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Allan H. Taylor
Vought Corporation
Hampton, Virginia

L. Robert Jackson and Irving Weinstein
Langley Research Center
Hampton, Virginia

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and Space Administration

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SUMMARY

Three thermal protection systems proposed for a hypersonic research airplane were subjected to high heating rates in the Langley 8-foot high-temperature structures tunnel. Metallic heat sink (Lockalloy), reusable surface insulation, and insulator-ablator materials were each tested under similar conditions. The specimens were tested for a 10-second exposure on the windward side of an elevon deflected 30°. The metallic-heat-sink panel exhibited no damage; however, the reusable-surface-insulation tiles were debonded from the panel and the insulator-ablator panel eroded through its thickness, thus exposing the aluminum structure to the Mach 7 environment.

INTRODUCTION

A hypersonic research airplane has been studied (ref. 1) which would be capable of a Mach 7 flight envelope as indicated in figure 1. The environment at this speed includes dynamic pressures of 47.9 kPa (1000 psf) and heating rates as high as 136 kW/m^2 (12 Btu/ft^2-sec). (See ref. 2.) Portions of the airplane such as the speed brakes and elevons will be exposed to local flow at angles of attack up to 30°. Interference heating and the possibility of flow separation may cause much higher local heating rates and corresponding shear forces. However, the exact location and magnitude of this interference heating is difficult to predict. The airplane thermal protection system (TPS) must be designed to withstand this environment with minimal refurbishment between flights. Therefore, the performance of each of the candidate TPS materials must be evaluated in this environment in order to assess their durability and subsequent suitability.

Three types of TPS were investigated in this study. The first type was a metallic-heat-sink structure, where the heat sink was designed to absorb the heat load and provide the primary structure. The second type was an insulator ablator, a silicone elastomer which pyrolyzes under the initial heat pulse and then radiates the heat load on the surface while insulating the aluminum primary structure. The third TPS studied was reusable surface insulation (RSI) which is also an insulator that radiates the heat load while insulating the primary aluminum structure. The RSI material is a matrix of tiles made of quartz fibers covered with a high-emittance glass coating. The tiles are individually bonded to a Nomex felt strain isolator pad (SIP) which is bonded to the primary structure.

The metallic-heat-sink (Lockalloy) TPS is proposed for use in areas of high heating by locally increasing the skin thickness to accommodate the expected heat load. The insulator-ablator material is proposed only for a low-heating-rate environment. The RSI system will augment the insulator-ablator system in the areas of high heating. Conceptually, the insulator ablator has a fail-safe feature in that the material will ablate in the presence of an unexpected high heat pulse, thus sacrificially protecting the primary structure.

The three protection systems were tested in the aerothermal environment of the Langley 8-foot high-temperature structures tunnel (8-ft HTST) which closely simulates the Mach 7 flight conditions. The objective of the test program reported herein is to evaluate the performance of the three candidate systems when subjected to a high-pressure and high-heating-rate environment caused by interference heating.

Use of trade names or names of manufacturers in this report does not constitute an official endorsement of such products or manufacturers, either expressed or implied, by the National Aeronautics and Space Administration.

SYMBOLS

Measurements and calculations were made in U.S. Customary Units and are presented in both the International System of Units (SI) and U.S. Customary Units.

M Mach number

q dynamic pressure

$\dot{q}$ heating rate

σ stress

Subscripts:

cw cold wall

s shear

APPARATUS

The present tests were conducted by using a 147-cm-wide (58-in.), 300-cm-long (118-in.) panel holder shown in figure 2. Its configuration is rectangular with a 20° bevel at the leading edge. A rectangular cutout through the panel holder can accommodate test-panel sizes up to 108.0 by 152.4 cm (42.5 by 60.0 in.) with access to the back of the test panel by means of a removable plate on the back surface of the panel holder. The panel holder is protected by 2.54-cm-thick (1-in.) Glasrock foam tiles which were bonded to the substructure. Uniform turbulent flow over the panel holder is assured by trips located on the surface approximately 12.7 cm (5 in.) aft of the leading edge (ref. 3).

A 50.8-cm-wide (20-in.) by 134.6-cm-long (53-in.) cutout was provided in the surface of the panel holder to install test specimens as shown in figure 2. The forward end of the cutout received the simulated vehicle surface panel, and the aft end received the simulated elevon assembly.

TEST SPECIMENS

Three flat panels, 50.8 by 50.8 cm (20 by 20 in.) square, simulating the TPS of an elevon were made of Lockalloy, an insulator ablator, and the dense RSI materials. In addition, an insulator-ablator specimen 50.8 by 83.8 cm (20 by 33 in.) served as a representative vehicle surface upstream of the elevon in tests when the RSI or the insulator-ablator specimens were installed.

Lockalloy Specimen

The metallic-heat-sink specimen was fabricated from a 0.63-cm-thick (0.25-in.) plate of beryllium-aluminum (Lockalloy) material containing 57 percent beryllium and 43 percent aluminum. This material is more fully described in references 4 and 5. The surface exposed to the flow was painted with a high-emittance black paint. This panel was instrumented with 13, 30-gage, chromel-alumel thermocouples mounted flush on the surface of the panel. The thermocouple locations are depicted in figure 3. A metal panel was installed ahead of the Lockalloy elevon to simulate the vehicle surface. This panel was a 1.3-cm-thick (0.5-in.) stainless-steel plate approximately 50.8 cm (20 in.) wide and 83.8 cm (33 in.) long. It had bottom-tapped holes on the inside face for mounting. Instrumentation consisted of 21, 30-gage, chromel-alumel thermocouples and 15 pressure orifices equally spaced along the longitudinal center line. The thermocouples were installed on the surface by drilling small holes through the plate, drawing the thermocouple wire through, and then peening and grinding them flush with the surface.

Insulator-Ablator Specimen

The insulator-ablator material (SLA-220 in ref. 6) consists of silica fibers and microspheres in a matrix of silicone elastomer. The panel is 50.8 by 50.8 cm (20 by 20 in.) and 1.5 cm (0.6 in.) thick. The insulator ablator is bonded with a silicone adhesive to a 0.13-cm-thick (0.05-in.) aluminum panel with zee-stiffeners. The material was not preheated prior to testing because the heating in the tunnel would be sufficient to accomplish the initial pyrolysis during the test. The insulator ablator was tested in two forms, striated and honeycomb filled. The striated material has a gridwork of slits cut to a depth of approximately one-half the material thickness. The striations are spaced on 1.3 cm (0.5 in.) centers to avoid severe cracks resulting from pyrolysis-induced shrinkage. The honeycomb-filled material has an organic fiber reinforcement. The test specimen has a 25.4 by 50.8 cm (10 by 20 in.) panel of each material parallel to and on opposite sides of the flow center line as shown in figure 4.

This specimen was instrumented with sixteen 30-gage chromel-alumel thermocouples installed as shown in figure 4. All locations had thermocouples on the backface although, at the six locations indicated, additional thermocouples were installed 0.3 cm (0.12 in.) below the outer surface of the material. Figure 5 is a photograph of the panel prior to testing.

Vehicle Surface Specimen

The vehicle surface specimen was a model of the realistic airplane TPS ahead of the deflected-elevon specimens made of insulator ablator or RSI. The specimen is flat, approximately 50.8 cm (20 in.) wide and 83.8 cm (33 in.) long. The base is 0.239-cm-thick (0.094-in.) aluminum with 1.3-cm-thick (0.5-in.) honeycomb-reinforced insulator-ablator material bonded to the surface with silicone adhesive. Details of the cell structure as fabricated are shown in figure 6. Prior tests of this material (ref. 2) had shown surface erosion of the relatively brittle pyrolyzed layer. Therefore, prior to tunnel testing the specimen was heated to pyrolyze the surface to determine if eroded particles would damage the TPS on the elevon surface during tunnel testing.

The panel was pyrolyzed during three heating cycles from room temperature to 1005 K (1810° R) in a radiant-heating apparatus. The time-temperature profile, shown in figure 7, was used. The profile represents the predicted external skin-temperature history for a hypersonic-research-airplane flight. A closer view of the cell structure of the honeycomb material after the heating cycles is shown in figure 8. Reference 2 describes prior testing of the insulator-ablator material in a low-heating-rate environment.

RSI Specimen

The RSI material was mounted on a stiffened aluminum panel similar to the insulator-ablator material. Additional stiffness was added by attaching a 0.32-cm-thick (0.125-in.) aluminum plate to the inner flanges of the zee-stiffeners. The aluminum skin plate was covered with 12.7-cm (5.0-in.) square tiles which were 2.2 cm (0.875 in.) thick. These tiles were made of a high-density silica fiber (352 kg/m^3 (22 lb/ft^3)) covered with a high-emittance reaction-cured-glass (RCG) coating approximately 0.25 mm (0.01 in.) thick. The tiles were separated from the aluminum panel by a Nomex felt strain isolator pad (SIP). This system was bonded together by using a silicone adhesive on both sides of the SIP. The tile array and instrumentation locations are depicted in figure 9. The instrumentation on this specimen consisted of 24, 30-gage, backface thermocouples. They are located on three equally spaced rows parallel to the flow direction. Figure 10 is a photograph of the specimen prior to testing. The gaps between the tiles were packed with a Micro-Quartz batting, and the periphery of the panel was packed with Refrasil batting.

INSTALLATION OF ELEVON SPECIMENS

The square elevon specimens were mounted in a steel frame which could be positioned at discrete angles of attack by means of a pivoted support web. The test specimens were mounted on the windward side of the simulated elevon. The details of the simulated-elevon assembly and attachment to the panel holder are shown in figure 11.

The aluminum panel of the insulator-ablator specimen was mounted to the steel frame. For the RSI panel, the gap between the specimen and the elevon-holder periphery was filled with Refrasil batting. A duct-sealing compound was used on the insulator-ablator panel to effect a seal between the aluminum substructure and the frame.

The heat-sink panel was attached to the steel frame with four clevis fittings with one fitting fixed and the others allowed to slip to accommodate thermal expansion. A separate seal assembly was used consisting of a welded frame of aluminum angles and a pillow of Fiberfrax batting contained in a Refrasil cloth cover cemented to the surface. The seal was attached so that the pillow was compressed by the inside surface of the Lockalloy panel when installed.

A welded steel skirt was positioned around the steel frame to cover the opening on the sides and back of the installed frame to prevent hot tunnel gas flow from entering the panel-holder cavity. Also, steel fences, which extend below the panel holder (see fig. 2), were used on both sides of the panel holder. The tops of the fences were flush with the panel-holder surface to allow use of the schlieren equipment to photograph the panel holder and elevon junction.

FACILITY

The specimens were tested in the aerothermal environment of the Langley high-temperature structures tunnel (8-ft HTST). This tunnel is a hypersonic blowdown facility that simulates the flight environment in a Mach number range between 6 and 7 at altitudes ranging from 24.4 to 40 km (80 000 to 130 000 ft) for time periods up to 2 minutes. The test medium is generated by the combustion of methane and air (ref. 7) in a high-pressure combustor. The reaction products are then expanded through an axisymmetric contoured nozzle to a nominal exit Mach number of 7. The nozzle has an exit diameter of 2.4 m (8 ft); however, the uniform test core is only about 1.2 m (4 ft) in diameter. The flow exits as a free jet for 4.3 m (14 ft) and enters a supersonic diffuser. Downstream of the supersonic diffuser is a single-stage annular air ejector. The flow from the ejector mixes with the hot gases in a long straight mixing tube and is then decelerated by a conical frustrum-type diffuser. A schematic drawing of this facility is shown in figure 12.

Test models are mounted in the sting-mounted panel-holder apparatus, previously described. The panel holder is retracted and covered during wind-tunnel startup and shutdown. The insertion and retraction is accomplished by an injection system which fully inserts the panel holder in about 2 seconds. The panel holder and test chamber are shown in figure 13. A more detailed description of the facility, the panel holder, and the measured aerothermal parameters may be found in references 3 and 8.

ENVIRONMENT

The test environments, given in table I and indicated in figure 1, closely simulate the inflight heating anticipated on a deflected control surface at a Mach number of 7. The initial heating rates and shear forces on the heat-sink elevon for the tests at $q = 47.9$ kPa (1000 psf) are given in figure 14. A more detailed heating-rate analysis supported by experimental data from a series of calibration tests is presented in reference 8. As indicated, a peak heating rate of 800 kW/m^2 (70 Btu/ft^2-sec) and a shear of 430.9 Pa (9 psf) were imposed on the elevon. Although the Lockalloy heat sink and RSI are candidates for the high-heating and shear environments (refs. 9 and 10), the insulator-ablator material is proposed for low-heating-rate regions such as the vehicle surface where $\dot{q} \leq 68$ kW/m^2 (6 Btu/ft^2-sec). Thus, tests of the insulator ablator in the elevon environment provide performance data on this material for extreme flight conditions. The elevon heating rate of 800 kW/m^2 (70 Btu/ft^2-sec) permits a test time of approximately 10 seconds before the heat-sink material reaches its design temperature limit of 589 K (1060° R). Therefore, a 10-second exposure was used in all tests to assess material performance in like environments.

TEST PROCEDURE

The sting-mounted panel holder was rapidly inserted into the hot stream once stable flow conditions were established. The specimens were not preheated prior to insertion. After testing, the panel holder was retracted and the tunnel was shut down.

Electrical outputs from the thermocouples were recorded on magnetic tape by an analog-to-digital data-recording system. In addition to schlieren photographic coverage, motion pictures were made with three cameras mounted in the tunnel and focused near the intersection of the elevon and panel holder.

Due to the potential hazard of beryllium contamination, special precautions were taken in handling and testing Lockalloy. Special clothing and gloves were used for handling, and all tunnel personnel were briefed on the health hazard that could be encountered without proper handling.

In order to determine the amount of residual beryllium or beryllium compounds in the tunnel after tests, a series of swipe tests were formulated. About 30 discrete areas on the panel holder and tunnel were sampled by wiping a clean filter paper over the area. The filter papers were then chemically decomposed and analyzed for beryllium content by using a Perkin-Elmer 303 atomic-absorption spectrometer.

TESTS

A total of five tests were made under the conditions shown in table I. Three tests were conducted on the Lockalloy specimen. A 10-second exposure time was calculated by using the CAVE computer program (ref. 11) to produce a maximum surface temperature of 589 K (1060° R). The results of the analysis were verified on a stainless-steel calibration plate (ref. 8). The first test was made at $M = 6.70$ with a nominal dynamic pressure of 47.9 kPa (1000 psf) at free-stream conditions, with the panel holder at 0° angle of attack and the elevon deflected 30°. The second test was at a higher nominal dynamic pressure, 57.5 kPa (1200 psf) with $M = 6.73$, whereas the third test was conducted at $M = 6.06$ with a dynamic pressure of 54.58 kPa (1140 psf).

One test (test 4 of table I) was conducted on the insulator-ablator panel at conditions similar to the first Lockalloy test. (See table I.) The panel holder was inserted at 0° angle of attack with the elevon deflected 30°. The dynamic pressure was nominally set at 47.9 kPa (1000 psf) and a test time of approximately 10 seconds was used. For this test the vehicle surface specimen was installed in the front part of the panel-holder cavity, thus exposing the insulator-ablator material to both high and low heating-rate conditions.

One test (test 5 of table I) was made on the RSI panel, by using the insulator-ablator surface-specimen forward panel, at conditions similar to those of the first Lockalloy test and the insulator-ablator test.

RESULTS AND DISCUSSION

Schlieren photographs of all three test specimens are shown in figure 15. The top photograph was taken during the first Lockalloy test. A thinned boundary layer is visible just above the intersection of the panel holder and the elevon in each case. No shock impingement or flow separation is evident. The boundary layer is noticeably thicker in the lower two photographs, possibly due to either mass addition to the flow from the surface-panel specimen mounted ahead of these two specimens or the increased surface roughness of the pyrolyzed insulator-ablator panel over the stainless surface panel.

Lockalloy Specimen

The Lockalloy specimen was tested under the conditions outlined in the first three tests of table I. The temperature distributions along the center line of the specimen are shown in figure 16 for all three tests. The temperature distributions are compared with similar tests of a 1.3-cm-thick (0.5-in.) stainless-steel specimen (ref. 8). The model was fully inserted in the stream for about 10 seconds on each test. It can be seen in the area of highest heating rate that the temperature spike is quite visible for the stainless-steel panel of reference 8, whereas the high conductivity of the Lockalloy dissipates the heat pulse and holds a nearly uniform temperature throughout the panel in all cases. The maximum temperature difference on the face of the Lockalloy panel was never greater than 56 K (100° R). Figure 17 is a photograph of the Lockalloy specimen after the third test. The only discernible difference between this photograph and that taken prior to the testing is the local removal of small areas of paint caused by impacts from debris in the flow stream. At about 7.6 cm (3 in.) aft of the hinge line on both sides a small area of Lockalloy was completely bared due to the high local temperature and shear removing the paint. Bluing of the side skirt also suggests higher heating in this area.

The mass spectrograph analyses of the three swipe tests and the calibration swipe tests show no detectable concentrations of beryllium either before, between, or after the three tests of the Lockalloy panel in this environment. Since the only damage to the Lockalloy specimen was paint erosion due to particle impacts which are not typical for true flight environment, this panel was suitable for further testing and would require no refurbishment.

Insulator-Ablator Specimen

Only one test (test 4 of table I) was made on the insulator-ablator specimen, and the test parameters are listed in table I. Shortly after insertion into the stream the surface thermocouples indicated an extremely rapid temperature rise (fig. 18). This indicates that the 0.3-cm-thick (0.12-in.) layer of insulator ablator over these thermocouples was removed by this time. The two surface thermocouples in the highest heating-rate area near the hinge line, locations 12P and 2P in figure 4 were apparently exposed first. The surface degradation followed rapidly up the elevon. All surface thermocouples were exposed in less than 3 seconds. This indicates that one-fifth of the 1.5-cm-thick (0.6-in.) material was removed at these locations after this short exposure time. Backface thermocouple readings are presented in figure 19. The backface (BF) temperature starts to rise after a 2-second exposure. After 8 seconds the temperature rise rate is quite high, over 56 K (100° R) per second. The lowest rates were observed on the thermocouples that remained in place under the honeycomb material. These are designated 15BF and 13BF in figure 19.

The maximum acceptable operating temperature for aluminum is 422 K (760° R). (See ref. 10.) At this temperature aluminum has only 80 percent of its room-temperature properties, and the properties fall off quite rapidly beyond this temperature. As can be seen from figure 19, only the backface readings under the honeycomb-filled material were under 422 K (760° R) at the end of 10 seconds.

The mode of failure of the insulator ablator is also unique. The material was expected to ablate under high-heat loads; however, in this test the virgin material apparently sheared away before reaching ablation temperatures. Figure 20 is a photograph of the panel following the test. A large quantity of the material has been removed and incipient melting of the aluminum substructure is evident in several locations. The photograph in figure 21 is a closeup view of the trailing edge of the panel showing the relative performance of the two insulator-ablator materials. Virgin material is evident in both the striated and honeycomb-filled materials. The striated material shows the characteristic grooving along the slits which continue aft into the unstriated thickness. The honeycomb-reinforced material shows little charring and is pyrolyzed near the leading-edge hinge line. Less than 2.5 cm (1 in.) from the leading edge the honeycomb cells show evidence of severe charring and the insulator still exhibits pyrolization. However, further up the panel the virgin material is again visible, surrounded by the severely charred honeycomb core. The charring of honeycomb core is not as severe at the aft end as it is near the leading edge. Also, the core improves the shear resistance of the material.

Figure 22 is a photograph of the specimen in the test stream approximately halfway through the test. The bright areas indicate high-temperature locations. In these locations the material has reached radiation equilibrium temperature. However, most of the area is dark, indicating that the material has not reached radiation equilibrium temperature. This can be caused by material erosion most probably initiated by the high shear forces created in the flow before the material could be heated to radiation equilibrium temperature. This is the apparent cause since a significant amount of the remaining insulator ablator is virgin unpyrolized material.

Figure 22 also shows the heating at the top edge which is more pronounced near the center of the panel. The heating rate in the corners was apparently less than that near the center, and erosion of the material at the trailing edge is more severe near the center.

Vehicle Surface Specimen

Two tests were made on the vehicle surface specimen concurrent with the insulator ablator and RSI elevon tests. (See tests 4 and 5 of table I.) Since the surface specimen was oriented at 0° angle of attack to the flow, the heating and shear forces were lower than would be expected in service - almost an order of magnitude lower than the heating rates imposed on the elevon specimens. There was no increase in the backface thermocouple readings during either test and no visible erosion of the surface.

The insulator-ablator material was serviceable following prepyrolization and approximately a 20-second exposure at the low-heating-rate conditions. This panel would require no maintenance to provide continued thermal protection at heating rates of 68 kW/m^2 (6 Btu/ft^2-sec).

RSI Specimen

The silica RSI specimen was subjected to an environment similar to that of the Lockalloy and insulator ablator. Figure 23 is a photograph of the specimen in the test stream during the test. The light areas indicate that the surface of the RSI is heated. The brightest areas are caused by the higher temperatures induced by flow in the gaps where the tile walls are not free to cool by radiation. The gap flow is impinging on the leading edge of the downstream tile because of the staggered joints. This impingement causes higher local heating as indicated by the brightest areas in line with the gaps.

A posttest photograph of the model is shown in figure 24. Some minor pitting of the RSI coating is noted. This is assumed to be the result of debris in the flow stream, which would not be representative of real flight conditions. Also, some inter-tile batting has been removed, and the remaining peripheral and inter-tile batting is visible. Inspection of the panel after testing revealed that four tiles were loose. The backface thermocouple readings did not rise appreciably during the test.

The RSI material effectively insulated the aluminum panel from the deflected elevon environment. However, the four loose tiles would require some maintenance and the batting between the tiles would require either replacement, especially in the streamwise direction, or a better means of retention.

CONCLUDING REMARKS

The performance of three thermal protection systems was evaluated in an aerothermal environment simulating interference heating on an elevon deflected 30° at a Mach number of 6.7 and a dynamic pressure of 47.9 kPa (1000 psf). The metallic-heat-sink material (Lockalloy) was the only material considered to be reusable after a 10-second exposure to this environment. In fact, the Lockalloy was shown to be reusable at higher dynamic pressures and higher heating rates.

There is no degradation of the Lockalloy and no evidence of beryllium contamination when exposed to this high-heating-rate environment. This absence of contamination concurs with other test results and indicates that no significant health hazard is associated with the proper use of Lockalloy. Moreover, the high lateral conductance of the Lockalloy damped the peak temperature associated with peak heating rates imposed on the specimen. This feature could avoid or minimize overheating in areas of unpredicted high heating rates.

The insulator-ablator material failed at the elevon test conditions of 47.9 kPa (1000 psf), and some damage was sustained on the reusable-surface-insulation (RSI) specimen. The insulator-ablator material did not ablate as predicted. The virgin material was quickly removed by wind shear, thus exposing the aluminum substructure. The honeycomb-filled insulator ablator exhibited slightly better shear resistance, but it also was severely degraded. It should be noted that the insulator-ablator material was not considered applicable for these high-heating-rate applications. However, areas of severe heating are not easily predicted. For these extreme test conditions, the fail-safe ablation concept of the material was shown to be invalid. The material eroded prior to reaching ablation temperature.

The honeycomb-reinforced insulator-ablator material as tested on the vehicle surface specimen is adequate for the low shear and heating rates experienced at low angles of incidence to the local flow. The cracking caused by the shrinkage of the material apparently does not degrade the capability of the thermal protection system. These cracks, however, may pose operational problems due to water entrapment.

Four RSI tiles were partially debonded after testing and considerable joint packing was lost, thus indicating a need to develop a better packing and edge seal to avoid gap flow. This gap flow may cause thermal strains in the substrate which in itself could promote the bond failure. The debonding of the RSI tiles did not degrade its thermal performance. Some pitting of the coating of the tiles was precipitated by particle impacts.

Langley Research Center
National Aeronautics and Space Administration
Hampton, VA 23665
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TABLE I.- TEST CONDITIONS

[Elevon deflected 30°; panel holder at 0° angle of attack]

Test	Elevon material	Vehicle surface insert	Total combustor temperature		Total combustor pressure		Free-stream Mach number	Dynamic pressure		Test duration, sec
			K	°R	kPa	psia		kPa	psf	
1	Lockalloy	AISI 347[b]	1788	3218	13 148	1907	6.70	47.9	1000	10.10
2	Lockalloy	AISI 347[b]	1852	3334	16 485	2391	6.73	57.5	1200	8.89
3	Lockalloy	AISI 347[b]	1472	2649	16 720	2425	6.06	54.58	1140	9.45
4	Ins/Abl[a]	Ins/Abl[a]	1901	3422	13 796	2001	6.76	47.9	1000	9.89
5	RSI	Ins/Abl[a]	1777	3199	13 659	1981	6.80	49.46	1033	9.75

[a]The abbreviation Ins/Abl denotes insulator-ablator material.
[b]The abbreviation AISI denotes AISI types 347 stainless steel.

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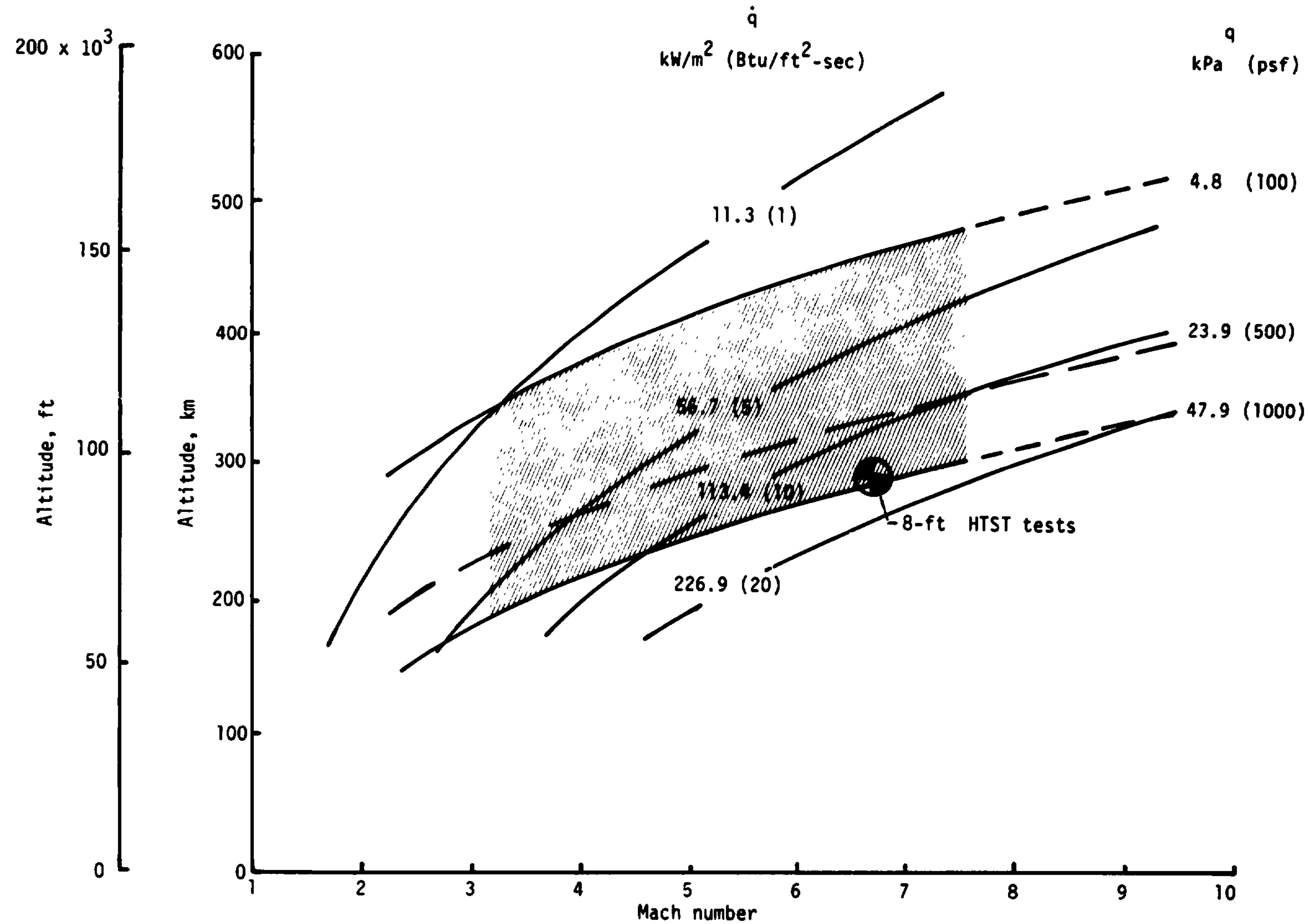

Figure 1.- Flight envelope for a hypersonic research airplane.

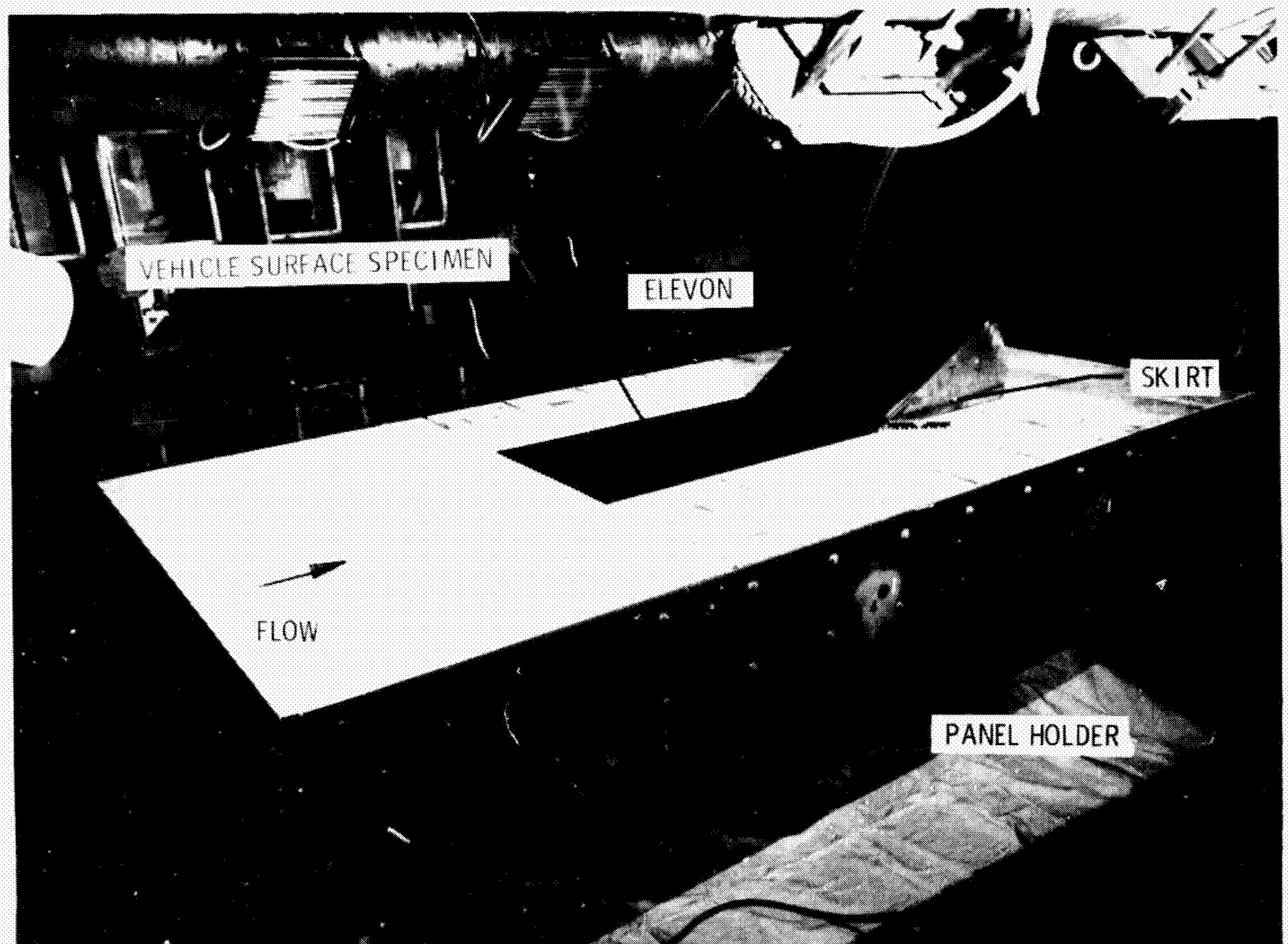

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Figure 2.- Panel-holder installation in 8-ft HTST.

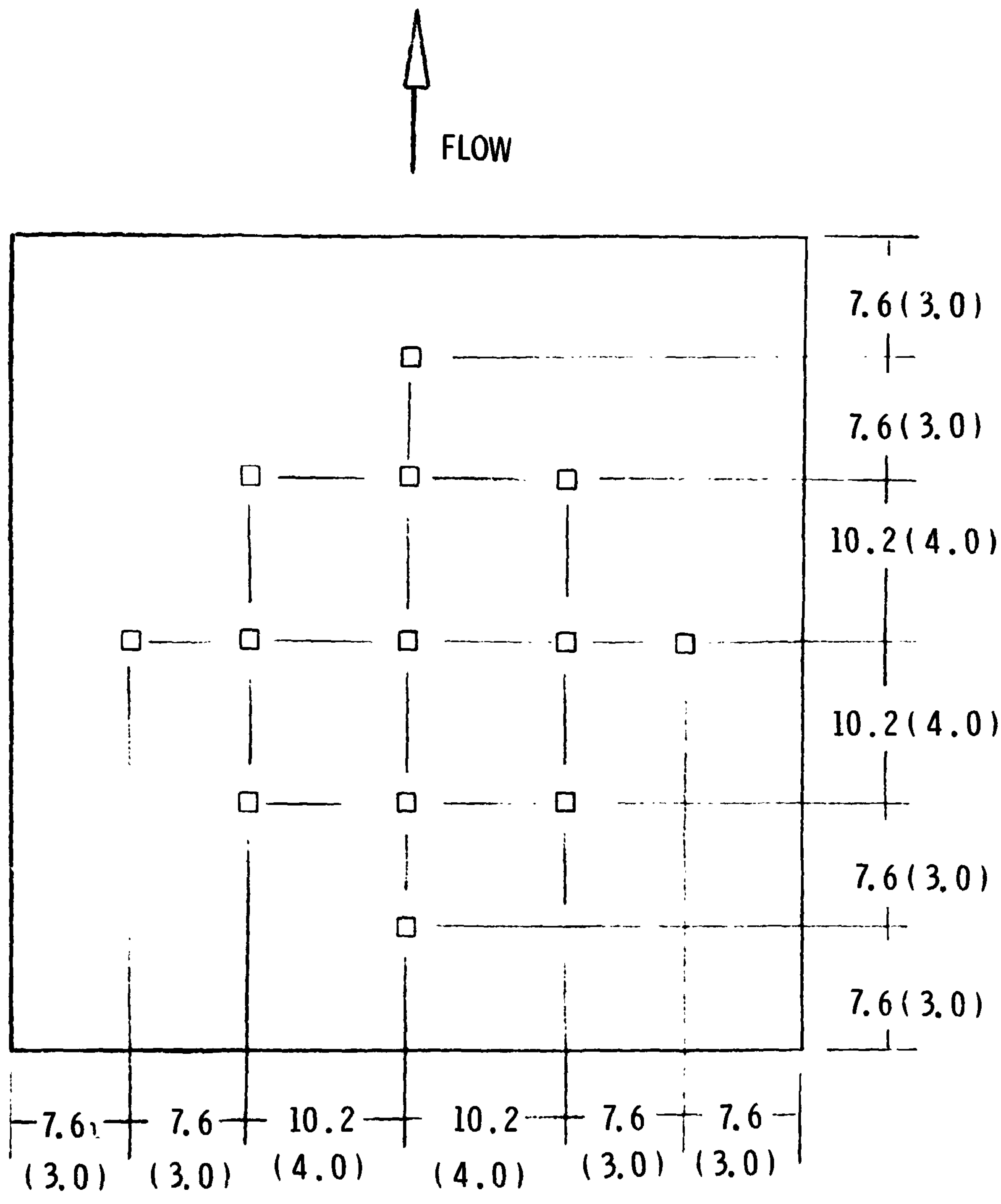

Figure 3.- Thermocouple locations in Lockalloy specimen. All dimensions are given in centimeters (inches).

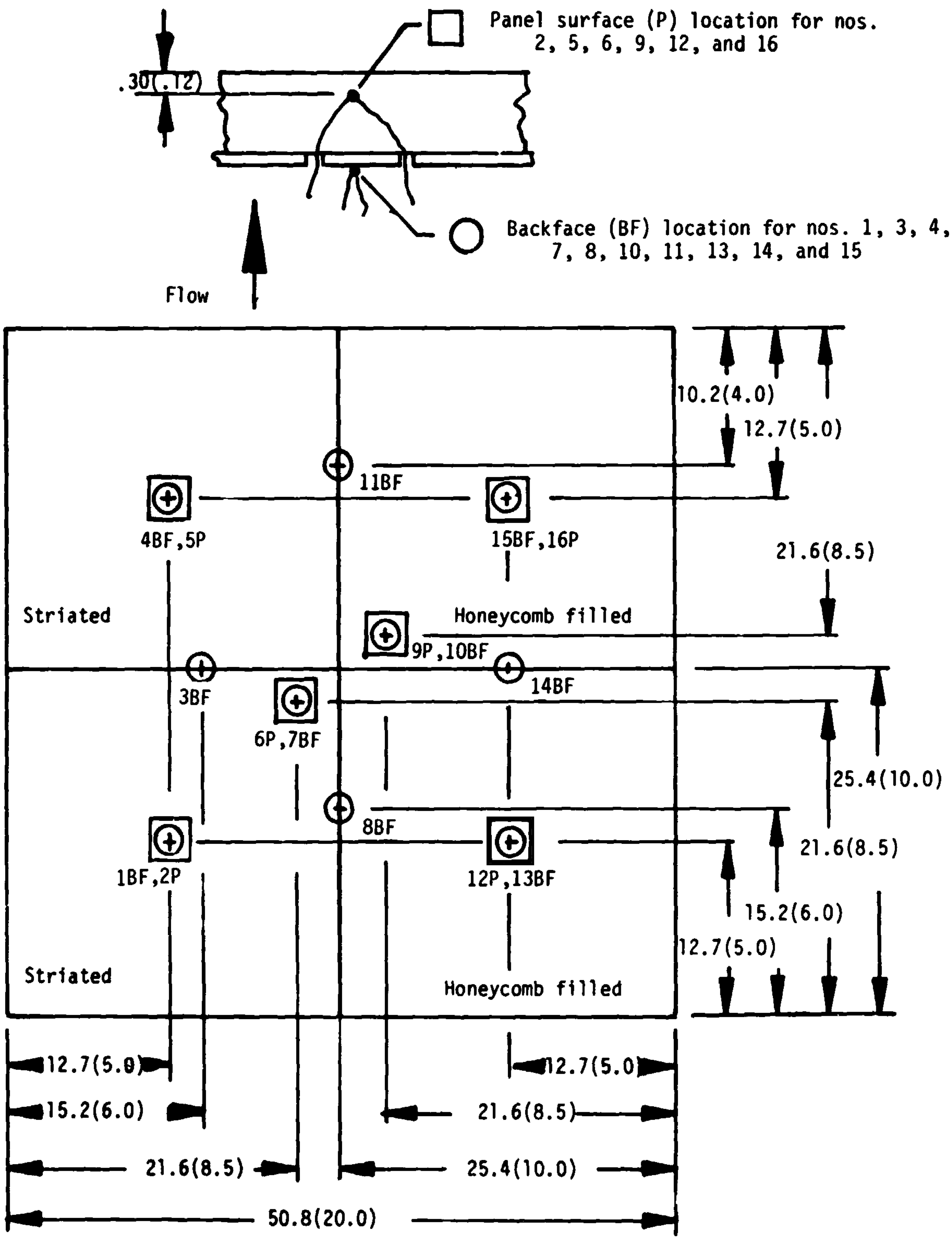

Figure 4.- Thermocouple locations on insulator-ablator specimen. View looking at panel surface. All dimensions are given in centimeters (inches).

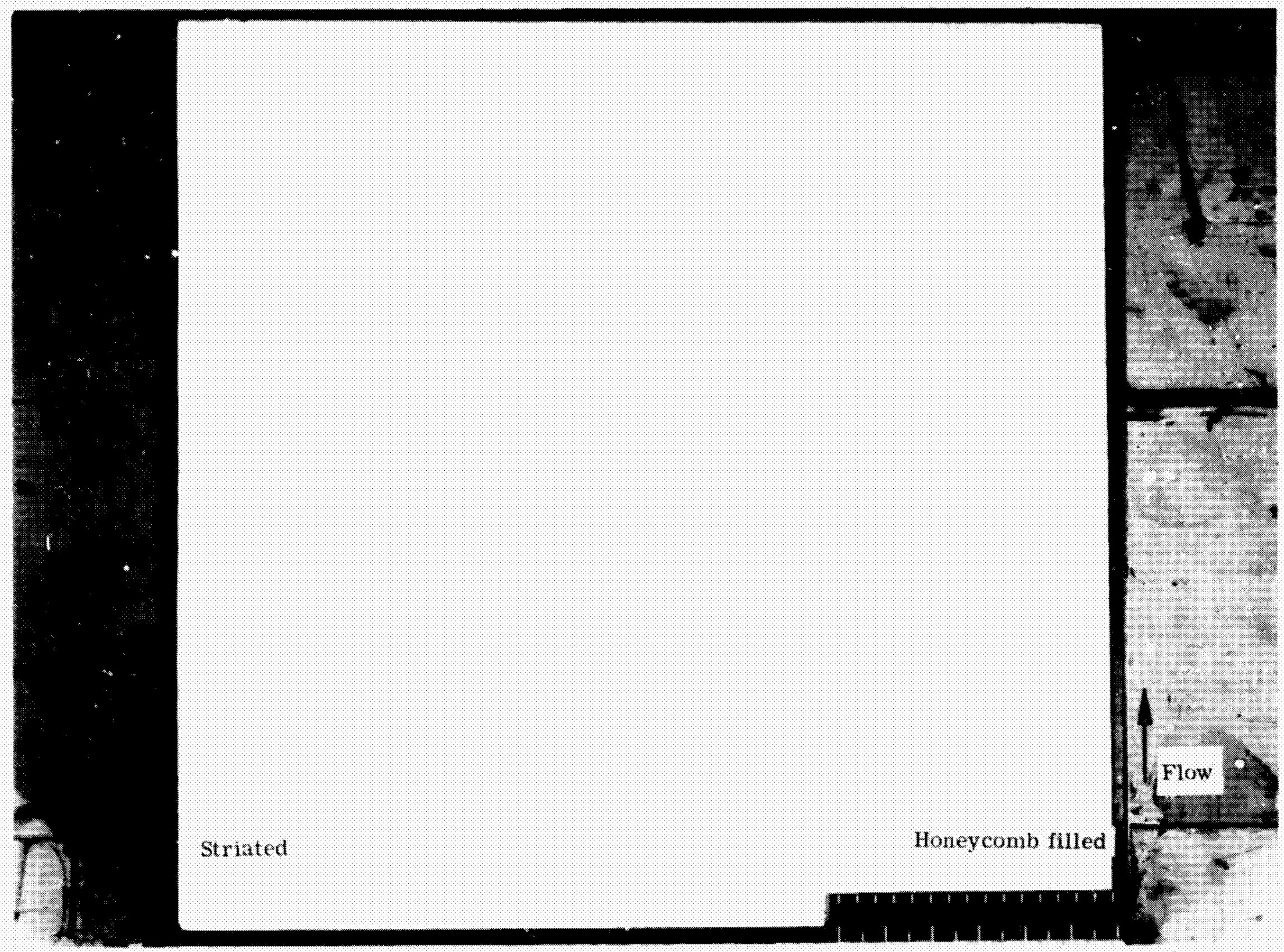

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Figure 5.- Insulator-ablator specimen installed in the panel holder.

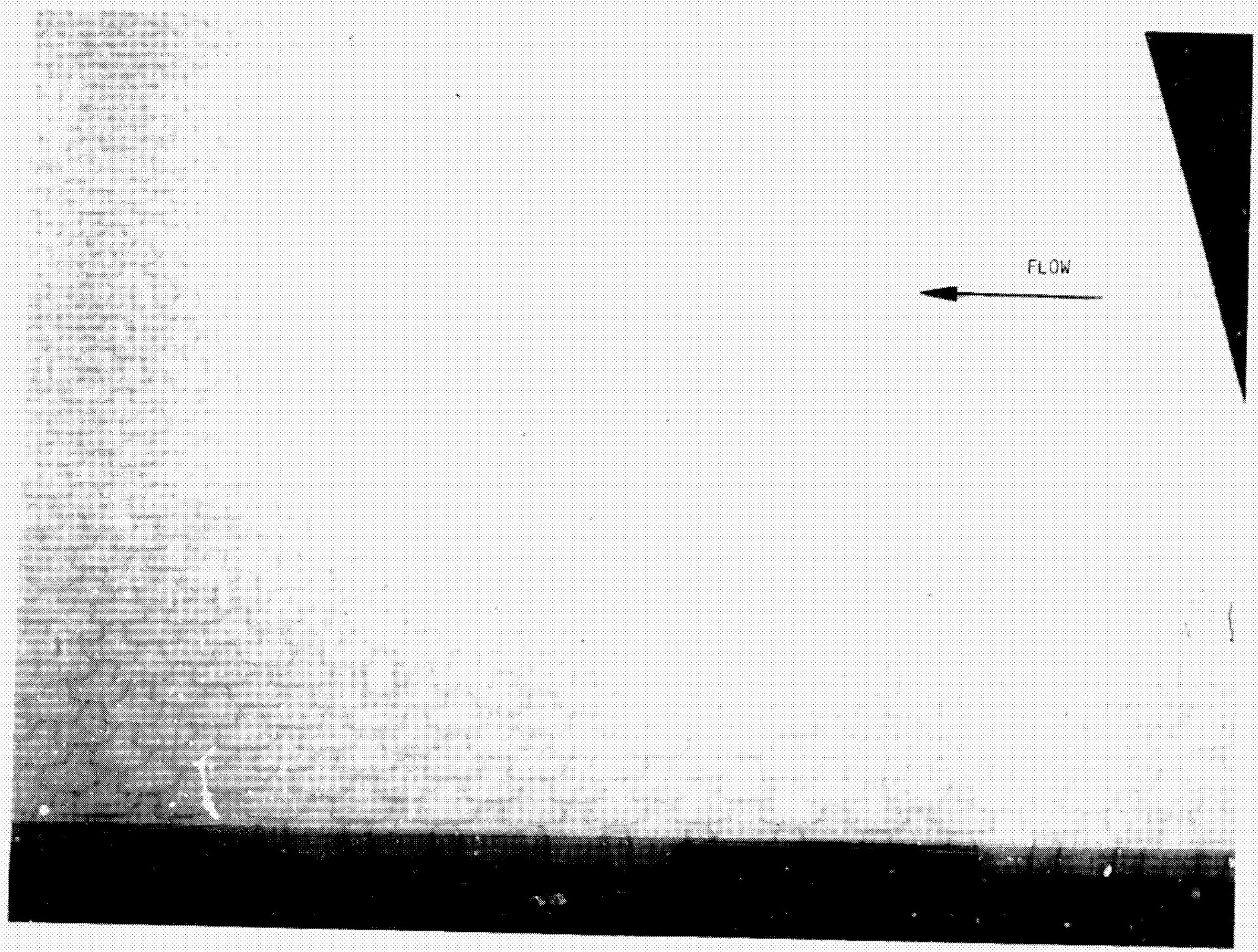

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Figure 6.- Honeycomb-filled insulator-ablator material prior to heating.

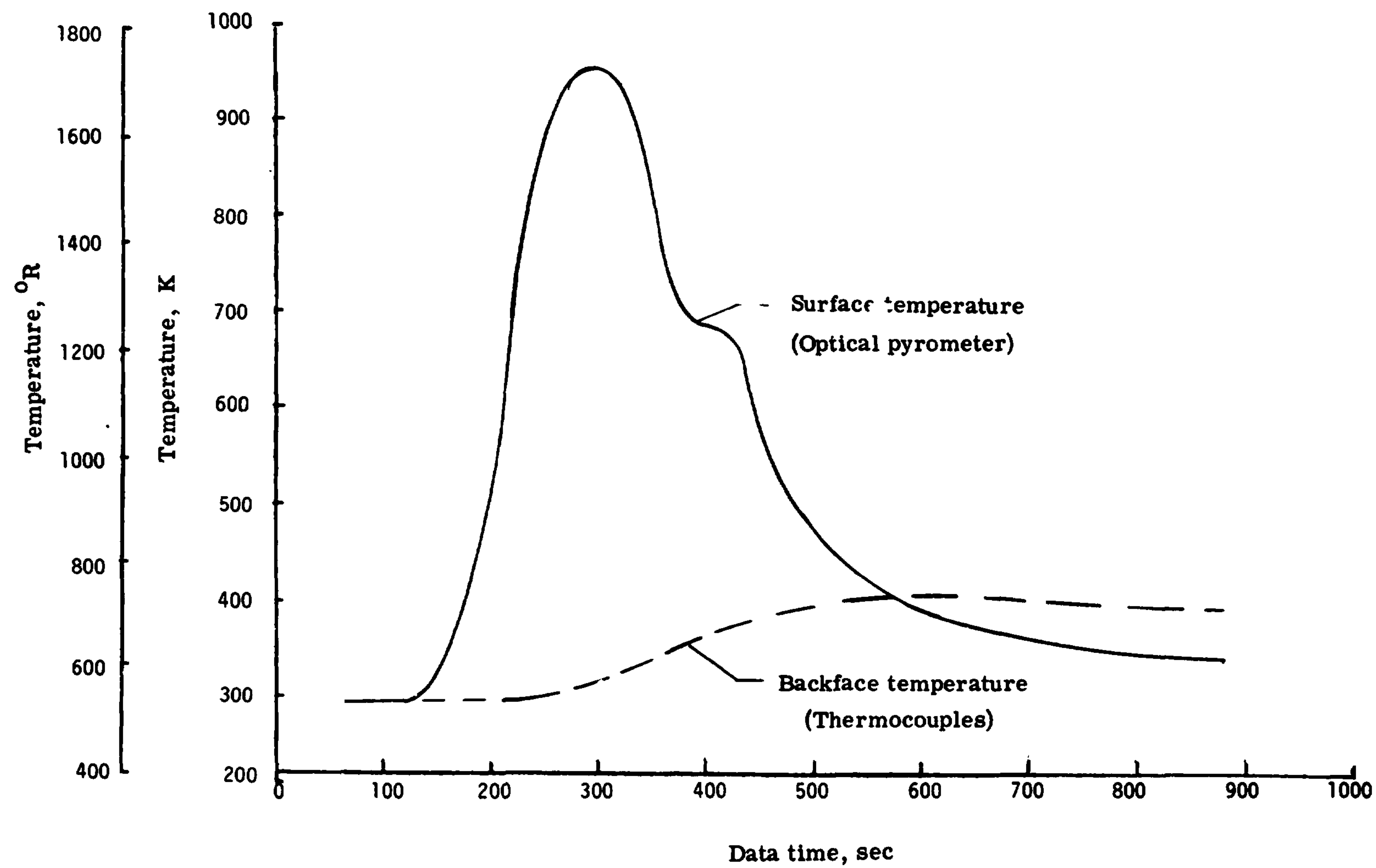

Figure 7.- Temperature history of the honeycomb-filled insulator-ablator vehicle surface specimen.

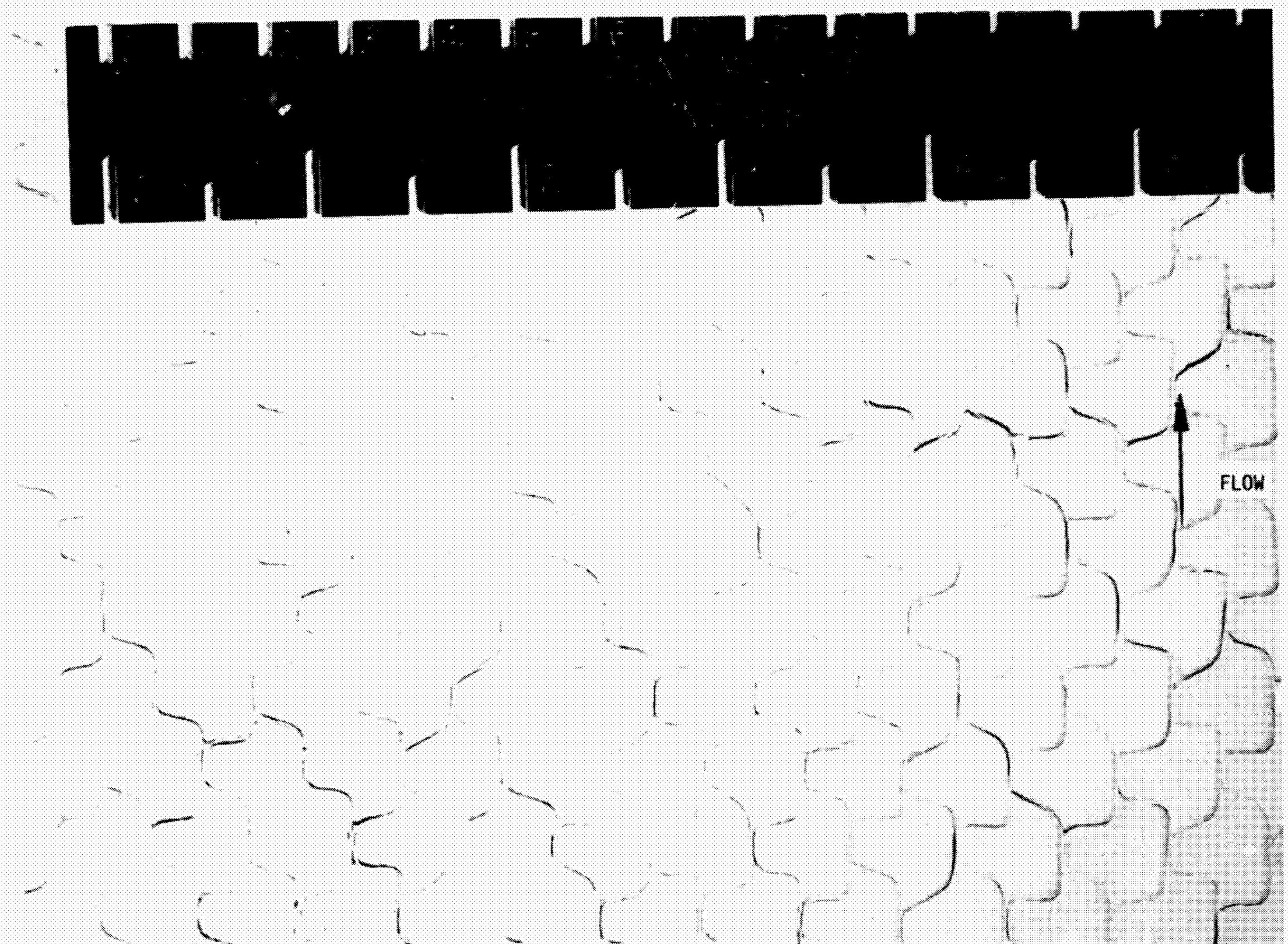

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Figure 8.- Shrinkage of the honeycomb-filled insulator-ablator cells.

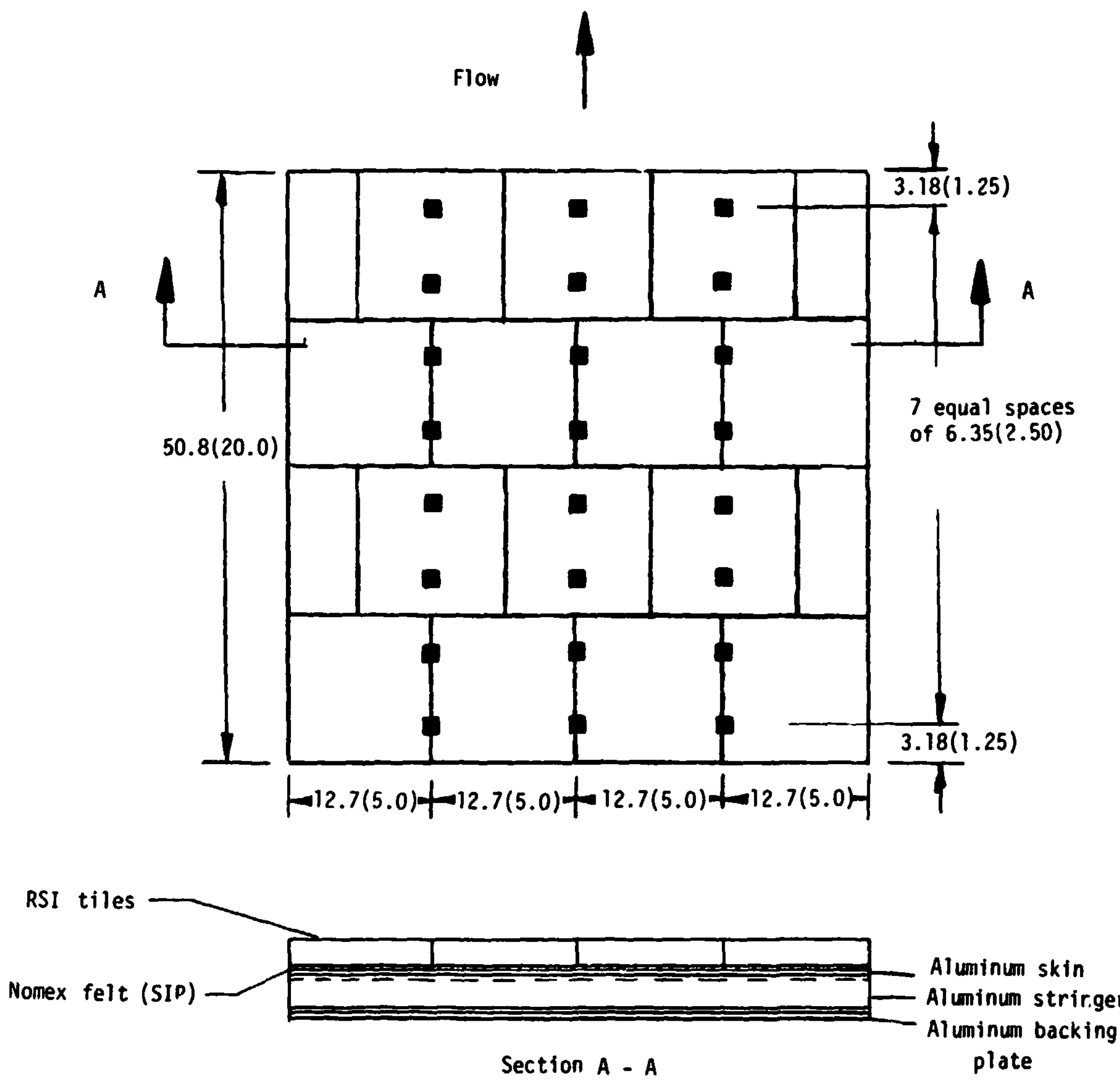


Figure 9.- Thermocouple locations on RSI specimen. All dimensions are given in centimeters (inches).

Figure 10.- The RSI specimen installed in panel holder.

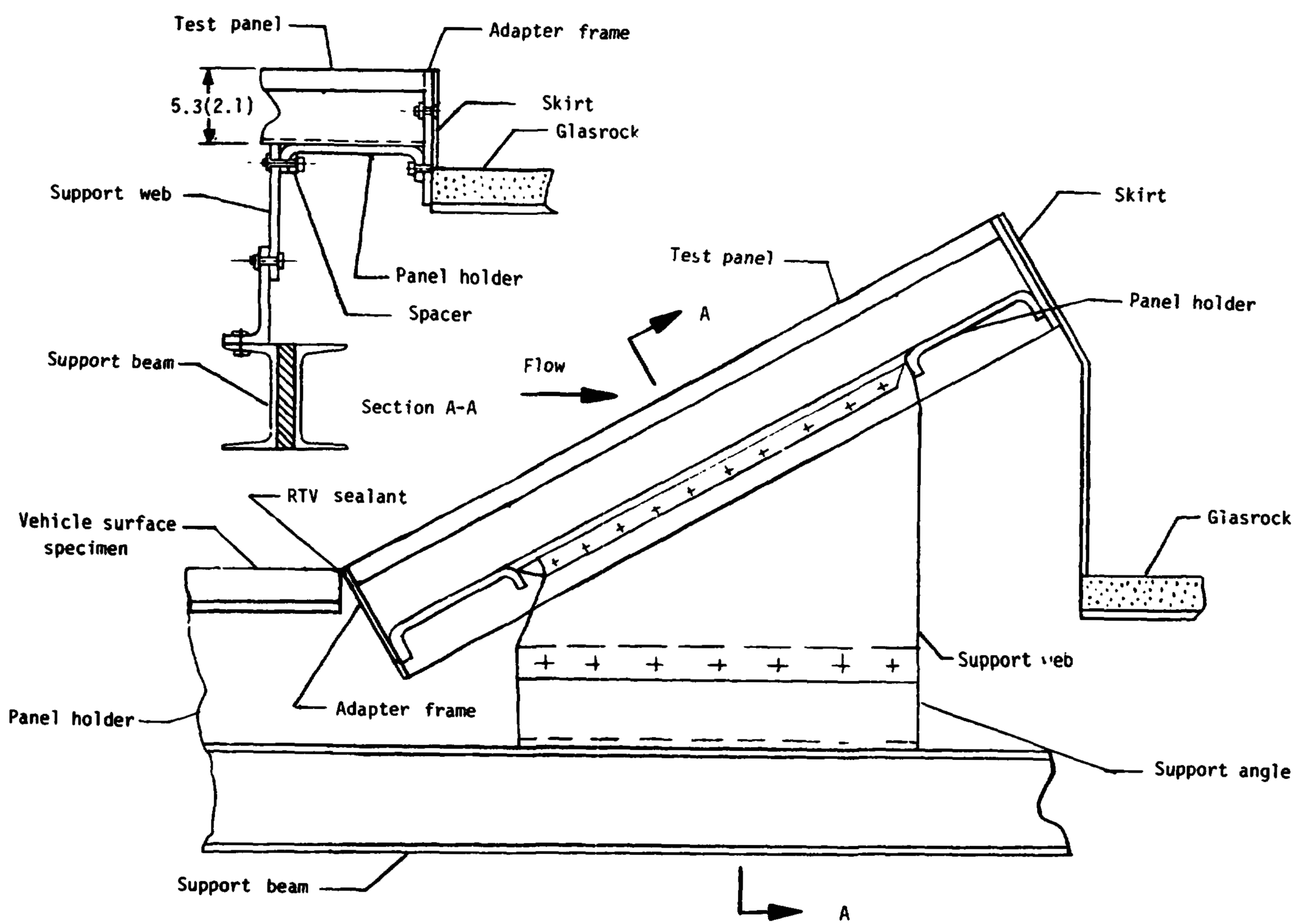
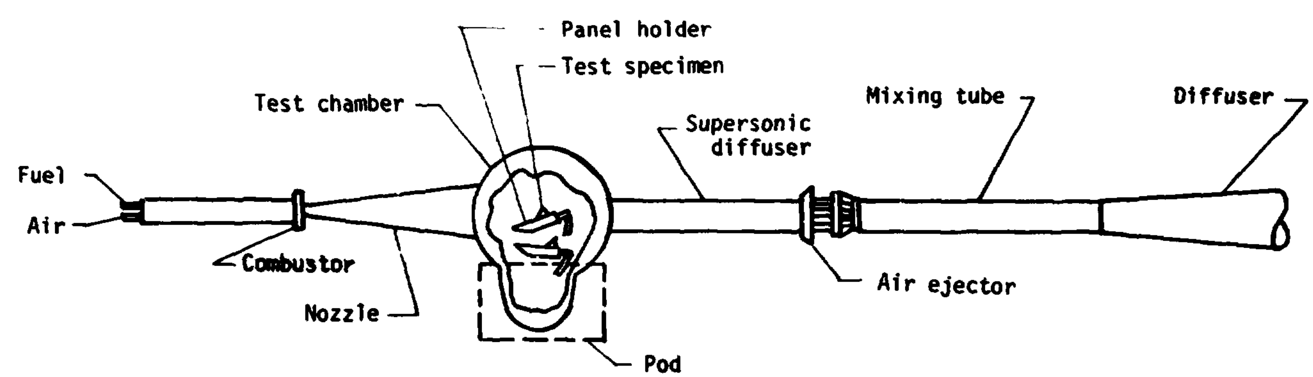


Figure 11.- Details of simulated elevon assembly. Side view shown. All dimensions are given in centimeters (inches).



Nominal Mach number:	7.0	Unit Reynolds number:	0.3×10^6 to 3×10^6
Test-section size:	2.44 m(8.0 ft) diam x 4.27 m(14.0 ft) long	Dynamic pressure:	16.3 to 68.9 kPa (340 to 1440 psf)
Total pressure:	3447.4 to 24131.6 kPa(500 to 3500 psia)	Altitude simulation:	24 to 40 km (80,000 to 130,000 ft)
Total temperature:	1111 to 2000 K (2000 to 3600 °R)	Running time:	20 to 140 sec

Figure 12.- Parameters of the Langley 8-foot high-temperature structures tunnel.

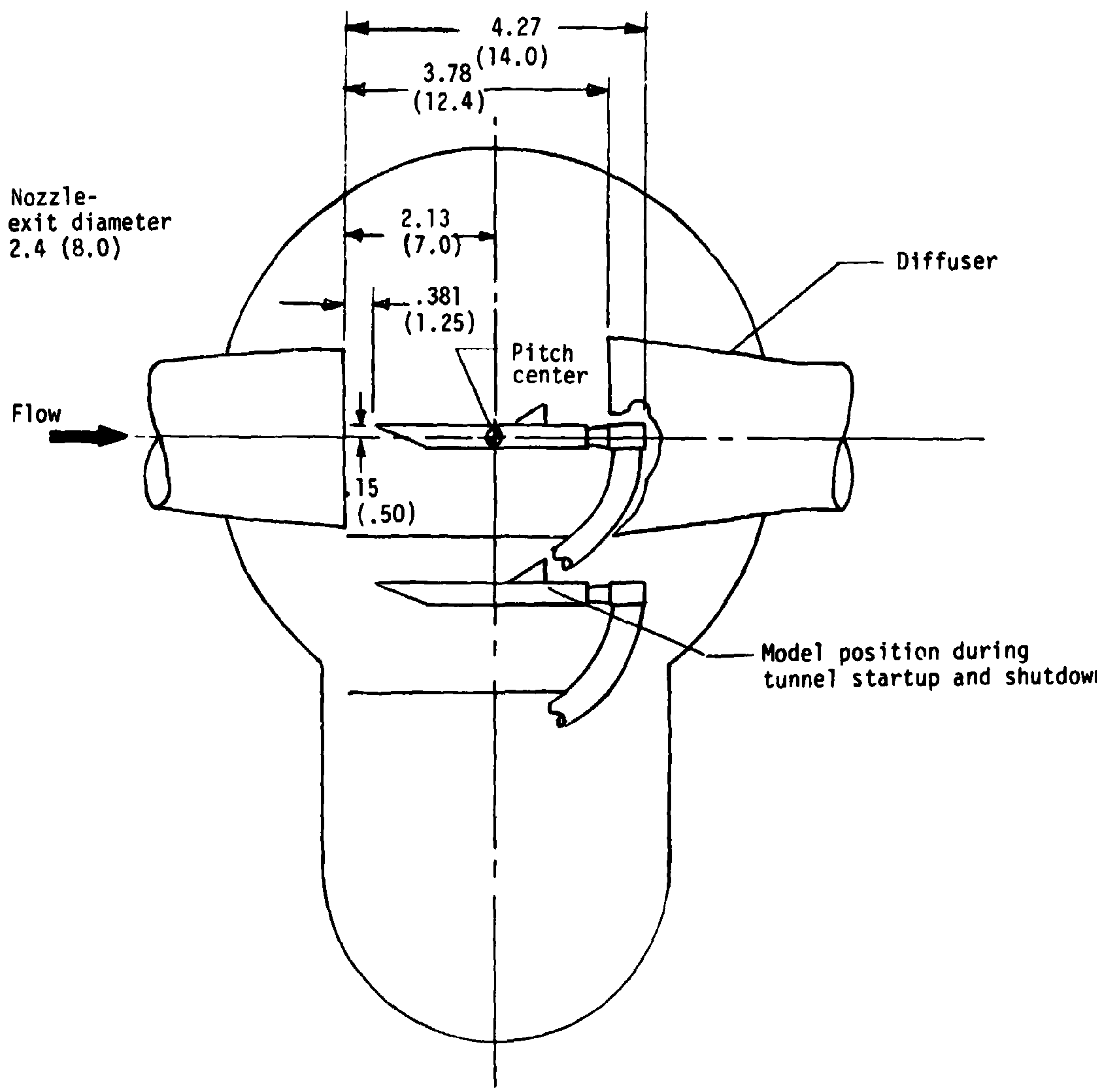


Figure 13.- Cross section of 8-ft HTST test section. All dimensions are given in meters (feet).

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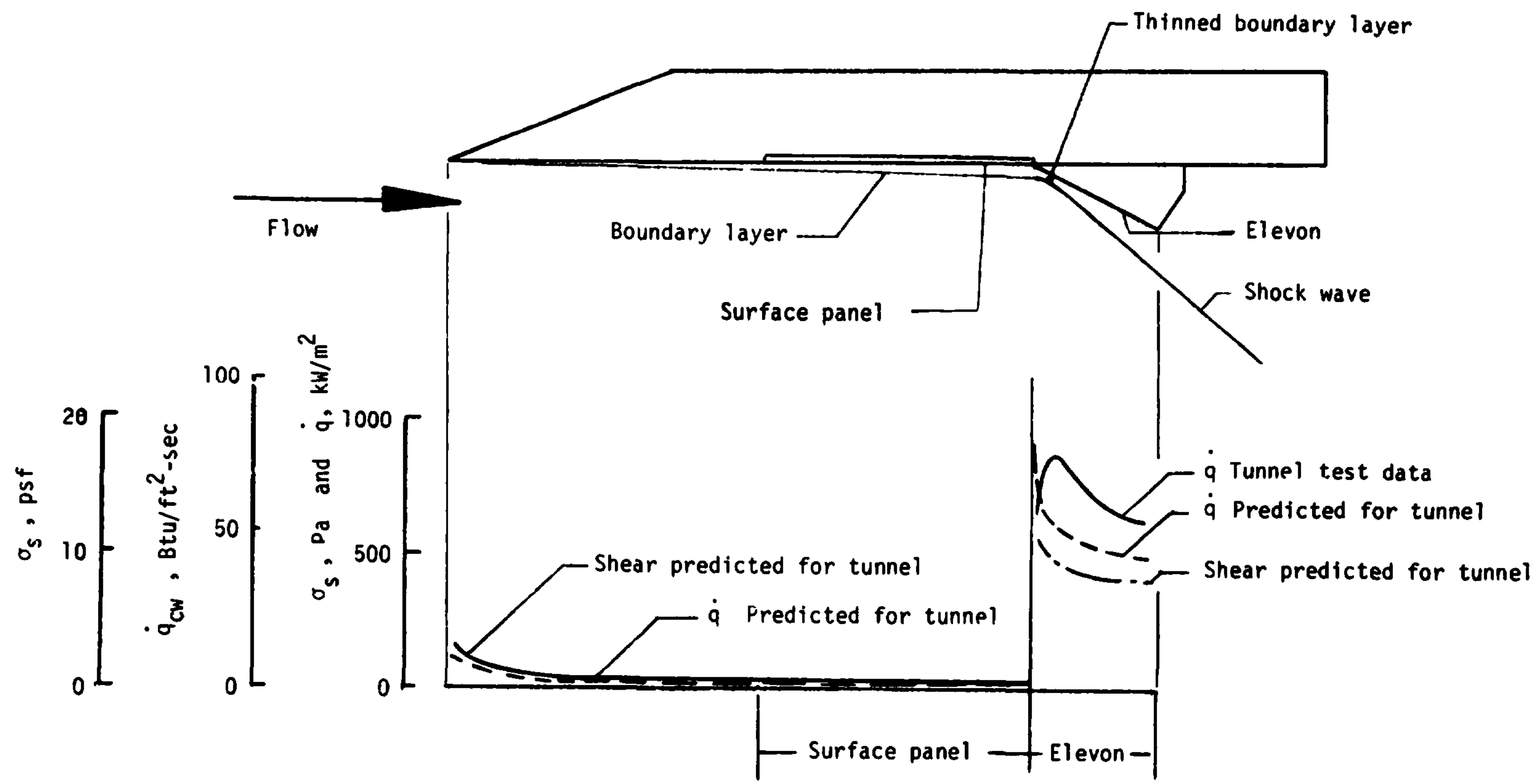

Figure 14.- Initial heating rate and shear forces on deflected elevon and surface panel at $M = 6.7$ and $q = 47.88$ kPa (1000 psf).

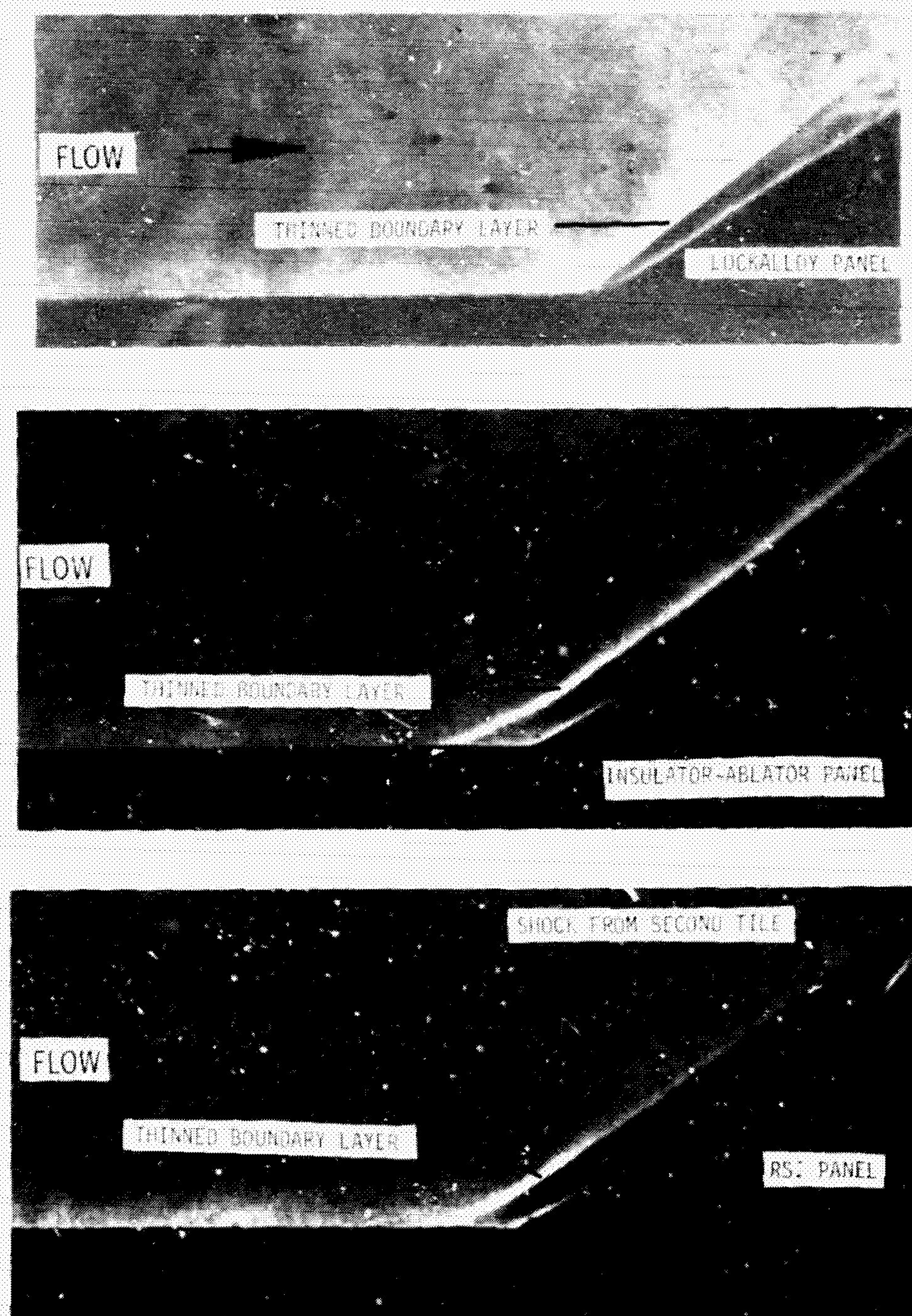

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Figure 15.- Schlieren photographs of TPS tests.

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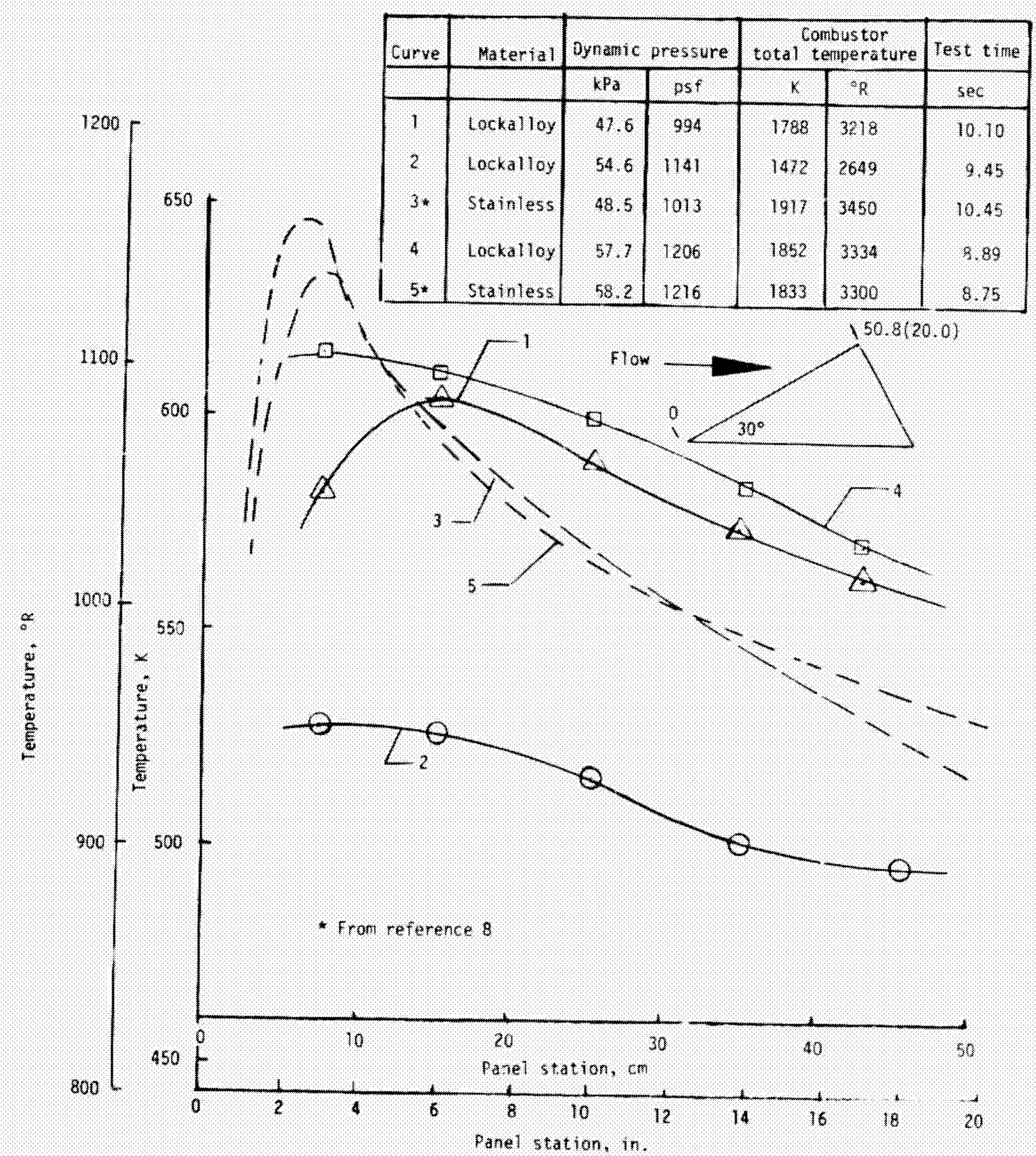

Curve	Material	Dynamic pressure		Combustor total temperature		Test time
		kPa	psf	K	°R	sec
1	Lockalloy	47.6	994	1788	3218	10.10
2	Lockalloy	54.6	1141	1472	2649	9.45
3*	Stainless	48.5	1013	1917	3450	10.45
4	Lockalloy	57.7	1206	1852	3334	8.89
5*	Stainless	58.2	1216	1833	3300	8.75

Figure 16.- Comparison of temperature distributions along length of test panels.

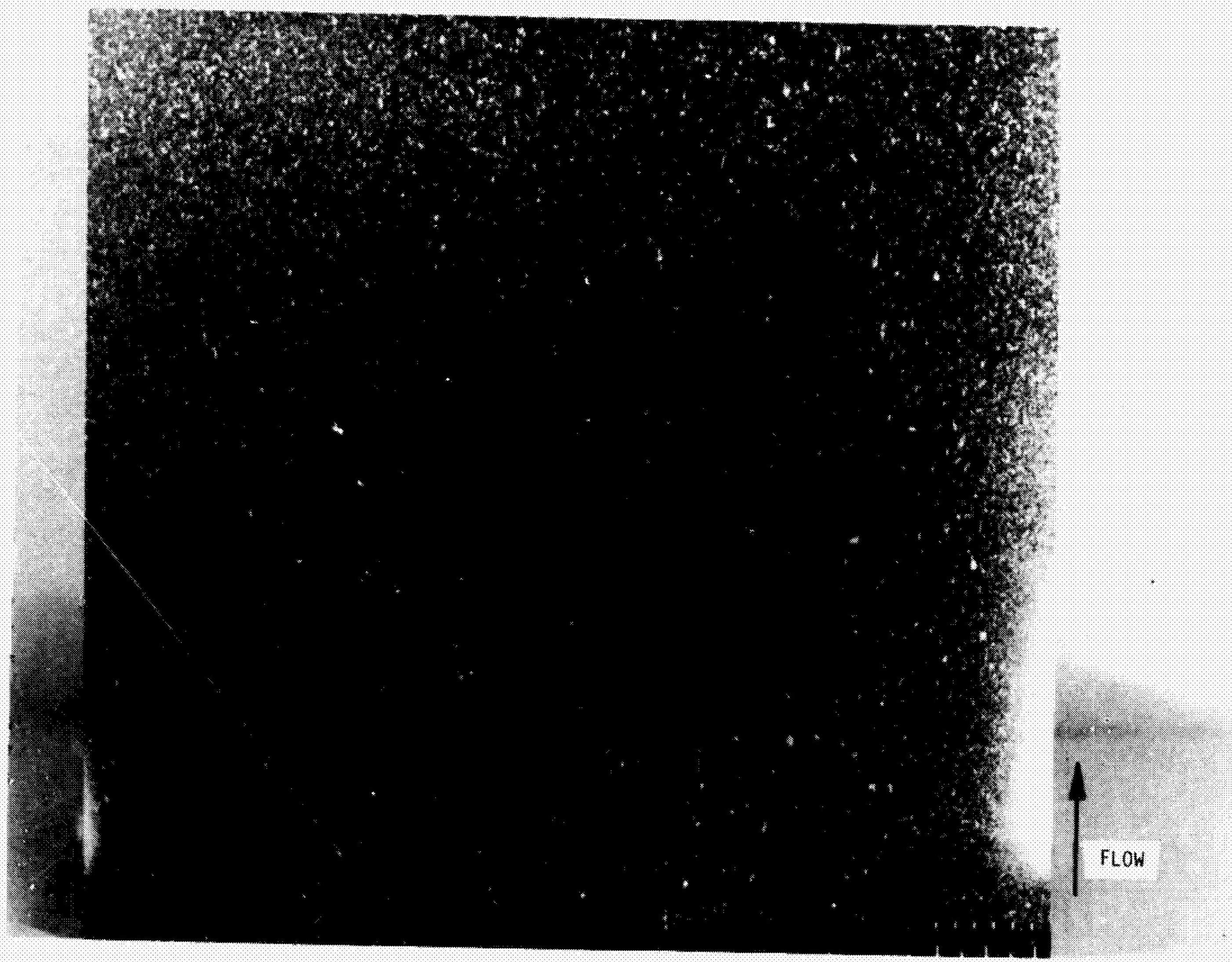

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Figure 17.- Lockalloy specimen removed from panel holder.

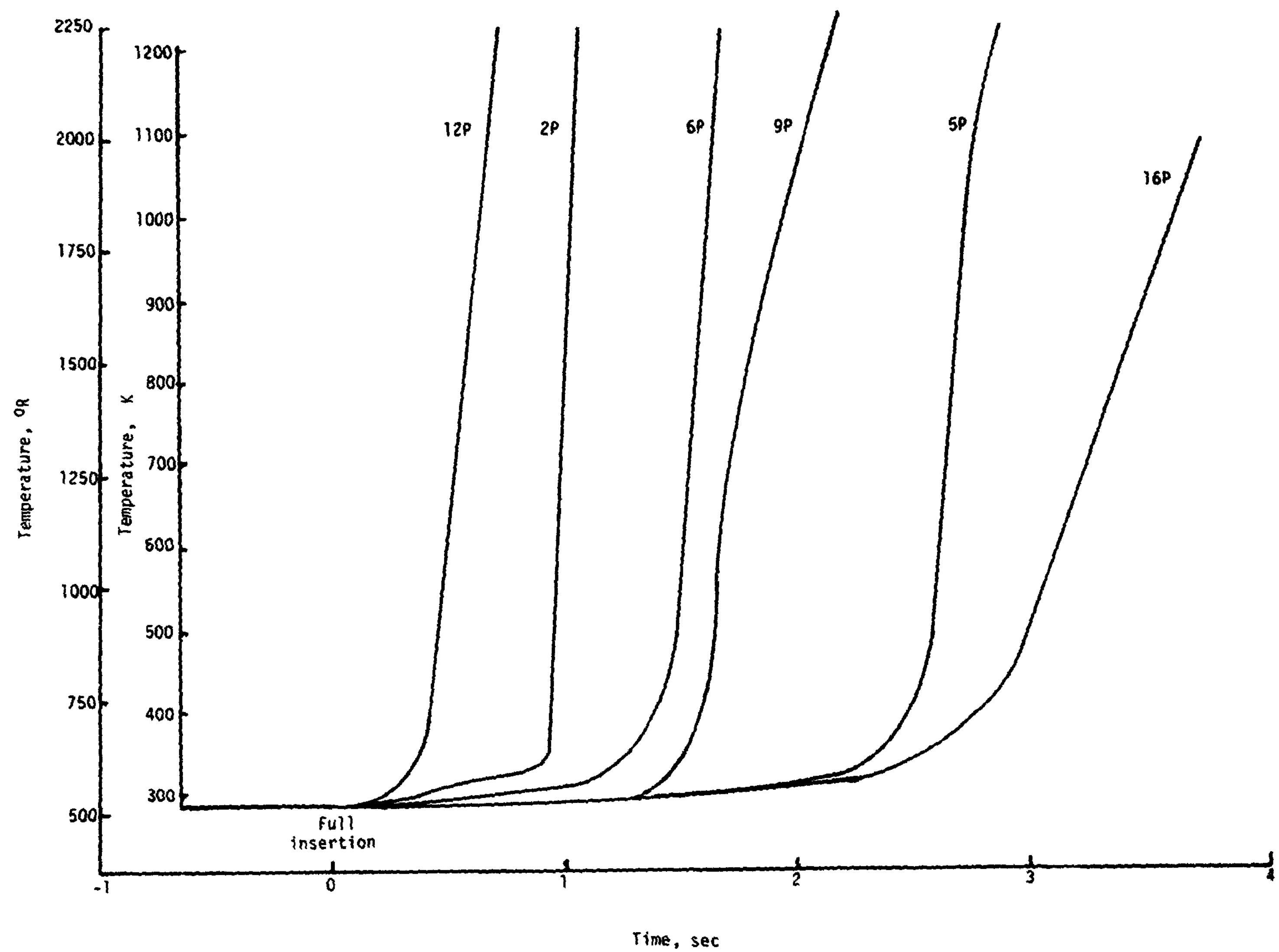

Figure 18.- Surface thermocouple readings during the insulator-ablator test.

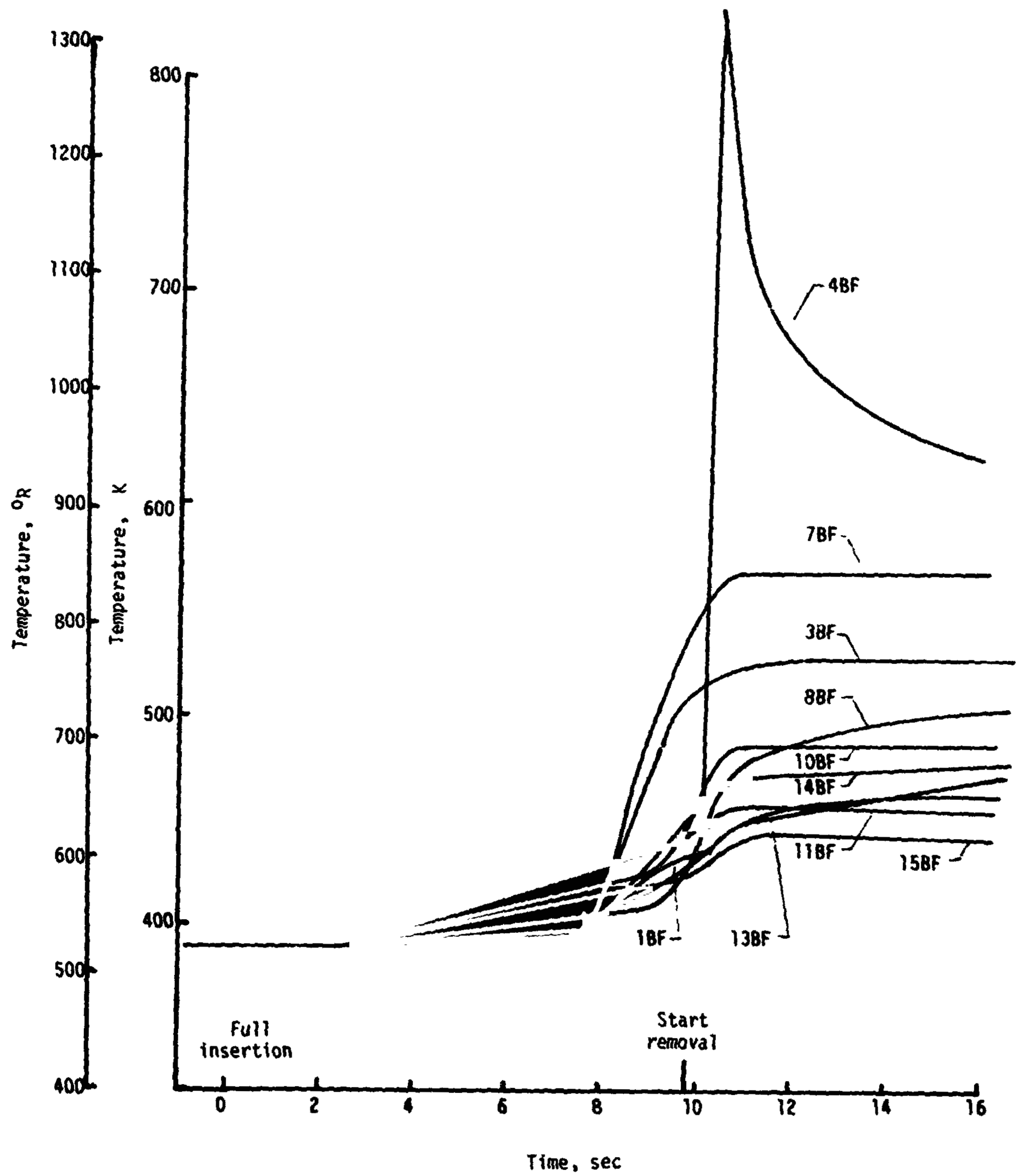

Figure 19.- Backface (BF) thermocouple readings during the insulator-ablator test.

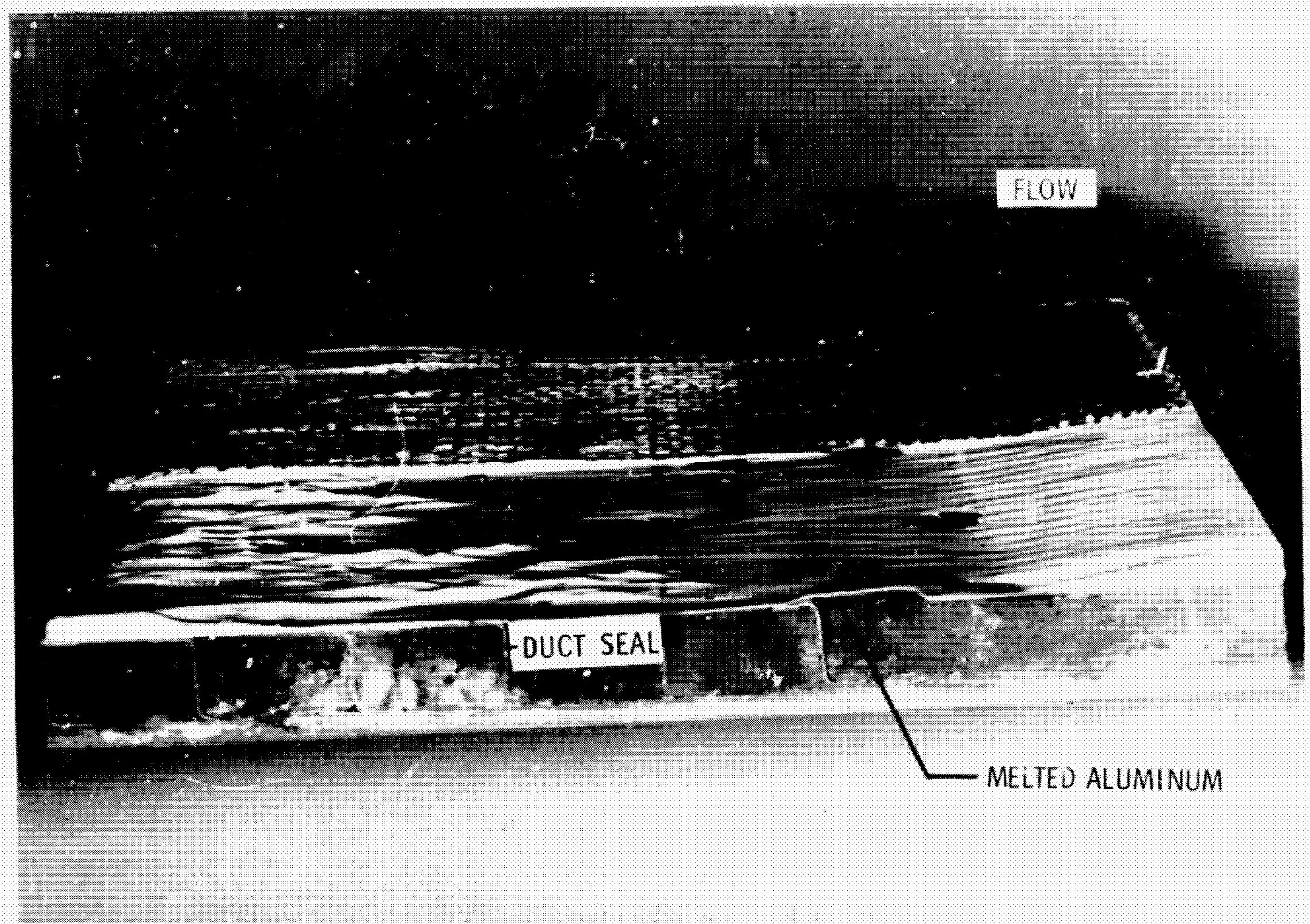

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Figure 20.- Insulator-ablator specimen after testing.

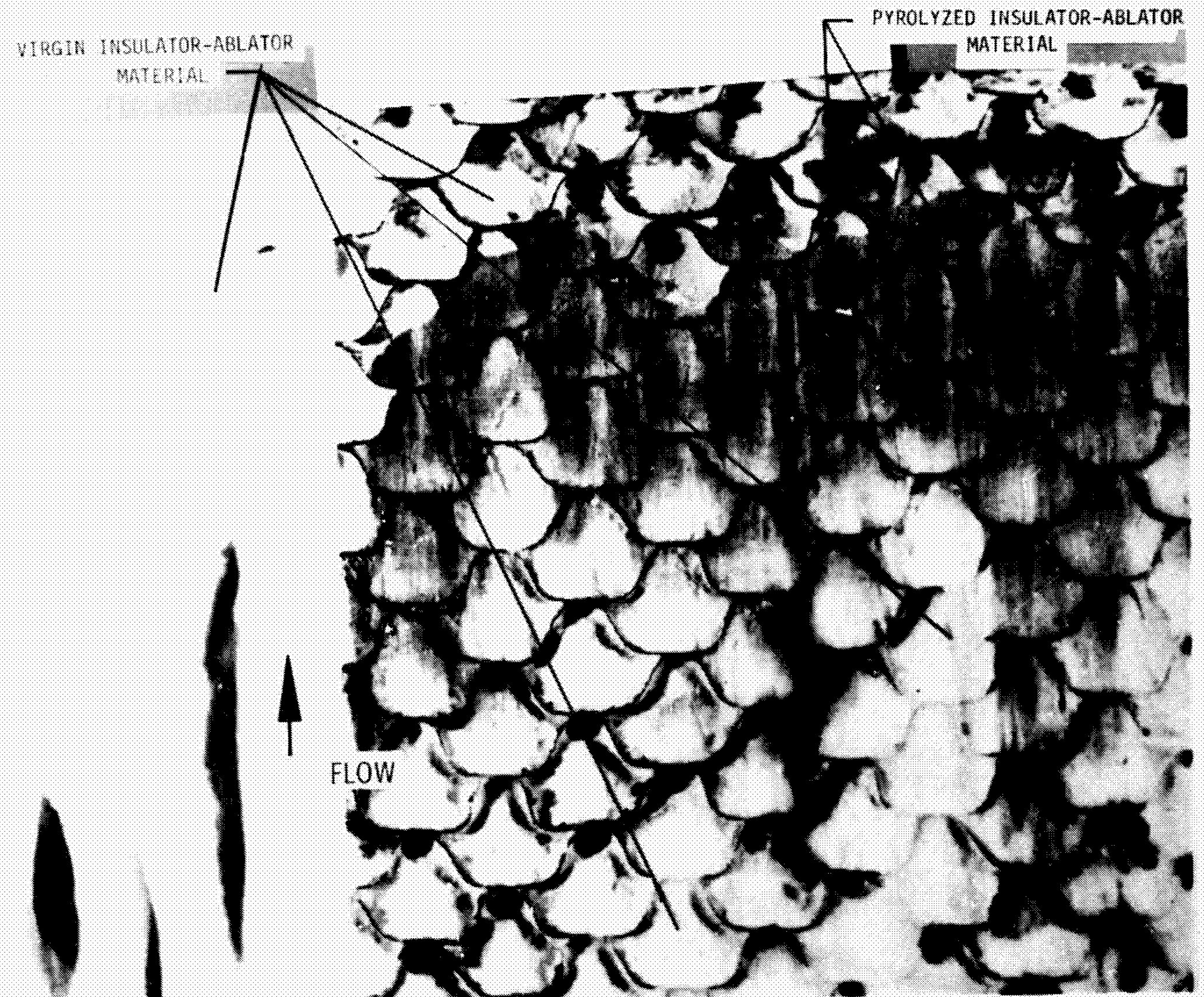

Figure 21.- Closeup view of trailing edge of insulator-ablator material showing virgin material.

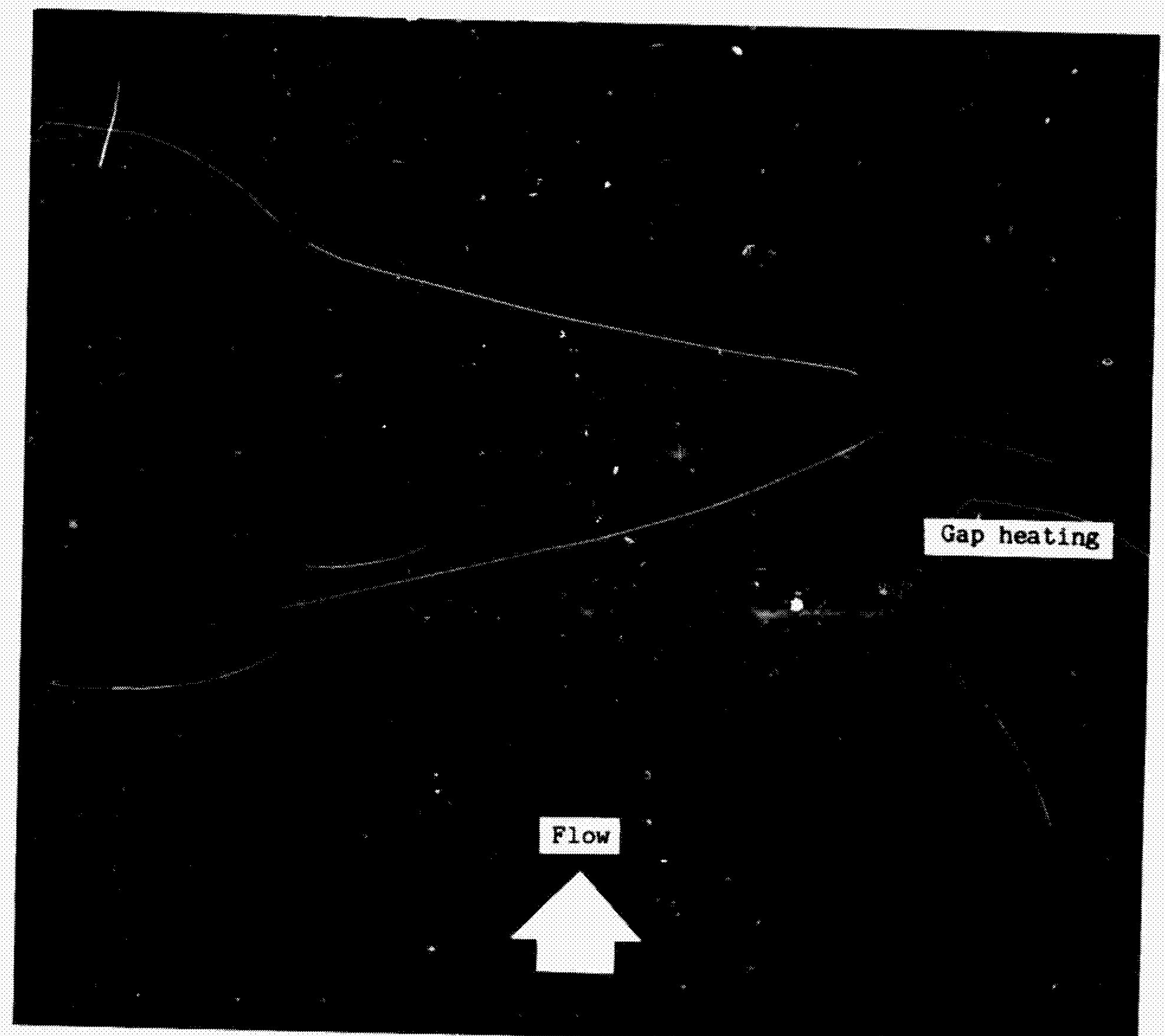

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Figure 23.- The RSI specimen in test stream showing areas of heating.

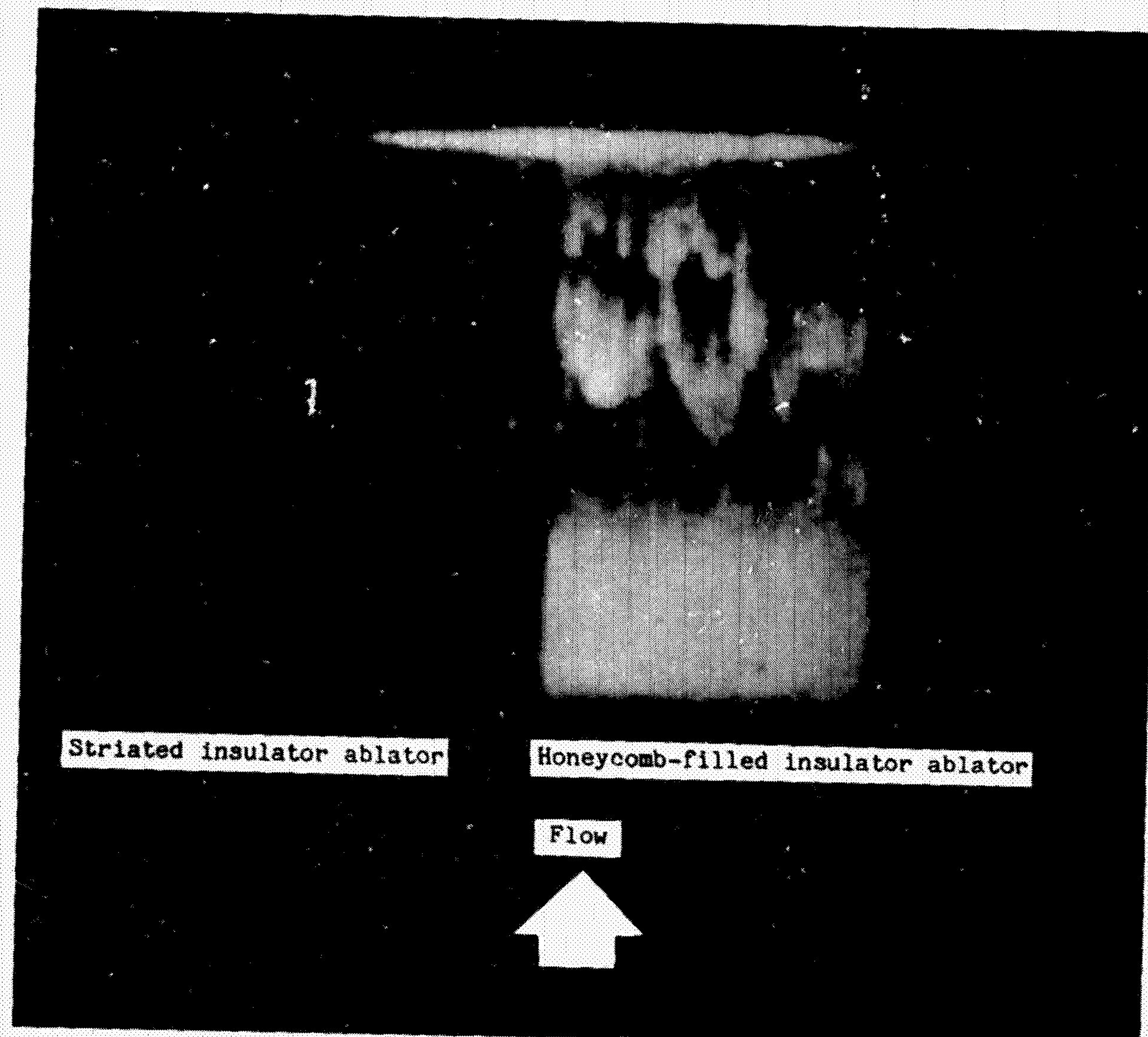

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Figure 22.- Insulator-ablator specimen in test stream showing areas of heating.

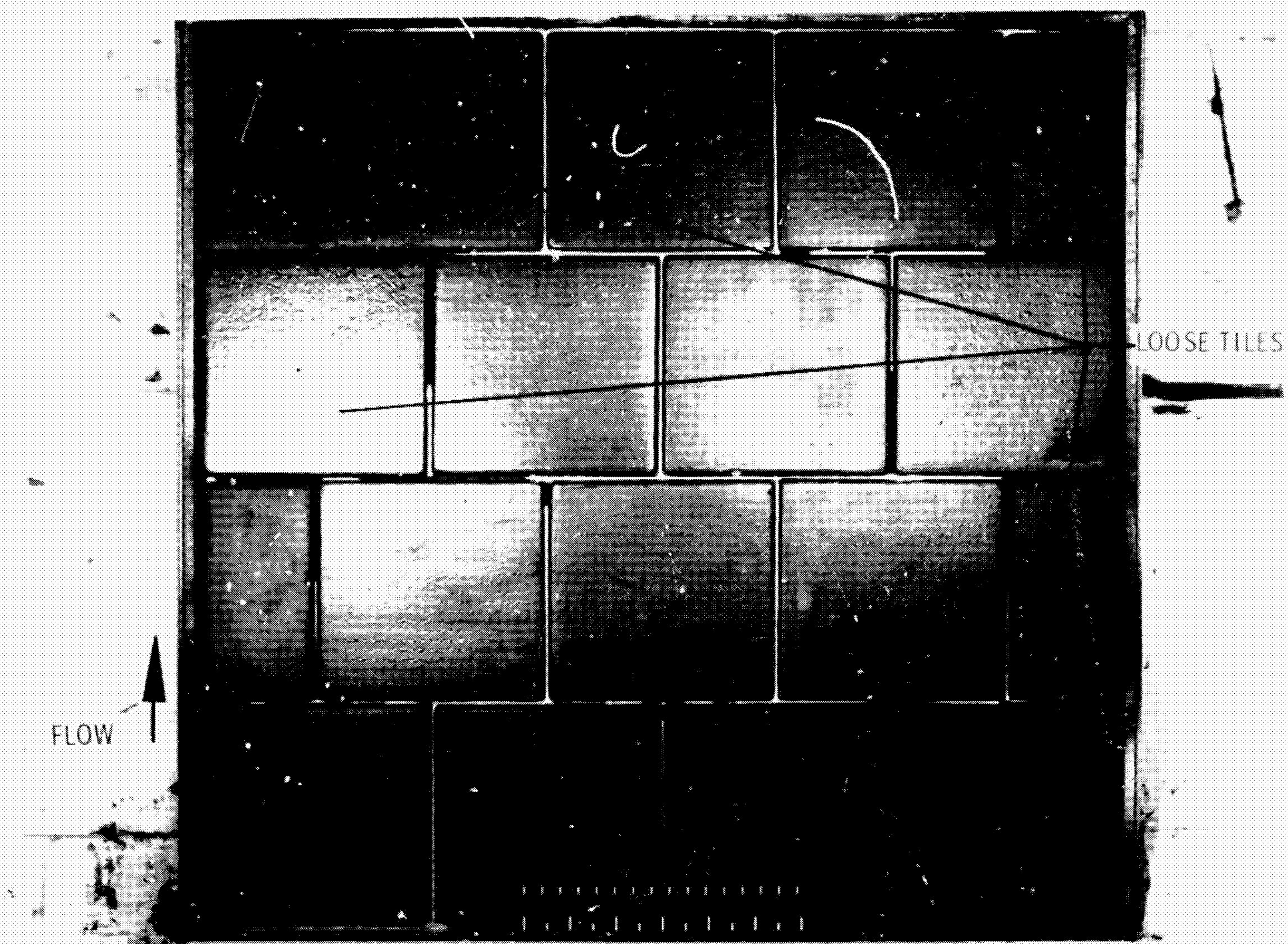

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Figure 24.- Damage of RSI specimen after testing.

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15. Supplementary Notes

Allan H. Taylor: Vought Corporation, Hampton, Virginia.

16. Abstract

Three thermal protection systems proposed for a hypersonic research airplane were subjected to high heating rates in the Langley 8-foot high-temperature structures tunnel. Metallic heat sink (Lockalloy), reusable surface insulation, and insulator-ablator materials were each tested under similar conditions. The specimens were tested for a 10-second exposure on the windward side of an elevon deflected 30°. The metallic-heat-sink panel exhibited no damage; whereas the reusable-surface-insulation tiles were debonded from the panel and the insulator-ablator panel eroded through its thickness, thus exposing the aluminum structure to the Mach 7 environment.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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