AD-649246

AFFDL-TR-66-132

20070917070

THERMAL TESTING OF EXPANDABLE SOLAR COLLECTORS

ALLAN W. GUNDERSON

TECHNICAL REPORT AFFDL-TR-66-132

DECEMBER 1966

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AIR FORCE FLIGHT DYNAMICS LABORATORY
RESEARCH AND TECHNOLOGY DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

NOTICES

200 - February 1967 - C0192-21-451

AFFDL-TR-66-132

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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, as a formal record of the testing of expandable solar collectors as part of Task No. 817004. The test program at the Structures Test Branch was directed by Allan W. Gunderson as project engineer, and Charles R. Waitz as instrumentation engineer. This report covers tests conducted between April 1964 and June 1965. Manuscript released by the author August 1966 for publication as a RTD Technical Report.

This technical report has been reviewed and is approved.

Sanford Lustig
SANFORD LUSTIG
Acting Chief
Structures Test Branch
Structures Division

ABSTRACT

The Solar Collector Test Program was initiated to determine the structural response of expandable and unfurlable solar collectors to a simulated space thermal environment. The heating of the collectors was by T-3 infrared heat lamps, and cooling was obtained by liquid nitrogen boil-off. The collector structures in both instances performed as expected and no unusual deflections were measured.

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ILLUSTRATIONS

SECTION I

INTRODUCTION

The Air Force Flight Dynamics Laboratory was requested to run thermal and load simulation tests on various expandable structures furnished by the Aero Propulsion Laboratory, Support Techniques Branch. This report covers thermal testing on two solar collector models during the period of April 1964 through June 1965.

The first test article was a 20-foot long solar collector petal as shown in Figure 1. This was one segment of a 45-foot diameter unfurlable collector. The manufacturer was Electro-Optical Systems, Incorporated of Pasadena, California. The pedal was made entirely of electro-deposited nickel. The front face surface was deposited on a parabolic mandrel. A styrofoam core, shaped like the back face, was then attached to the front face. Coating the styrofoam with a conductive paint made it possible to deposit the back face directly to the core. The styrofoam core was then dissolved by a trichloroethylene bath. Total weight of the test petal was approximately 62 pounds.

The second collector was a 28-inch diameter urethane rigidized model made by Geophysics Corporation of America (GCA), Viron Division (see Figure 11). This collector was fabricated from gores of a two-layer drop-thread cloth sewn into a parabolic shape. The reflective surface was aluminized mylar adhered to the front face. The collector was then formed and rigidized over a parabolic mandrel.

The thermal cycling on the collectors was to simulate a near earth orbit of 90-minute duration. Heating of the collector occurs when it is in direct sunlight and cooling when in the earth's shadow.

SECTION II

TEST DEVELOPMENT

As part of the solar collector test requirements, it was necessary to develop a controlled cooling system which could work in combination with the present elevated temperature heating system. A series of compatibility and development tests were required to obtain a workable system. A number of Conoflow Model 73N12FC control valves were acquired as surplus material from a dismantled wind tunnel to control the required flow. Valve action was by an electric signal controlling a pneumatic actuator. The valves were first checked to determine if they could operate at the temperature of the liquid nitrogen. The valves were connected to the output line of a pressurized liquid nitrogen Dewar and were actuated with liquid nitrogen flowing through them. The valves proved satisfactory from this standpoint so a method of control was next investigated. The original control mechanism with the valves was for a set point (constant temperature) control. This was not readily adaptable to a programmed (variable temperature) input. A control method was obtained by using a Research, Incorporated, Model 4080 heat controller output through a DC amplifier and then to the control valve. This method used the 4080 output in reverse of normal - calling for control when the thermocouple was too warm instead of too cold as on the heating mode.

A test panel was fabricated for system checkout before using the actual test article. Cooling coverages and rate were both investigated. It was found that cooling by a spray tube could be effective and have satisfactory distribution over the test panel surface.

SECTION III

TEST SET-UP

The test equipment development and working description will describe the 20-foot solar petal. The same control arrangement was used on the 28 inch collector. The solar collector petal was tested in an aluminum enclosure (Figure 2) to contain the nitrogen coolant and also to protect bystanders from the heat lamp brilliance. One of the test requirements was to simulate a zero "G" condition. This was accomplished by calculating the weight per section of the petal and relieving this weight by a beam-pendulum arrangement as shown in Figure 2.

Because of the very thin skin (approximately .025 inches), and the rapid heat transfer the test was set-up whereby all heating would be done on the front face and all cooling from the back face. A baffle plate was placed alongside the specimen in the test enclosure to reduce the billowing action of the coolant. All data connections were made as shown in Figure 6. Data were fed to the Structures Test Branch High Speed Data Acquisition and Processing System.

The program signal for the heating and cooling was generated by a Research, Incorporated Data-Trak analog programmer. This sends a voltage level corresponding to the temperature desired to the Research, Inc. 4080 Recorder-Controller. The 4080 then compares the program signal level to the specimen feedback temperature (thermocouple output) to see if they are equal. (Null position.) If not, the controller will adjust its output to correct the situation. For the heat side of the cycle the 4080 output, because of an "off null" position, causes the Research, Inc. Model 4079 thyratron power unit to raise (or lower) the voltage to the heat lamps. On the cooling portion of the cycle the 4080 output is amplified to a level necessary for control of the Conoflow servovalves which open or close the liquid nitrogen valve as required.

On the 28-inch Viron solar collector, because of the light weight of the structure, the zero "G" suspension was not used; instead a three-point suspension was used which allowed it to deflect under thermal stresses (see Figure 12).

SECTION IV

TEST CONDITIONS

The tests run on each of the collectors were three real-time cycles of 90 minutes each, and 48 rapid cycles of nine minutes each. The first real-time cycle varied from room temperature to +125°F, down to -50°F, then returning to room temperature. The second and third real-time cycles followed the same outline with temperature limits of +175° to -100°F, and +225° to -150°F, respectively. The rapid cycles all had as limits +225° to -150°F. Temperature profile followed is shown in Figure 7.

SECTION V

TEST RESULTS

On the 20-foot petal the deflection was the most critical measurement. The focus for the assembled parabolic reflector must be held to close tolerances; therefore, the deflections of one petal affects the total output greatly. The deflection measurements plotted versus temperature indicated the petal tended to straighten during the cooling cycle. Representative data plotted from these tests are presented in Figures 8 through 10. Complete data compiled during these tests are not presented in this report because it is voluminous and in tabular form. However, it will be retained on file at the Structures Test Branch (FDTT), Wright-Patterson Air Force Base, Ohio.

The petal was examined after each series of runs for cracks at weld joints, and buckles or distortions from the thermal loading. No evidence of failure was observed. In Figure 1, showing the original petal condition, the manufacturing flaws can be seen. As this was a prototype model, the assumption can be made that future petals would have a better finish and even better structural integrity.

On the Viron 28 inch solar collector, deflection was also the main data requirement. Figure 12 shows the test set-up used. The structure was also observed after each run to determine if the thermal cycling would loosen the aluminized mylar from the front face. No defects were found at any time. Representative data from these tests are shown in Figures 14 through 15.

The tests as run were aimed at thermal simulation only. The data would, of course, be more valid if a vacuum chamber were used and a cold wall were used for cooling. This would apply only to the real-time cycles, as the rapid cycles could not be run in a vacuum.

SECTION VI

CONCLUSIONS

The two solar collectors tested represented two different design concepts to be used for space power systems. The 20-foot petal design is an unfurlable structure, whereas the 28-inch Viron is of the expandable structure design concept. Both collectors remained structurally sound during the thermal cycling. These tests have proven the manufacturing methods to be sound, but some improvements have to be made to get the optical reflectivity and parabolic accuracy desired.

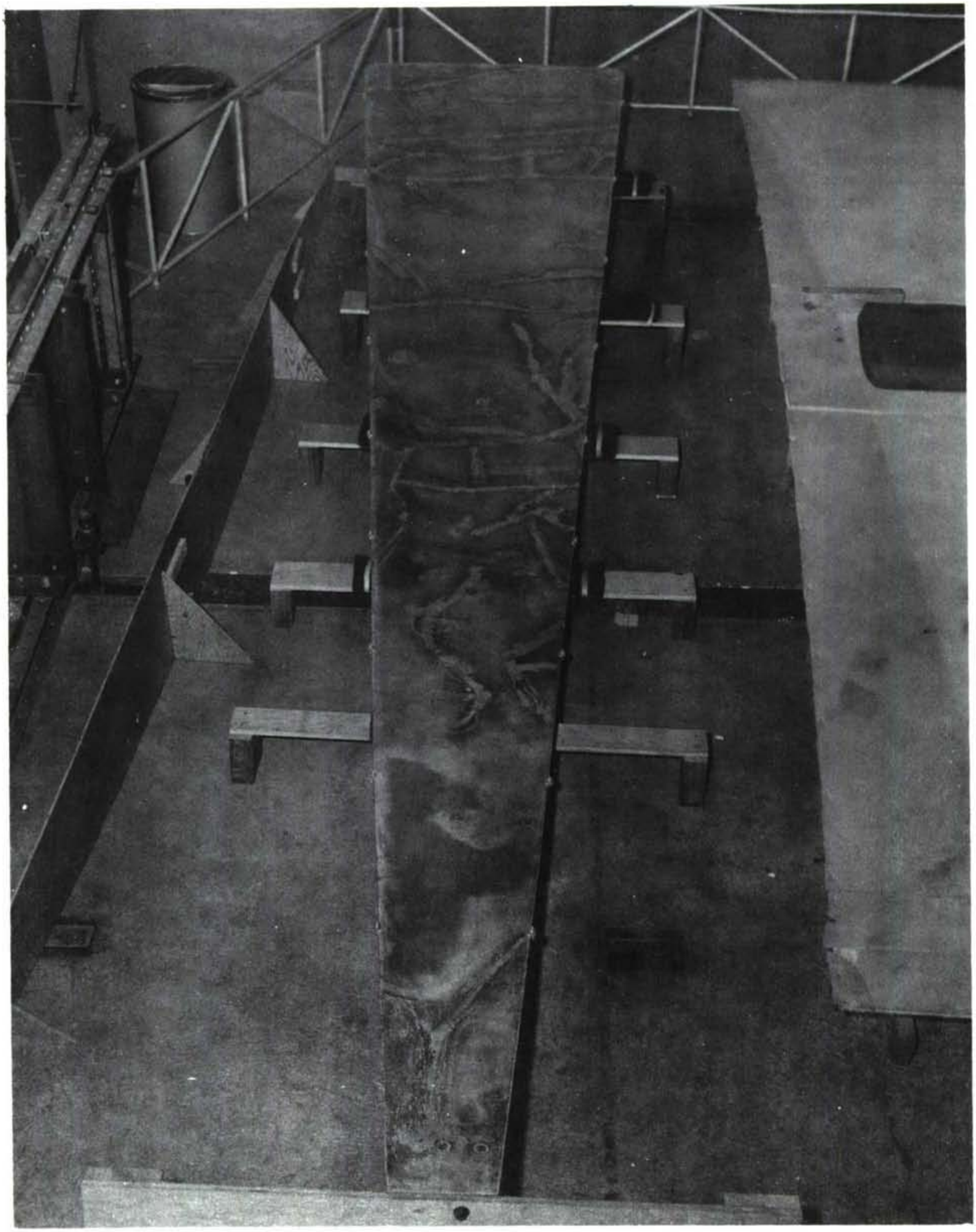


Figure 1. 20-Foot Solar Petal as Received

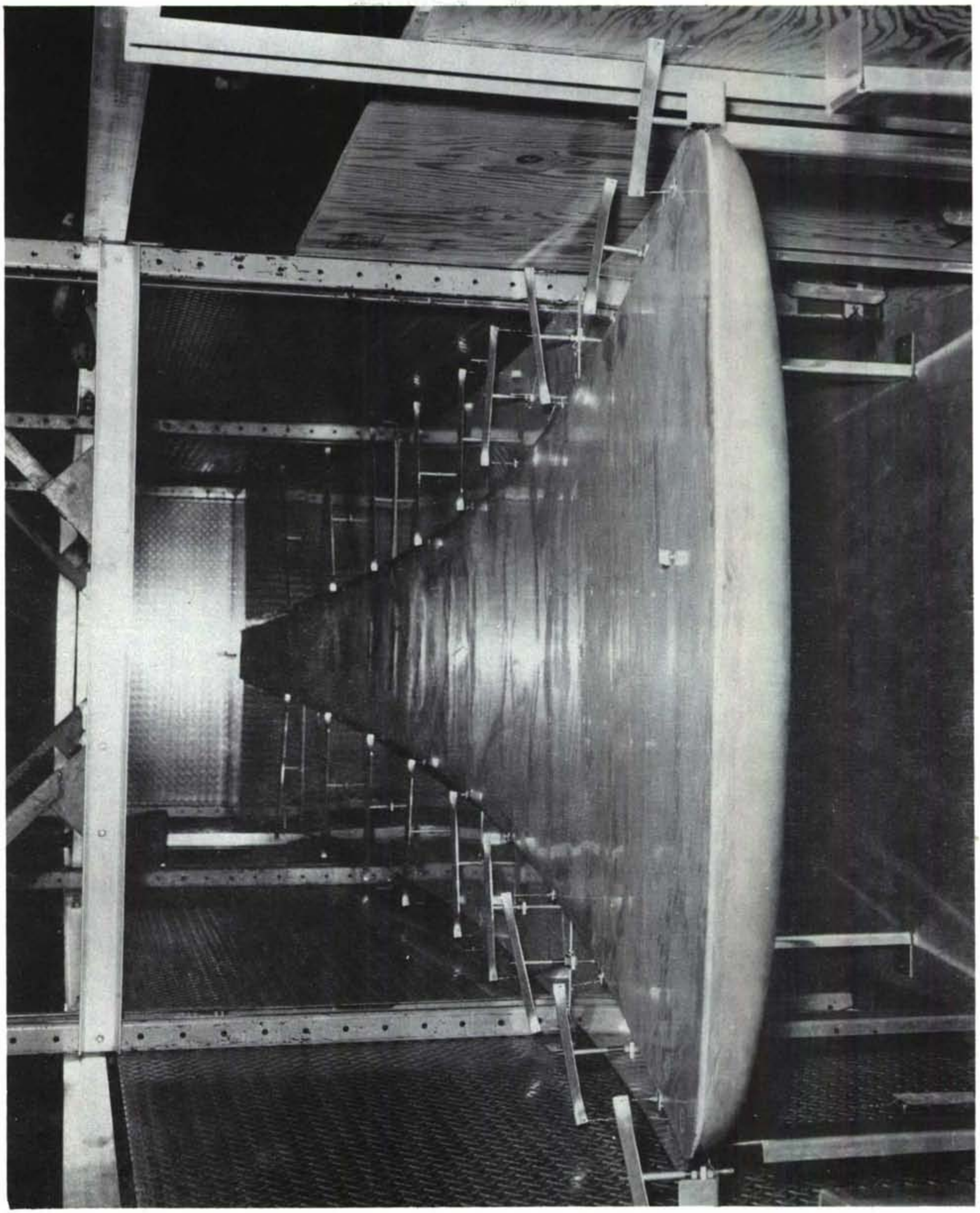


Figure 2. 20-Foot Solar Petal Mounted in Aluminum Enclosure

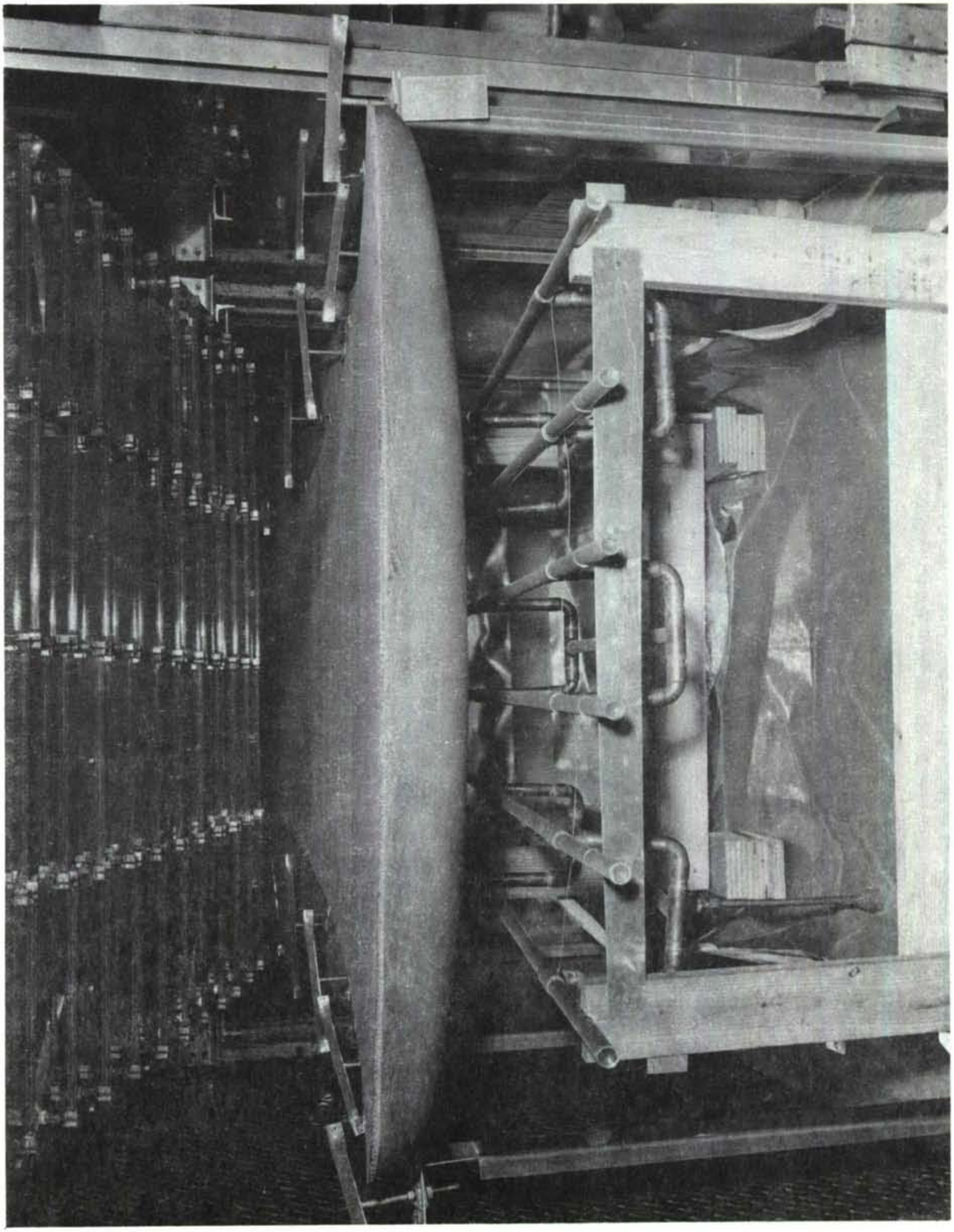


Figure 3. 20-Foot Solar Petal Showing Heat Lamps, Spray Cooling Tubes and Dead Weight Supports

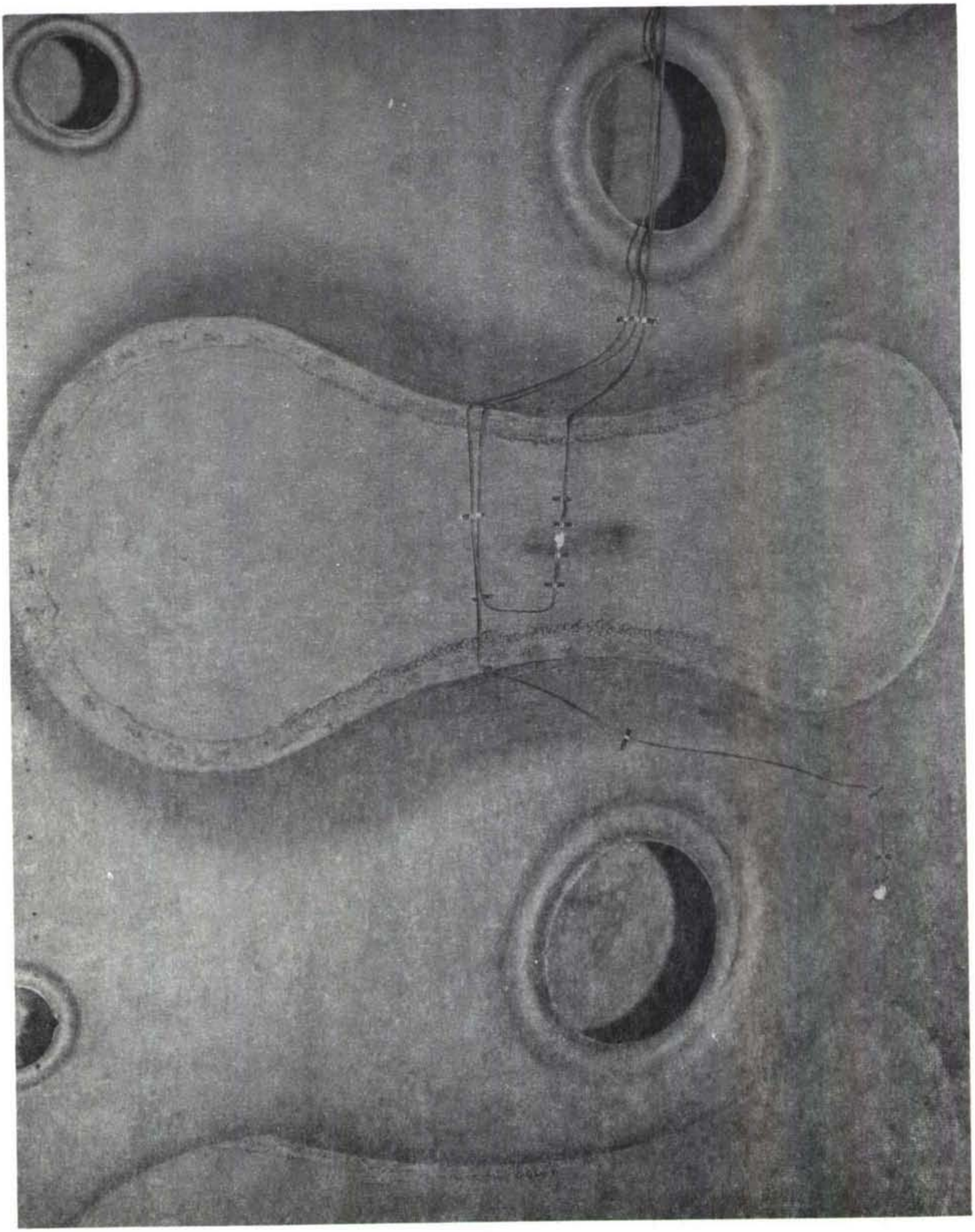


Figure 4. Close-up of Back Face of 20-Foot Solar Petal Showing Typical Thermocouple Mounting

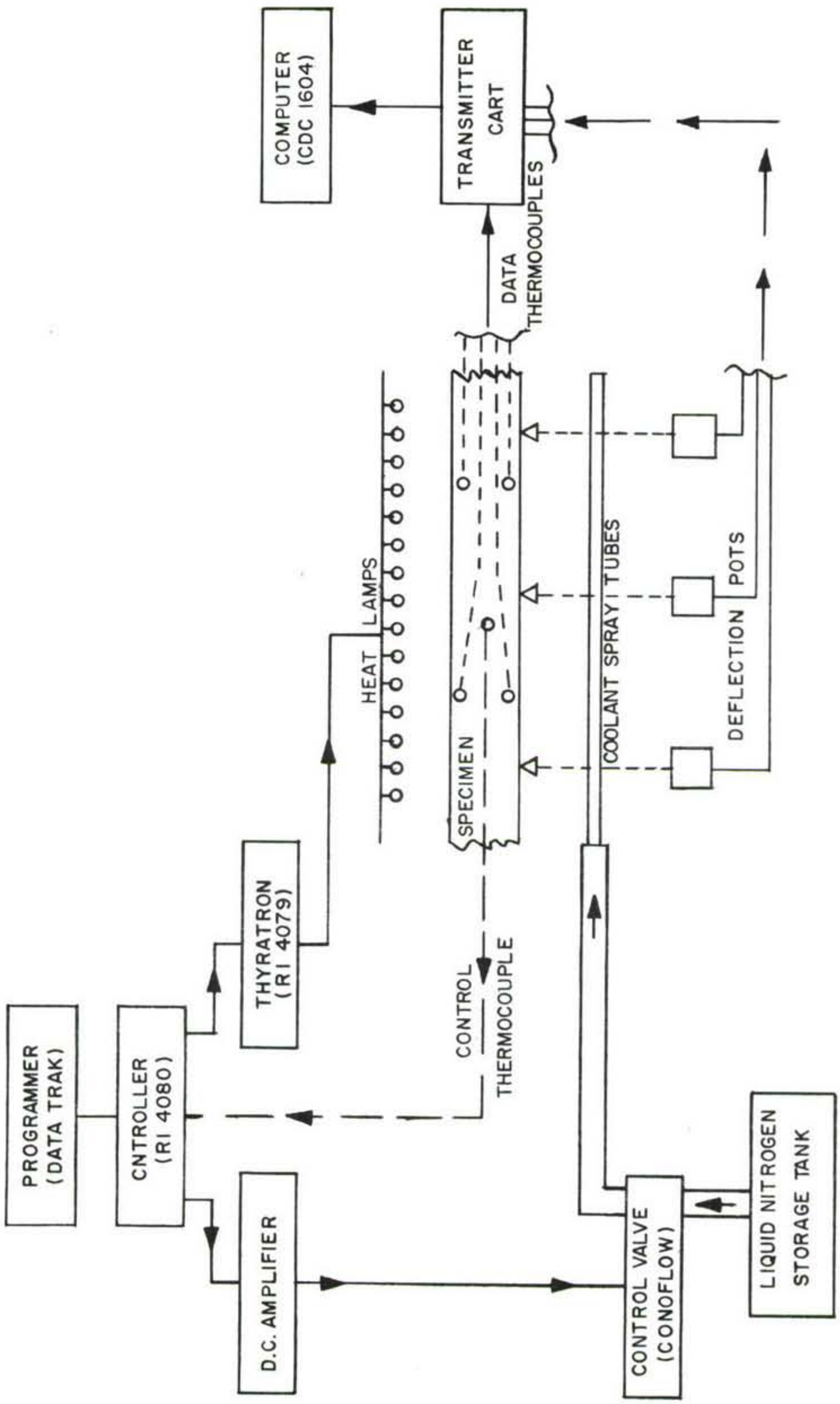


Figure 5. Control and Data Block Diagram

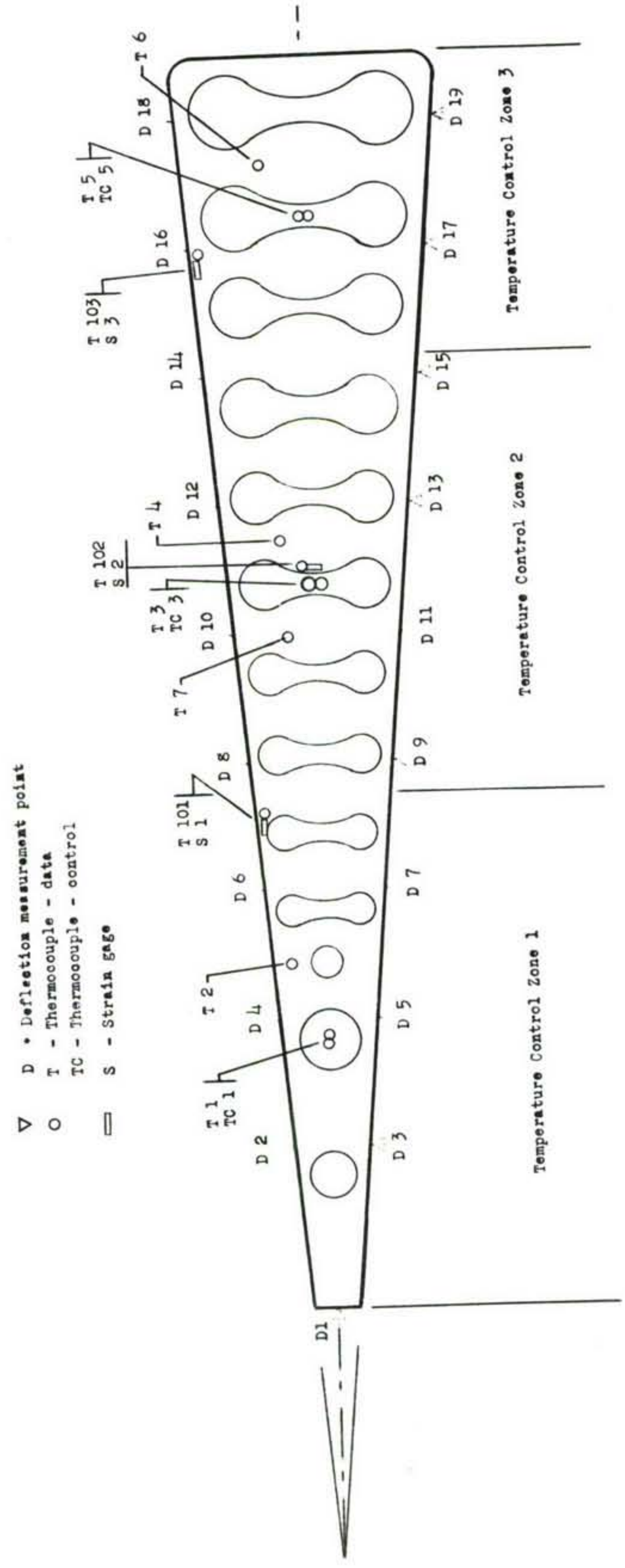


Figure 6. 20-Foot Solar Collector Petal Instrumentation Locations All Test Conditions

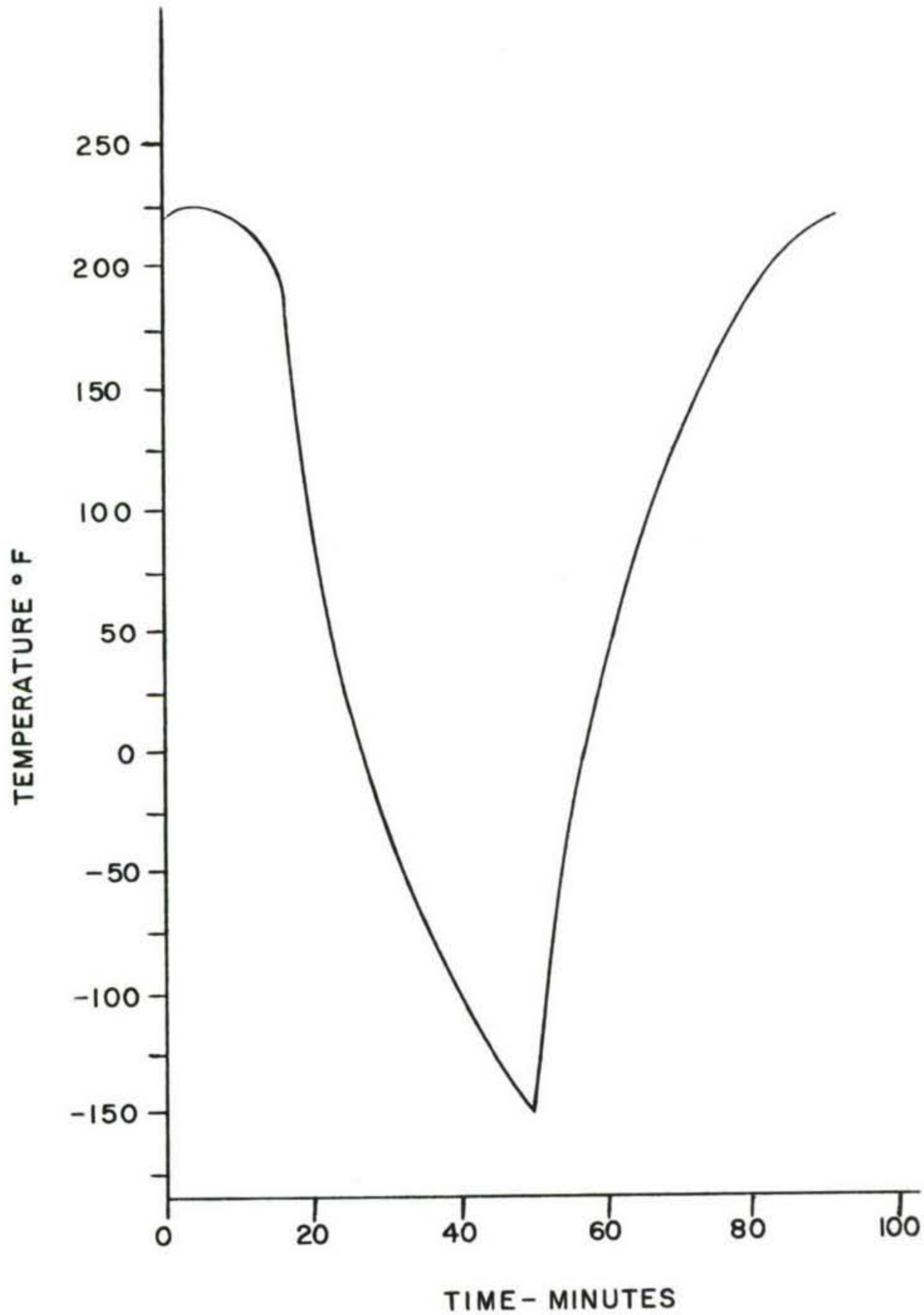


Figure 7. Time-Temperature Profile Adapted to Solar Collector Tests

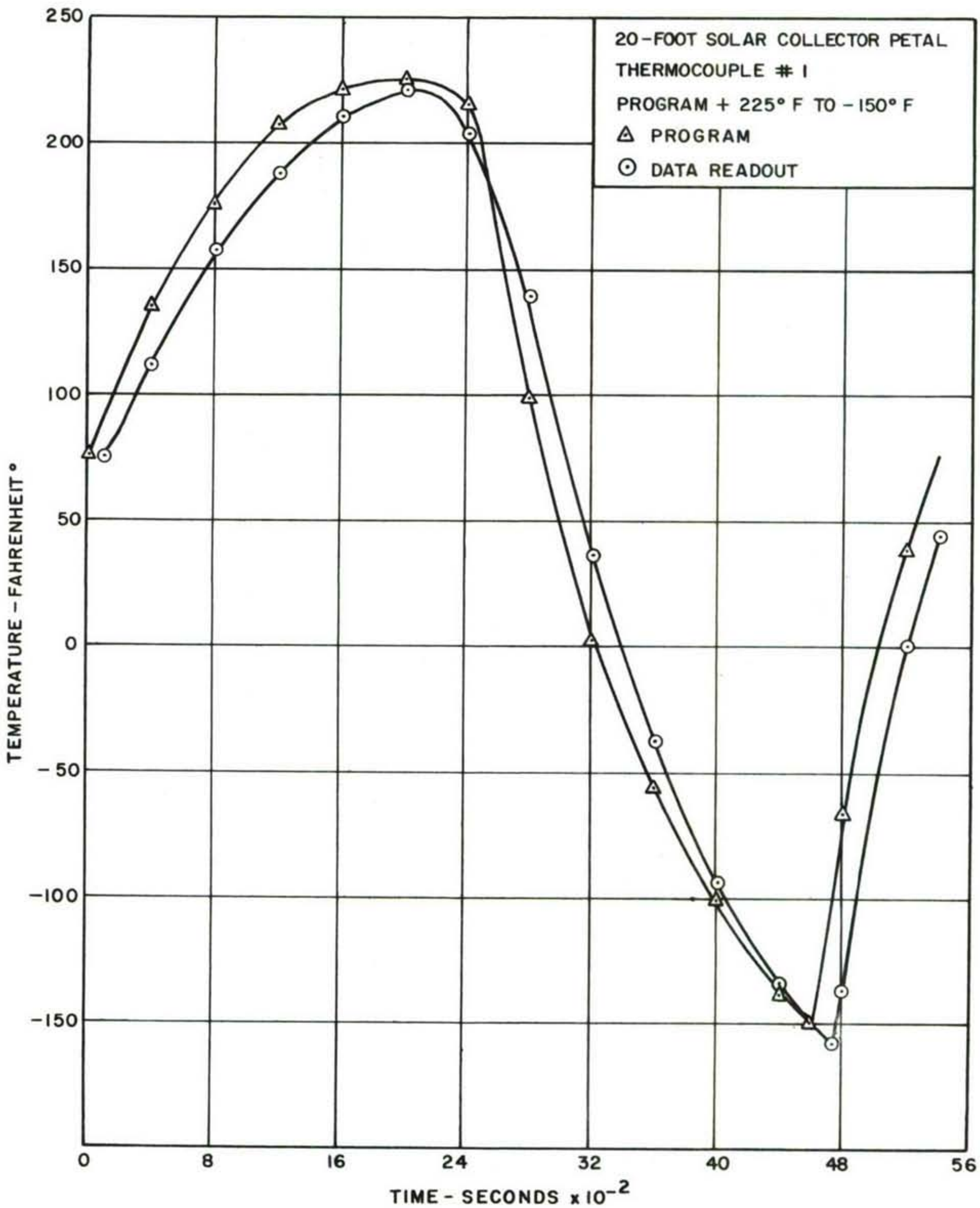


Figure 8. Program Temperature versus Data Readout Temperature During 90-Minute Program

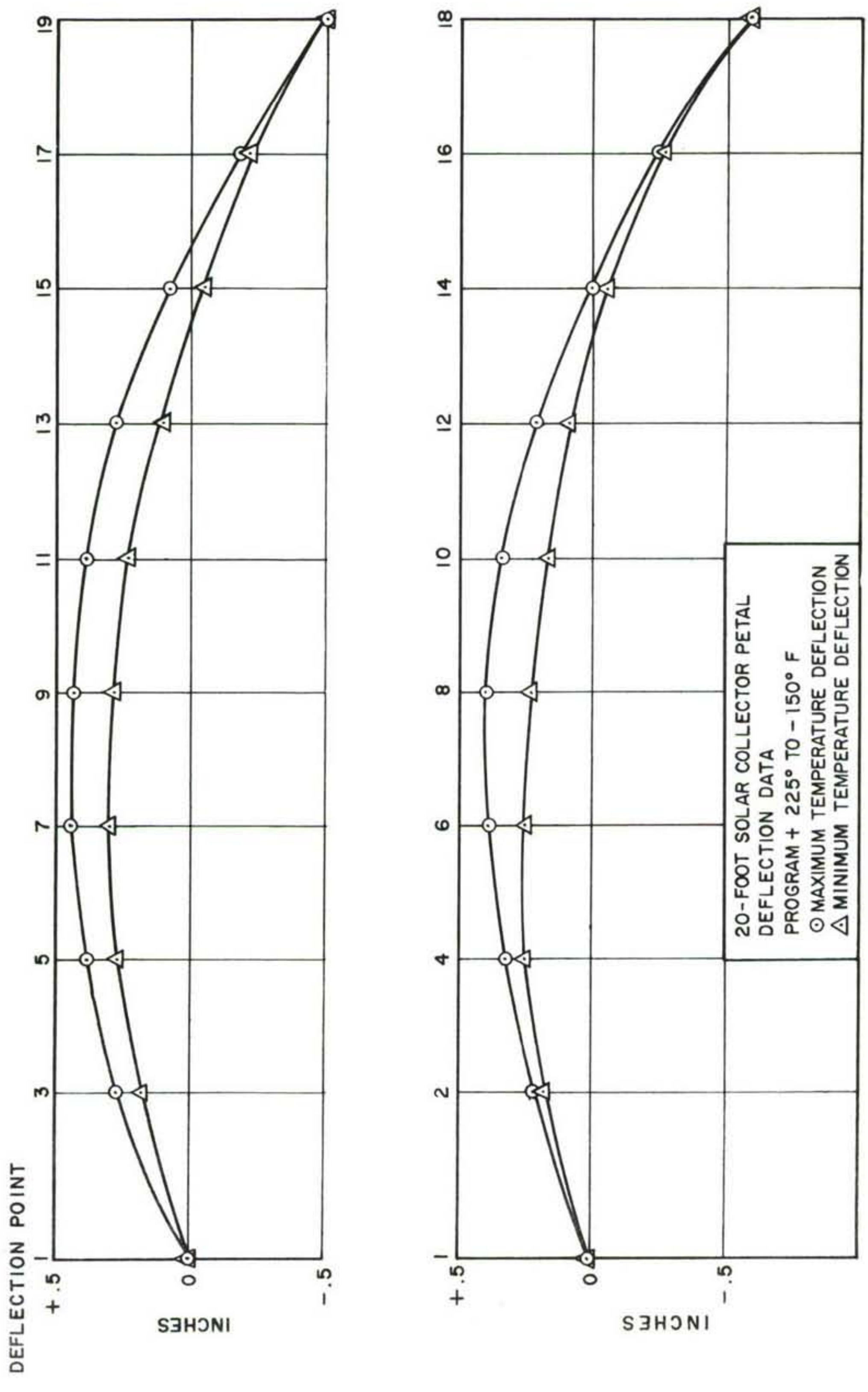


Figure 9. Deflection Changes from Maximum Temperature to Minimum Temperature

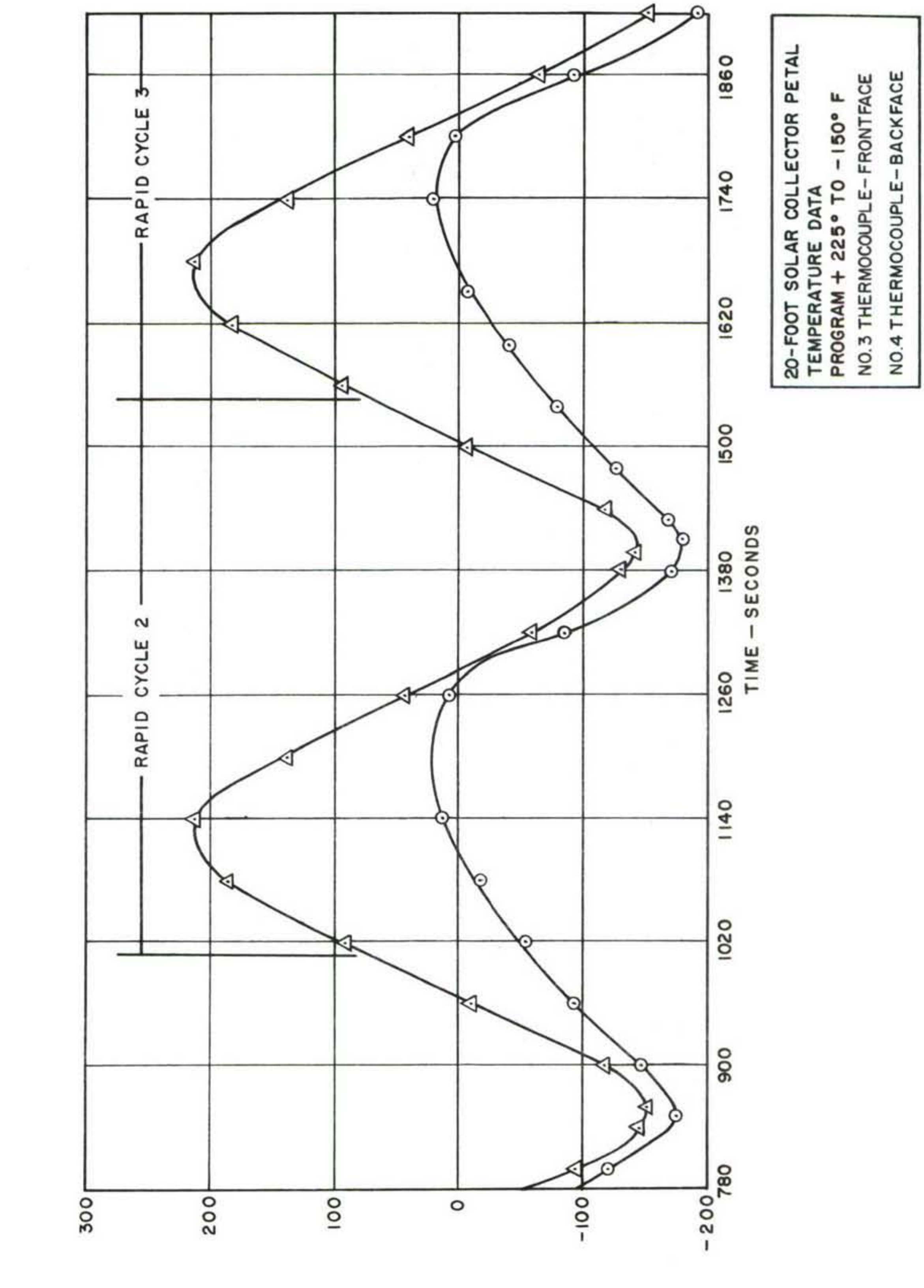


Figure 10. Thermocouple Plots Showing Temperature and Response Lag on Rapid Cycles

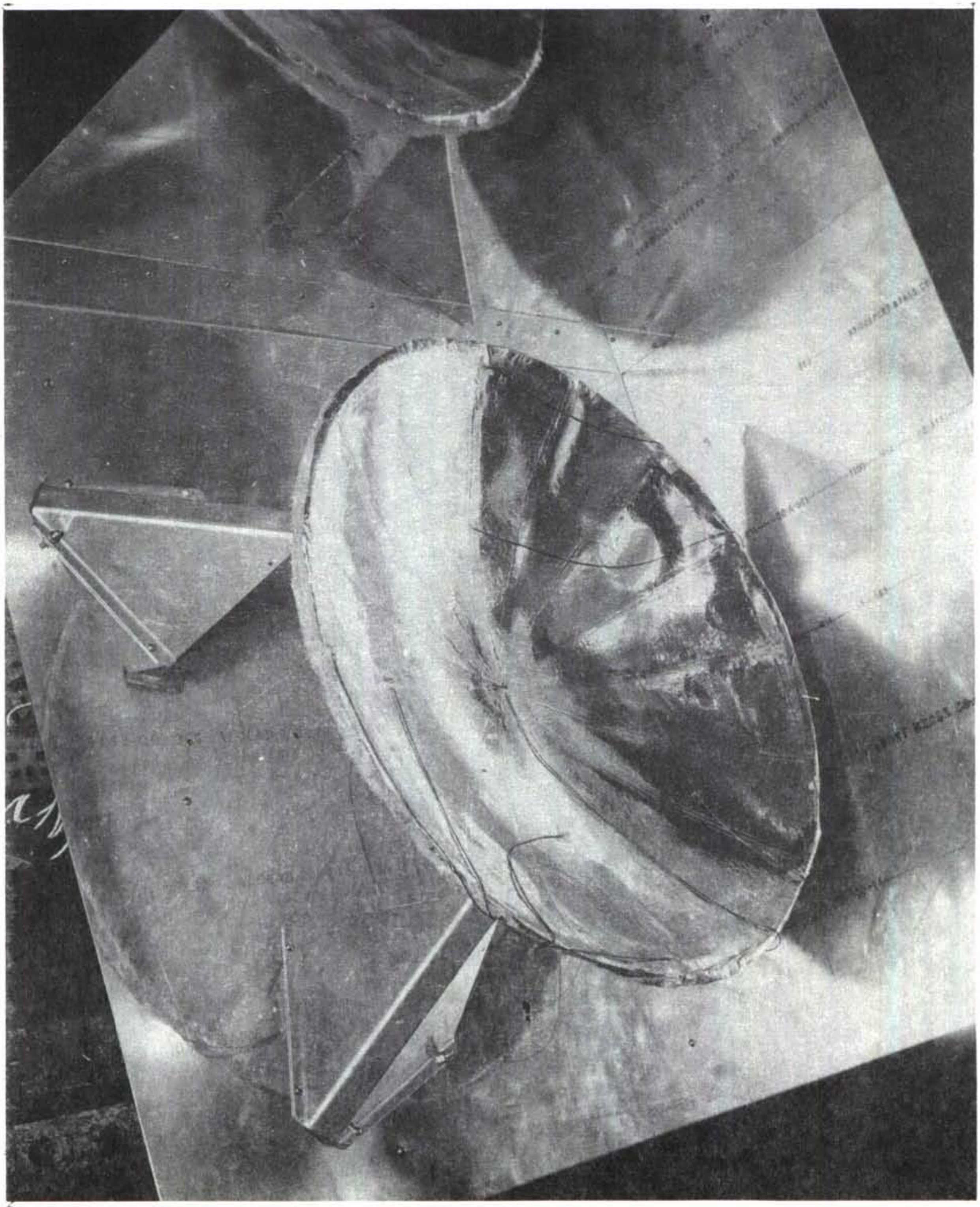


Figure 11. 28-inch Viron Solar Collector Mounted in Test Enclosure

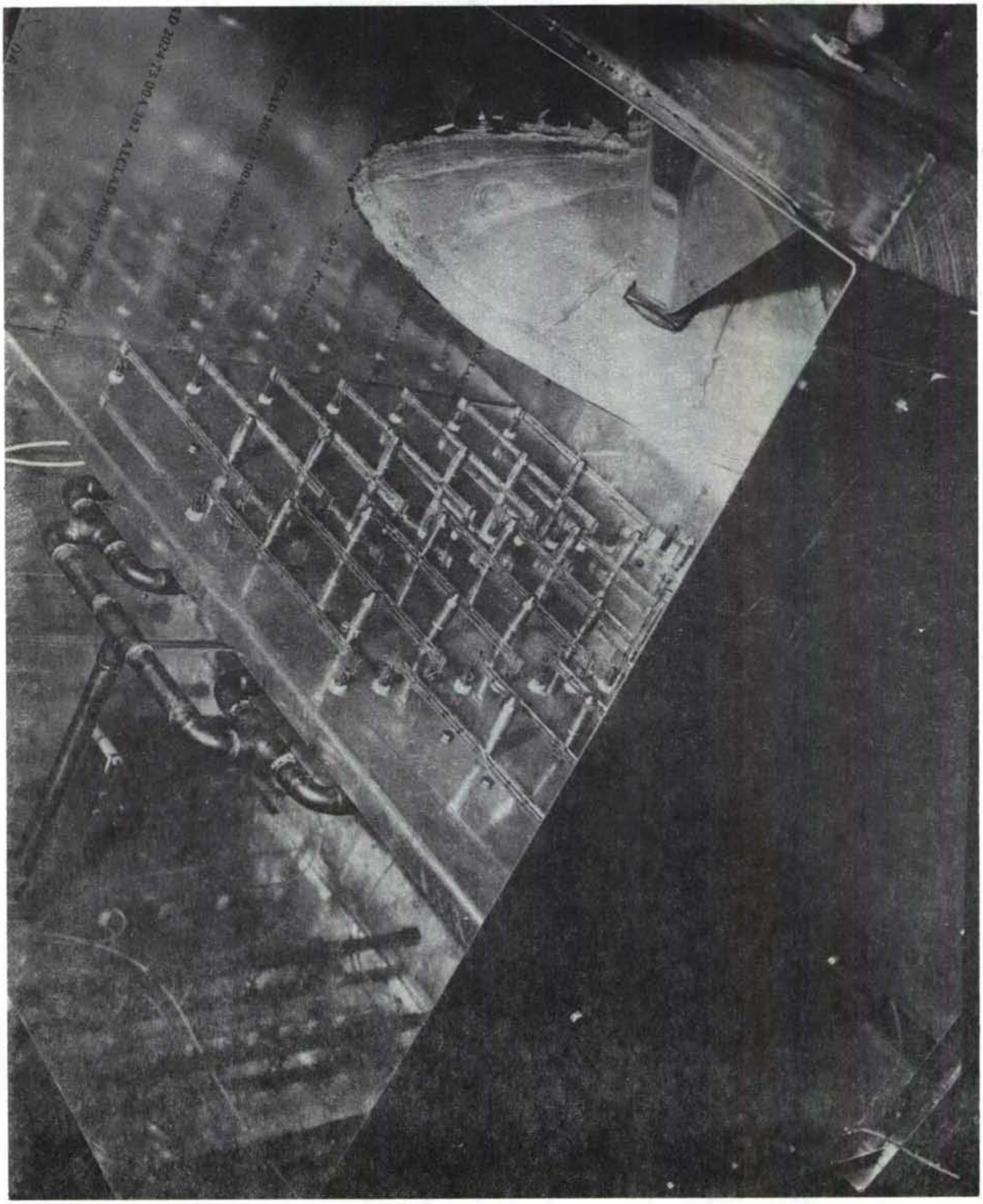


Figure 12. 28-inch Viron Solar Collector with Heat Lamps and Spray Cooling Nozzles Mounted

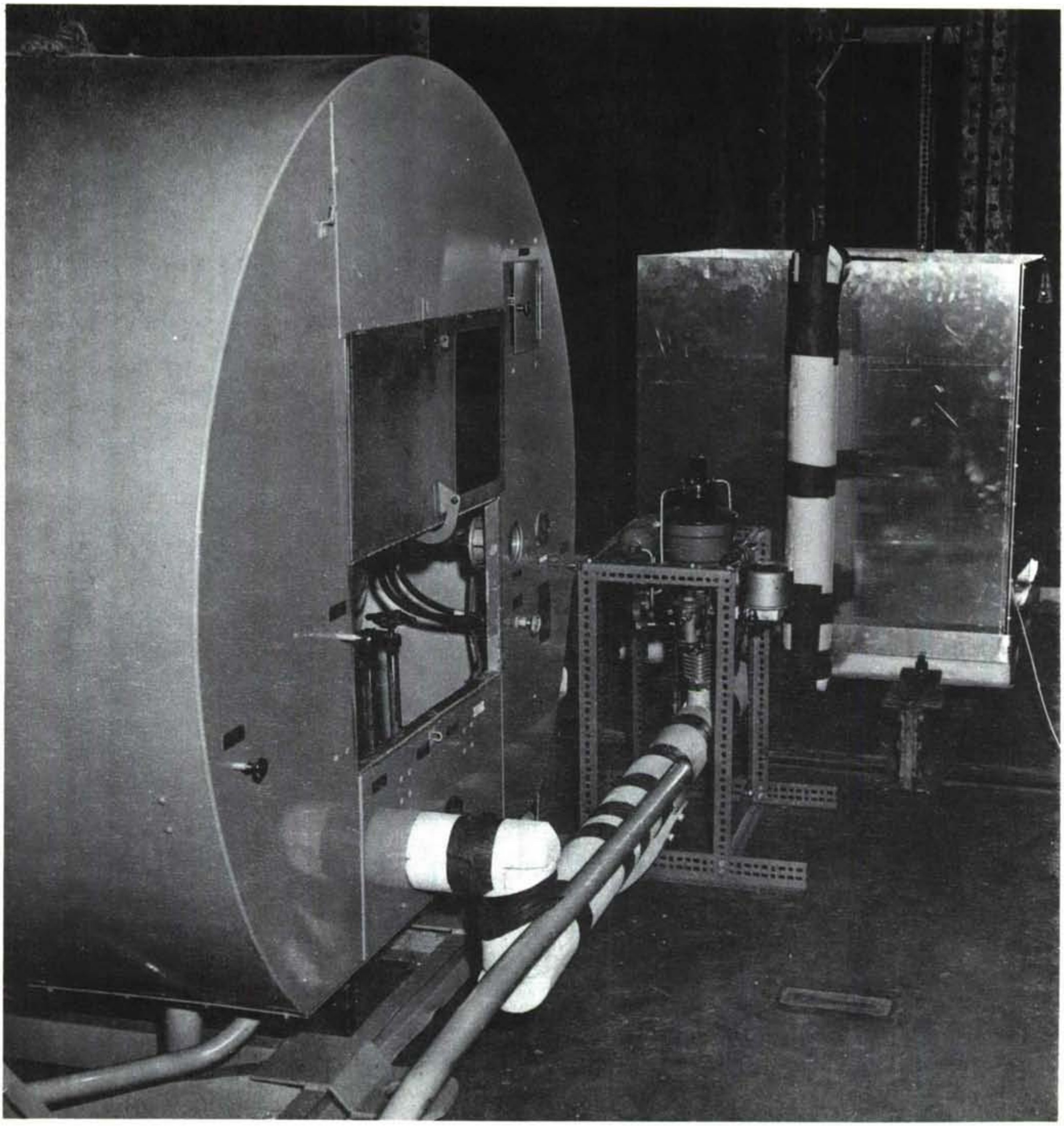
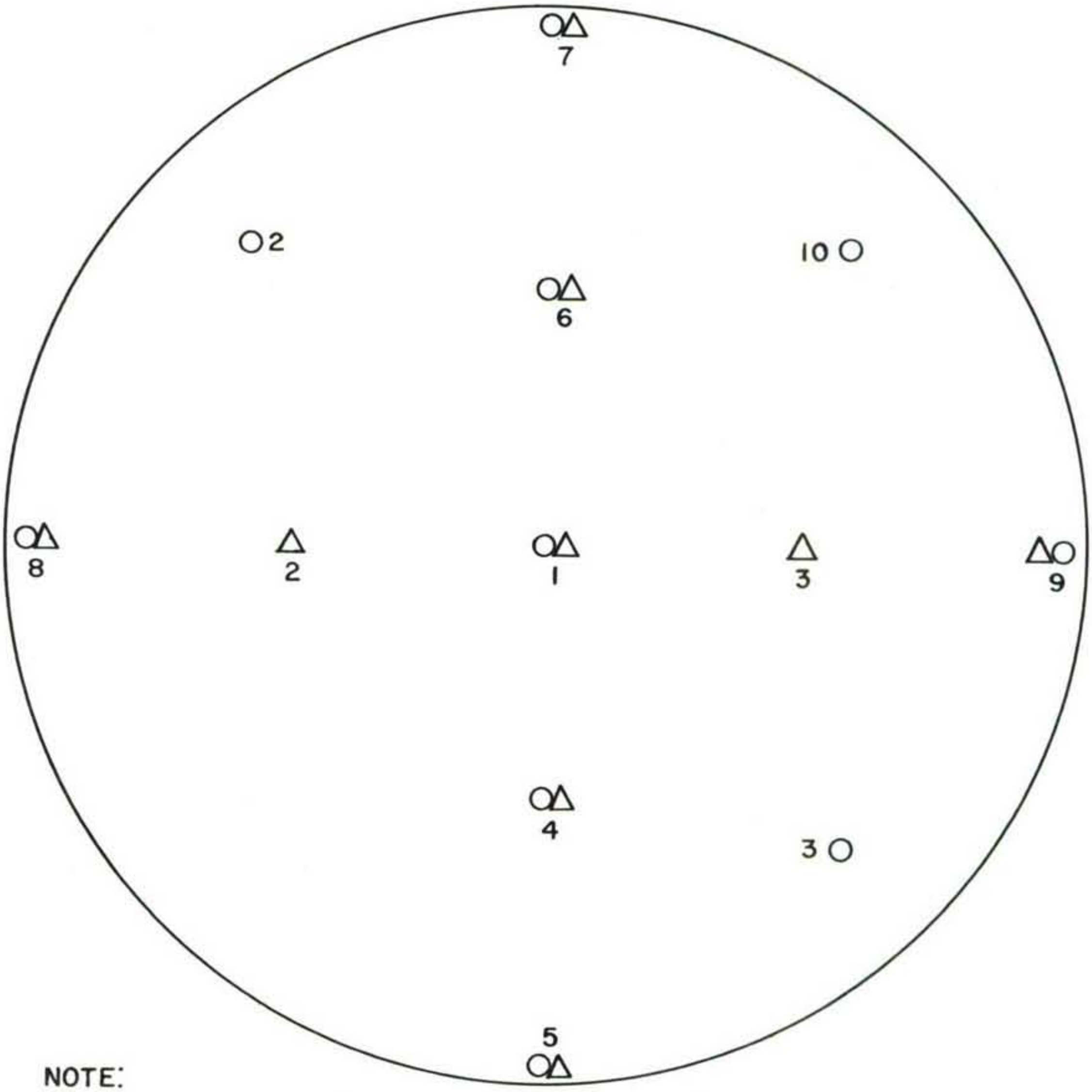


Figure 13. 28-inch Viron Test Set-up Showing Liquid Nitrogen DeWar and Conoflow Control Valve



NOTE:

1. Concave surface. View is into the reflective surface.
2. △ Thermocouple locations

   O Deflection transducer locations
3. O 2, 3, and 10 are on the aluminum mounting brackets
4. Thermocouple wire is 36 gauge Iron - Constantan ISA - J

Figure 14. 28-inch Viron Solar Collector Instrumentation Locations

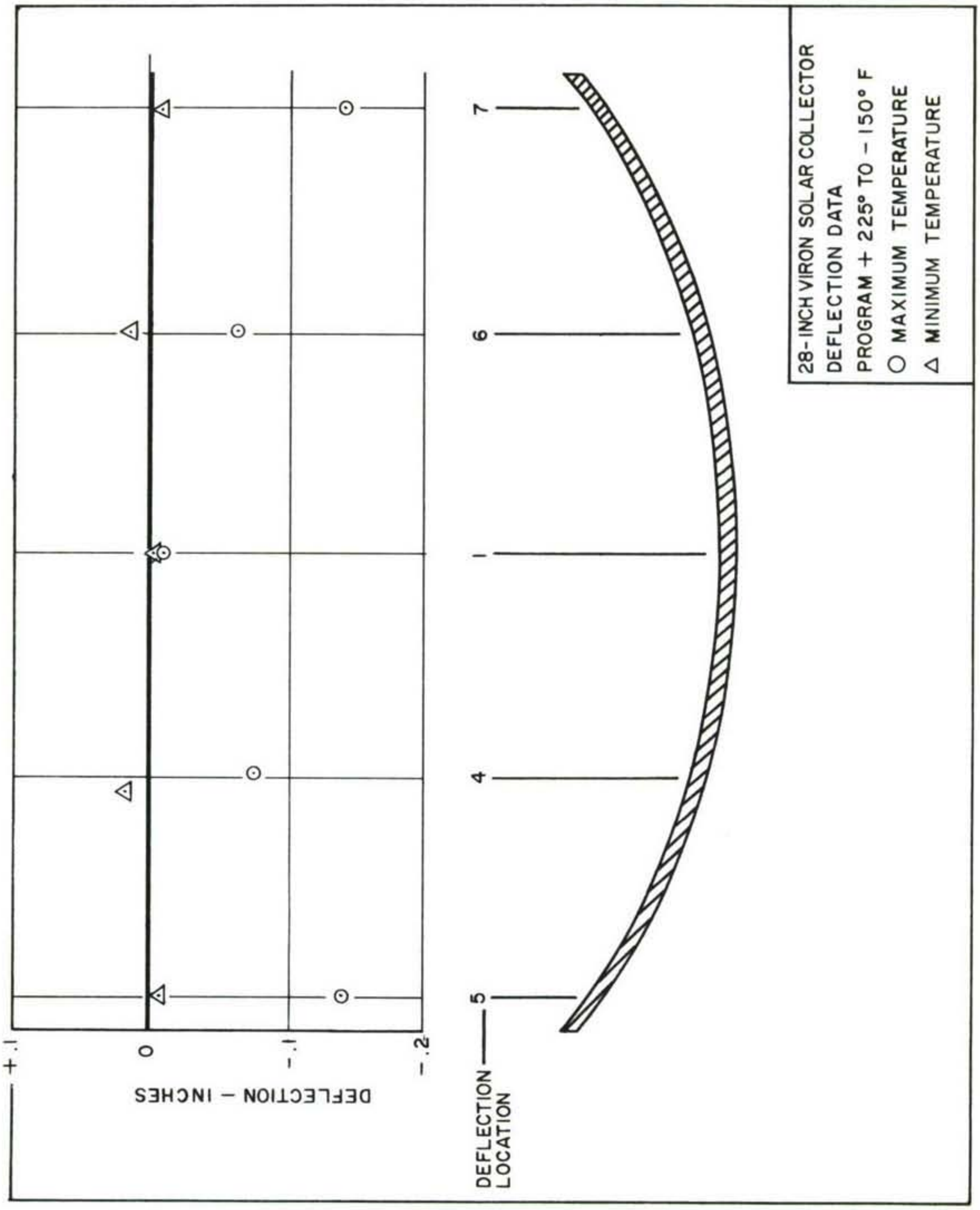


Figure 15. Deflection Changes Between Maximum and Minimum Temperatures

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3. REPORT TITLE

THERMAL TESTING OF EXPANDABLE SOLAR COLLECTORS

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final

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

GUNDERSON, ALLAN, W.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1966	24	

8a. CONTRACT OR GRANT NO. b. PROJECT NO. 8170 c. Task No. 817004 d.	9a. ORIGINATOR'S REPORT NUMBER(S) AFFDL-TR-66-132 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

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