ENVIRONMENTAL COMPATIBILITY OF THE ALL-SILICA RIGID SURFACE INSULATION

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RESULTS OF DEVELOPMENT TESTING OF LMSC SILICA RSI
(Figure 1)

Testing of the compatibility of the all-silica RSI with aspects of the orbiter environment other than reentry heating, has also been accomplished. These tests have included: a cyclic salt spray environment with specimen exposure to five simulated flight cycles each consisting of a 4-hr MIL STD salt fog exposure and simulation of a reentry heating cycle; a lost tile test, in which a tile in the center of a tile array was deliberately, destructively removed, and then the array was subjected to simulated reentry heating in a flow facility in an effort to evaluate the effect on adjacent tiles of the loss of a single tile; acoustic tests including a 15 minute exposure to 174 dB; cold soak tests including 5 minutes at 116°K (-250°F); effects of ultraviolet exposure on surface optical properties with up to about 5,800 equivalent sun hours; and a water absorption test with simulated ascent and reentry heating subsequent to water exposure.

The results of these tests in terms of influence on the Shuttle orbiter design are presented along with a description of test conditions and test specimens. In general, the results indicate compatibility of the all-silica RSI with the orbiter environment.

RESULTS OF DEVELOPMENT TESTING OF LMSC SILICA RSI

SIMULATED REENTRY TESTING

- TESTS BY LMSC, NASA/MSC, NASA/ARC
- MULTICYCLE – RADIANT AND CONVECTIVE
- ACCUMULATED TEST EXPOSURE TO DEMONSTRATE PERFORMANCE AND STABILITY

SPECIALIZED ENVIRONMENTAL TESTING

- LAUNCH CONDITIONS
- ORBIT CONDITIONS
- REENTRY – SPECIALIZED CONDITIONS

Figure 1

TEST SPECIMENS
(Figure 2)

Specimens numbered 1 through 3 were used in the freeze/thaw and the salt fog tests described below:

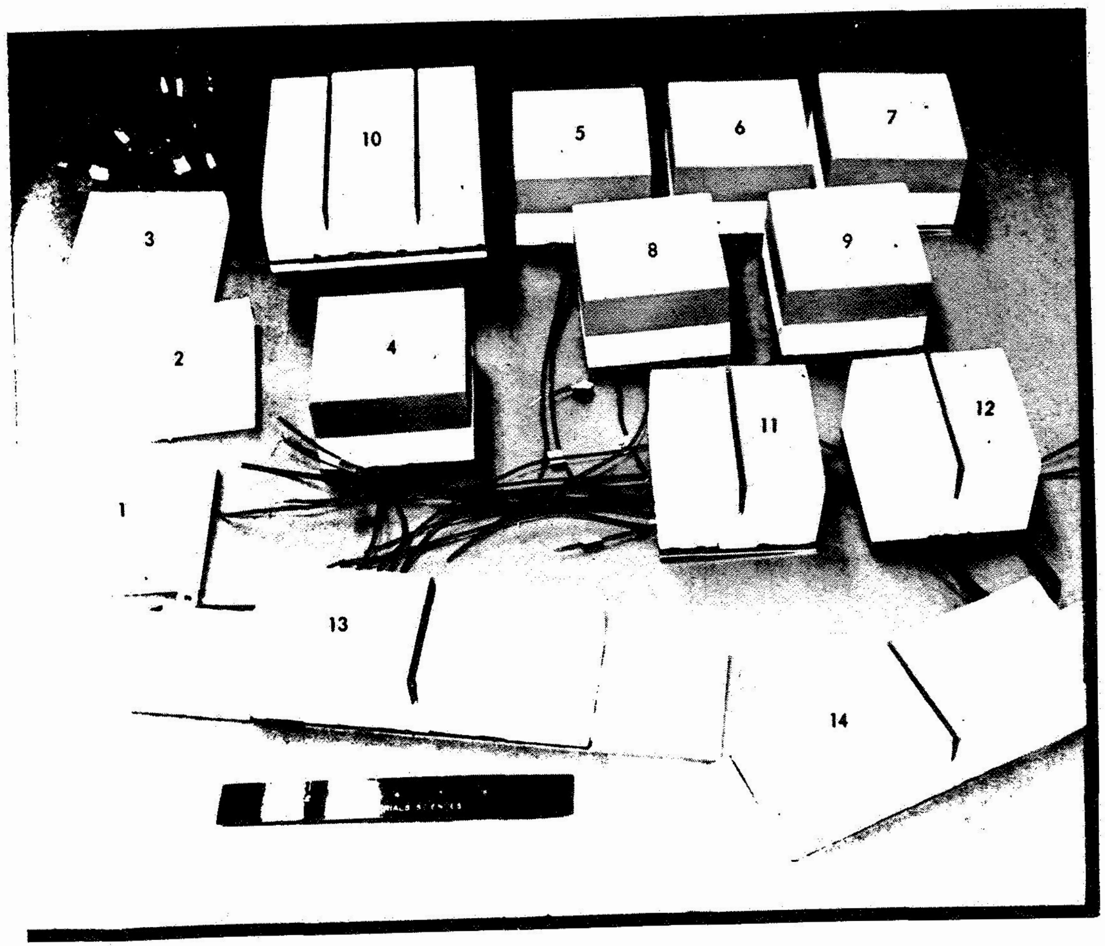
Freeze/Thaw. These tests were performed to determine if the silica RSI would be affected by exposure to moisture followed by freezing and thawing. Specimens were exposed to moisture environments varying from 50 to 100 percent relative humidity for a minimum two-hour period and then a 255°K freeze temperature for a minimum of 8 hours. The specimens were then thawed in an ambient environment for a minimum of 8 hours. This cycle was repeated twice more, but with thaw temperatures of 534°K and 811°K (oven exposures). The specimens were weighed, measured, and visually inspected after each cycle. The average variations in weights and dimensions recorded were within the uncertainty/repeatibility of the measurements.

Salt Fog. Concern for the effects of salt exposure on RSI materials has led to investigations regarding appropriate testing with a salt environment. LMSC has elected to use the MIL-STD-810B, Method 509, Procedure I. The 10 by 10 by 2.5-cm (4 by 4 by 1-in.) specimens were (1) subjected to four salt fog exposures of one hour duration; (2) weighed; (3) exposed to a radiant lamp simulation of the reentry heating pulse at 1 atmosphere pressure; and (4) weighted again. This procedure was followed for five cycles. Recorded weight changes were within the uncertainty of the measurement. These specimens were oversprayed with hydrophobic solution after the heating because this treatment was a part of the "baseline" concept in the early part of 1972 when this test was performed. The coating had some cosmetic changes (i.e., there was a somewhat mottled appearance to it), but there was no significant change in surface emittance.

Ascent depressurization tests were run using Specimens 4 through 9 and Specimen 12. The specimens were subjected to a moisture environment ranging from a 50- percent relative humidity to rain for a minimum of two hours and then exposed to a simulated ascent and reentry heating and pressure test. Since they were waterproof, these specimens did not absorb water in significant quantities. They survived this test without significant weight changes or degradation.

The remaining specimens were used in studies related to tile joint designs.

TEST SPECIMENS



SPECIMEN NO.	SPECIMEN TEST
1	FREEZE/THAW AND SALT FOG
2	FREEZE/THAW AND SALT FOG
3	FREEZE/ THAW AND SALT FOG
4	ASCENT DEPRESSURIZATION
5	ASCENT DEPRESSURIZATION
6	ASCENT DEPRESSURIZATION
7	ASCENT DEPRESSURIZATION
8	ASCENT DEPRESSURIZATION
9	ASCENT DEPRESSURIZATION

Figure 2

ACOUSTIC OVERSHOOT MODEL
(Figure 3)

Acoustic testing has been performed on single and multiple all-silica RSI tile arrays with sound pressure levels of 160.7, 170, and 174.5 dB. A six-tile array was tested in the Ames Research Center 9 by 7 wind tunnel at the two lower levels and one-tile and two-tile specimens were tested in the LMSC progressive wave tube at the two higher levels. The six-tile array (2 tiles wide by 3 tiles long) suffered no apparent degradation after the 160.7-dB test, but after the 167.8-dB test, one tile had broken completely free; however, this is attributed to the fact that it was in contact with the adjacent downstream tile rather than having the required clearance. Further, it is noted that the other tile, which was symmetrically located in the stream and was not in contact with any adjacent tile, did not break loose. The specimens tested for 15 minutes in the progressive wave tube showed no failure of the basic all-silica RSI or its coating. However, in the two-tile sample the directly exposed FI-600 seal strip material disintegrated at 170 dB, while the seal strip material in the tile joint survived the 170-dB level but disintegrated at the 174.5-dB level. The conclusion from this testing is that the basic all-silica RSI can withstand acoustic sound pressure levels up to 174.5 dB. This appears to be well above the range of levels for which the orbiter TPS will be designed.

ACOUSTIC OVERSHOOT MODEL

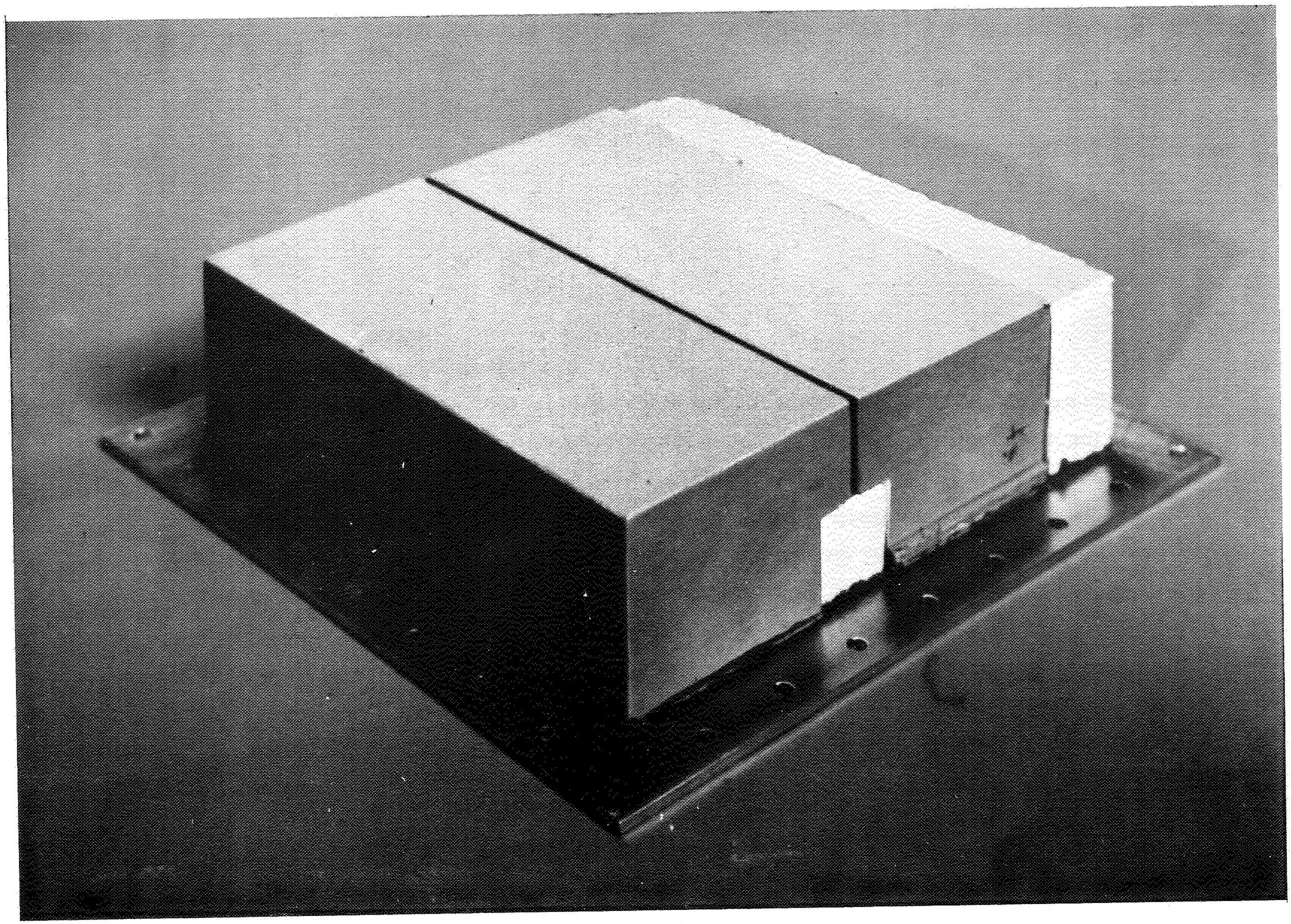


Figure 3

116° K (-250° F) COLD SOAK SPECIMEN
(Figure 4)

The on-orbit cold soak condition of 116°K poses a severe test for the commonly used bonding agents because they undergo a glassy transition with a dramatic increase in modulus when temperatures drop below 170°K. As part of the investigation of attachment systems compatible with this environment, two 30.5 x 5 x 5 cm (12 by 2 by 2-in.) all-silica RSI tiles were bonded to aluminum plates, one using a foam pad 0.16 cm (0.063-in.) thick (RM RL-1973) bonded between the aluminum and the tile illustrated, and the other with a 0.025 cm (0.01-in.) thick Invar strip (to serve as a strain arrestor plate) bonded between the aluminum and the tile. These two specimens were chilled to 116°K and then returned to room temperature with no apparent damage. In addition, the aluminum base plates were loaded in tension to yield (at room temperature) with no apparent damage to the tiles or attachment systems.

116°K (-250°F) COLD SOAK SPECIMEN

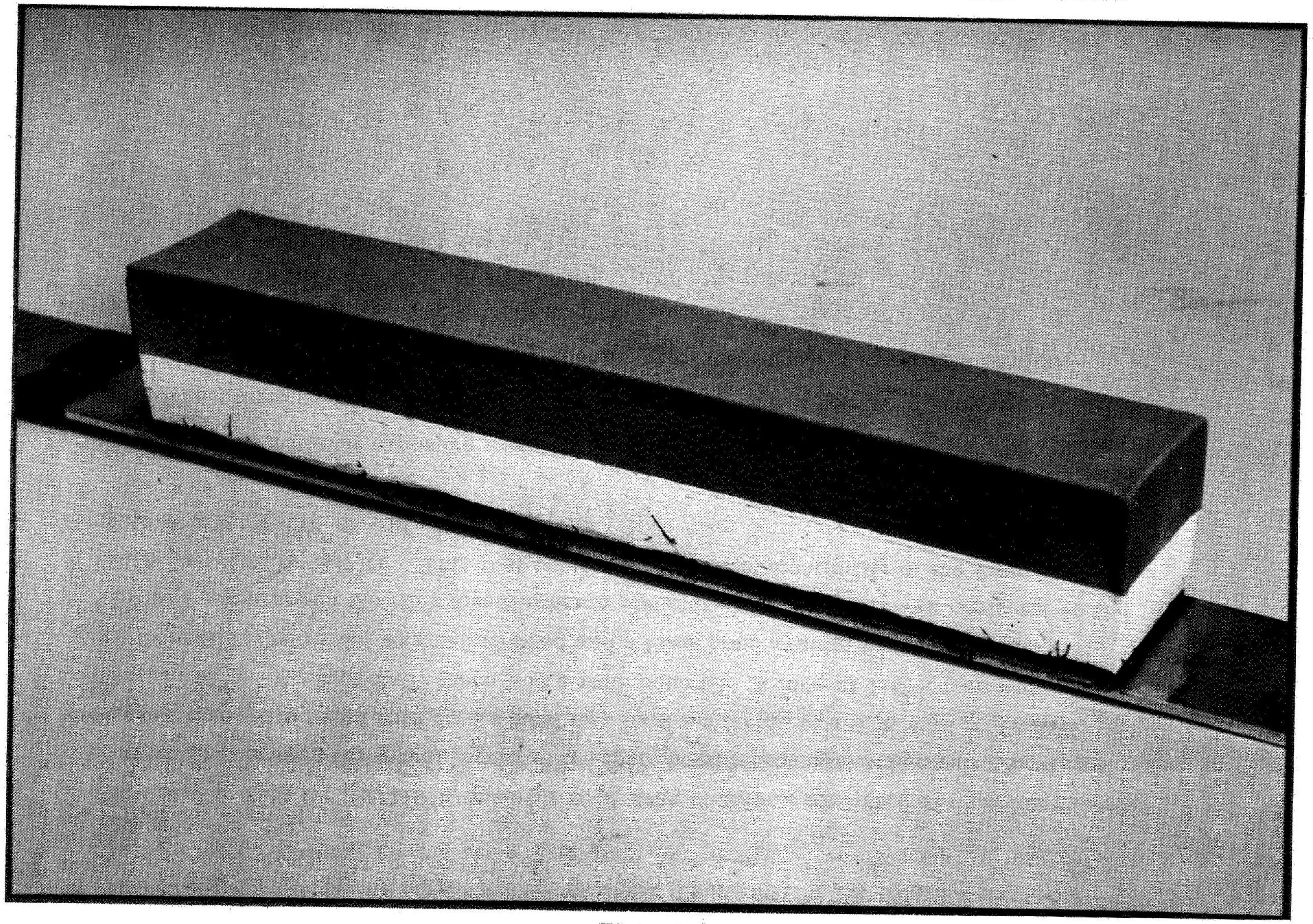


Figure 4

116° K (-250° F) TESTING OF 15 BY 60 CM PANEL
(Figure 5)

Additional testing for the 116°K on-orbit cold-soak condition consisted of a performance comparison between the direct bond and the foam bond attachment schemes. The 15 by 60 cm, three-tile panel with direct bond was first subjected to 137°K with no failure, and then to 116°K. As expected, there was a near bond tile failure at 116°K (see photo). Subsequently, the model was refurbished and a foam bond system with 2 mm thick RL-1973 pad between the tiles and aluminum structure was used. It was subjected to the 116°K test with no failure. This test demonstrates the compatibility of the foam bond system with the 116°K cold soak condition.

Vacuum and ultraviolet exposure were shown to have no effect on weight and coating emittance. Vacuum tests consisted of 30-day hard vacuum at room temperature and 394° K. Samples of the coating were subjected to 5700 equivalent sun hours of ultraviolet exposure with no degradation of emittance.

116°K (-250°F) TESTING OF 15 BY 60 CM PANEL

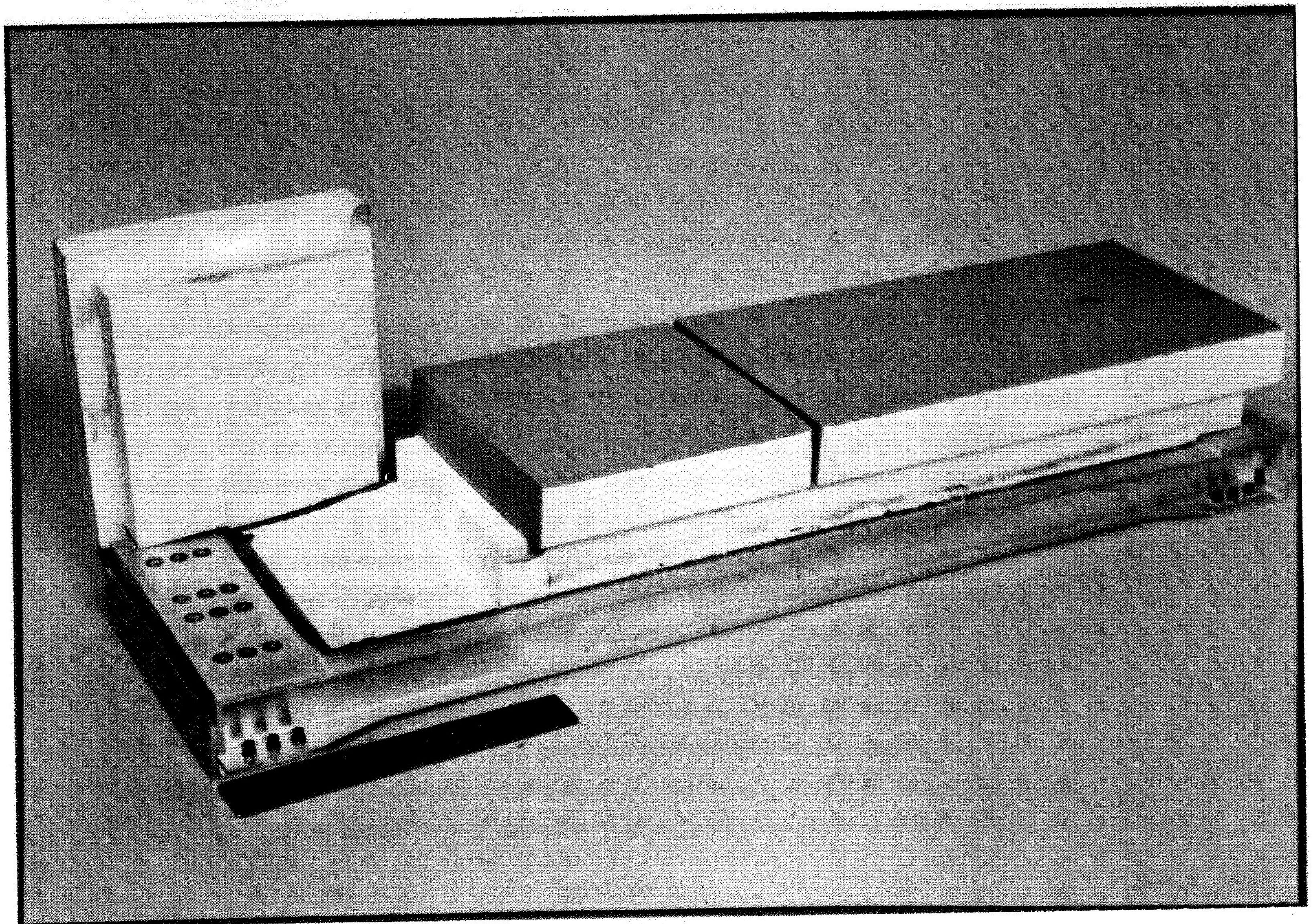


Figure 5

LOST TIME MODEL — PRETEST
(Figure 6)

To obtain an initial evaluation of the effects of a "lost tile" in an RSI tile array (such as might occur due to bird impact during launch, collision during on-orbit docking, EVA accident, etc.), the nine-tile array pictured had the center tile deliberately removed to the point where about 1.9 cm thickness of tile remained. This specially prepared model was then placed in a model holder so that the surface of the array was inclined at 45 deg to the centerline of the exhaust of the hydrogen jet heater. The heater was controlled using a surface thermocouple located in the center tile of the upstream tile row for feedback, and controlling to the predicted flight surface temperature response for Area 2 perturbed. The 1.02 by 1.02 by 0.51 cm tiles were bonded with RTV-560 to a 38 by 38 by 2.5 cm titanium-aluminum honeycomb-sandwich. The hydrogen jet heater provides a 2500 to 3600°K flame for hot flow testing at heat rates up to 735 X 10^4 W/m^2. Pretest calibration tests were run to determine flame conditions required to achieve peak LI-1500 surface temperature of 1535°K. The test consisted of a simulation of the reentry heating surface temperature response with feedback control.

LOST TILE MODEL – PRETEST

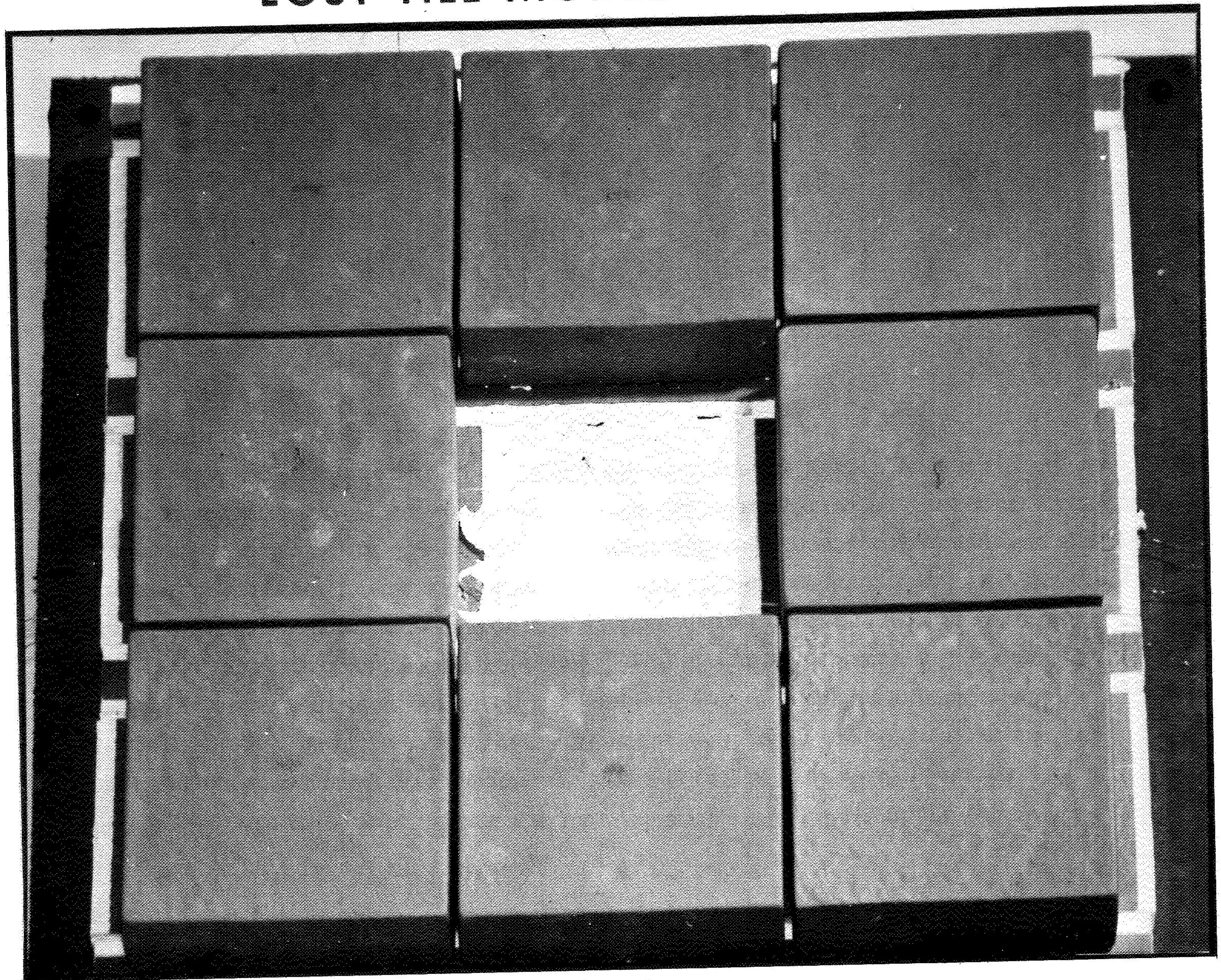


Figure 6

LOST TILE MODEL IN HOLDER — POST TEST
(Figure 7)

As indicated, the purpose of the test was the evaluation of the effects of accidental tile loss, and one of the qualitative conclusions drawn is that no progressive, catastrophic failure resulted. That is, no tiles came off or burned through, and the maximum temperature on the titanium portion of the structure was 700°K; this was within an acceptable, one time reentry survival bound. With this simulated accident, the adjacent tiles (particularly downstream) show degradation where the tile in the joint areas was overheated, and were this on a flight vehicle, refurbishment would be required. However, confidence in capability of this system was further enhanced when the specimen was subsequently utilized in tests (to obtain acoustic transmission data on the honeycomb structure) that included acoustic exposure to 147.5 dB, where no tiles fell off or showed any further degradation.

LOST TILE MODEL IN HOLDER - POST TEST

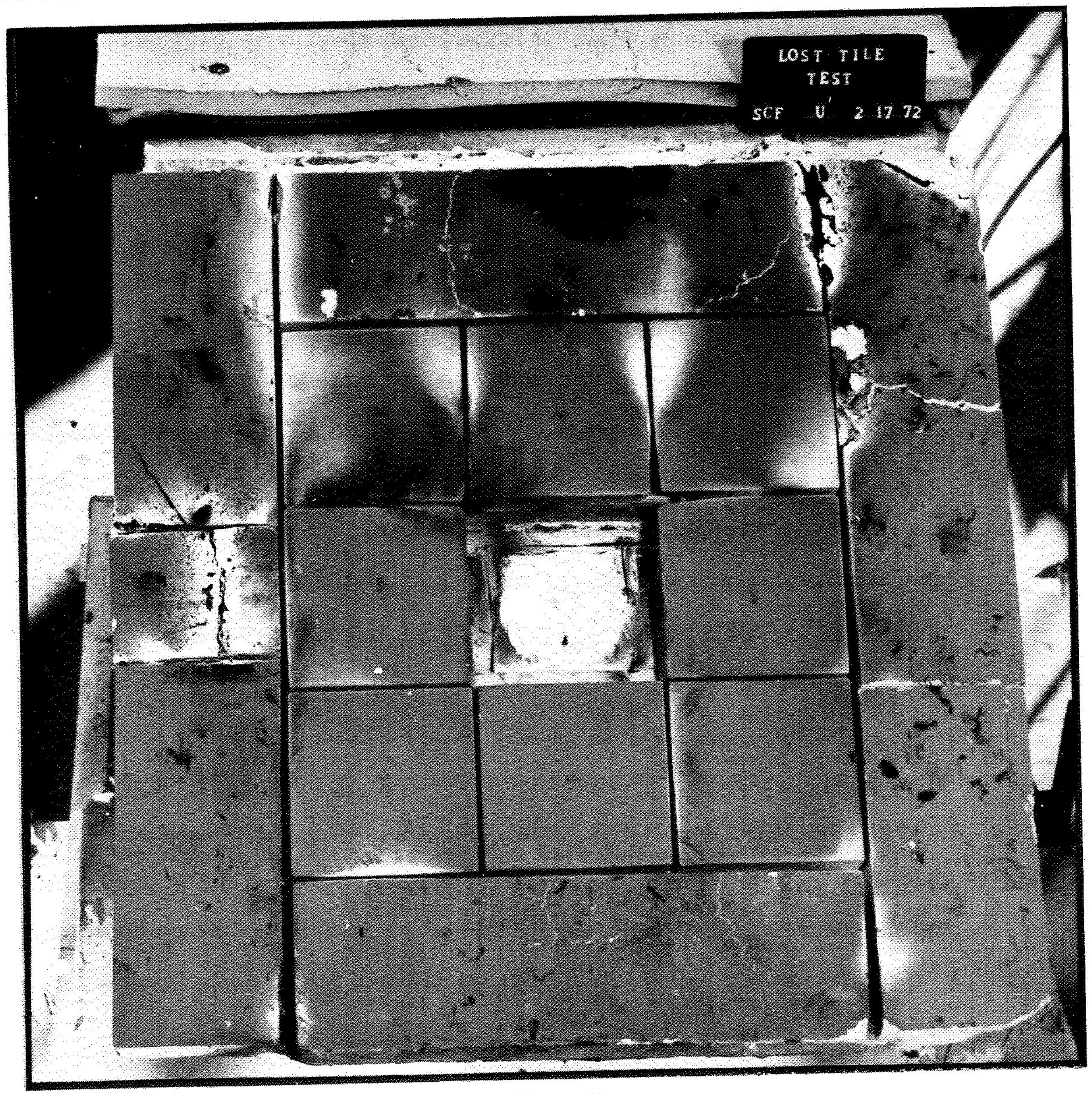


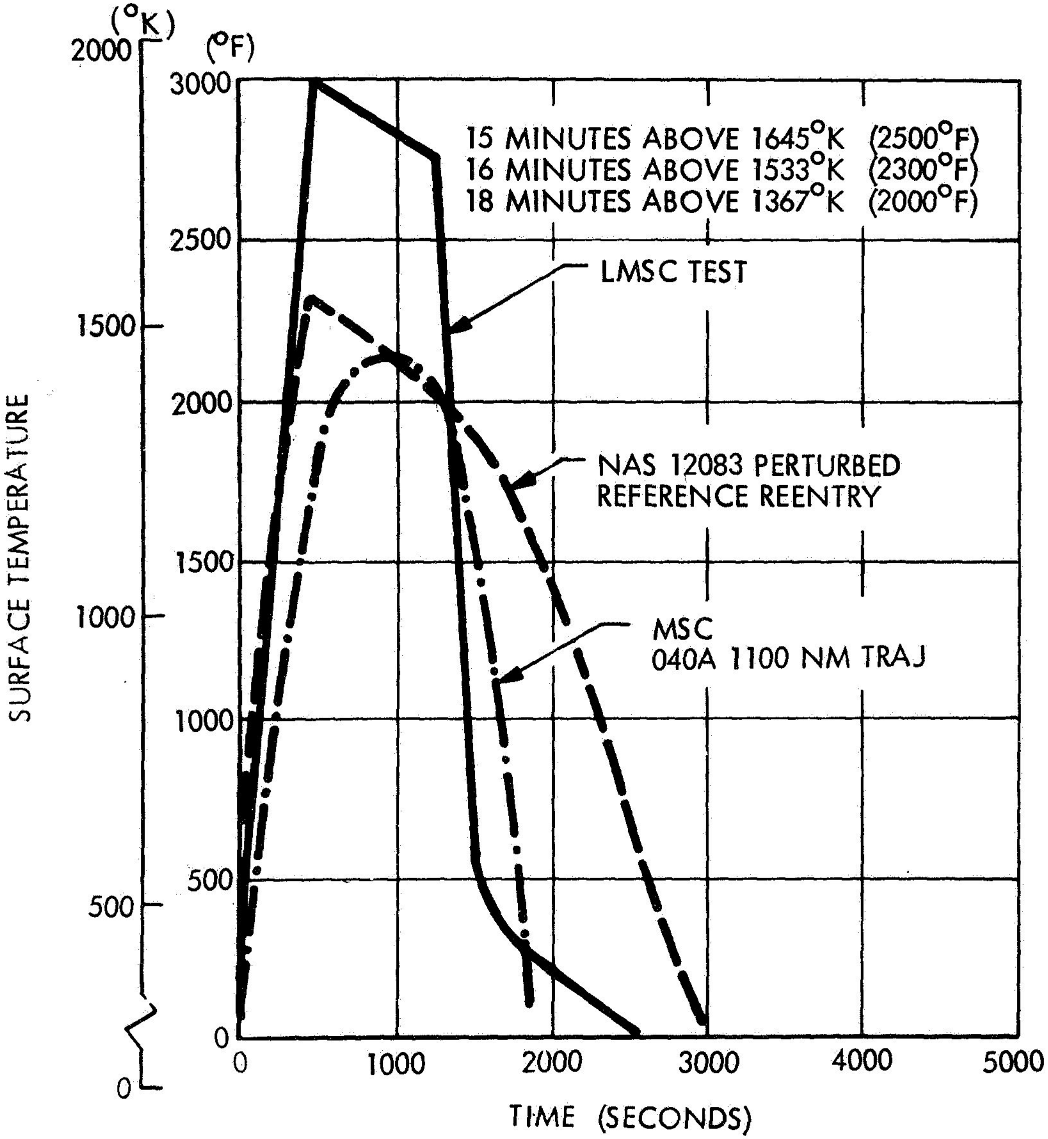
Figure 7

LI-1500/0042 COATING TEMPERATURE OVERSHOOT TEST
(Figure 8)

As part of the investigation of the cability of the all-silica RSI material, the specimen shown was subjected to a "temperature overshoot" environment that consisted of three radiation simulated reentry heating pulses up to a temperature of 1644° K (as used for the 100-cycle tests described in the paper entitled "Silica RSI Entry Simulation Tests," by R. P. Banas, et al, in Section 20 of these Proceedings) and then brought up to 1924°K surface temperature according to the curve shown. It should be noted that this test included 18 min above 1368° K, 16 min above 1535° K, and 15 min above 1644° K. Additionally, the heat rate required to produce the 1924° K surface temperature is larger than the heat rate for 1644° K by almost a factor of two and this represents a significant temperature overshoot. Although there is some surface slumping evident and such a tile would be replaced rather than reflown, there was no catastrophic failure of the all-silica tile; thus it has been demonstrated that this system can tolerate significant excursions from the planned environment. Analysis of this hypothetical flight condition indicated that the structure temperature at the time equivalent to touchdown would be about 430° K with a maximum temperature around 485° K.

Arc-jet test run during December 1971 at Aerotherm further confirms the "foregoing nature" of the all-silica RSI. Samples were tested for five 30-min cycles at a calorimeter-measured heating rate in excess of 90.4 X 10^4 W/m^2 (to be compared with the 24.8 X 10^4 W/m^2 required to produce 1535° K surface temperature), and although there was distortion of the sample, this test demonstrated the ability of the all-silica system to provide one-time thermal overshoot protection to the structure.

LI-1500/0042 COATING TEMPERATURE OVERSHOOT TEST



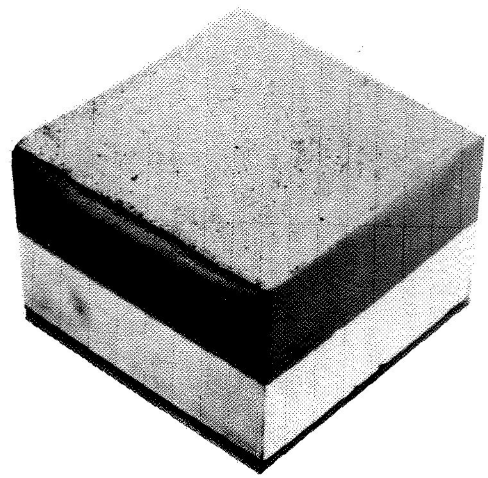


Figure 8

RAIN EROSION — 563 KM/HR
(Figure 9)

Rain erosion test results, reported in Ref. 1 are shown in Figure 9. The 563 km/hr data presented show a variation in rain exposure effects for rain intensities from 0.635 cm/hr to 2.54 cm/hr and for 10 and 20 deg angle of attack. The data show that the all-silica RSI system is not affected at 10 deg angle of attack, while the other systems experience severe erosion in one-half hour. At 20 deg angle of attack it shows generally better performance (on the basis of the qualitative statements quoted from Ref. 1); however, an example of the superior performance of LI-1500 can be seen by looking at the quantitative data provided for the 2.54 cm/hr, 20-deg angle-of-attack condition, where the "one spot eroded" corresponds to a weight loss on the LI-1500 specimen of 55 milligrams in 5 min, while the HCF and REI suffered weight losses of 530 milligrams in 2.5 min, and 1695 milligrams in 2 min, respectively.

RAIN EROSION — 563 KM/HR

R.I. (RAIN INTENSITY) = .635 CM/HR

	α = 10 DEG	α = 20 DEG
LI-1500	NOT TESTED	SLIGHT IN 14 MIN
HCF		SLIGHT IN 5 MIN
REI		SEVERE IN 7.5 MIN

R.I. = 1.27 CM/HR

	α = 10 DEG		α = 20 DEG	
LI-1500	NONE } 5 MIN	NONE IN 60 MIN	SLIGHT IN 2.5 MIN	SLIGHT IN 30 MIN
HCF	NONE } 5 MIN	SEVERE IN 30 MIN	SLIGHT IN 3.0 MIN	SLIGHT IN 4 MIN
REI	NONE } 5 MIN	SEVERE IN 30 MIN	SLIGHT IN 2.5 MIN	SEVERE IN 4.5 MIN

R.I. = 2.54 CM/HR

	α = 10 DEG	α = 20 DEG
LI-1500	NONE } 5 MIN	ONE SPOT ERODED IN 5 MIN
HCF	NONE } 5 MIN	SLIGHT EROSION IN 2.5 MIN
REI	NONE } 5 MIN	SLIGHT EROSION IN 2.0 MIN

Figure 9

SUMMARY
(Figure 10)

Testing to date has demonstrated the compatibility of the all-silica RSI system to a variety of Space Shuttle Orbiter environmental aspects for launch, on-orbit, and special reentry conditions.

Among the more important results are the success of the cold soak tests, which indicate the suitability of the foam/bond attachment system with an 2 mm thick foam pad for strain isolation, and the reentry temperature overshoot tests (to 1924° K), which show that this RSI system can tolerate considerable dispersion in reentry heating environment.

With continued development, more testing will be performed particulary with combined environments and improved simulation of the orbiter environment. However, the work to date has served to substantiate the LMSC choice of the all silica material.

SUMMARY

CAPABILITY OF ALL SILICA MATERIAL HAS BEEN DEMONSTRATED FOR:

<u>LAUNCH PHASE</u>

FREEZE THAW
SALT FOG
ACOUSTIC TESTS
ASCENT PRESSURE DROP

<u>ON-ORBIT</u>

STABILITY IN VACUUM
COLD SOAK

<u>REENTRY/SPECIAL CONDITIONS</u>

LOST TILE TEST
TEMPERATURE OVERSHOOT
RAIN EXPOSURE

Figure 10

REFERENCE

1. "Rain Erosion Characteristics of Thermal Protection System Materials At Subsonic Velocities," N. E. Wahl, Technical Report AFML-TR-72-145, August 1972.