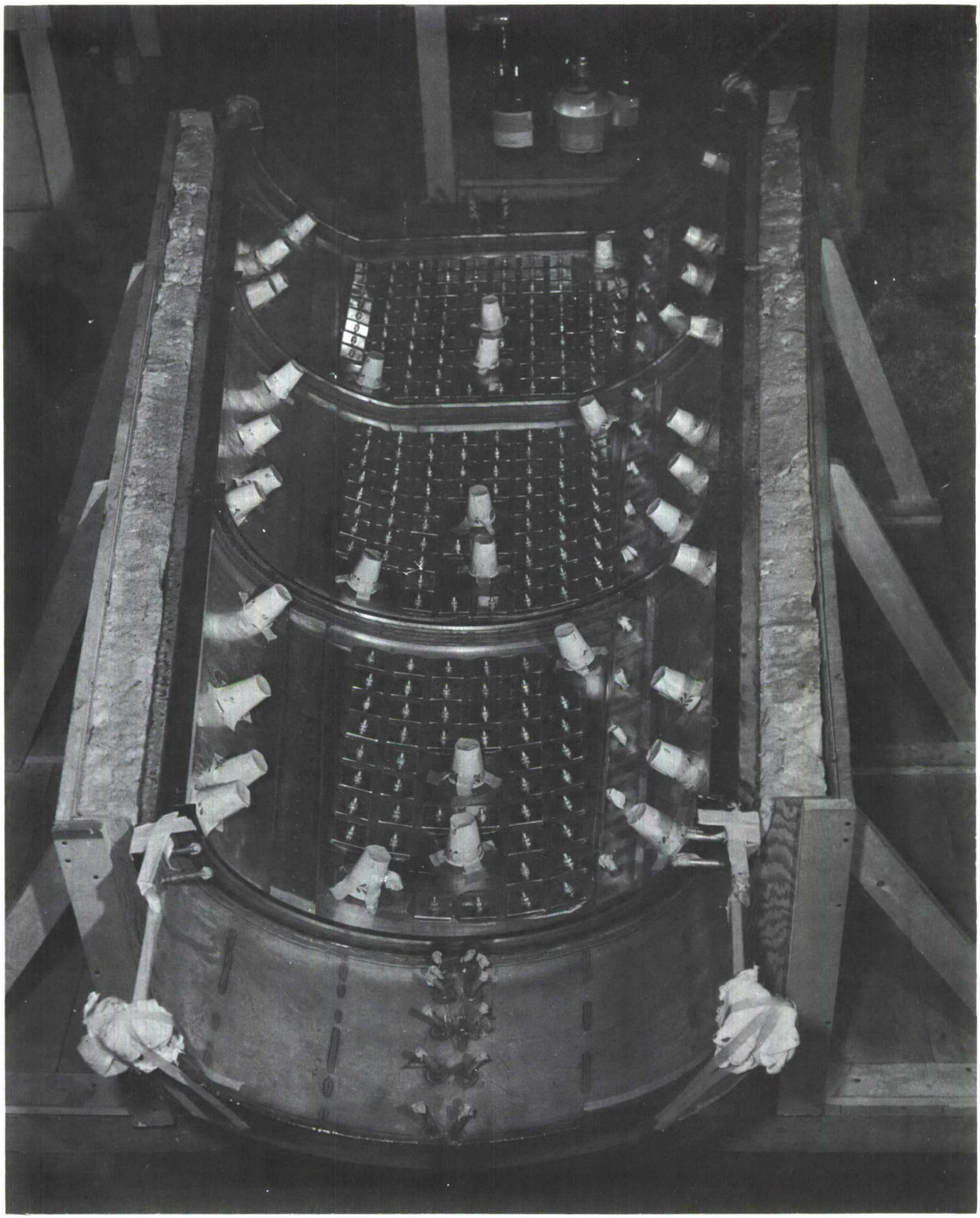


Figure 2. Tension Plate Layout

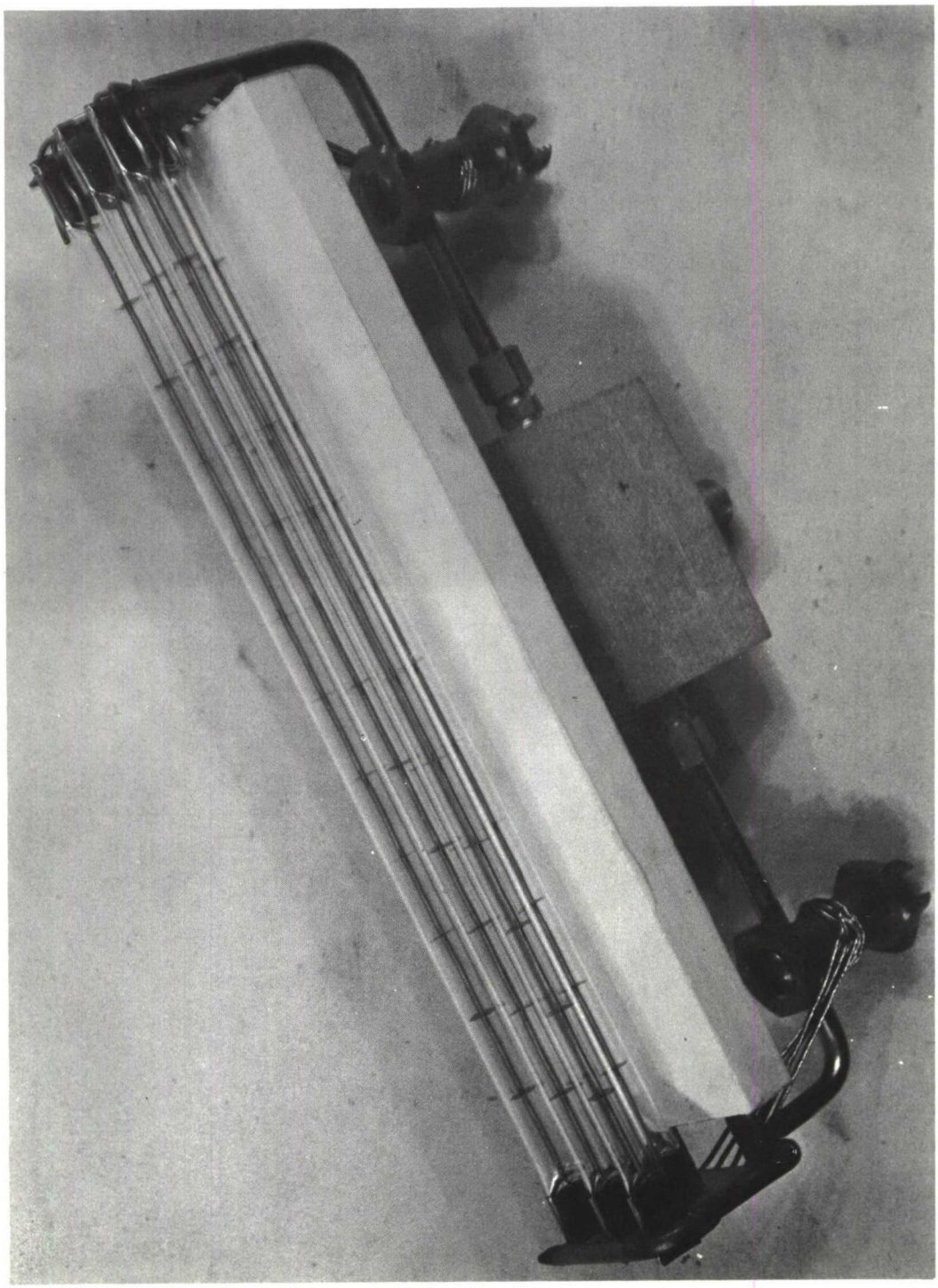


Figure 3. Pyro-Metric Infrared Heater Assembly

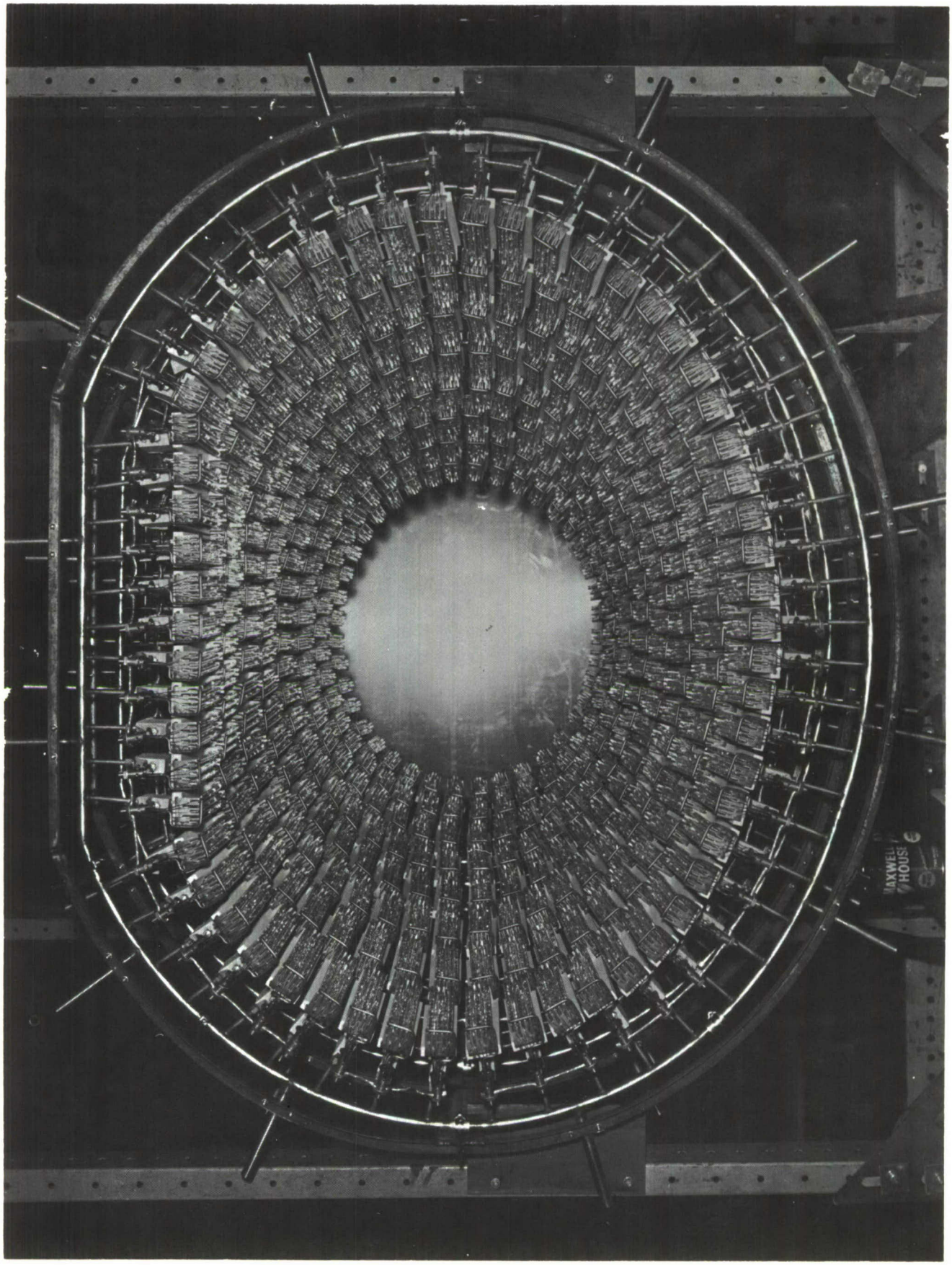
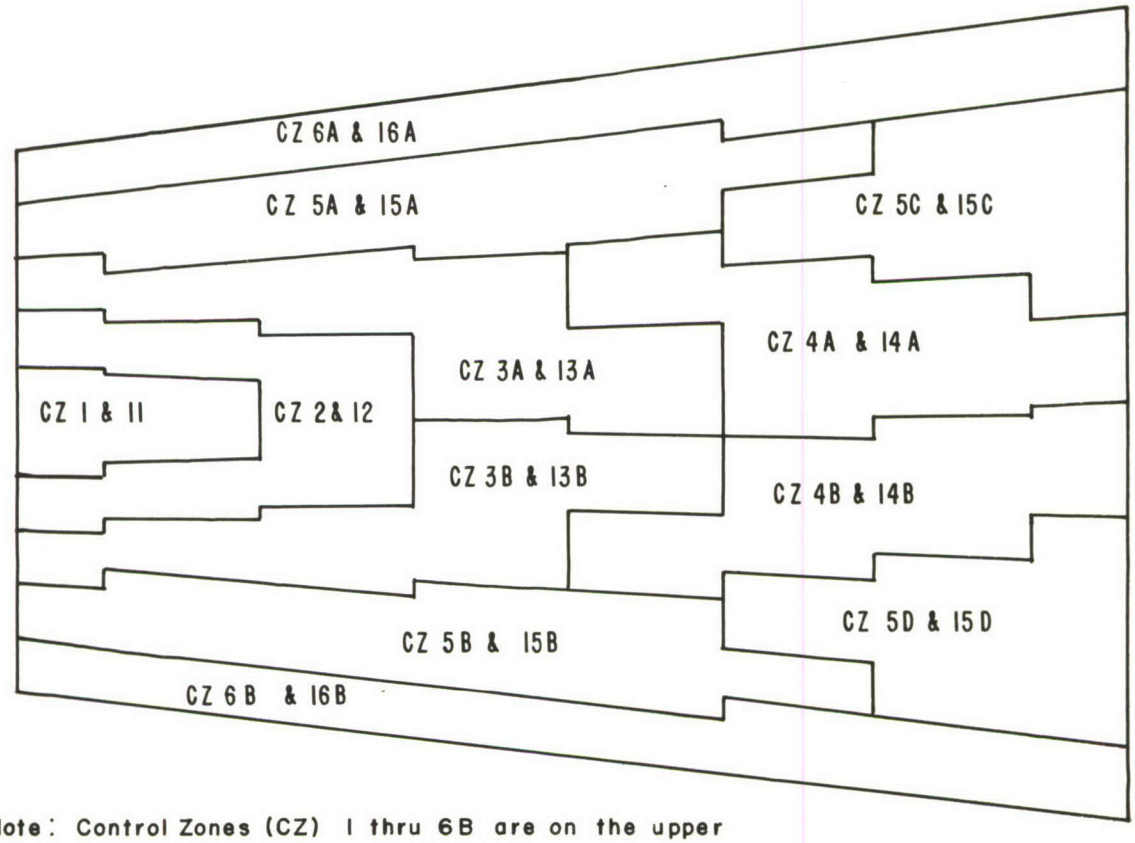


Figure 4. Infrared Heater Air Manifold and Support Frame



Note: Control Zones (CZ) 1 thru 6B are on the upper surface and Zones 11 thru 16B are on the lower surface.

Figure 5. Control Zone Layout

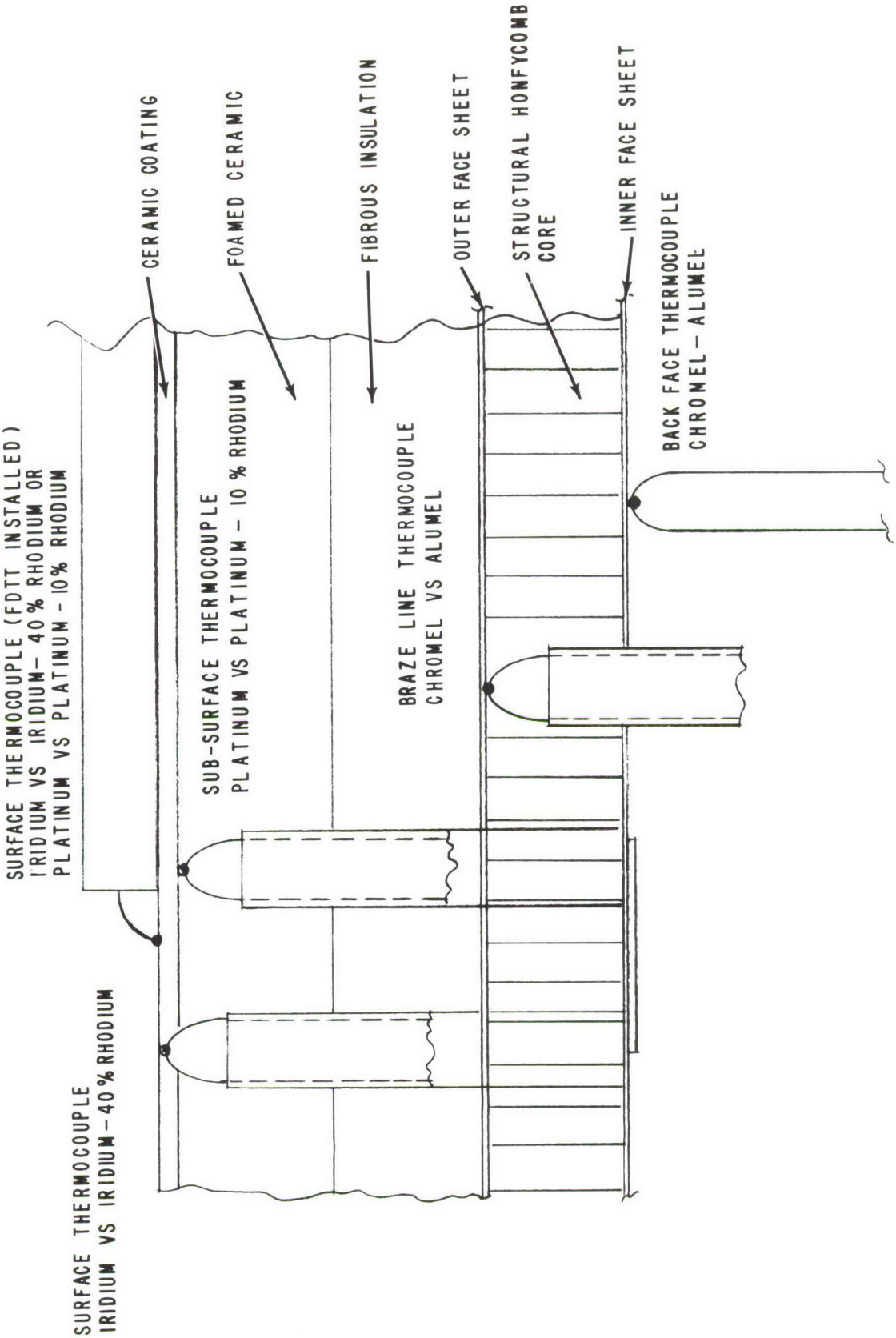


Figure 6. Thermocouple Installation

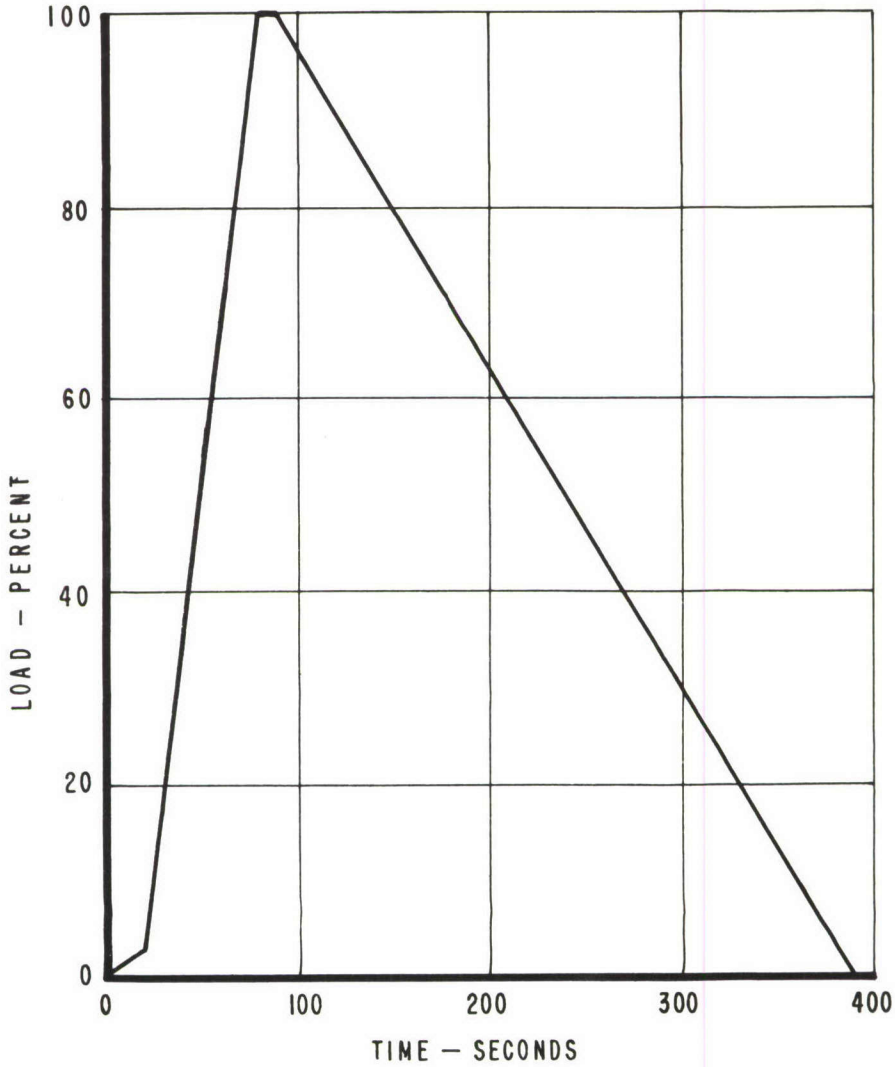


Figure 7. Time-Load Program

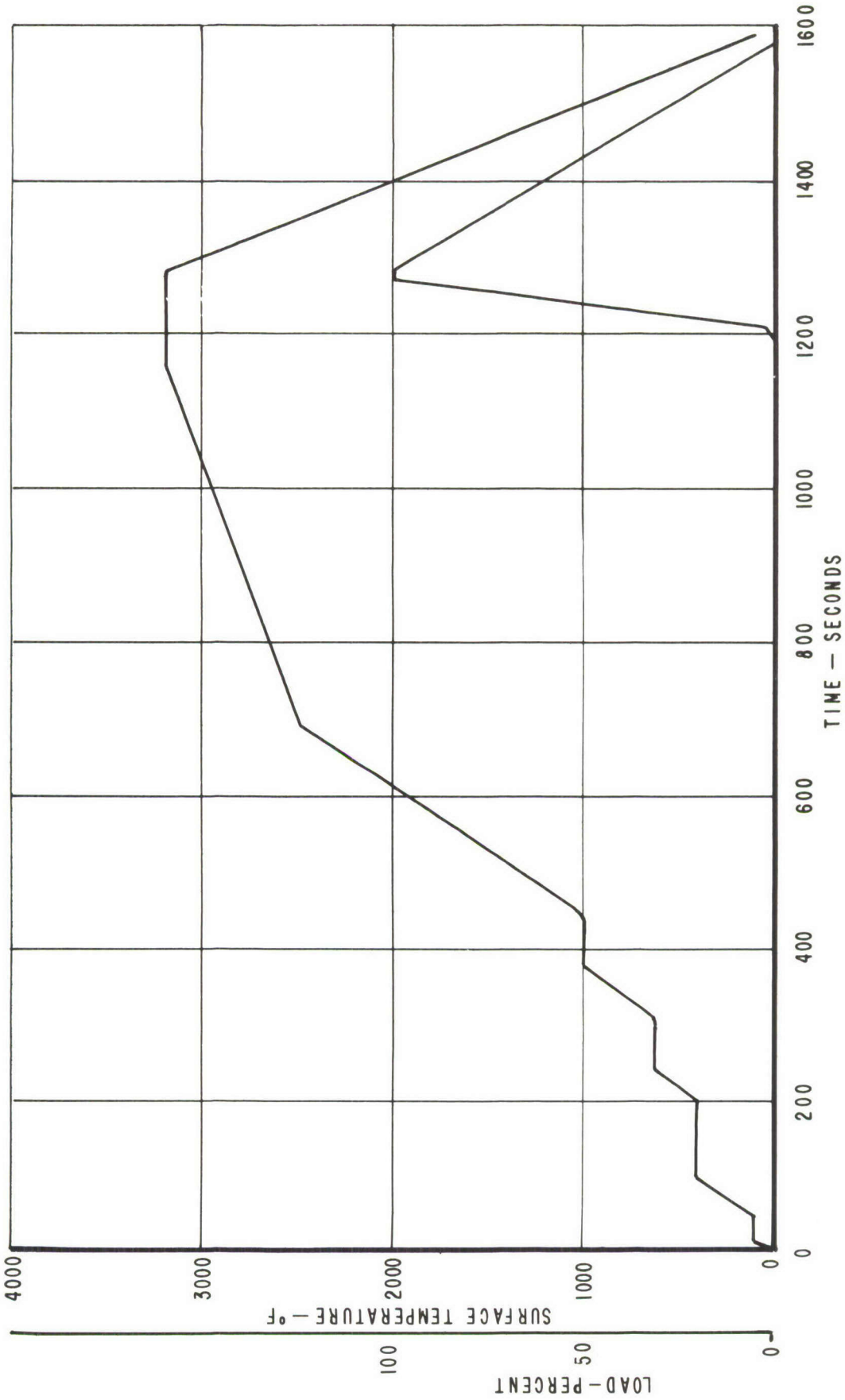


Figure 8. Temperature and Load vs Time

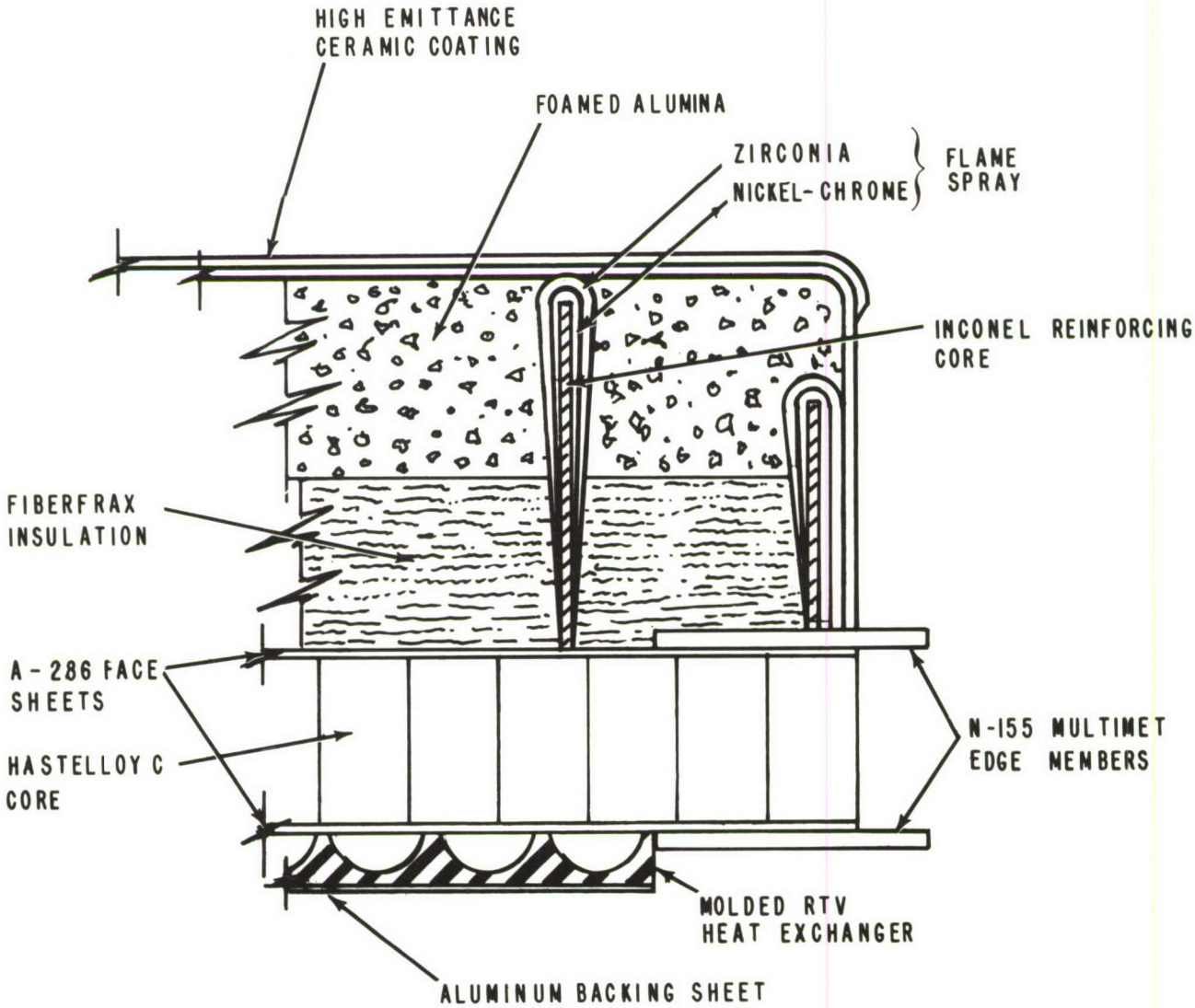


Figure 9. Thermantic Construction

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Structures Test Branch
Structures Division
Air Force Flight Dynamics Laboratory

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. REPORT TITLE
THERMANTIC STRUCTURE TEST PROGRAM

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final - December 1964 to October 1965

5. AUTHOR(S) *(Last name, first name, initial)*
Hughes, Thomas F.

6. REPORT DATE
June 1966

7a. TOTAL NO. OF PAGES
28

7b. NO. OF REFS
3

8a. CONTRACT OR GRANT NO.

b. PROJECT NO. 1368

c. Task No. 136804

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AFFDL-TR-66-76

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES
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11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Air Force Flight Dynamics Laboratory

13. ABSTRACT

A re-entry vehicle section built of Aeronca's thermantic construction was tested to demonstrate the performance of the structure at the design conditions. The design point for the structure is the peak loading and temperature portion of the first re-entry cycle with equilibrium temperatures overall. Three conditions were tested. Static Test I and Static Test II were room temperature, load only tests. There was no damage to the structure from these tests. Static Test III was a combined elevated temperature and load test. The elevated temperature portion of this test was started and aborted five times because of various equipment failures. Each elevated temperature run caused the coating to crack. The highest temperatures were recorded during the last run. Temperatures on the lower surface ranged from 2800° to 3195°F. The temperatures on the upper surface ranged from 2824° to 3176°F. An infrared heating system was developed for this program, capable of heating large structures to temperatures in excess of 3000°F.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Structural Testing Elevated Temperature Testing						

INSTRUCTIONS

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