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PRELIMINARY ARC-JET TESTS OF ABLATOR/RSI JOINTS IN SIMULATED SPACE SHUTTLE ASCENT AND ENTRY HEATING

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INTRODUCTION

The thermal protection system (TPS) for the space shuttle orbiter is expected to consist of arrays of reusable surface insulation (RSI) tiles. This material is very efficient thermally, but has been found to be susceptible to mechanical damage which could impair the good thermal performance. To insure the integrity of the TPS, selected RSI tiles may have to be replaced, most likely by an ablative material. The ablator may be installed on the orbiter either before launch or in orbit to replace damaged or lost RSI tiles. Although ablators are available that can provide adequate thermal protection for most shuttle applications, an unresolved technical issue (ref. 1) is the effects of the ablator/RSI joints (or gaps) on the thermo-mechanical performance of the TPS. Areas of concern include possible increased surface heating caused by joint-induced changes in the boundary layer or by differential surface recession, mechanical damage to the RSI tiles because of ablator expansion during heating, and increased heating within open gaps causing severe thermal degradation and high bond-line temperatures. Another area of concern is the effect of the double heat pulse (ascent followed by entry) on the integrity of the ablator char layer.

This paper discusses the results of preliminary arc-jet tests to determine the performance of ablator/RSI panels in simulated space shuttle ascent and entry heating environments.

UNITS

The units for the physical quantities used herein are given in the U.S. Customary Units. Appendix A is included for the purpose of conversion to the International System of Units.

MATERIALS, TEST SPECIMENS AND PROCEDURES

Two ablative materials have been recommended for possible shuttle applications (ref. 1) and were used in the present test program. One of the materials used was the Viking heat shield material designated by the manufacturer as SLA-561. This material is a silicone elastomeric resin filled with cork, hollow silica microspheres, hollow phenolic microspheres, and chopped silica fibers. For the present tests, the material was reinforced by a phenolic-glass honeycomb, resulting in a density of about 14 lbs/ft^3. The other material tested was used on the PRIME vehicle heat shield and is designated by the manufacturer as ESA-3560. This material is a honeycomb reinforced, filled, silicone elastomeric composition with a density of about 30 lbs/ft^3. The higher density material is recommended for areas on the orbiter where the surface recession of SLA-561 may be unacceptably high. The RSI material used was the 9 lbs/ft^3 formulation with the coating designated 0042.

The test specimens consisted of a 3-inch square, 1-3/8-inch thick piece of ablative material surrounded by RSI, making a complete test panel 5 inches square with all heated surfaces as flush as possible (fig. 1). The ablator and the RSI were bonded directly to a 1/8 inch thick Bakelite backing sheet and were oriented so that the arc-jet gas flow was at a 45-degree angle to the ablator/RSI gaps. The gaps were unfilled and ranged in width from 0.003 inch to 0.034 inch before testing. The joints between the RSI pieces were sealed with ceramic adhesive to prevent gas flow out the sides of the test panels. However, after most of the tests, the adhesive had cracked and some flow out the joint probably occurred.

Each test panel was instrumented with 24 thermocouples, the locations of which are shown in figure 2. The thermocouples shown next to the ablator/RSI gaps were potted in grooves along the surface of the RSI facing the ablator. The other thermocouples were located at the back surface of the ablator and the RSI. All thermocouples were monitored continuously during the tests. The test panels were mounted on a wedge-shaped water-cooled test fixture as shown in figure 3. The test fixture was oriented in the arc-jet so that the surface of the test panel was at a 32-degree angle-of-attack with respect to the gas flow.

All tests were conducted in the supersonic arc-powered tunnel, designated Apparatus B of the Langley Entry Structures Facility. Details of the arc-jet facility are given in reference 2. Heating rates to the panels were determined with a 5-inch square, thin-skin calorimeter and pressures were measured with pressure transducers attached to small orifices in a 5-inch square copper plate. Heating rate and pressure distributions over the test panels are shown in figures 4 and 5, respectively. All tests were in air.

Five panels were tested, two of which were subjected to ascent heating as well as entry heating and three of which were subjected to entry heating only. The ascent heating pulse used is shown in figure 6. This pulse corresponds to the heating environment at orbiter body point 1030. Entry heating was simulated by a constant heating rate of either 17 or 20 Btu/ft^2-s. The test conditions are summarized in Table 1. The test section pressure was only about 0.0026 atm. Therefore, from the corners of the ablator through the RSI/RSI joint a pressure gradient of about 1.0 psi/inch existed. This pressure gradient is extremely severe compared to pressure gradients on the shuttle heat shield.

The test procedure for the entry exposures was generally as follows: the arc-jet operating conditions were established and the test environment allowed to stabilize; heating-rate and pressure measurements were made; the test panel was inserted into the stream and exposed to the test environment; after removal of the test panel, the heating rate and pressure were again measured. The tests were terminated when any one of the thermocouples at the base of a gap indicated a temperature rise-rate which could imminently lead to degradation of the Bakelite backing sheet. For the ascent heating, the heating rate was varied during the tests by changing the arc-jet current according to a predetermined sequence. Gap widths and ablator thickness were measured before and after each test.

RESULTS AND DISCUSSION

Panels 1 and 2 were exposed to ascent and entry heating. Ascent heating had a negligible effect on the SLA-561 and the RSI material. Back surface temperatures typically rose less than 10°F during the ascent tests. The maximum temperature rise in the gaps, 1/2 inch and 1 inch from the back surface, was about 15°F and 100°F, respectively. The ablator surface showed some slight discoloration (darkening) but no charring or recession. Also the ablator did not shrink or swell measurably and hence, the gap widths remained unchanged. The RSI did not show any changes at all during ascent testing.

A summary of the ablator/RSI gap measurements before and after entry testing is given in Table 2. In all the panels with SLA-561 ablator, the gaps were somewhat larger (average change of about 0.02 inch) after testing than before testing. However, close-up motion pictures of selected areas of the gaps showed that most of the change in gap-width occurred during cooldown after heating because of the shrinking of the ablator. The gap-width did not appear to change significantly during testing.

The ESA-3560 material expanded slightly during entry heating and the gap widths either remained unchanged or decreased slightly. The expansion, however, was not enough to close the gaps completely or to cause any damage to the surrounding RSI. The ESA-3560 also expanded slightly in the thickness direction, but again, the swelling did not have any affect on the thermal or mechanical response of the RSI.

The temperatures in each panel at the end of entry testing are shown in figure 7. Perhaps the most significant comparisons to be made are between the temperatures at the base of the gaps and the ablator and RSI back surface temperatures at nearby locations. Unless otherwize noted, abnormally high temperatures in the gaps (especially at the bottoms of the gaps) were probably caused by leaks in the adjacent RSI/RSI joint resulting in hot gas flow through the gap.

Figure 7(a) shows the temperatures in panel 1 (SLA-561). The test of this panel was terminated prematurely at 236 s because of a facility malfunction. In general, the temperatures beneath the ablator were lower than those beneath the RSI, indicating that the thermal performance of the ablator is satisfactory (at least as good as that of the RSI) for the application of interest. The highest temperature at the base of a gap was 300°F (nearest the panel leading edge) which was about 205°F higher than the back surface temperatures at nearby locations. The differences between gap temperatures and temperatures beneath the ablator and RSI ranged to a low of 26°F. In this test, the ablator/RSI gaps did not appear to present any particular problem.

During entry testing, panel 2 (figure 7(b)) developed a gas leak where the thermocouple wire went through the Bakelite near the trailing corner of the ablator and allowed gas flow down into the model holder in that area. The increased heating caused the high temperatures shown in the figure and, in fact, burned through the Bakelite located at the base of the gap. The temperatures away from the burn-through area, however, were not excessive and in those areas the test panel again performed reasonably well. Given the severe pressure gradients that developed when the leak occurred, a porous type gap filler would probably not have completely prevented the gas flow into the gaps and the subsequent high temperatures.

The temperatures along gap 4 of panel 3 (see fig. 7(c) and Table 2) were somewhat higher than the corresponding temperatures in other panels because the ablator was apparently recessed slightly with respect to the RSI initially, creating a small forward facing step at the ablator/RSI gap near the panel trailing edge. The temperature at the base of the gap in this area was about 500°F greater than nearby ablator back surface temperatures, whereas temperatures within the other gaps were less than 300°F greater than surrounding back surface temperatures. The higher temperatures in panel 3 did not produce any noticeable gap perturbations.

The fourth SLA-561 panel was tested at a higher heating rate (20 Btu/ft^2-s) than the other SLA 561 panels and in general, higher back surface temperatures were recorded (fig. 7(d)). The differences in temperatures at the base of the gaps and at nearby back surface locations were not appreciably different than for the panels tested at the lower heating rate. Again, no correlation was apparent between gap width and temperatures within the gaps.

Figure 7(e) shows the temperatures at the end of entry testing of panel 5 (ESA-3560). One anomaly in the data is that the thermocouple nearest the front surface in gap 2 indicated a lower temperature than did the deeper thermocouples. The reason for this behavior is not known. Otherwise the panel performed well and as expected with the temperatures at the base of the gaps ranging from 82 to 230 °F higher than surrounding back surface temperatures.

Photographs of panels 4 and 5 after entry testing are shown in figures 8 and 9, respectively. The extensive damage to the RSI was done in a prior test when the arc-jet developed a water leak and the surface of the test panel was exposed to high velocity steam. Because of the limited supply of RSI, the damaged material was patched and reused.

CONCLUDING REMARKS

Five ablator/RSI panels were tested in simulated Shuttle heating conditions to determine heat pulse effects on the ablator and the ablator/RSI joints. Two of the panels were subjected to both ascent and entry heating. The other three panels were subjected to entry heating only. Two ablative materials, a 14 lb/ft^3 material (SLA-561) and a 30 lb/ft^3 material (ESA-3560), were tested.

The double-pulse heating (ascent plus entry) had no effect on the char-layer integrity of the low-density ablator. The ascent heat pulse merely darkened the ablator surface and did not appreciably char the surface.

Evaluation of the effects of entry heating on the ablator/RSI joints was difficult because, with the panel configuration used, severe pressure gradients developed within the joints during testing. These pressure gradients caused hot-gas flow through the joints, considerably increasing temperatures within the joints. Given these severe gradients, a porous-type gap filler may not have prevented the gas flow into the gaps. In joints where pressure leaks apparently did not develop, temperatures within the joints were reasonable compared to ablator and RSI back surface temperatures. Thus, the results of these tests indicate that gap fillers in ablator/RSI joints (with gaps less than about 0.050 in.) may not be necessary.

APPENDIX A

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

PHYSICAL QUANTITY	U.S. CUSTOMARY UNITS	CONVERSION FACTOR (*)	SI UNITS (**)
Density	lbm/ft^3	16.018463	kg/m^3
Enthalpy	Btu/lbm	2.32×10^3	J/kg
Heating Rate	Btu/ft^2-s	1.134893×10^4	W/m^2
Pressure	lbf/in^2	6.895×10^3	N/m^2
Temperature	°R	1.8	K
Thickness	in.	2.54×10^{-2}	m

* Multiply value given in U. S. Customary Units by Conversion factor to obtain equivalent value in SI unit

** Prefixes to indicate multiples of units are as follows:

Prefix	Multiple
centi (c)	10^{-2}
kilo (k)	10^3
mega (m)	10^6

REFERENCES

1. Tompkins, S. S.; Brewer, W. D.; Clark, R. K.; Pittman, C. M.; and Brinkley, K.L.: An Assessment of the Readiness of Ablative Materials for Preflight Application to the Shuttle Orbiter. NASA TM 81823, July 1980.

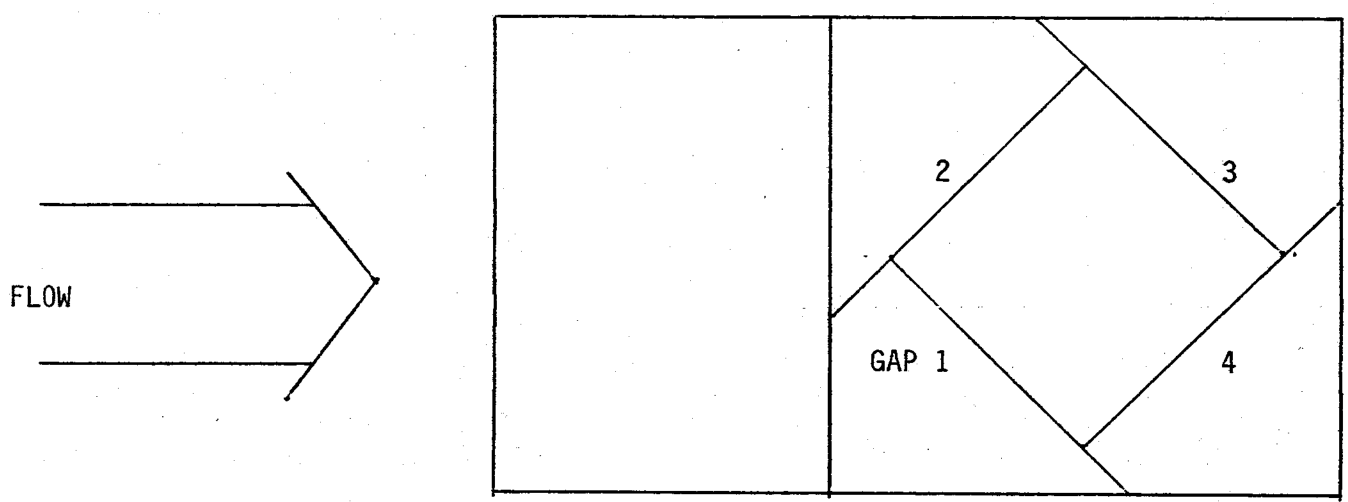
2. Brown, R. D., and Jakubowski, A. K.: Heat Transfer and Pressure Distributions for Laminar Separated Flows Downstream of Rearward-Facing Steps With and Without Mass Suction. NASA TN D-7430, 1974.

TABLE 1.- TEST CONDITIONS

PANEL NO.	ABLATIVE MATERIAL	ASCENT HEATING	ENTRY HEATING RATE, BTU/FT^2-S	ENTHALPY BTU/LB	PRESSURE ATM
1	SLA-561	Yes	17	2400	0.039
2	SLA-561	Yes	17	2400	0.039
3	SLA-561	No	17	2400	0.039
4	SLA-561	No	20	2800	0.039
5	ESA-3560	No	20	2800	0.039

TABLE 2.- SUMMARY OF ABLATOR/RSI GAP WIDTH MEASUREMENTS

PANEL NO.	ABLATIVE MATERIAL	HEATING RATE BTU/FT^{2}S	TEST TIME, S	GAP WIDTH, INCHES								AVERAGE CHANGES INCHES
				GAP 1		GAP 2		GAP 3		GAP 4		
				INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	INITIAL	FINAL	
1	SLA-561	17	236	.019	.030	.020	.037	.005	.020	.015	.044	+.018
2	SLA-561	17	550	.003	.017	.005	.005	.003	.012	.007	.050	+.015
3	SLA-561	17	500	.003	.015	.015	.050	.005	.020	.025	.050	+.022
4	SLA-561	20	450	.034	.045	.005	.015	.045	.060	.010	.035	+.015
5	ESA-3560	20	400	.005	.005	.018	.005	.010	.005	.005	.005	-.005



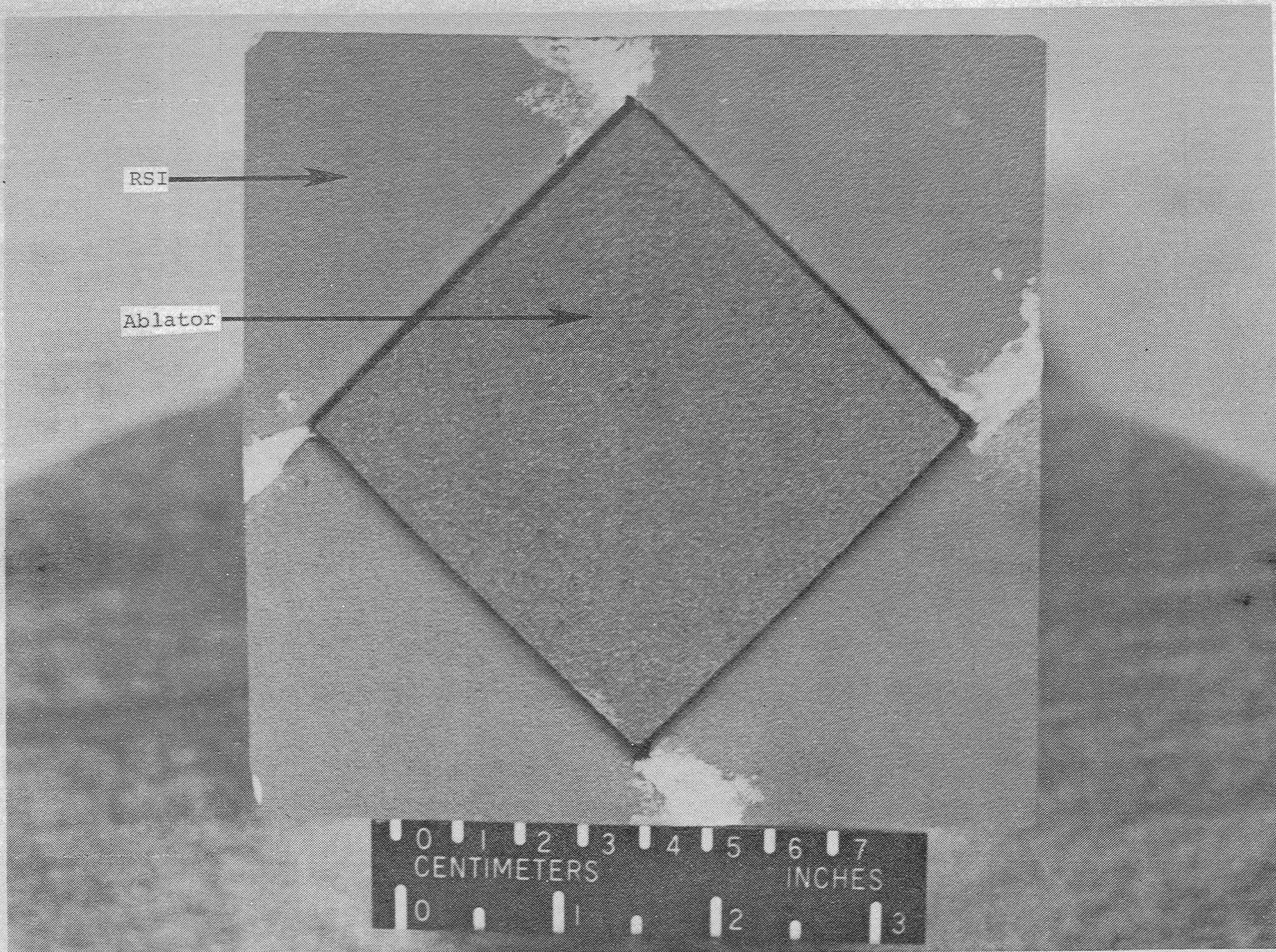


Figure 1.- Test panel before testing.

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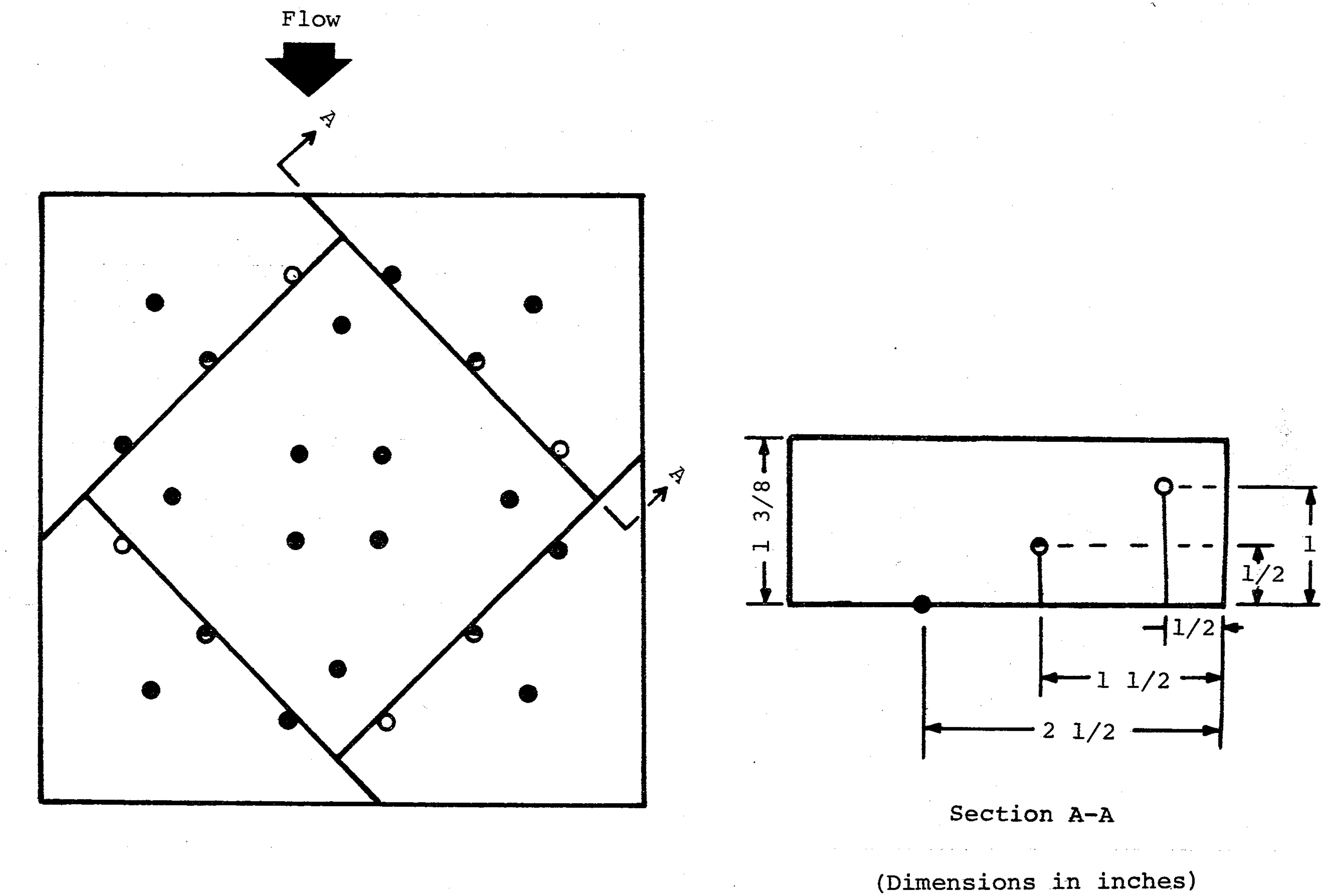


Figure 2.- Thermocouple locations for all test panels.

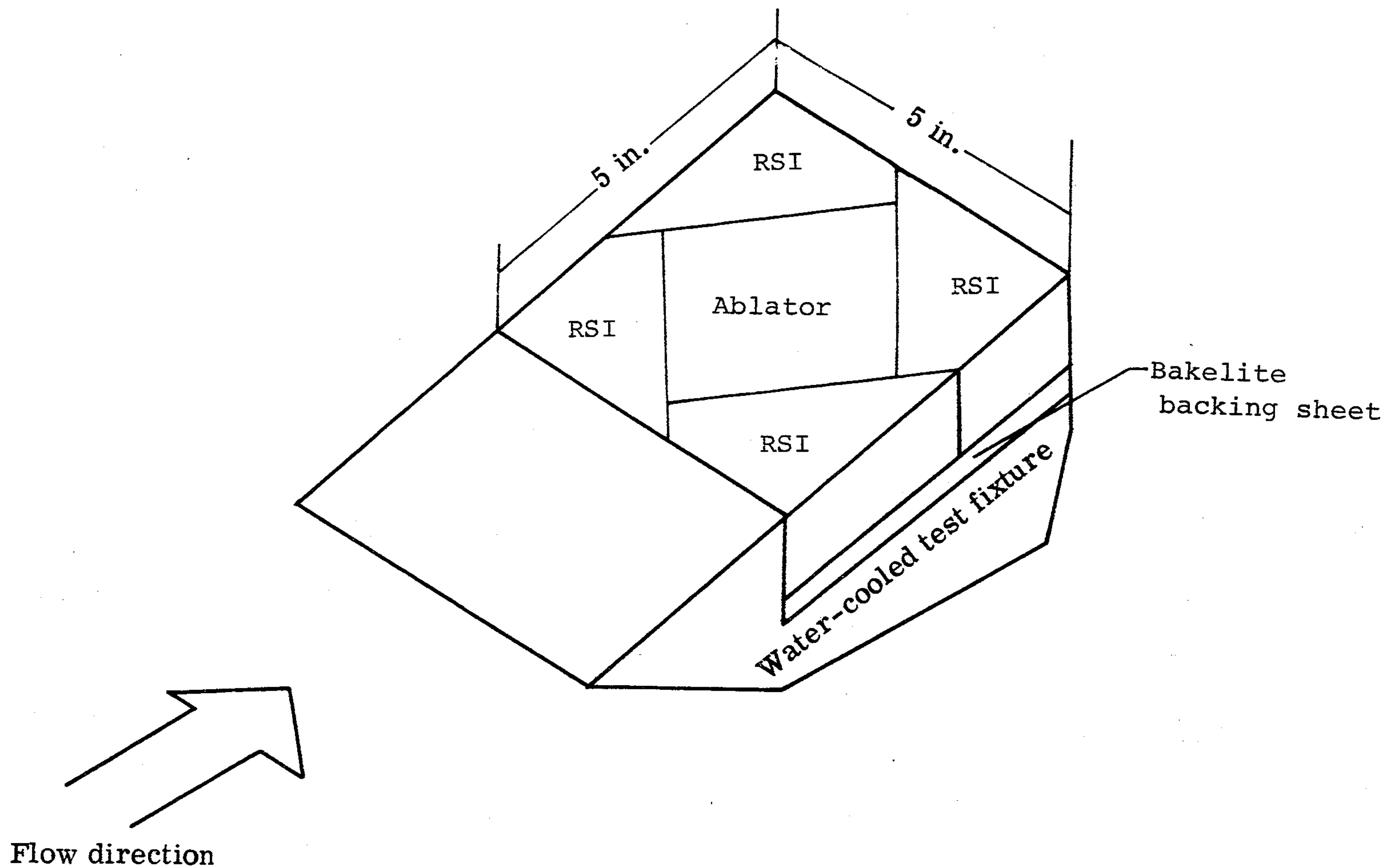


Figure 3.- Test panel and test fixture configuration.

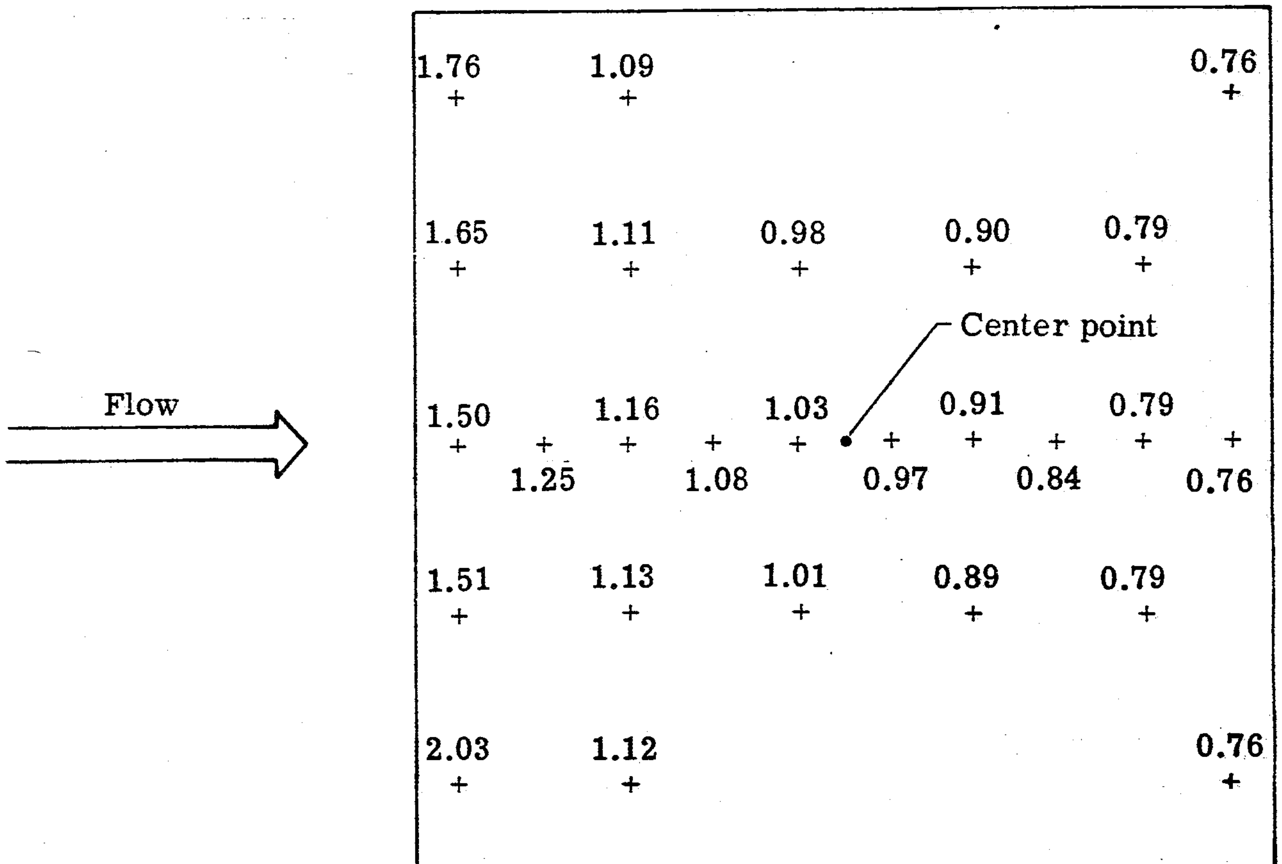


Figure 4.- Typical heating rate distribution normalized to center point.

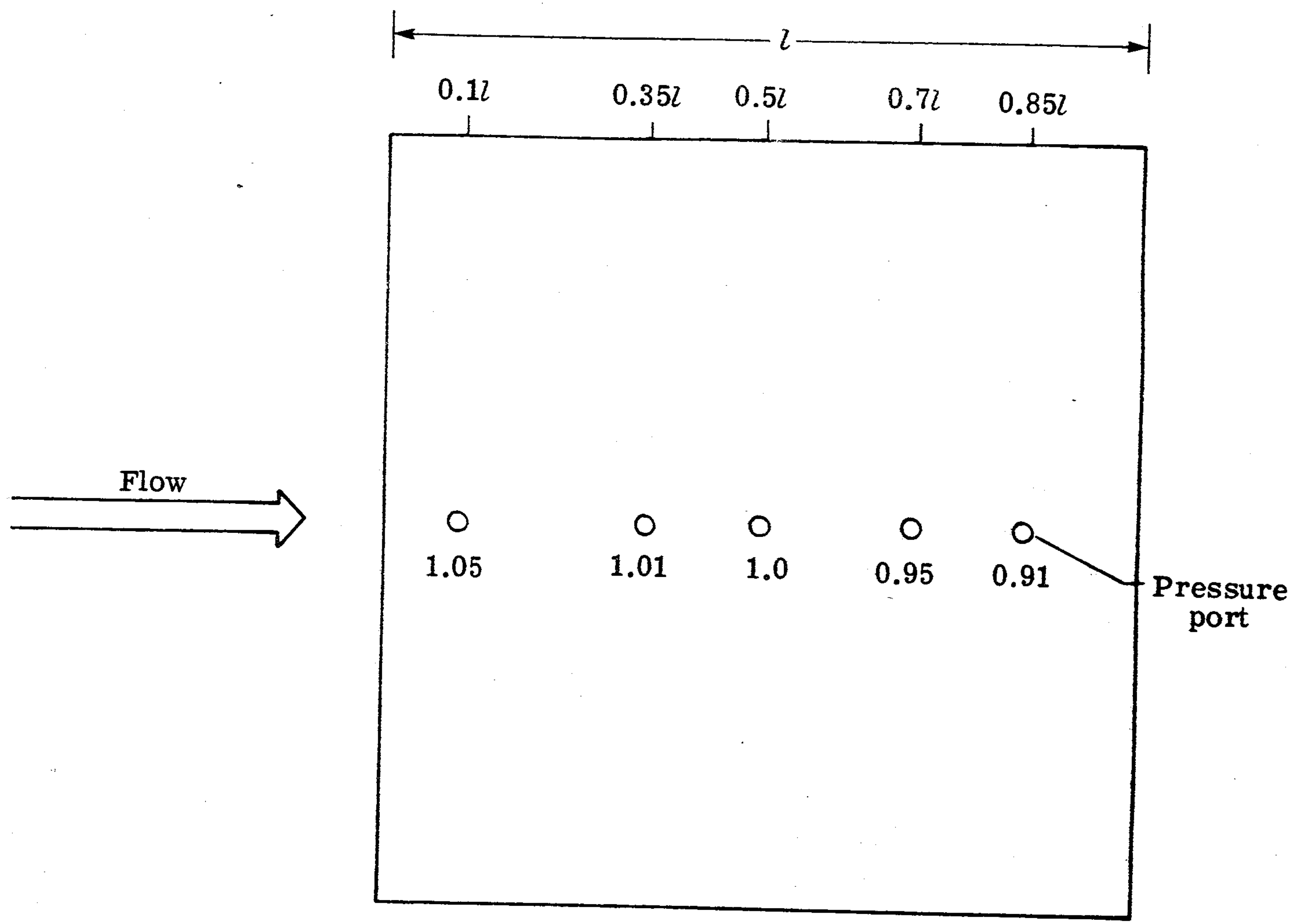


Figure 5.- Typical pressure distribution normalized to center point.

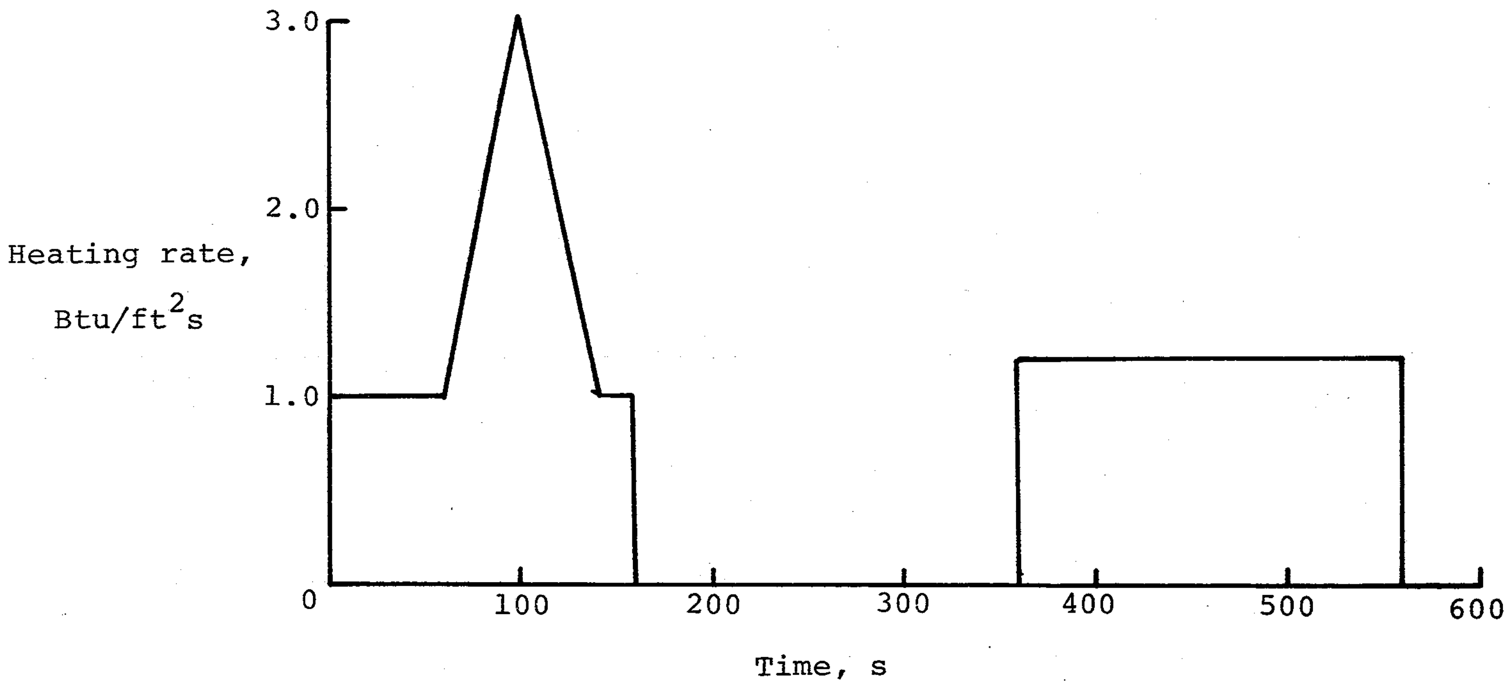
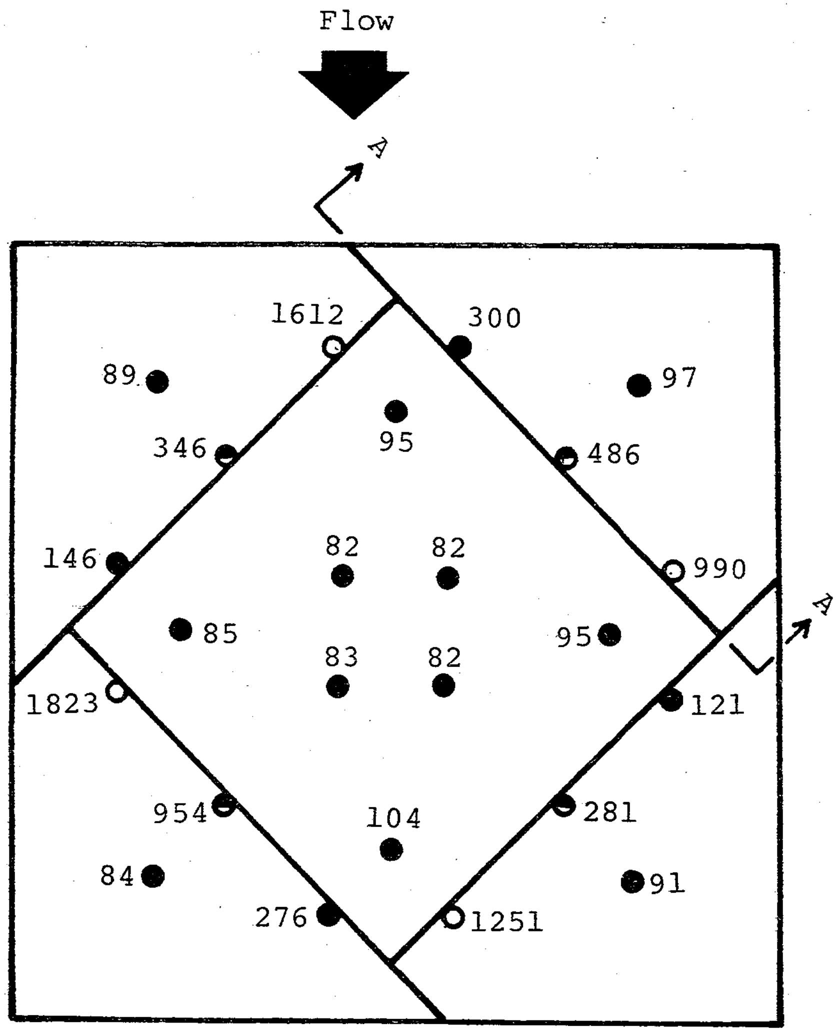
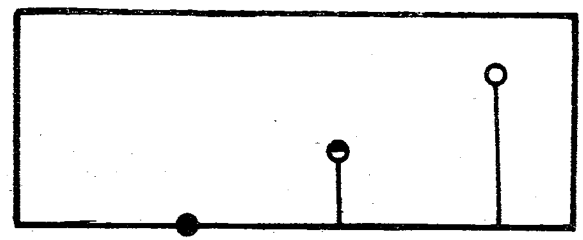


Figure 6.- Arc-jet simulation of Orbiter ascent heating-body point 1030.

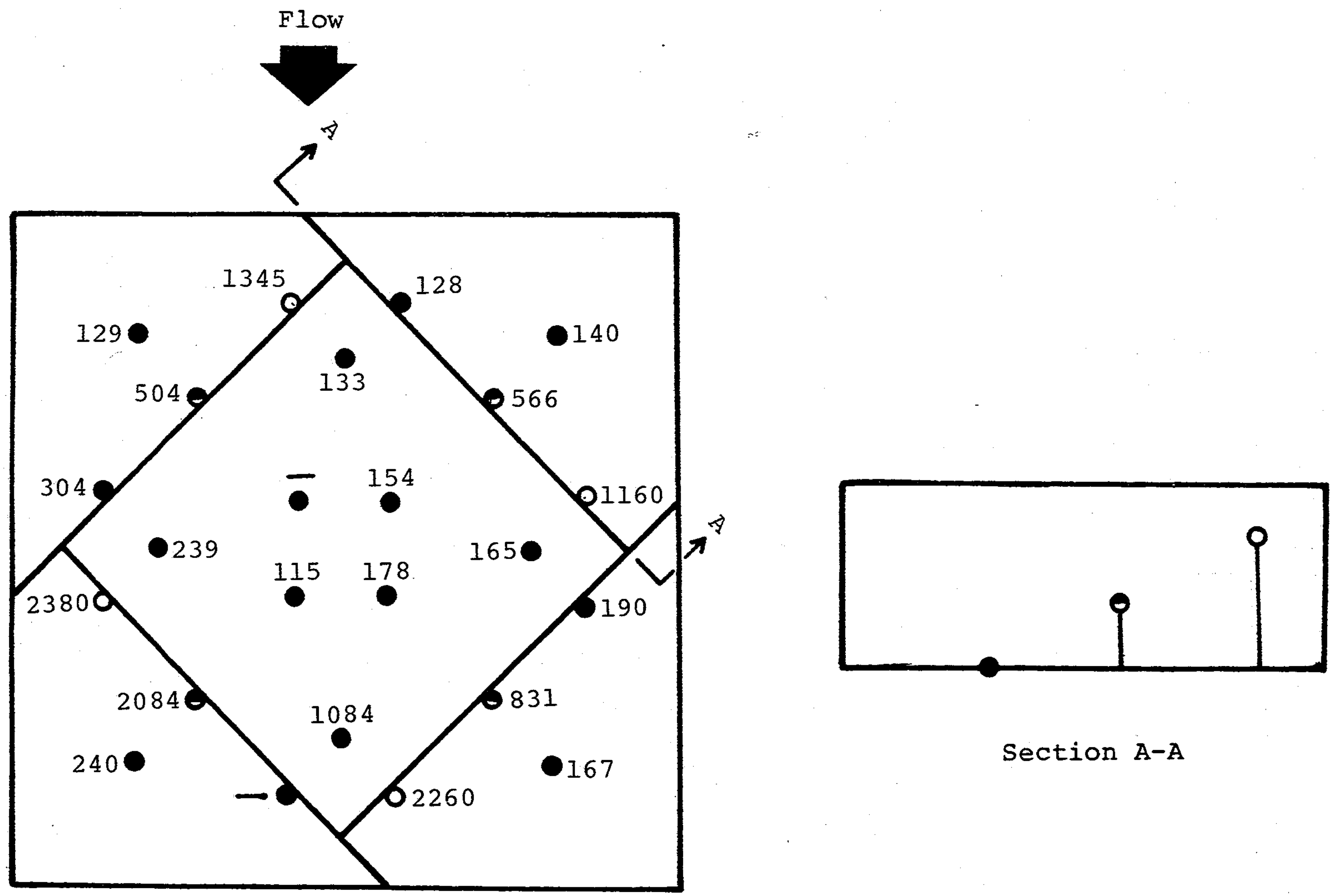




Section A-A

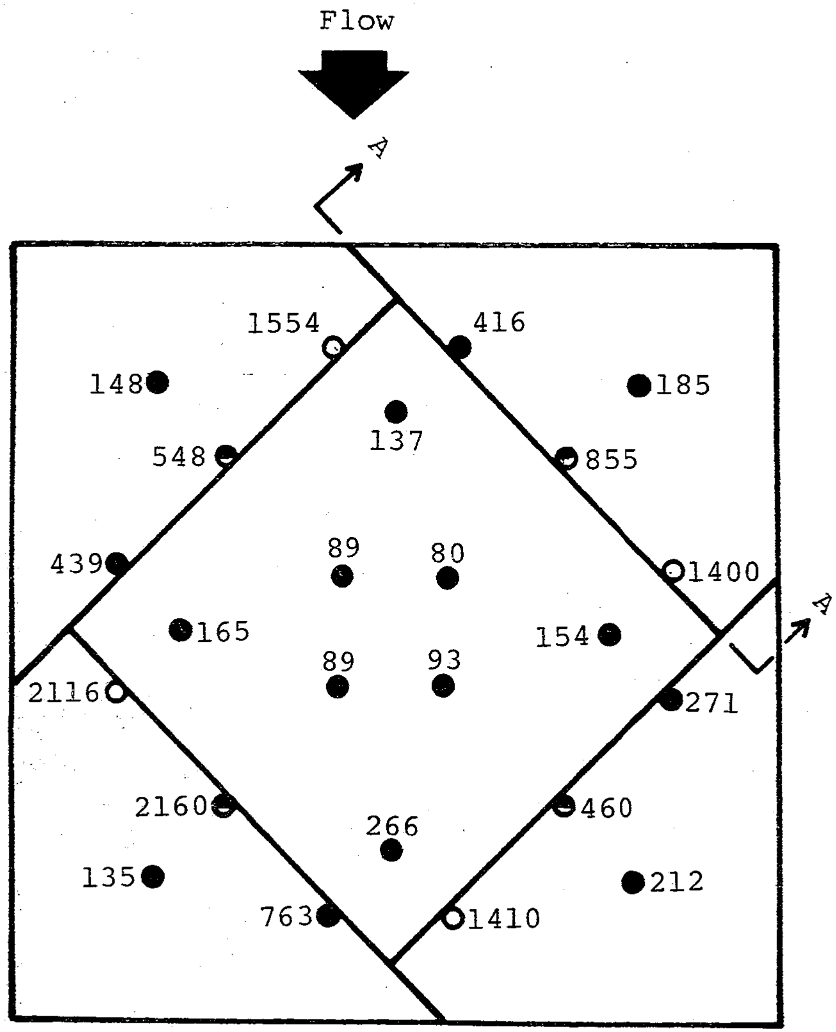
(a) Panel no. 1, SLA-561
Ascent plus 236s entry at 17 Btu/ft^{2}s

Figure 7.- Measured temperatures at end of entry heating test, F.

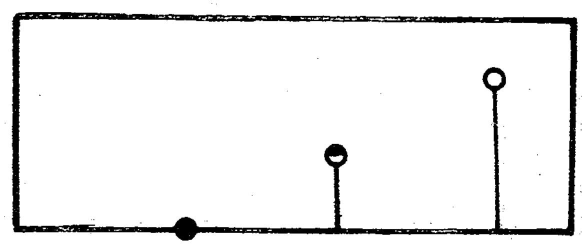


(b) Panel no. 2, SLA-561.
Ascent plus 550s entry at 17 Btu/ft^{2}s

Figure 7.- Continued.

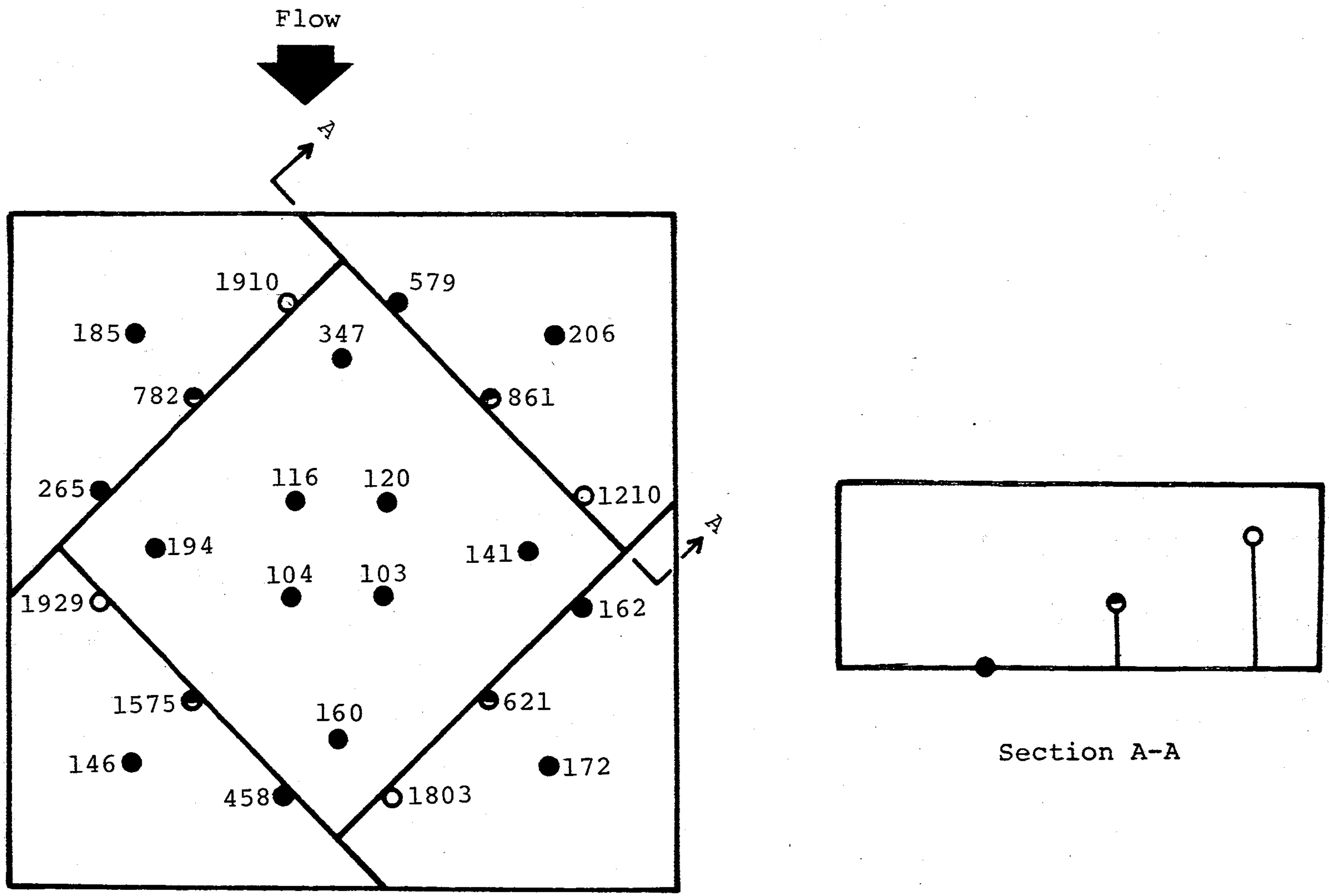


(c) Panel no. 3, SLA-561
500s entry at 17 Btu/ft^{2}s



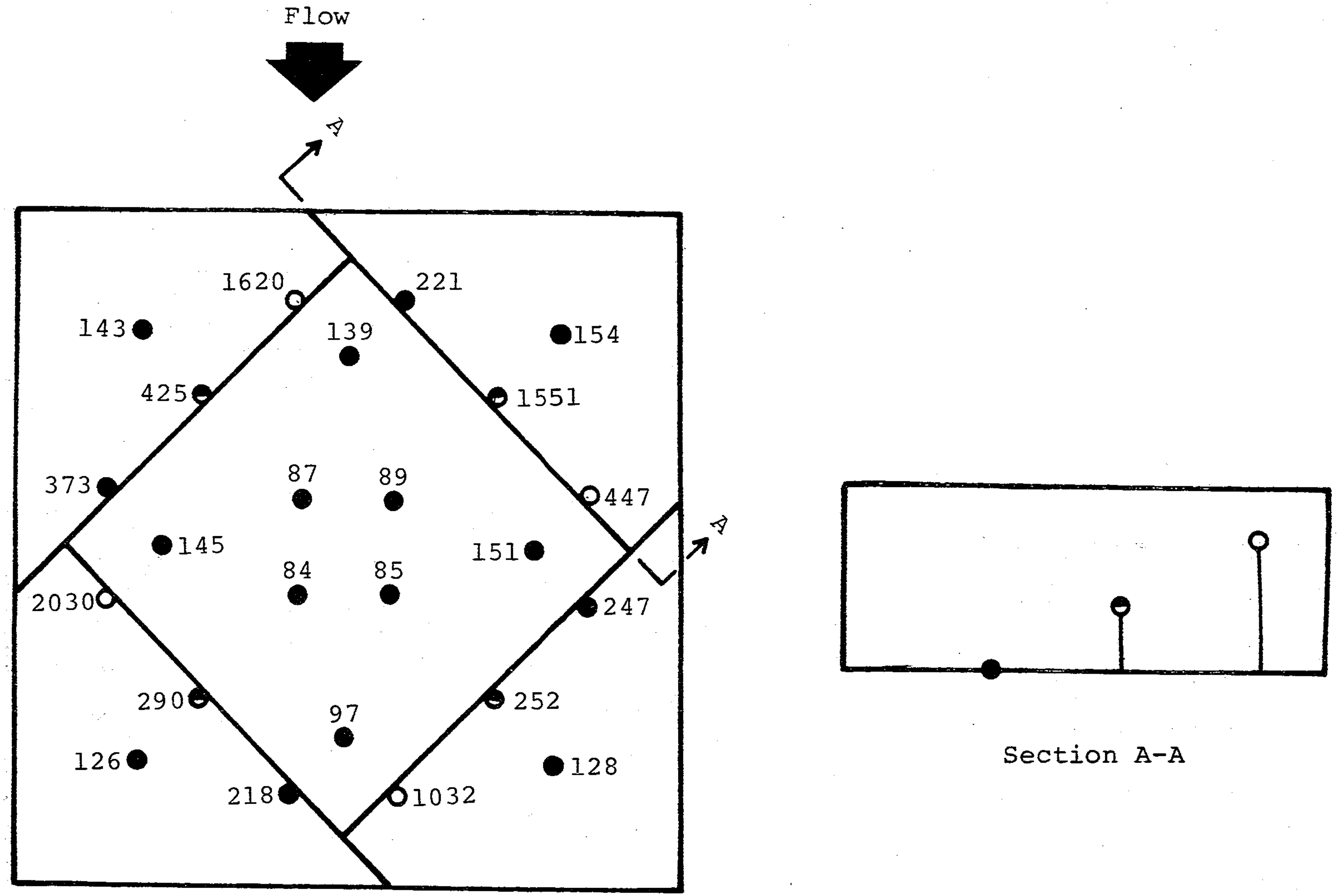
Section A-A

Figure 7.- Continued.



(d) Panel no. 4, SLA-561
400s entry at 20 Btu/ft^2s

Figure 7.- Continued.



(e) Panel no. 5, ESA-3560
400s reentry at 20 Btu/ft^{2}s

Figure 7.- Concluded.

Figure 8.- Panel no. 4, SLA-561 after 450s entry test at 20 Btu/ft^{2}s.

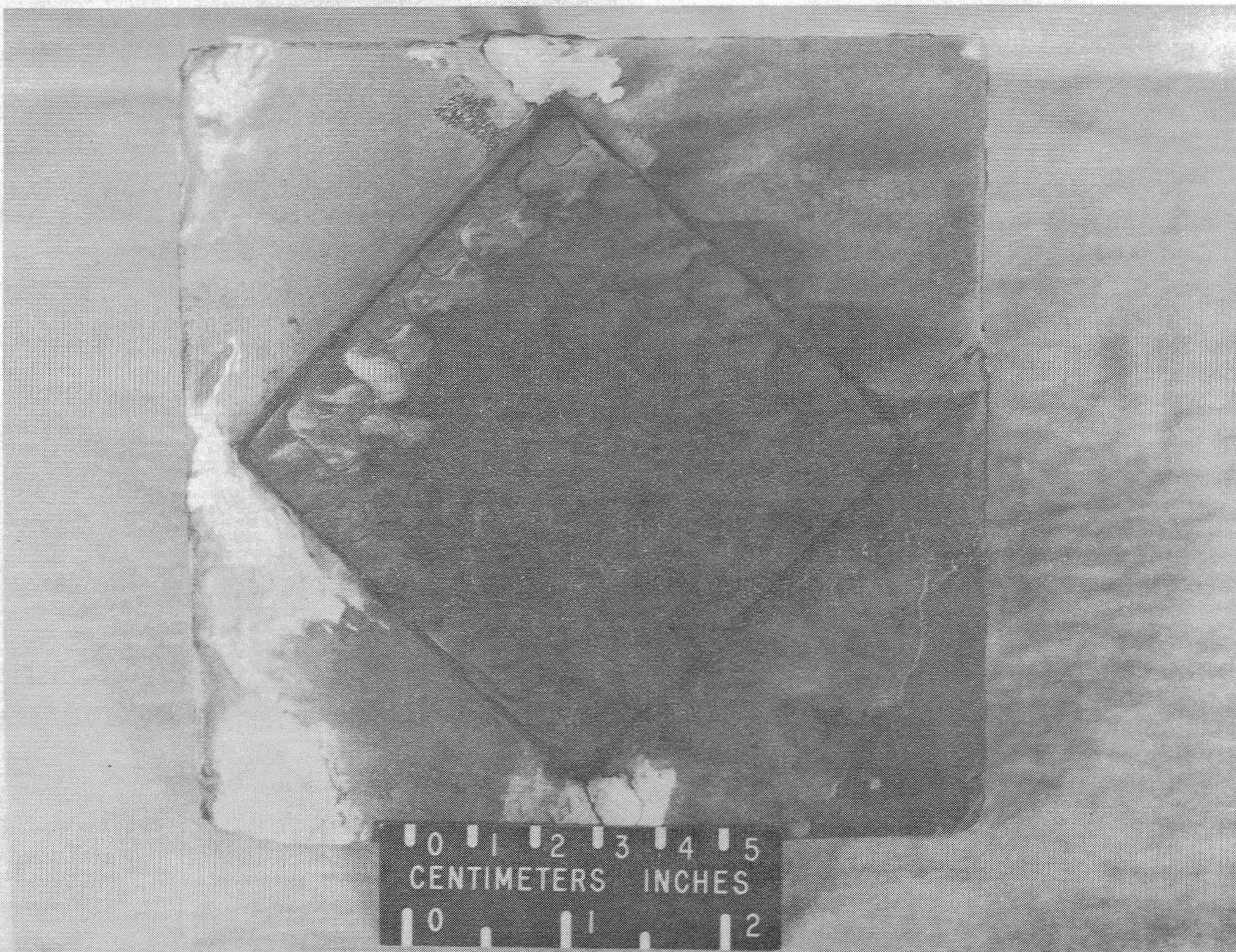


Figure 9.- Panel no. 5, ESA-3560 after 400s entry test at 20 Btu/ft^{2}s.

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16. Abstract

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