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MULTIWALL/RSI CONCEPT FOR LOCAL APPLICATION TO SPACE SHUTTLE BODY FLAP

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MULTIWALL/RSI CONCEPT FOR LOCAL APPLICATION TO SPACE SHUTTLE BODY FLAP

by

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SUMMARY

A titanium multiwall/reusable surface insulation (MW/RSI) TPS concept designed to prevent local erosion of the RSI tiles on the upper surface of the Space Shuttle Orbiter body flap was investigated. The concept, which consisted of a combination of a titanium multiwall tile and an RSI tile, was evaluated by thermal analysis and structural and thermal testing of one configuration to assess the attachment scheme and thermal behavior. Results indicate that the MW/RSI concept will remain attached to the vehicle and provide the thermal protection required.

INTRODUCTION

Two localized areas on the upper portion of the Space Shuttle body flap have experienced erosion-type damage to the LI-900 Reusable Surface Insulation (RSI). It is suspected that impingement of exhaust gases from two downward firing vernier engines located high on the aft fuselage erode the fragile surface of the RSI.

A potential solution to the erosion problem is the use of titanium multiwall (M/W) to provide a more durable Thermal Protection System (TPS) surface. The multiwall concept was developed (refs. 1-3) to be attached directly to the vehicle skin using mechanical fasteners. However, in the application of M/W as a potential solution of the erosion problem, the Shuttle program required that the multiwall tile be bonded to an RSI tile which in turn would be bonded to the vehicle skin. This requirement makes it necessary to bond a strain isolation pad (SIP) between the multiwall tile and the RSI tile as well as between the RSI tile and the vehicle skin to protect the fragile LI-900 material from differential thermal strains. A sketch of the titanium multiwall/RSI (MW/RSI)concept is shown in figure 1.

In the present study, the attachment scheme and thermal performance of the MW/RSI concept was evaluated. The evaluation included thermal analysis of the MW/RSI concept with two-, three-, and four-layers of dimpled sheet bonded to the RSI and included thermal and structural tests of the concept with four dimpled layers. This report presents the results of the evaluation.

THERMAL ANALYSIS

Three analytical models and the test model are shown schematically in figure 2. These models were thermally analyzed using the SPAR finite element analysis program (refs. 4 and 5). The purpose of the analysis was to determine if thermal characteristics of the MW/RSI concept would prevent the aluminum structure beneath the TPS from exceeding 350°F and would also prevent the Multiwall-RTV-SIP (MW/RTV/SIP) bond line from exceeding 550°F.

The thicknesses of the multiwall and RSI were varied in the three analytical models so that the total TPS thickness was held constant at 1.24 inches which is a nominal thickness of existing TPS on the Space Shuttle in the region of interest on the upper body flap. The thermal mass of the Space Shuttle in this region was represented by an aluminum sheet with a thickness of 0.093 inch.

The test model was thermally analyzed to obtain temperatures to compare with test data. The multiwall and RSI for the test model were obtained from available components, and the thicknesses were different from the thicknesses for the three analytical models.

In the thermal analysis, the outer surface of each model was subjected to the temperature histories shown in figure 3. The nodes in each model were connected by two-node conduction elements (K21). The values of thermal conductivity used in the analysis for titanium multiwall, RSI, and aluminum are taken from references 6-8 and are given as a function of temperature in table I. The surface temperature history (1000°F maximum) is representative of the ascent temperatures experienced on the upper body flap in the region of concern and is more severe than the temperature history experienced during entry. Consequently, this ascent temperature history determines the minimum TPS requirement at this location. An adiabatic wall was assumed to be located beneath the aluminum sheet. This assumption is generally conservative since usually, on a vehicle, some heat loss to additional structure or to the opposite side of the fuselage will occur.

FABRICATION

Dimensions of the MW/RSI test specimen are given in figure 4. The specimen was composed of a 0.68 inch thick titanium multiwall tile, a layer of 0.160

inch thick SIP, a 0.40 inch thick LI-900 RSI tile, another layer of 0.160 inch thick SIP, and an 0.5 inch thick aluminum plate. Planform dimensions of the specimen were 6 by 6 inches. The SIP was bonded to the baseplate, RSI tile, and the multiwall tile by RTV-560 adhesive using the same adhesive thicknesses and bonding procedures as used on the Shuttle. The SIP and RSI tile were obtained from the Shuttle production line. The multiwall tile was cut from an existing 12 inch by 12 inch panel that had been previously exposed to a surface temperature of 1000°F for 20 hours. The multiwall tile was fabricated using Liquid Interface Diffusion (LID) bonding, described in reference 9, and was composed of 4 dimpled titanium sheets 0.003 inch thick, 3 interior flat titanium sheets 0.0015 inch thick, an outer titanium sheet 0.004 inch thick, and an inner titanium sheet 0.003 inch thick. The LID bond contact points were 0.075 inch in diameter. A photo of the test specimen components partially assembled is shown in figure 5. The assembled test specimen is shown in figure 6.

The test specimen approximates the dimensions of the potential tile application except for the thickness of the aluminum plate which was 0.5 inch to accomodate attachment to a tensile test machine. The flatwise tensile strength of the test specimen is expected to be lower than that for the present LI-900 tiles because only one side of the RSI tile in the test specimen was densified before being bonded to the SIP. Thus, the tile will have a much lower strength at the SIP/undensified tile interface as discussed in reference 10.

Two thermocouples were installed on each of the inner and outer cover sheets of the multiwall tile and on the bottom of the aluminum baseplate. The thermocouples were positioned on the tile as indicated in figure 4. They were attached to the multiwall tile by spotwelding the bead formed by the juncture of the two leads to the cover sheet. The thermocouples were installed on the aluminum baseplate by drilling a shallow hole in the baseplate and potting the thermocouple bead in the hole with EA 934 epoxy.

TESTS

The test specimen was subjected to the thermal and bond verification tests indicated in table II. The purposes of the thermal tests were to evaluate the thermal response of the MW/RSI concept to the simulated Shuttle thermal environment and to generate data for comparison with the one-dimensional thermal analysis of the system. After an initial bond verification test to determine if the specimen was properly bonded, the model was subjected to five thermal cycles with a maximum temperature of 1000°F, an interim bond verification test, and two over-temperature cycles with a maximum temperature of 1200°F. After the thermal tests, a bond verification test was conducted to verify that the tile system had not become unbonded. The specimen was then pulled to failure.

Thermal Tests

A single bank of 10-inch long, 2000 watt quartz tube lamps was used to apply the temperature history shown in figure 3 to the surface of the test specimen. The lamps were attached to a water-cooled, gold-plated reflector with a 0.75 inch spacing between filaments. As shown in figure 7, the specimen rested on, and was surrounded by, Glasrock insulation. Figure 8 shows the test set-up with two sides of the Glasrock removed to expose the specimen. Fibrous insulation (Q-fiber felt) was placed around the perimeter of the multiwall to prevent convection currents from occurring at the edges. (The multiwall did not have close-outs since it was cut from a larger panel). The thermocouple on the center top surface was used to provide a feedback signal to an analog controller which controlled the surface temperature. Temperatures at the surface, the MW/RTV/SIP interface, and the bottom of the aluminum plate were recorded on a multi-channel analog strip chart.

Bond Verification Tests

A hydraulically actuated universal test machine was used for the bond verification tests. A photograph of the test specimen during a bond verification test is shown in figure 9. The aluminum plate of the specimen assembly was bolted to a baseplate which was in turn attached to the hydraulic ram of the test machine. The top of the multiwall surface was attached to the crosshead of the machine through a vacuum chuck, swivel, and load cell. The vacuum chuck consisted of a flat aluminum plate with a rubber seal around the edge of the plate. The chuck was attached to the multiwall by a vacuum over a planform area of approximately 25 square inches. Three linear displacement transducers (deflectometers) were attached to the base plate to measure the deflection at 3 corners of the top surface of the multiwall. The output from the deflectometers and the load cell were recorded using an analog X-Y recorder.

The specimen assembly was mounted in the test machine, the vacuum chuck was attached, and the deflectometers were installed. A tensile load was slowly applied to the top of the multiwall until the bond joints were subjected to an average tensile stress of 10 psi, and then the load was slowly removed. In some cases (see next section), the vacuum seal was not maintained because of the flexibility of the 0.004 inch thick top surface of the multiwall, and separation of the vacuum chuck from the test specimen stopped the test at an average stress in the bond joints slightly less than 10 psi. The test specimen was not subjected to a compression load.

RESULTS AND DISCUSSION

Surface temperatures and the temperatures of the MW/RTV/SIP bondline from the thermal tests are shown in Figure 10. The figure includes the scatter of results from all seven tests and shows that, even for the over-temperature case, the bondline temperature reached only 390°F. This temperature is well below the allowable 550°F. The effect of the 0.5-inch aluminum plate on the bondline temperature of the multiwall was considered negligible since the maximum change in temperature of the aluminum was only about 14°F.

The measured bondline temperatures shown in Figure 10(a) are compared with predicted temperatures from the thermal analysis in Figure 11(a). The predicted temperatures were obtained from the one-dimensional thermal analysis discussed previously. The lower measured temperatures (345°F compared to 414°F for the analysis) are attributed to heat loss from the edges of the model and to a nonuniformity of radiant heating from the center to the test specimen edge. Consequently, the analytically determined temperatures would be less if a two-dimensional analysis were used in which heat losses and the nonuniform surface heating were taken into account. Thus, the results indicate that the one-dimensional analysis conservatively predicts too high a bondline temperature for the test model. However, this conservatism may be small in actual application on a vehicle where lateral heat losses and nonuniform heating are likely to be small. The predicted bondline temperatures are shown in figure 11(b). The maximum bondline temperatures for the two-, three-, and four-layer designs were 507°F, 433°F, and 374°F, respectively. Thus, all three of the potential designs meet the requirement of preventing the hotter bondline temperature from exceeding the allowable 550°F.

Analytical results for the over-temperature condition indicate that the maximum temperature of the MW/RTV/SIP bondline for the two-, three-, and four-layer designs were 642°F, 532°F, and 467°F, respectively. Thus, while the three-layer and four-layer designs are acceptable, the two-layer design does not meet the thermal requirements for the over-temperature case. The maximum temperatures of the 0.093 inch-thick aluminum representing the shuttle structure were calculated to be well below the 350°F allowable for all cases.

As previously mentioned, the test specimen was subjected to bond verification tests before, during, and after the thermal tests. In the first test (Test 1, Table II), a 10 psi flatwise tension stress was applied, but as previously discussed, difficulty with the vacuum chuck limited the subsequent tests to about 8 psi. To complete the failure test, a 0.5 inch thick aluminum loading plate was bonded to the multiwall surface. In the failure test, the specimen failed at 13.7 psi at the SIP/RTV/RSI bond joint where the RSI was not densified. Thus the failure test shows that the MW/RTV/SIP joint and the multiwall itself, which had previously been exposed to a surface temperature of 1000°F for 20 hours, will carry 13.7 psi. (Previous flatwise tension test results for titanium multiwall given in reference 6 indicate an average 28 psi failure stress for new titanium multiwall specimens and 12.3 psi for specimens exposed to 1000°F for 25 hours.)

The load-deflection curves obtained from the first and last flatwise tension bond verification tests are shown in Figure 12. The greater deflections that occurred during the last test (Test 10) are attributed to changes in the stiffness properties of the SIP material as it is loaded and unloaded. This change has been documented, and its importance in affecting mission life of the RSI insulation system has been identified (ref. 11). The difference in the deflections shown in Figure 12 is consistent with that identified for SIP in reference 10.

CONCLUSIONS

A MW/RSI TPS concept designed to prevent localized erosion of the RSI tiles on the upper surface of the Space Shuttle Orbiter body flap consisted of a combination of a titanium multiwall tile and an RSI tile. The design, which was constrained to a total thickness of 1.24 inches and exposed to a Shuttle boost thermal cycle with a maximum temperature of 1000°F, was evaluated by thermal analysis of several configurations of the concept and by structural and thermal testing of one configuration to assess the attachment scheme and thermal behavior.

One-dimensional thermal analyses of the design showed that the adhesive temperature at the MW/RTV/SIP bond line is limited to 374°F for a four-dimpled-layer configuration, 433°F for a three-dimpled-layer configuration, and 507°F for a two-dimpled-layer configuraton. Thus, all three configurations are acceptable in that they do not exceed 550°F which is considered a conservative upper temperature limit or the RTV bond line. Comparison of calculated and measured temperatures for a four-dimpled-layer configuration subjected to five representative thermal cycles with a maximum temperature of 1000°F further indicates that all three configurations are thermally acceptable.

Flatwise tension tests of the MW/RSI tile after thermal cycles showed an average stress of 13.7 psi before failure occurred at a RSI-SIP bond line. Since the RSI was not densified on the surface where the failure occurred, even larger flatwise tension strengths would be expected for the actual application where the RSI surfaces are densified. (Based on small coupon tests, the flatwise tension strength of titanium multiwall is 28 psi.)

Therefore, the results from these tests and analyses indicate that the proposed MW/RSI concept will remain attached to the vehicle and provide the thermal protection required.

REFERENCES

1. Jackson, L. Robert; and Dixon, Sidney C.: A Design Assessment of Multiwall Metallic Stand-off, and RSI Reusable Thermal Protection Systems Including Space Shuttle Application. NASA TM 81780, April 1980.

2. Jackson, L. Robert; Davis, John G.; and Wichorek, Gregory R.: Structural Concepts for Hydrogen Fueled Hypersonic Airplanes. NASA TN D-3162, 1966.

3. Shideler, J. L.; Webb, G. L.; and Pittman, C. M.: Verification Tests of Durable TPS Concepts. NASA TM 86313, Sept. 1984.

4. SPAR Structural Analysis System Reference Manual, Vol. 1, NASA CR-158970-1, Dec. 1978.

5. SPAR Thermal Analysis Processors Reference Manual, System Level 16, NASA CR 159162, Oct. 1978.

6. Shideler, John L.; Kelly, H. Neale; Avery, Don E.; Blosser, Max L.; and Adelman, Howard M.: Multiwall TPS -- An Emerging Concept. NASA TM 83133, May 1981.

7. Materials Properties Manual, Vol. 3 Thermal Protection System Materials Data. Rockwell International Shuttle Orbiter Division, Space Systems Group, May 1979.

8. Military Standardization Handbook, Metallic Materials and Elements for Aerospace Vehicle Structures, Vol. 1, Sept. 15, 1976.

9. Blair, W.; Meaney, J. E.; and Rosenthal, H. A.: Re-Design and Fabrication of Titanium Multi-wall Thermal Protection System (TPS) Test Panels, NASA CR-172247, Jan. 1984.

10. Sawyer, J. W.: Mechanical Properties of the Shuttle Orbiter Thermal Protection System Strain Isolator Pad. J. of Spacecraft and Rockets, V. 21, No. 3, May-June 1984.

11. Cooper, Paul A.; Holloway, Paul F.: The Shuttle Tile Story. Astronautics and Aeronautics, January 1981, pp. 24-36.

TABLE I.- THERMAL PROPERTIES

TEMP (°F)	MULTIWALL (Ref. 6) c_p	MULTIWALL (Ref. 6) k	RSI (Ref. 7) c_p	RSI (Ref. 7) k(1 atm)	SIP/RTV (Ref. 7) c_p	SIP/RTV (Ref. 7) k	ALUMINUM (Ref. 8) c_p	ALUMINUM (Ref. 8) k
0	.123	5.33×10^{-7}	.150	6.37×10^{-7}	.290	4.21×10^{-7}	.195	1.50×10^{-3}
100							.206	1.67
200	.135	7.19	.205	7.52			.216	1.85
300							.224	2.07
400	.146	9.58			.290	5.25	.237	2.29
500			.252	10.0			.242	2.39
600	.157	12.8	.261	11.0	.290	8.80	.250	2.42
800	.168	16.9	.279	13.1				
1000	.179	22.7	.288	15.2				
1200	.190	27.4	.292	17.7				
	ρ = .0056		ρ = .0052		ρ = .0071		ρ = .101	

c_p = specific heat, Btu/lbm-°F

k = thermal conductivity, Btu/in-sec-°F

ρ = density, lbm/in^3

TABLE II - History of Thermal and Bond Verification Tests

TEST NO.	TYPE TEST	MAXIMUM TEST CONDITION	REMARKS
1	Bond Verification	10 psi	Successful
2	Thermal Cycle	1000°F	Successful
3	Thermal Cycle	1000°F	Successful
4	Thermal Cycle	1000°F	Successful
5	Thermal Cycle	1000°F	Successful
6	Thermal Cycle	1000°F	Successful
7	Bond Verification	8.2 psi	Vacuum Seal Broke
8	Thermal Cycle	1200°F	Successful
9	Thermal Cycle	1200°F	Successful
10	Bond Verification	8.1 psi	Vacuum Seal Broke
11	Pull to Failure	13.7 psi	RSI-SIP Bond Failure

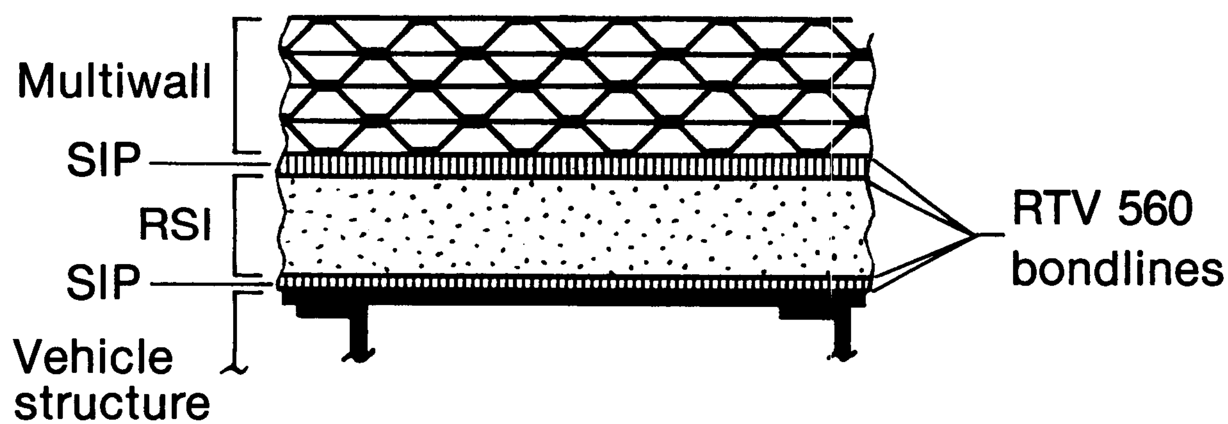
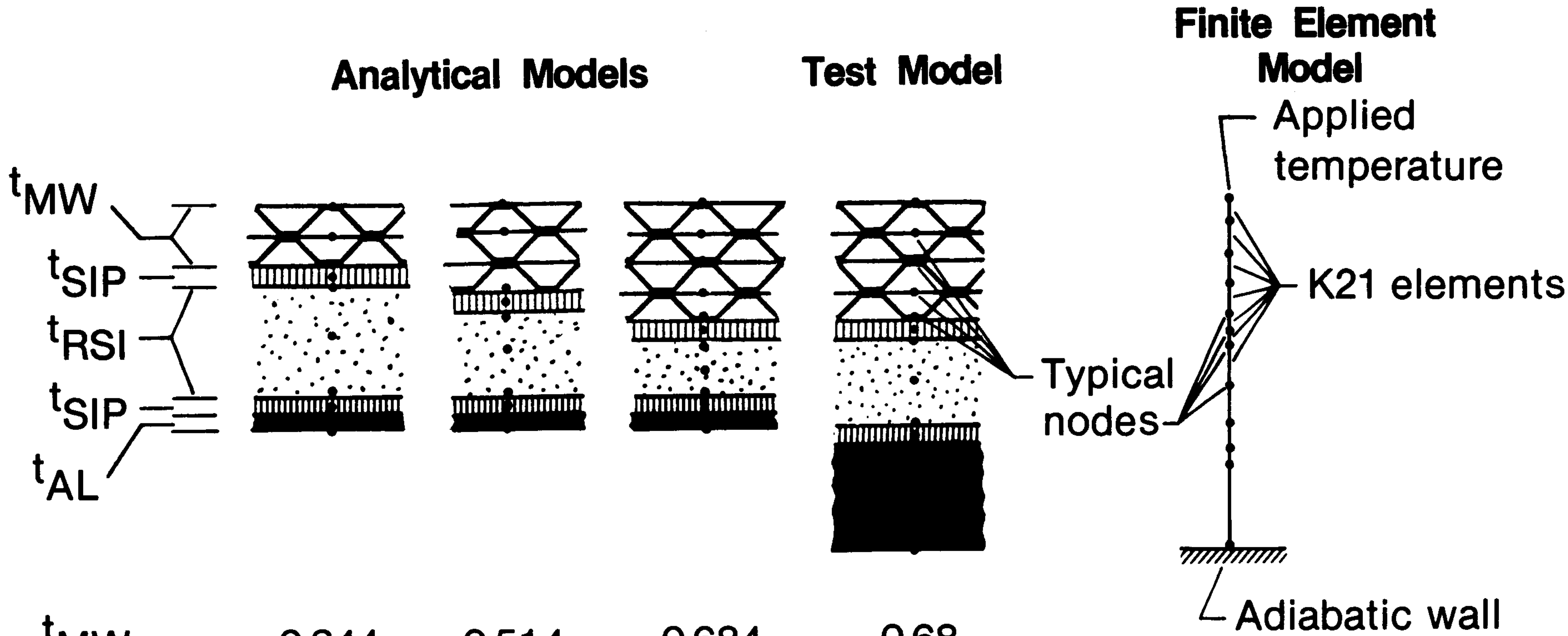


Figure 1. - Titanium multiwall/RSI concept.



t_{MW}	0.344	0.514	0.684	0.68
t_{RSI}	0.546	0.376	0.206	0.40
$2t_{SIP}$	0.350	0.350	0.350	0.35
t^{*} TOTAL TPS	1.24	1.24	1.24	1.43

$$t_{SIP} = \underset{(RTV)}{0.0075} + \underset{(SIP)}{0.160} + \underset{(RTV)}{0.0075} = 0.175$$

* neglects t_{AL}

Figure 2. - Thermal models of two-, three-, and four-layer multiwall/RSI concepts. Dimensions in inches.

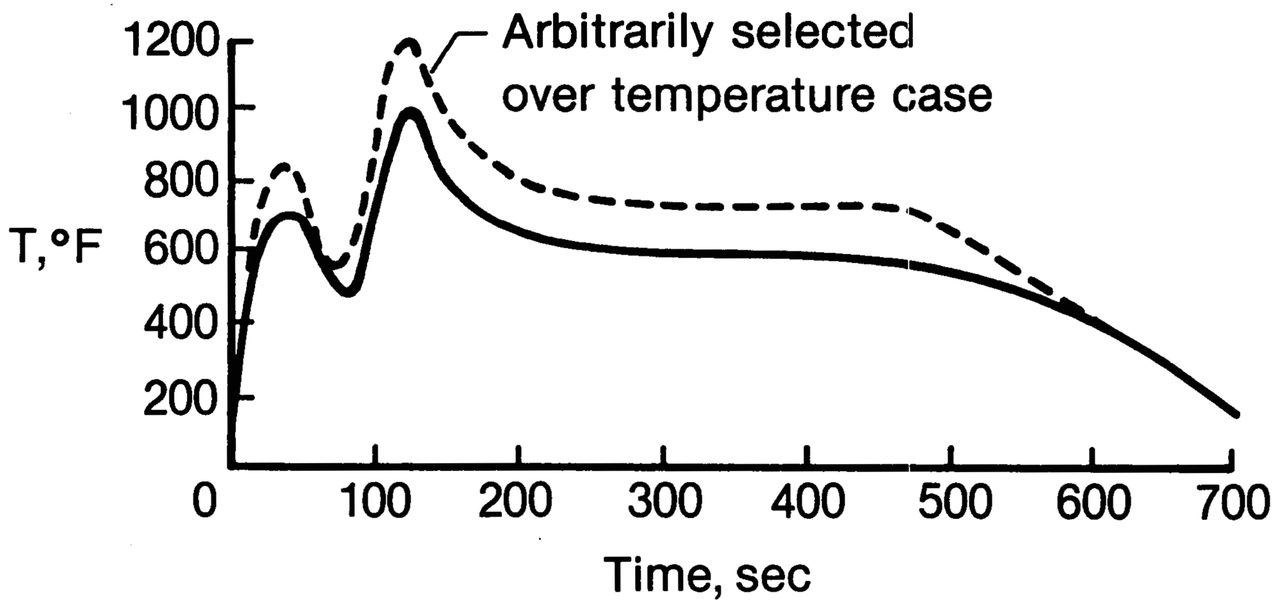


Figure 3. - Typical upper body-flap ascent temperature history.

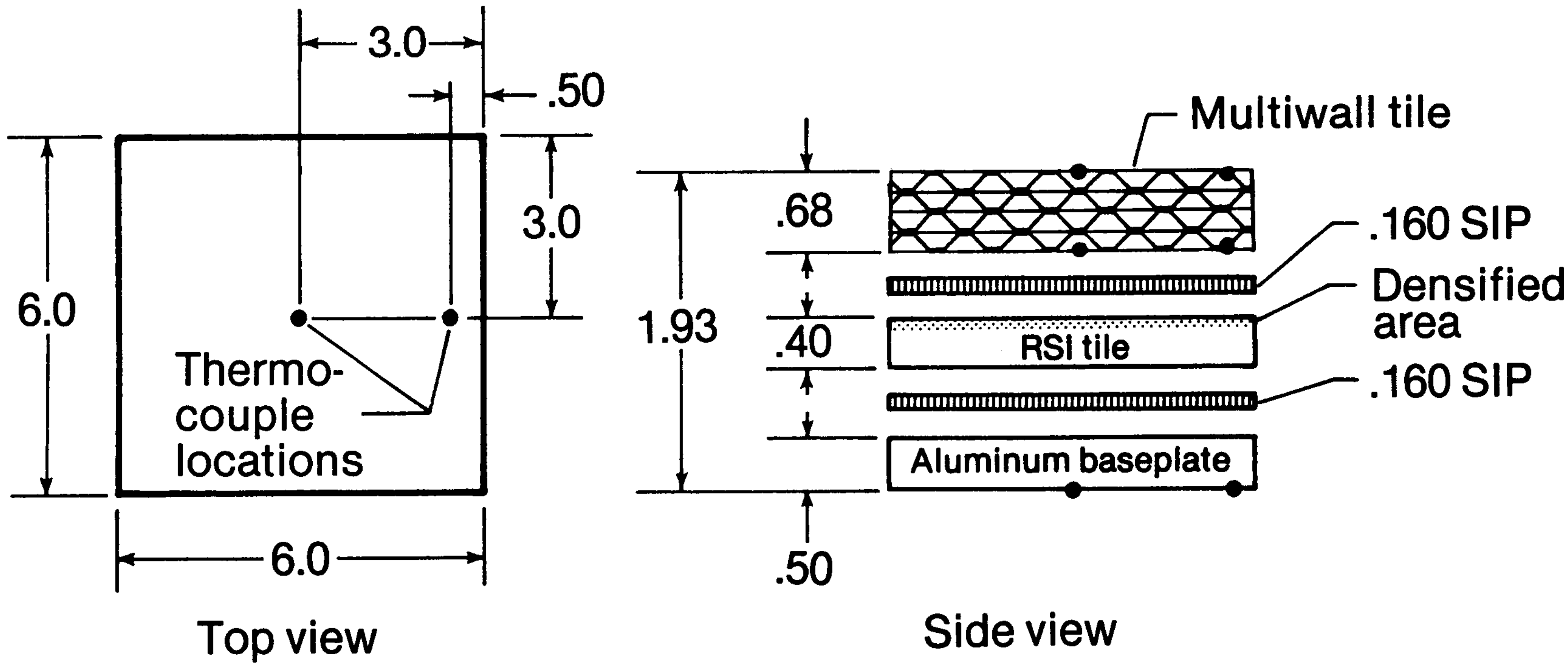


Figure 4. - Test specimen. Surfaces bonded with RTV-560 adhesive. Dimensions in inches.

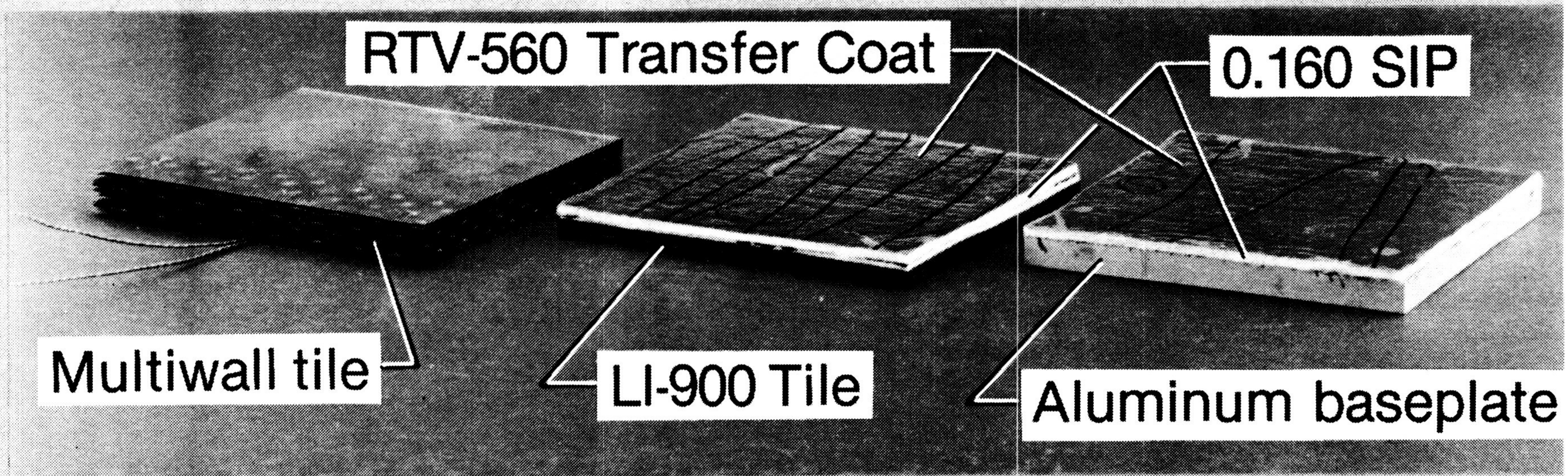


Figure 5. - Test specimen assembly components.

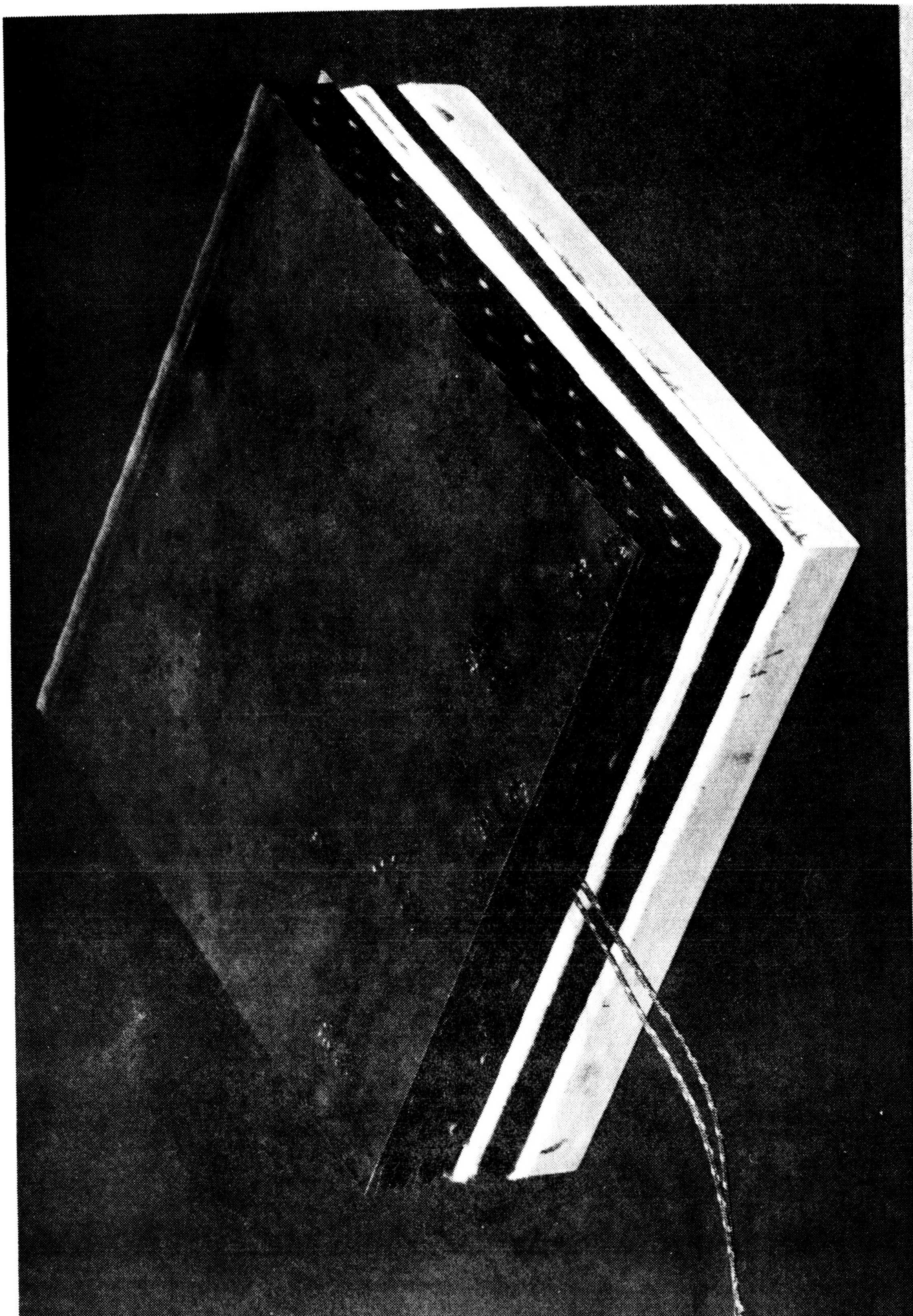


Figure 6. - Test specimen

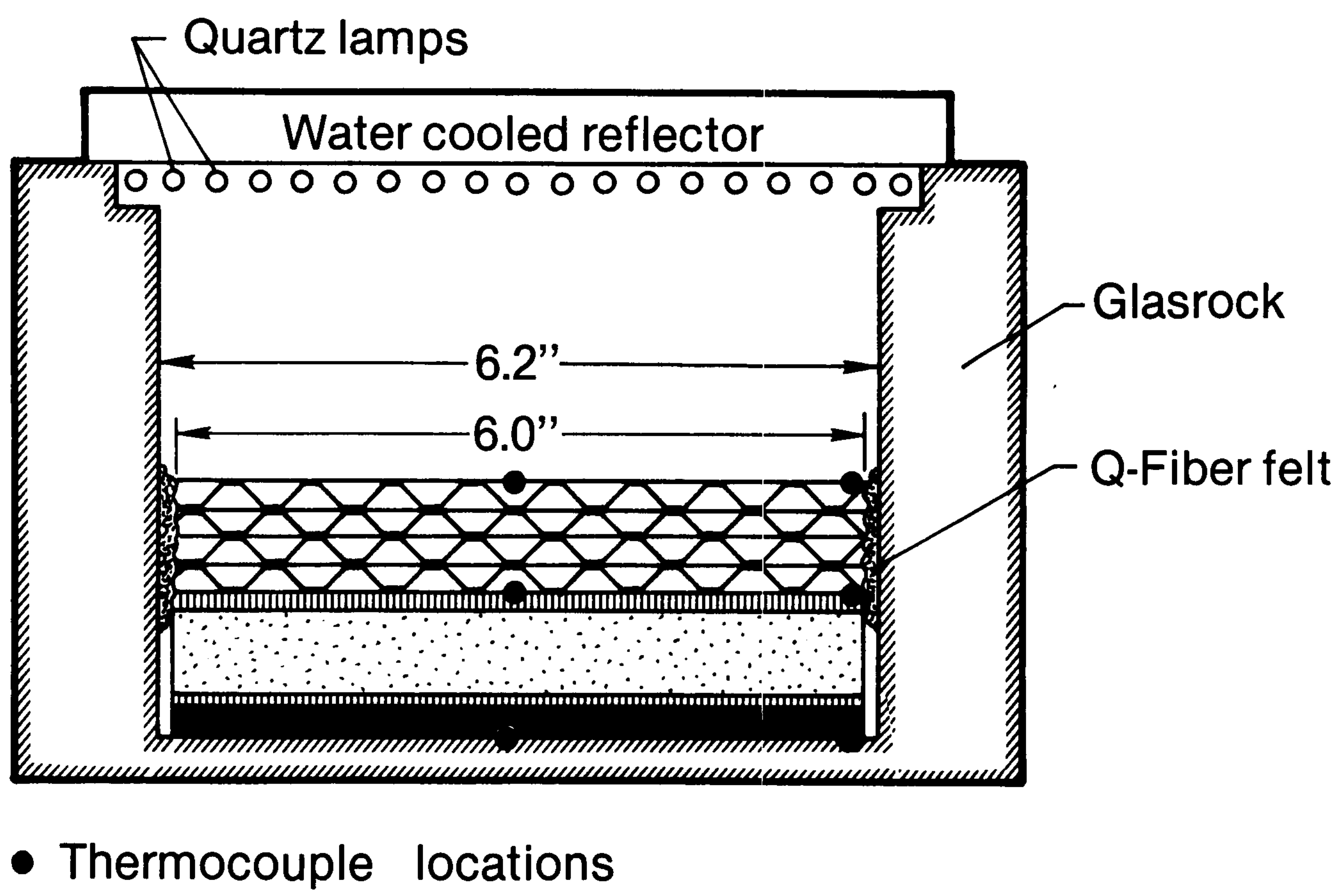


Figure 7. - Schematic of thermal test set-up. Dimensions in inches.

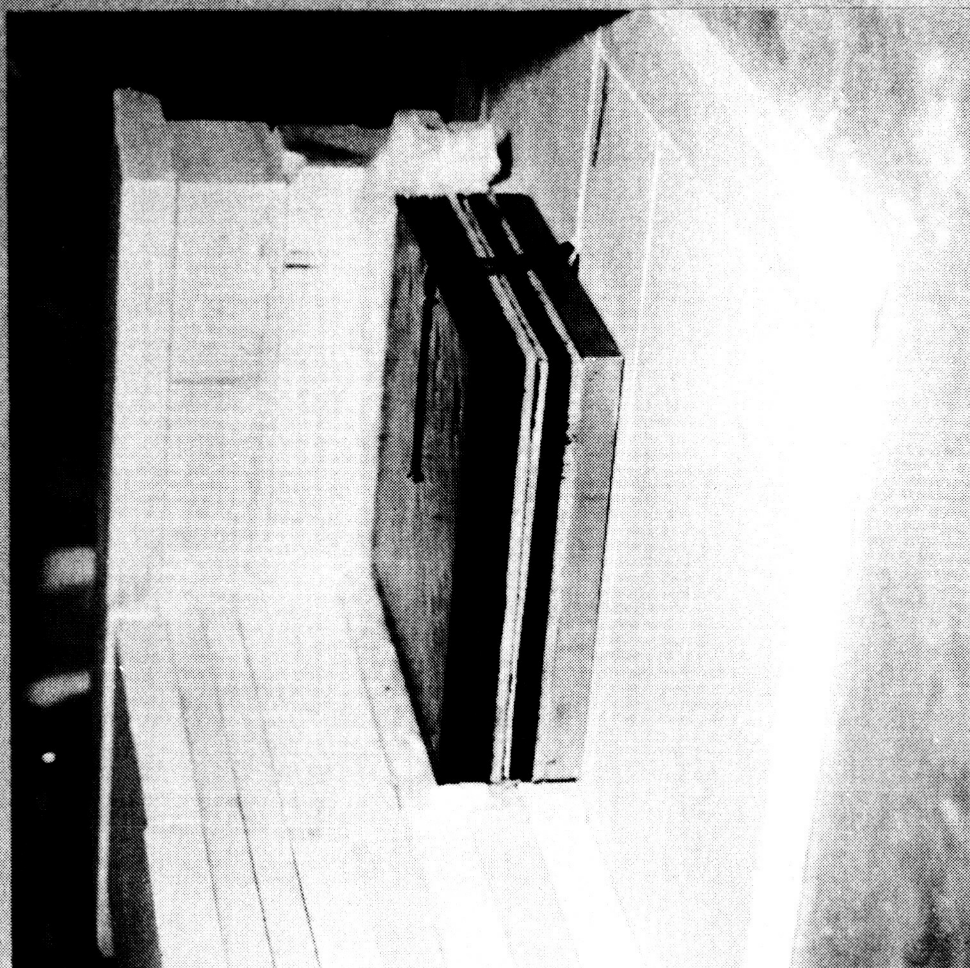


Figure 8. - Cut-away view of thermal test set-up.

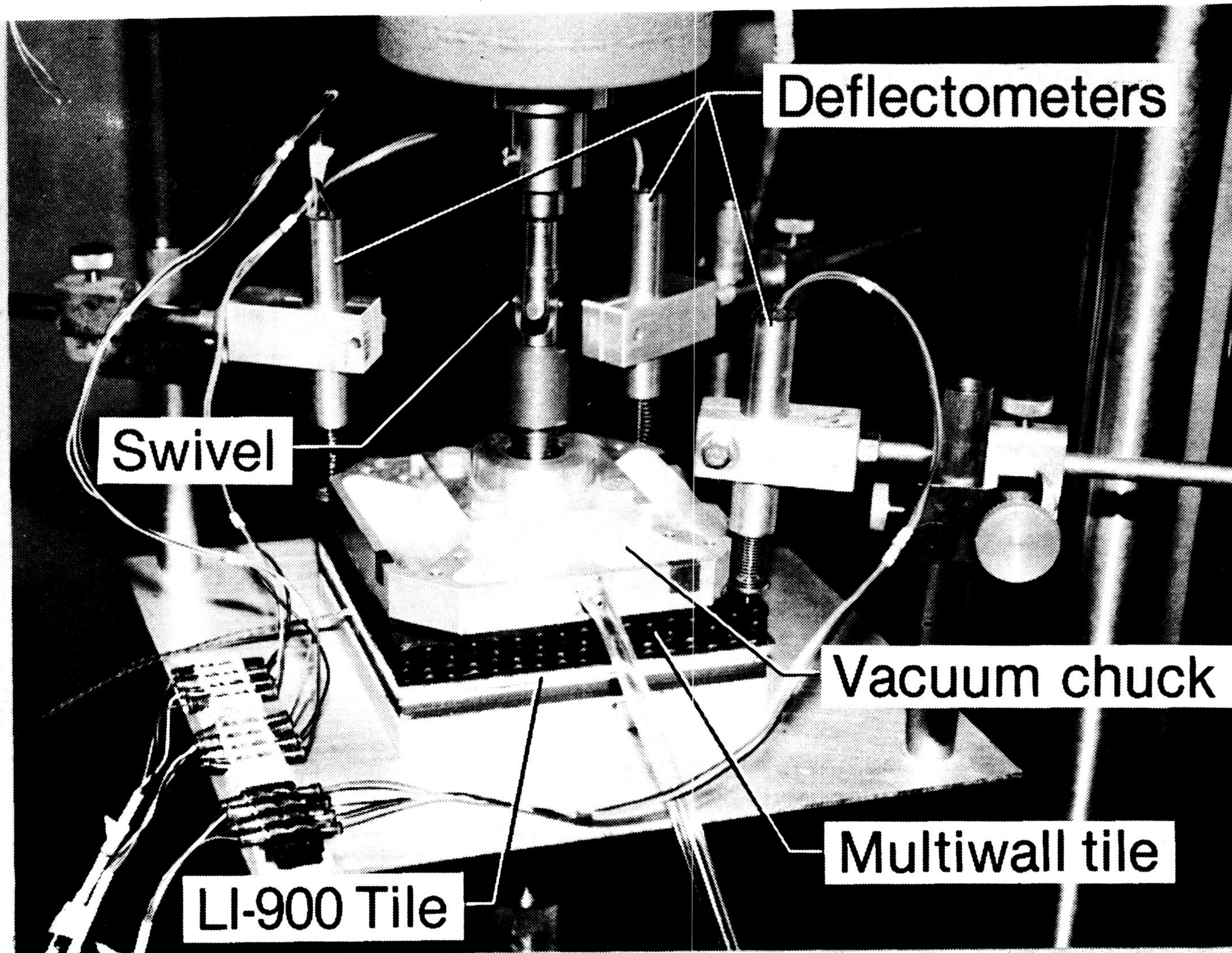
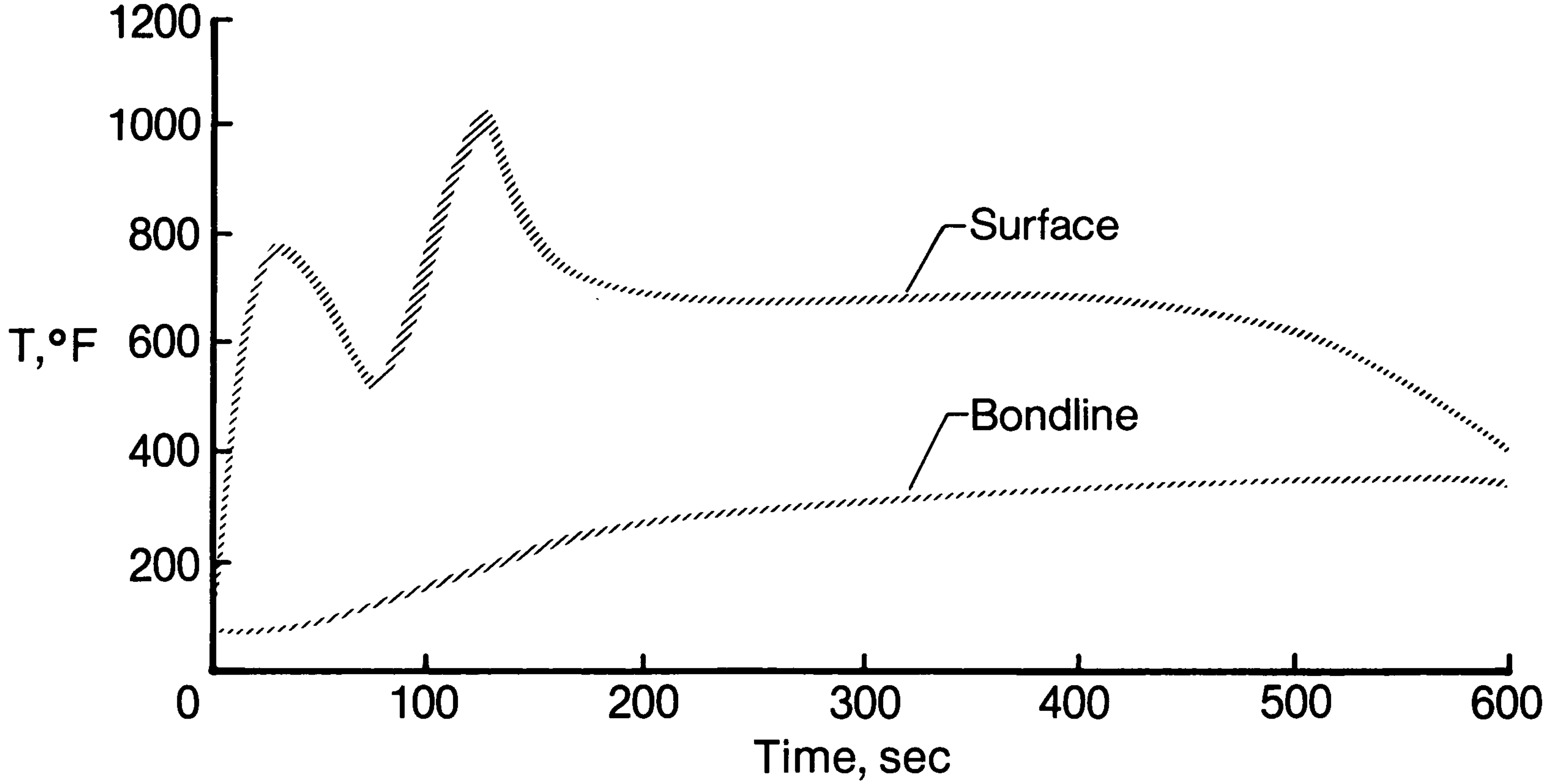
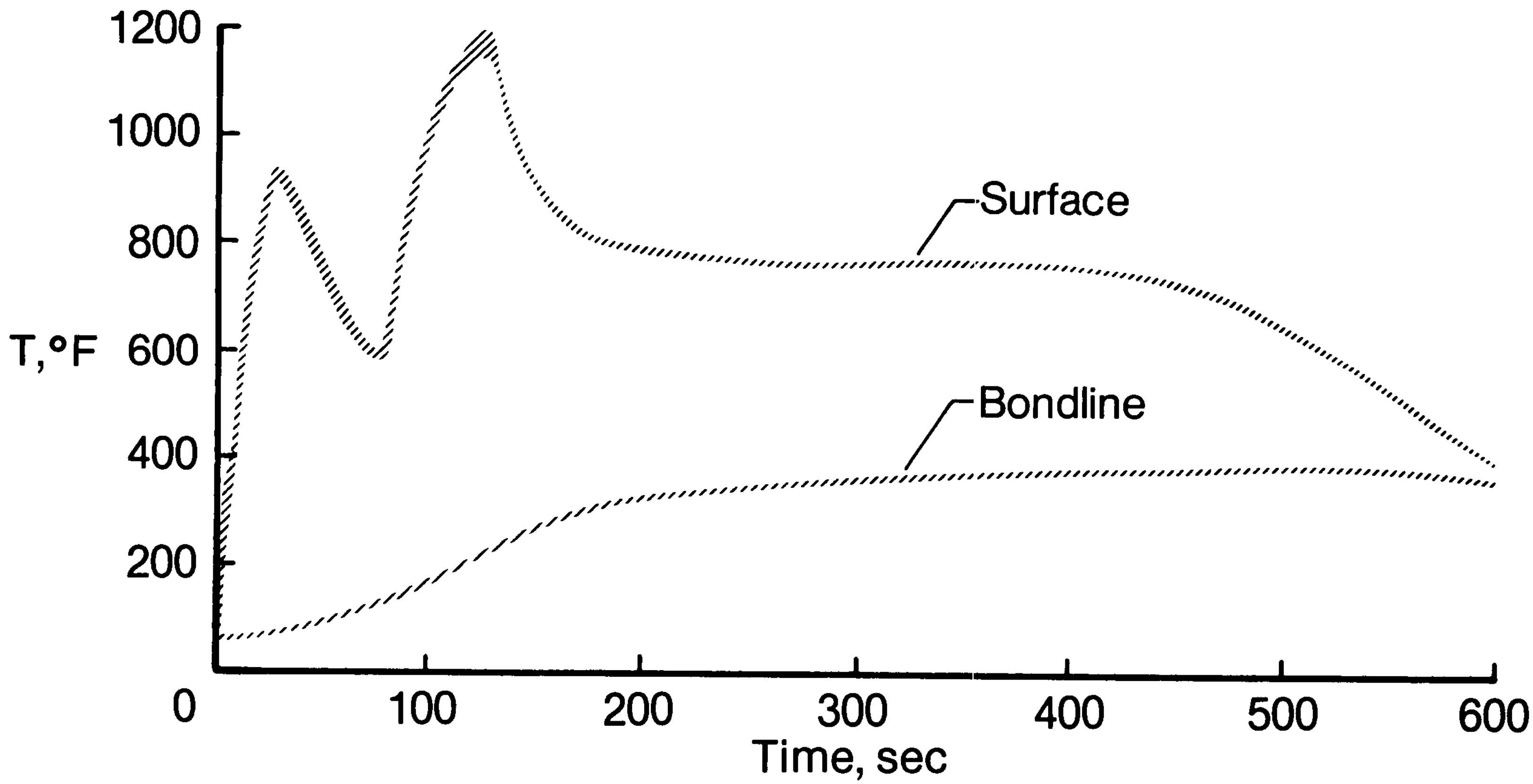


Figure 9. - Bond verification test set-up.



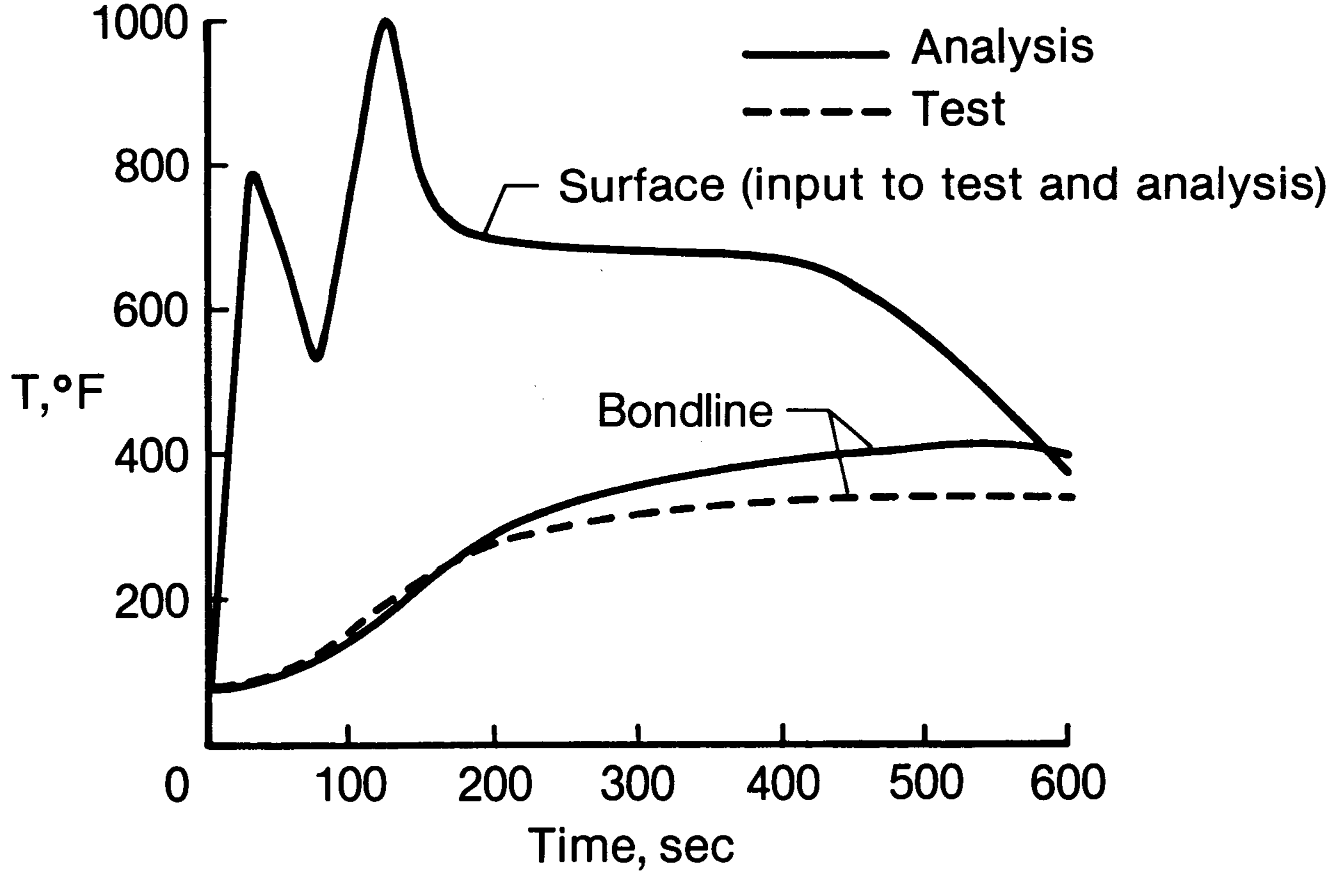
(a) Nominal 1000°F thermal tests (tests 2-6).

Figure 10. - Envelope of all thermal test results.



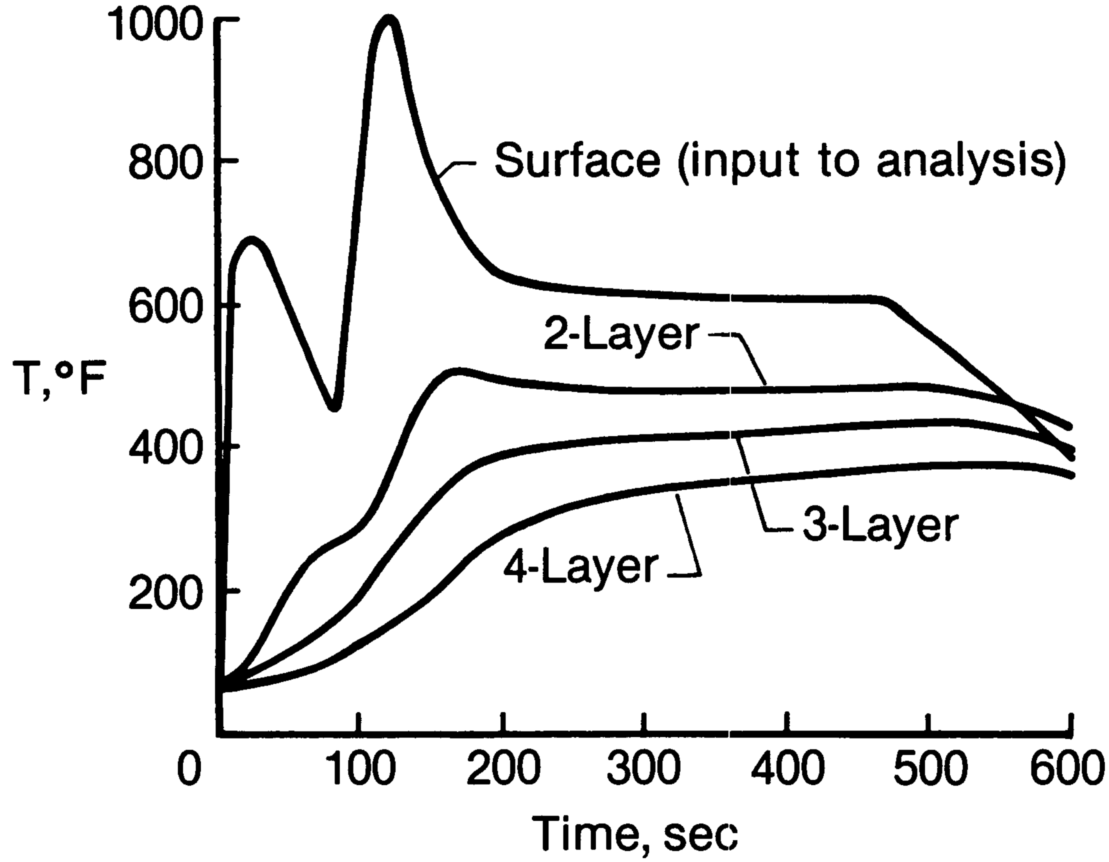
(b) Over-temperature tests (tests 8 and 9).

Figure 10. - Concluded.



(a) Predicted and measured temperatures for 4-layer test model.

Figure 11. - Multiwall/RTV/SIP bondline temperatures.



(b) Predicted bondline temperatures for three potential designs.

Figure 11. - Concluded.

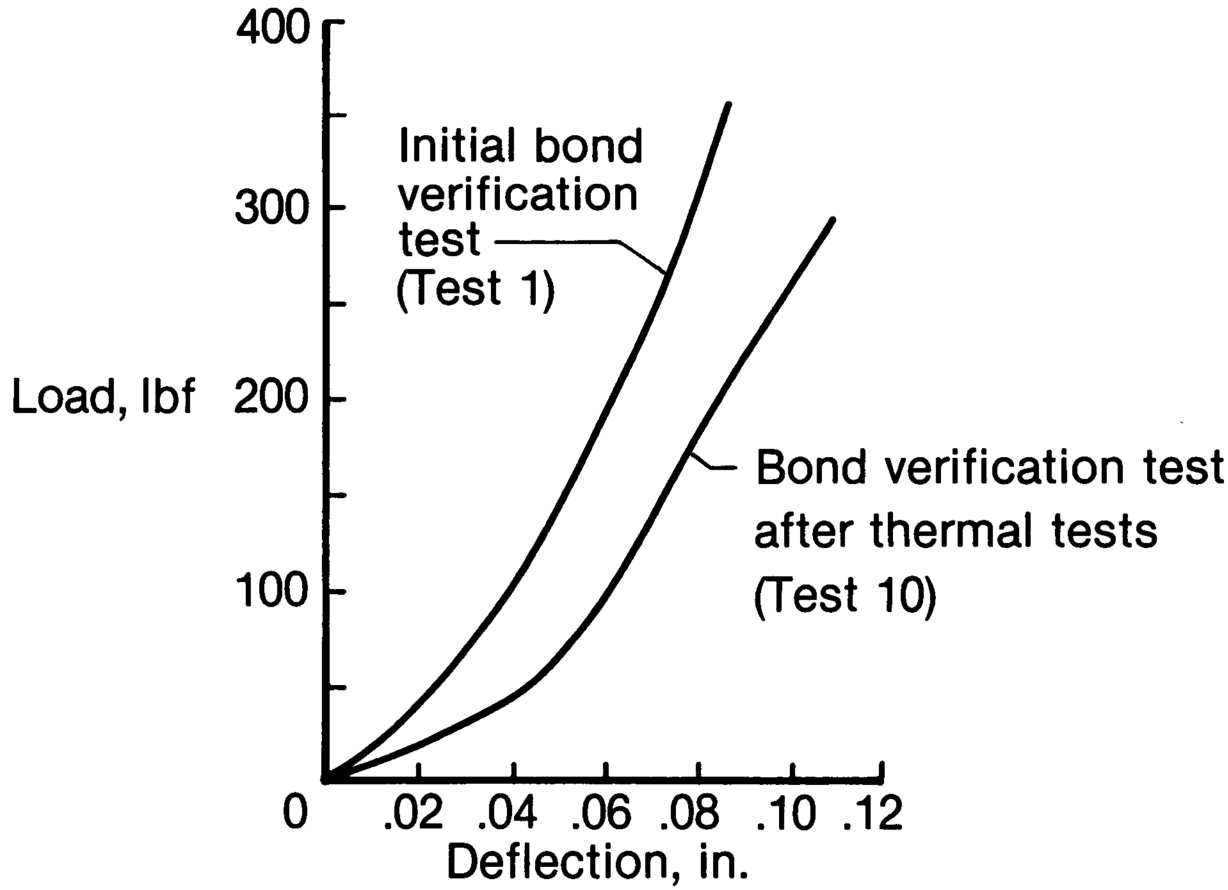


Figure 12. - Flatwise tension load-deflection characteristics.

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16. Abstract

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