CONVECTIVE HEATING TESTS OF REUSABLE SURFACE INSULATION JOINTS AND GAPS

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INTRODUCTION

One of the most important areas needing characterization for the Shuttle TPS and other entry vehicles is the effect of additional convective heating in gaps and joints. The size of the gap and the joint design are hallmark variables as well as boundary layer flow conditions. The gap-joint problem has many facets, and this paper addresses the study of experimental measurement of heating in gaps, effects on the mission and adequacy of several theories. This paper does not address the required gap size as affected by: tile size, tolerances associated with fabricating a tile and the assembly of the TPS, the dimensional changes in the structure due to temperatures and loads, or the manufacturing and refurbishment problems associated with the TPS. These other facets are important and also affect the TPS design.

The scope of this investigation and tests are given below. The information presented herein only scratches the surface of the gap-joint iceberg and additional investigations are warranted.

<u>Scope</u>

- Obtain comparative effects of gap width on the convective heating in RSI joints
- Compare thermal performance of candidate joint designs
- Effects of steps
- Derive heating distributions in the joints and then compare with theory

<u>Completed Tests</u>

- Wedge flow in the NASA-MSC 10-MW Arc Tunnel

<u>Scheduled Testing</u>

- Channel nozzle at NASA-MSC
- Thick boundary layer using tunnel wall in Langley's CFHT
- Arc tunnel tests of large RSI panel in Wright Field's 50-MW facility (tentative)

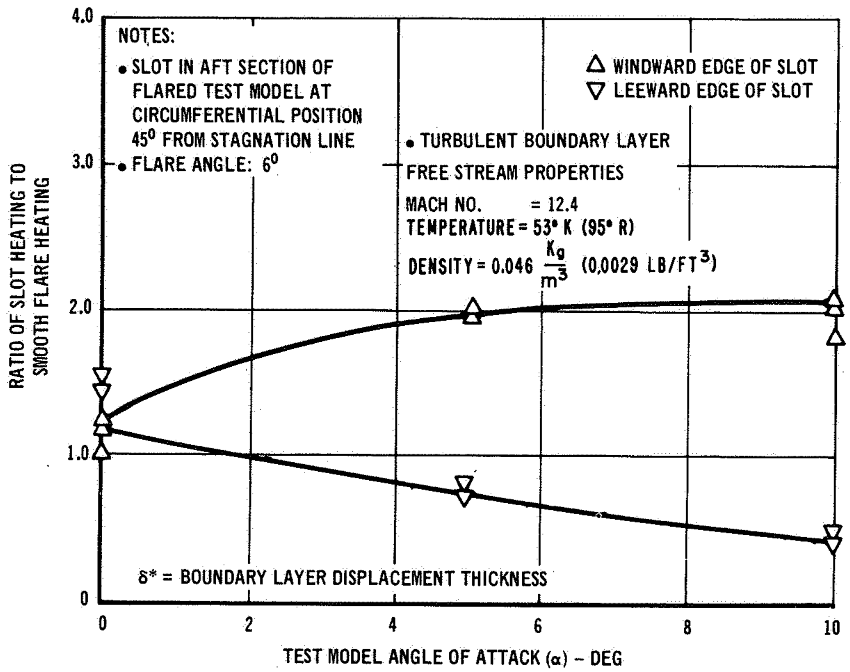
This work was sponsored by NASA-MSC as part of contracts NAS9-12082 and NAD9-12854, Development and Design Application of Rigidized Reusable Surface Insulation Thermal Protection System.

HEATING RATE RATIO IN LONGITUDINAL SLOT AS FUNCTION OF ANGLE OF ATTACK

(Figure 1)

Previous investigations have dealt with shallow gaps, such as shown in figure 1, but the RSI-TPS will have relatively deep gaps due to tile thickness requirements. As shown in the figure, heating on the windward and leeward edges of the slot diverges with angle of attack and shows an increase in heating over the heating on a smooth surface. The experimental portion of the present investigation consisted of fabricating a series of joint models for a wedge and performing a series of comparative tests in the NASA-MSC 10 MW Arc Tunnel.

HEATING RATE RATIO IN LONGITUDINAL SLOT AS FUNCTION OF ANGLE OF ATTACK



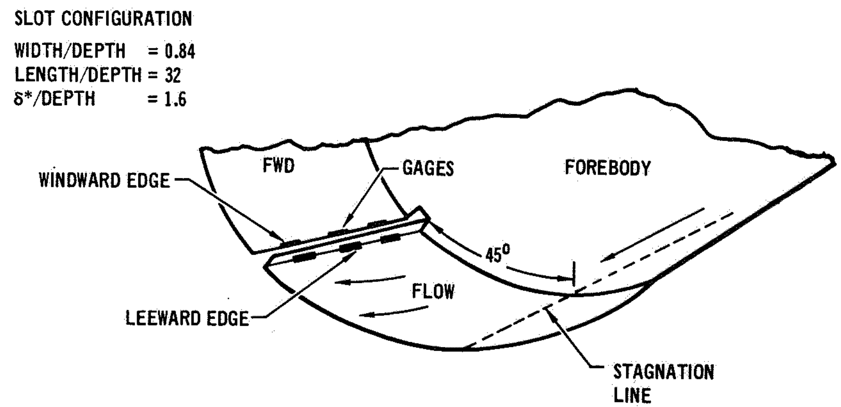


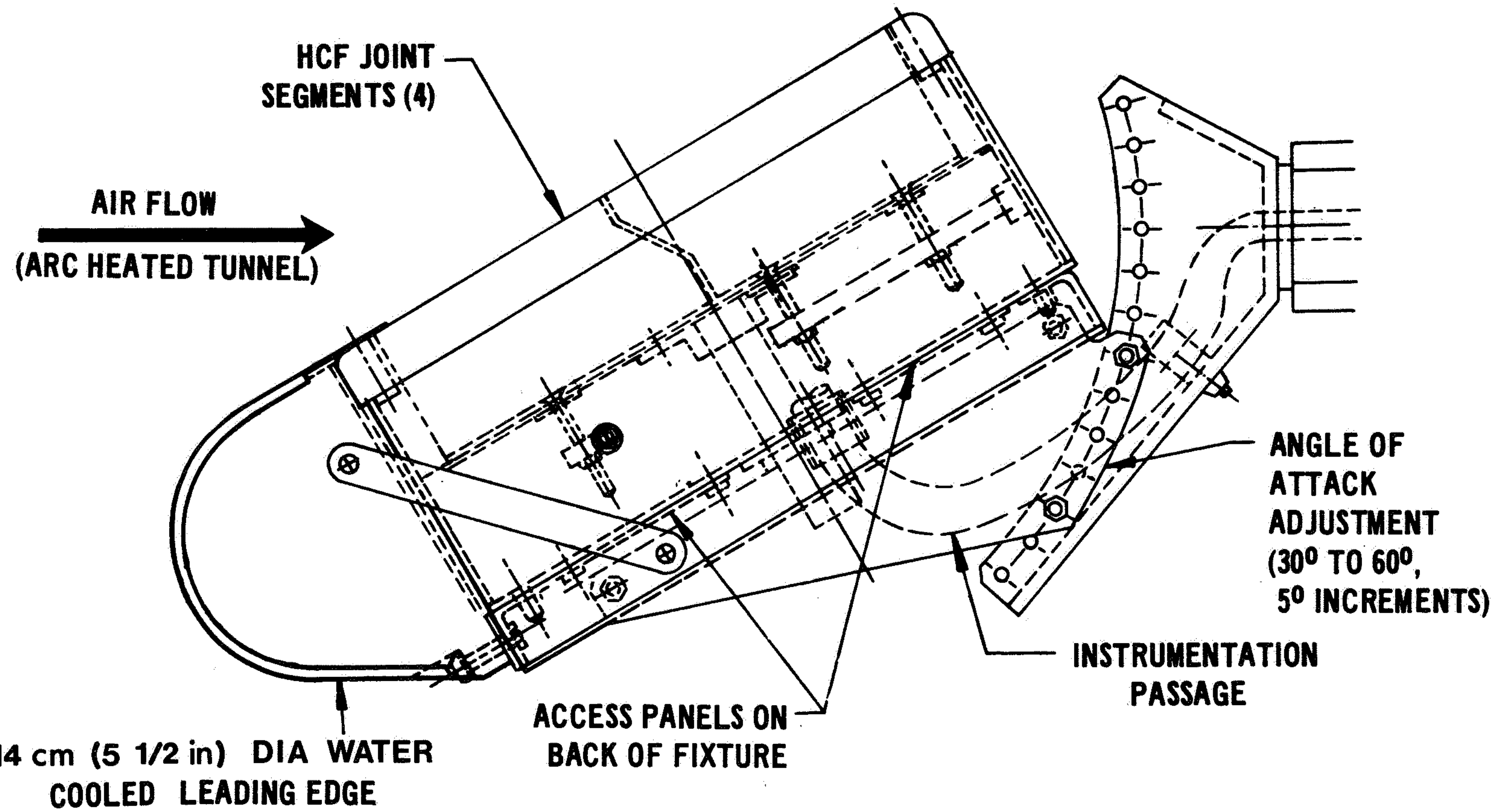
Figure 1

PLASMA WEDGE TEST FIXTURE FOR EVALUATING JOINTS, GAPS, AND STEPS

(Figure 2)

Sets of four tiles were designed to be interchangeable within a test fixture containing a gap setting mechanism. The fixture was designed so that the gaps would be reset between tunnel runs without removing the wedge from the Arc tunnel facility. The test fixture also contained a set of HCF guards around the tiles, and the test fixture (box) fits into a wedge with a 14 cm (5-1/2 inch) diameter leading edge (water cooled).

PLASMA WEDGE TEST FIXTURE FOR EVALUATING JOINTS, GAPS AND STEPS



*BASIC TEST FIXTURE ALSO FABRICATED BY MDAC (SSTP)

Figure 2

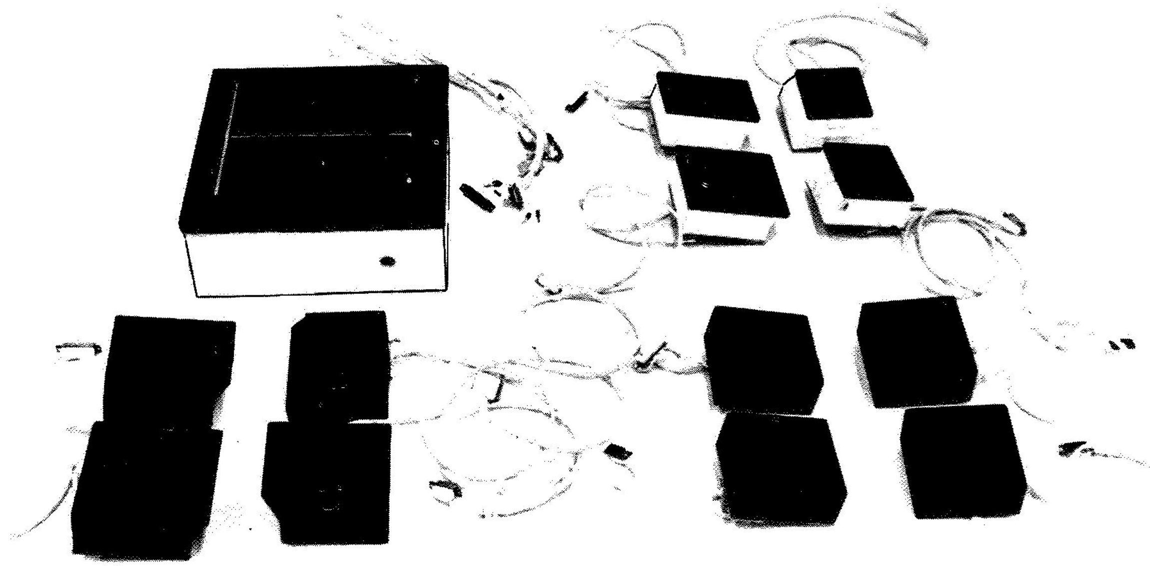
MODELS FOR ARC TUNNEL TESTS OF JOINTS AND GAPS

(Figure 3)

Twelve sets of joint models have been fabricated as shown in figure 3. Results for the contoured, butt, and butt step model are contained in this paper. The models are heavily instrumented, and the features of the model design are listed in the figure.

MODELS FOR ARC TUNNEL TESTS OF JOINTS AND GAPS

(30.5 x 30.5 CM TEST FIXTURE)



JOINT		TILE THICKNESS		
	INCH	1.25	2.00	2.50
	CM	3.17	5.08	6.35
CONTOURED		√	√	√
BUTT		√	√	√
BUTT STEP			±0.15*	
OVERLAP BLOCK			√	√
INCLINED TAPERED			√	√

*(INCH)

37 THERMOCOUPLES
- 4 SURFACE
- 16 JOINT
- 6 IN-DEPTH

- MSC 10 MW ARC HEATED TUNNEL
- WEDGE OR CHANNEL NOZZLE
- GAP SETTINGS EASILY ADJUSTED
- QUICK DISCONNECTS FOR INSTRUMENTATION
- FIBROUS INSERTS—STUDY EFFECTS OF ROVING

Figure 3

NASA-MSC 10 MW ARC TUNNEL

(Figure 4)

The tests performed to date were performed in the NASA-MSC 10 MW Arc Tunnel shown in figure 4. This view of the facility not only shows the sting for the wedge but also the channel nozzle to be used in the upcoming test series.

NASA-MSC 10 MW ARC TUNNEL

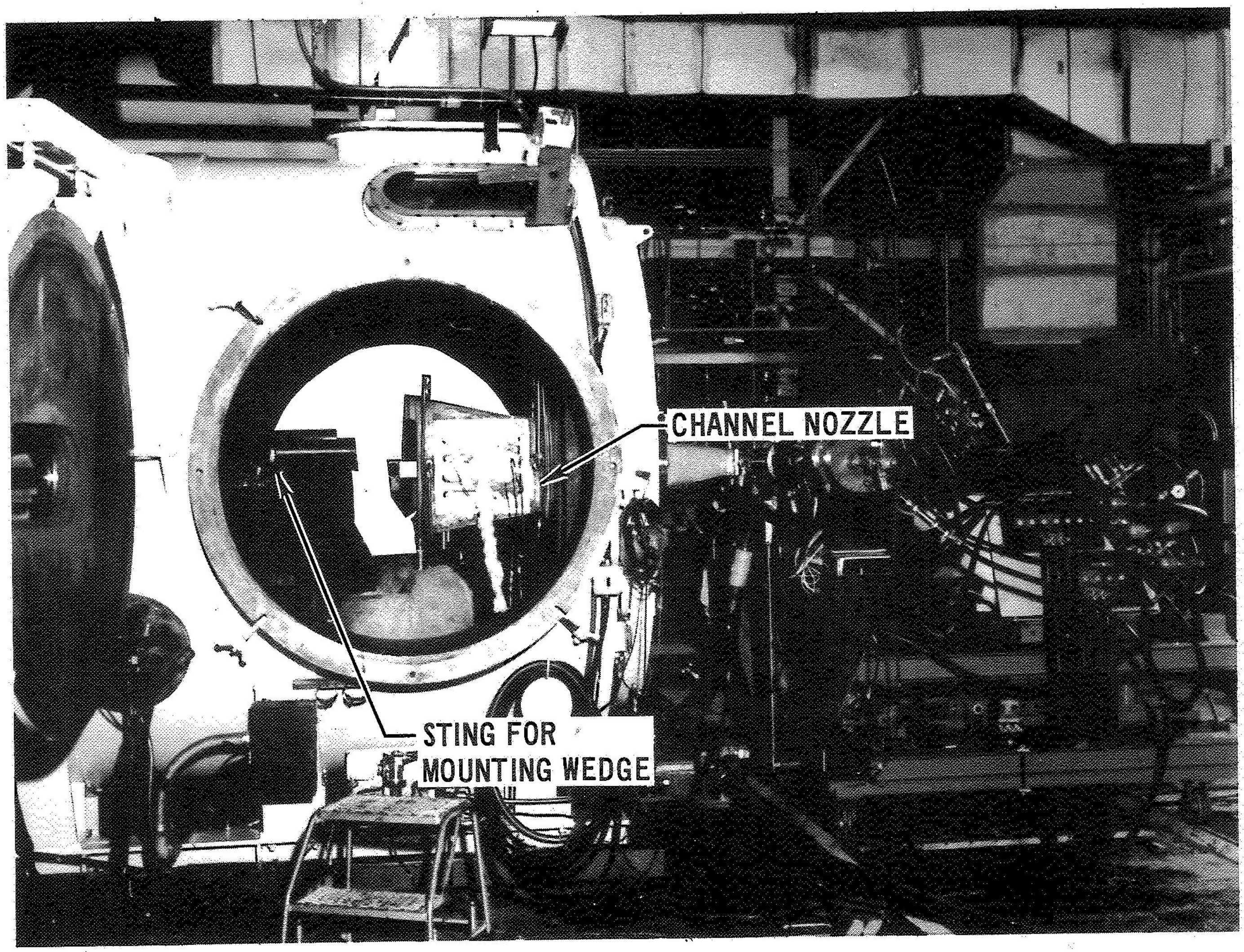


Figure 4

INSTALLATION OF HCF JOINT MODEL IN NASA-MSC 10 MW ARC TUNNEL

(Figure 5)

Figure 5 is a view of the wedge test fixture installed on the sting of the tunnel. The wedge is positioned over the radiant preheater for simulating the portion of the entry heat pulse below 1200°K (1700°F). When the surface thermocouples indicate 1200°K (1700°F), the model is swung into the flow stream of the tunnel.

INSTALLATION OF HCF JOINT MODEL IN NASA-MSC 10 MW ARC TUNNEL

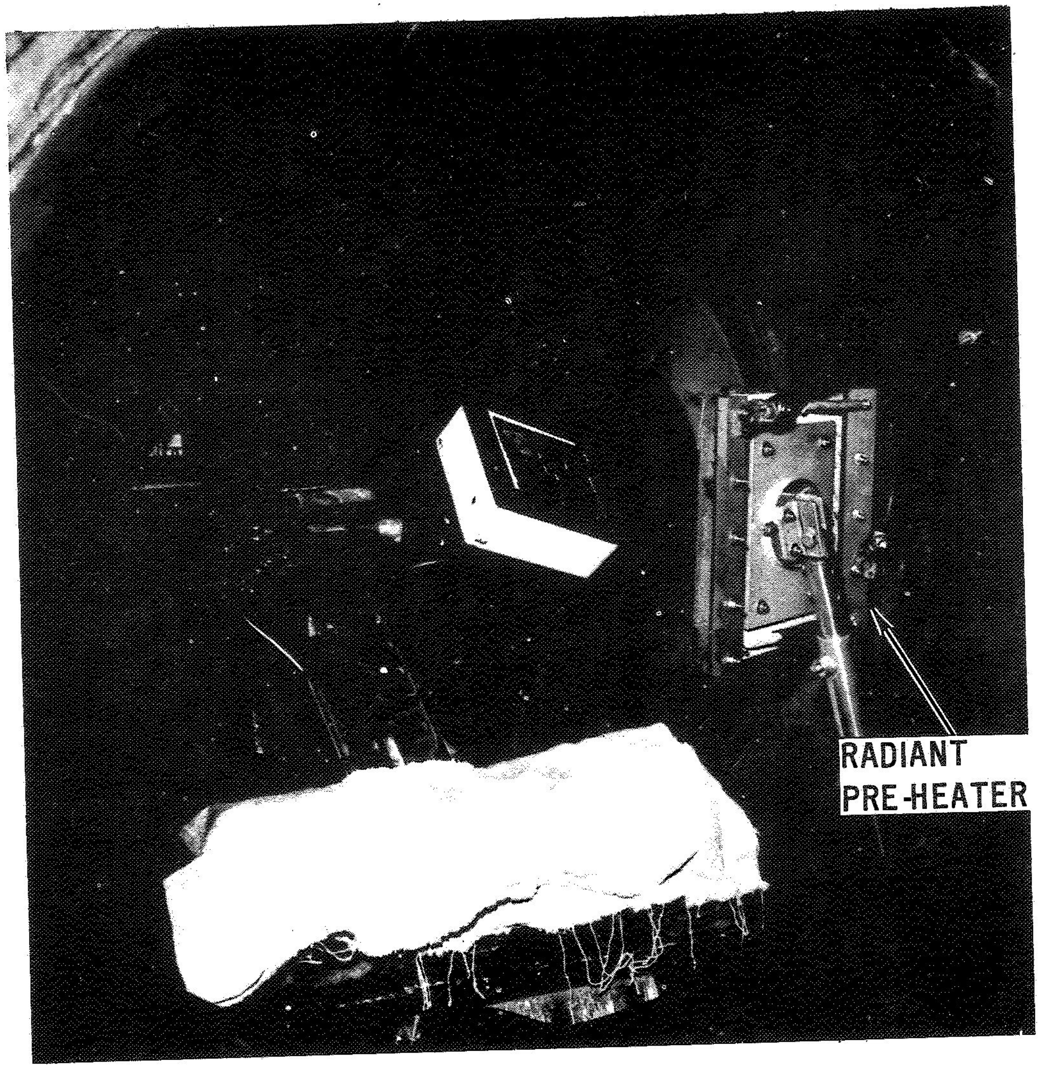


Figure 5

TESTING OF HCF JOINT MODEL IN NASA-MSC 10 MW ARC TUNNEL

(Figure 6)

A side view of the joint model during testing is shown in this figure.

TESTING OF HCF JOINT MODEL IN NASA-MSC 10 MW ARC TUNNEL

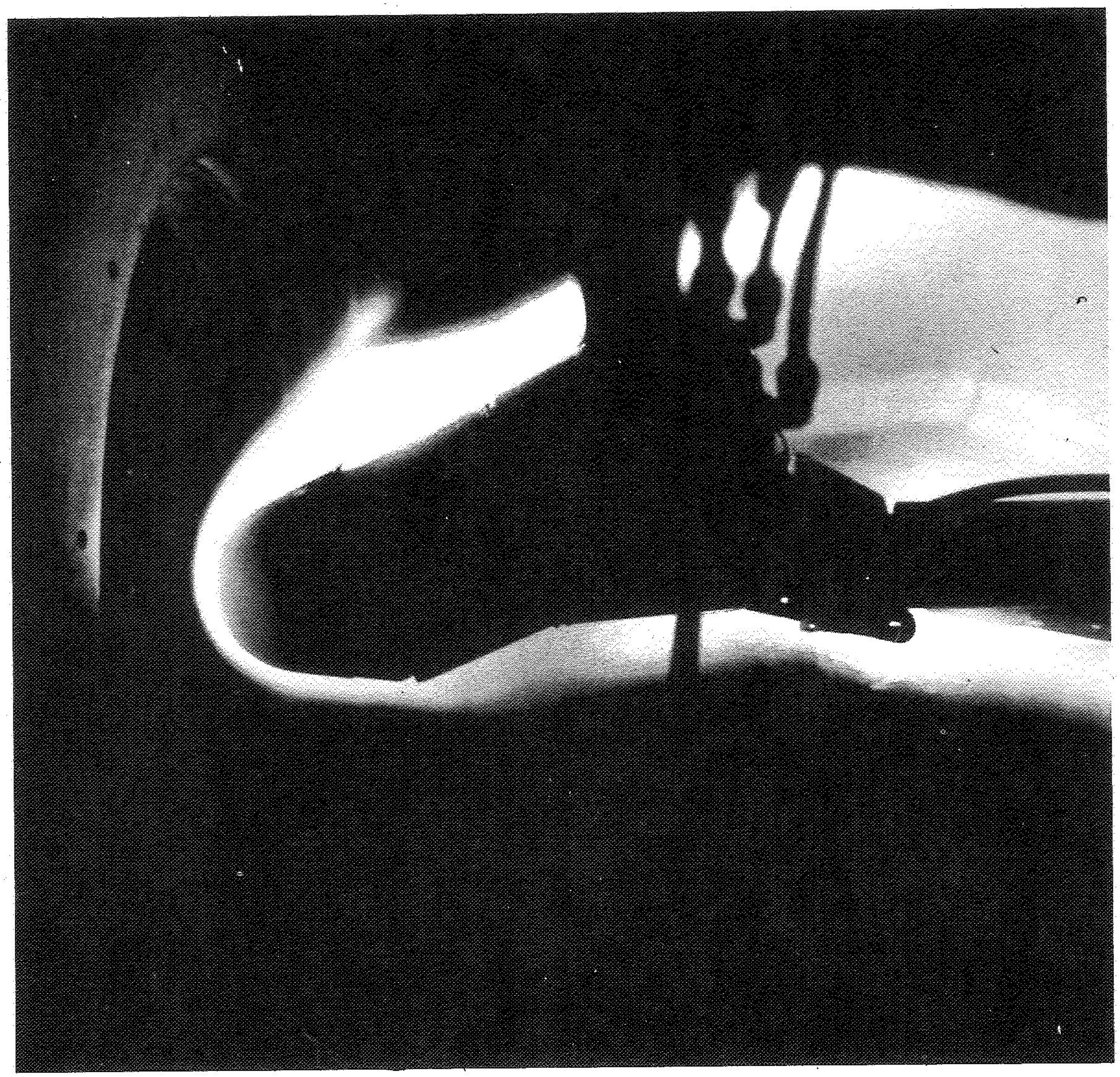


Figure 6

TESTING CONTOURED JOINT IN THE NASA-MSC 10 MW ARC TUNNEL

(Figure 7)

As can be seen in figure 7, the heating in the gaps was very high.

TESTING CONTOURED JOINT IN THE NASA-MSC 10 MW ARC TUNNEL

0.76 cm (0.30 INCH) GAP

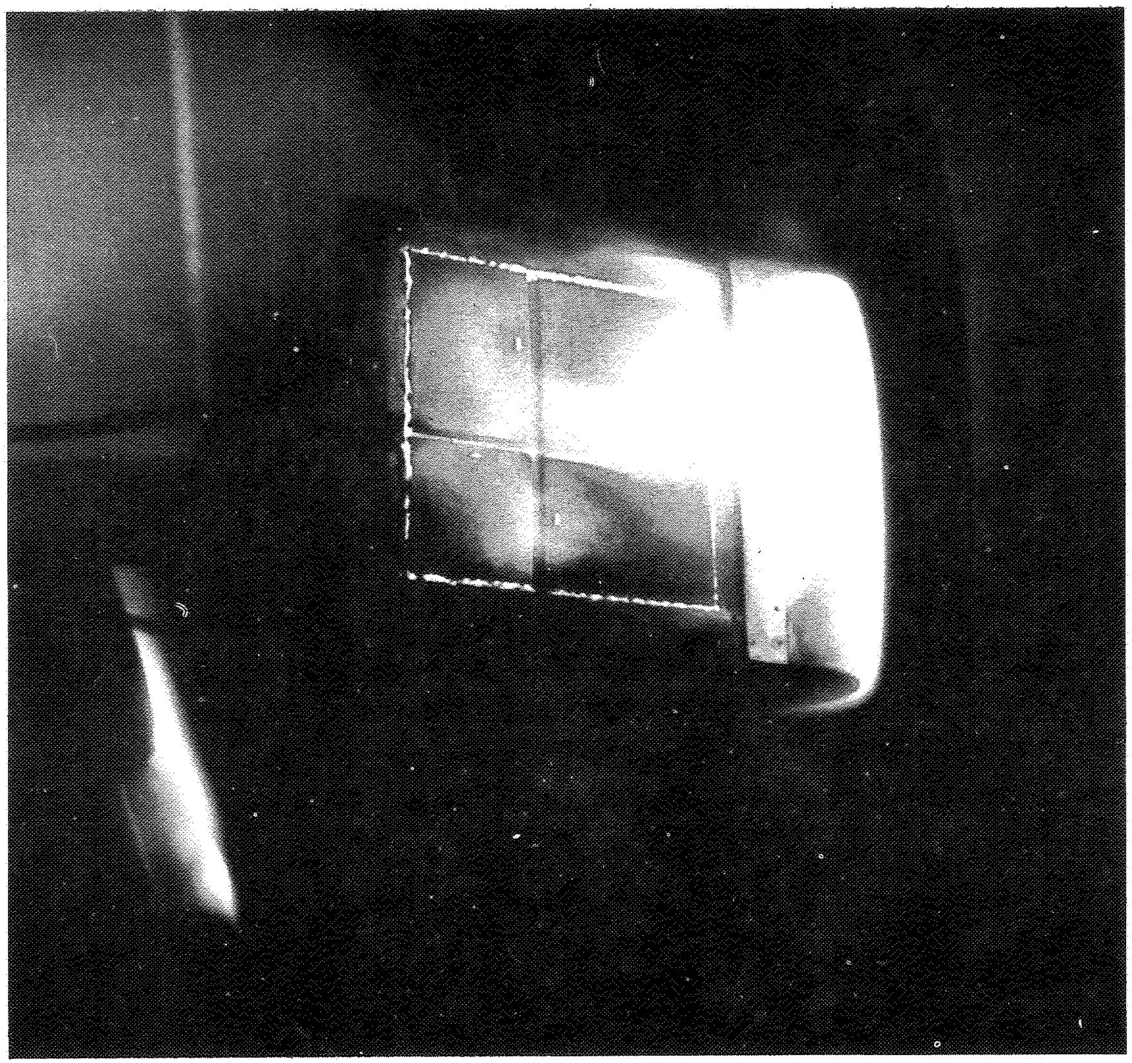


Figure 7

MEASURED TEMPERATURE OF HCF/JOINT MODEL IN MSC
10 MW ARC TUNNEL

(Figure 8)

The next four figures present temperature response data for some of the models tested. The temperature history of the tile surface and bondline, and the temperature distribution down the gap are shown in figure 8 for a typical model. The radiant heating and convective heating portions of the tests are also shown. It is interesting to note the increase in temperature and hence heating across the transverse gap (locations C and A). The shape of the temperature distribution down the faces of the gap is as expected.

MEASURED TEMPERATURE OF HCF/JOINT MODEL IN MSC 10 MW ARC TUNNEL

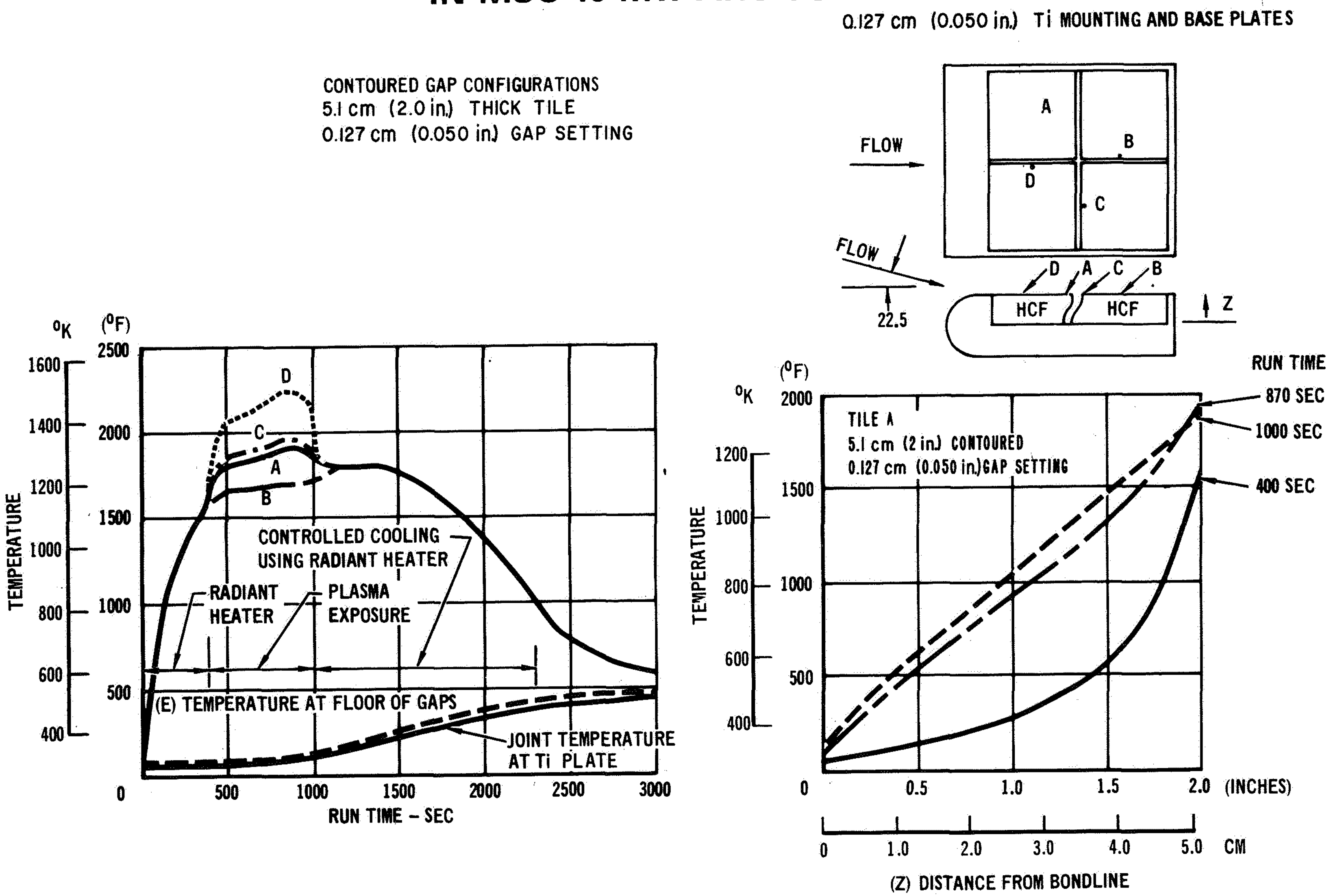


Figure 8

BONDLINE THERMAL RESPONSE AT INTERSECTION OF TILES WITH A FORWARD FACING STEP

(Figure 9)

The heat-up rate measured by the thermocouples at the bottom of the gap where the four tiles intersect experienced almost a linear increase in heat-up as the transverse gap was opened. Tests were performed at gap widths of 0.127, 0.381, and 0.762 cm (0.05, 0.15, and 0.30 inch) in order to obtain heating trends over a range of gap widths that might be contemplated for the TPS.

It can also be noted from these data that a 0.381 cm (0.15 inch) forward step did not result in an increase in heating at the downstream intersection of the tiles at the bottom of the gap. The reason most likely for this is that the parallel gap is small (held constant at 0.127 cm (0.05 inch) and minimal lateral outflow was present.

To get a feel for the magnitude of a tolerable heat-up rate, consider a temperature increase rate of 0.14°K (0.25°F)/sec acting for 800 seconds at peak heating conditions would produce a bondline temperature increase of 112°K (200°F). This added to a 311°K (100°F) initial temperature and a bondline temperature increase of 112°K (200°F) for the remainder of the trajectory produces a final bondline temperature of 534°K (500°F). Most adhesives/sponge attachments have approximately a 534°K (500°F) reuse limit. For a TPS attached to aluminum primary structure the aluminum is limited to approximately 450°K (350°F). Hence, a 0.14°K (0.25°F)/sec heat-up rate is most likely high.

BONDLINE THERMAL RESPONSE AT INTERSECTION OF TILES WITH A FORWARD FACING STEP

- 5.1 cm (2.0 in.) HCF TILES
- BUTT JOINT
- FORWARD FACING STEP (H) IS 0.381 cm (0.15 in.)
- PARALLEL GAP IS A CONSTANT 0.127 cm (0.05 in.) (G)
- MSC 10 MW ARC TUNNEL
- HCR ORBITER AREA 2P PEAK HEATING ENVIRONMENT

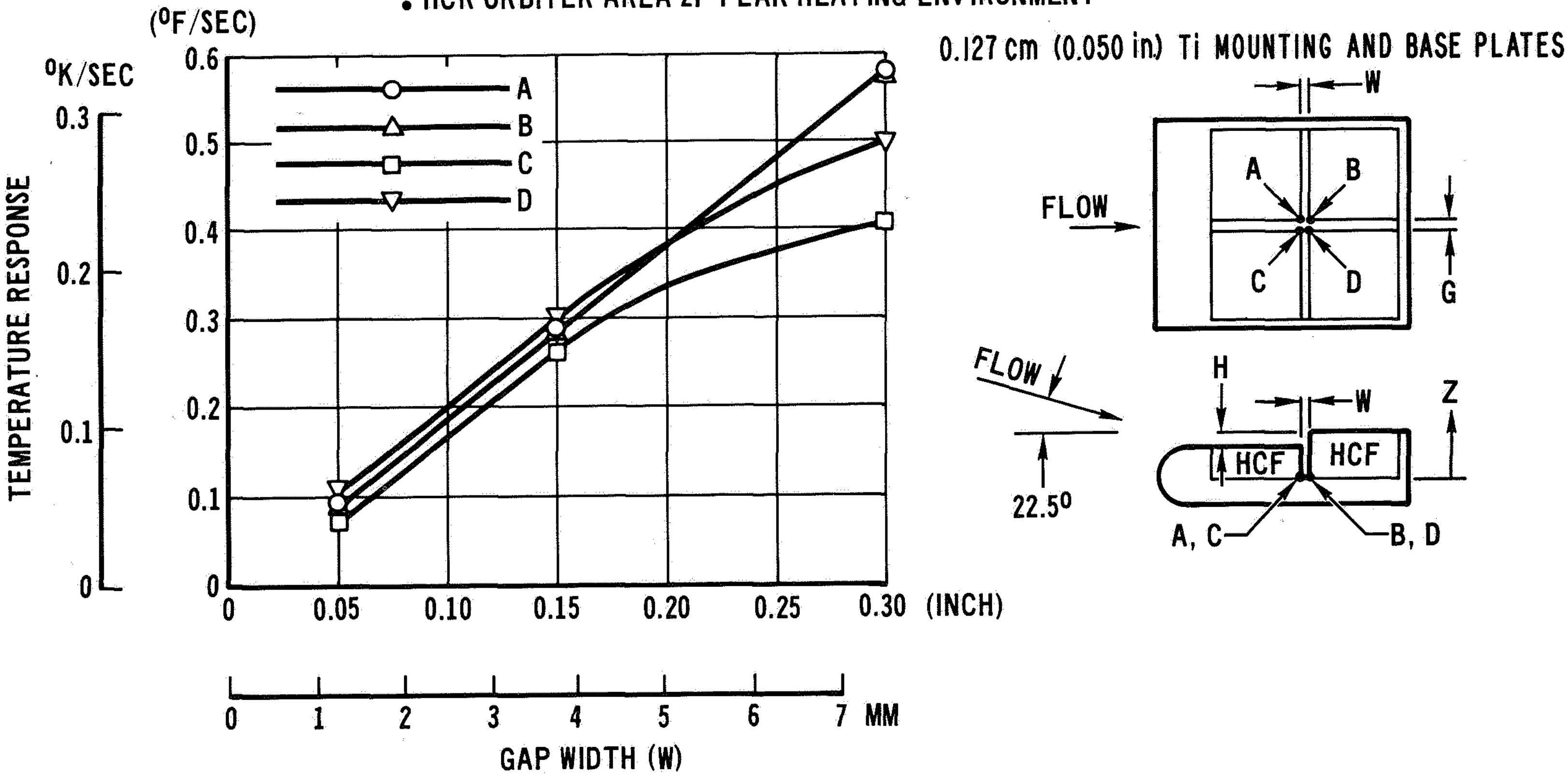


Figure 9

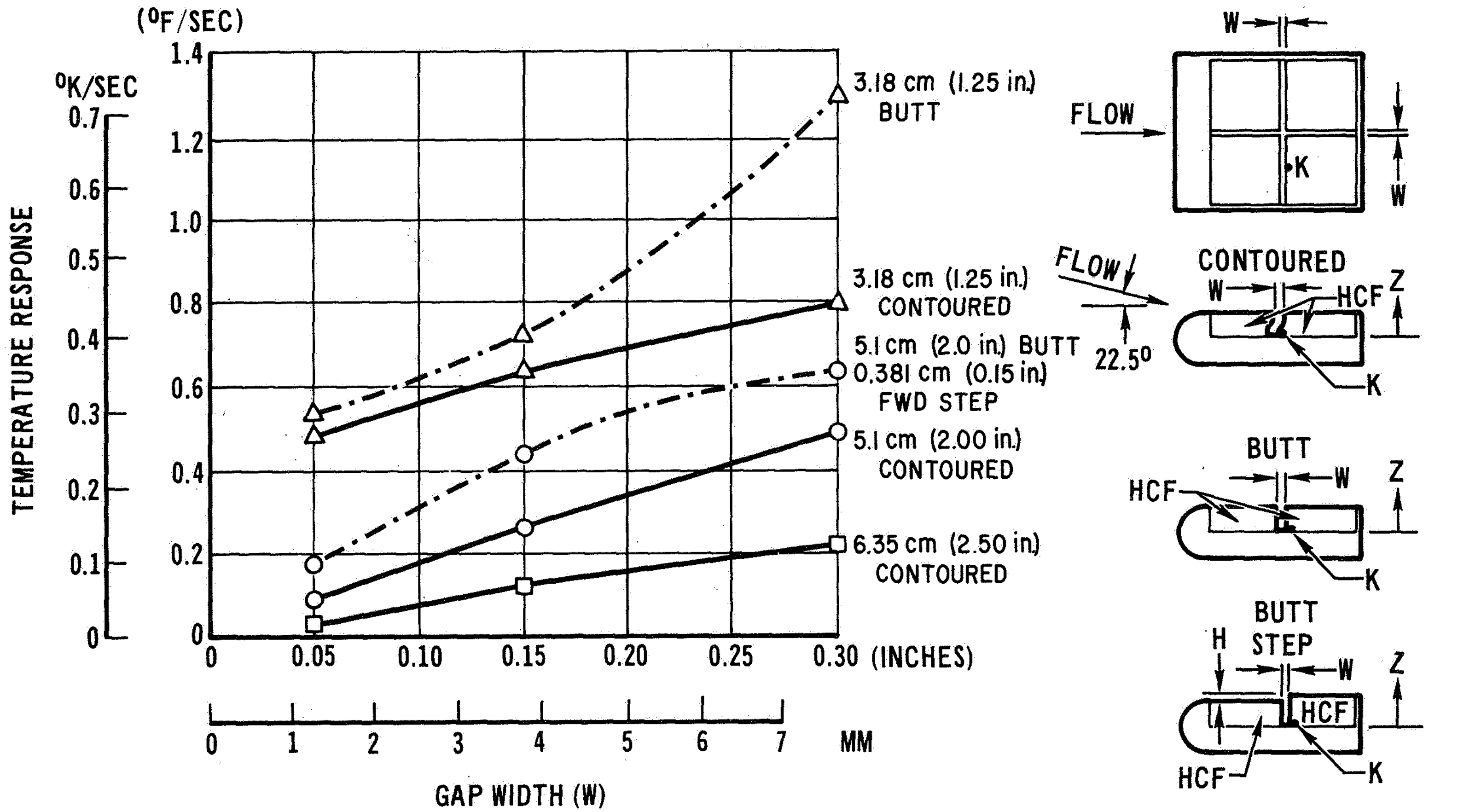
BONDLINE HEAT-UP IN TRANSVERSE GAPS (LOCATION K)

(Figure 10)

The effect of tile thickness on bondline heat-up for the transverse gap is shown in figure 10. As can be seen by examining the contoured joint data, a significant improvement in heat protection is provided by the thicker tiles. A comparison can be made between butt and contoured joints. The heat-up rate for the butt joint is more severe, especially for wider gaps.

BONDLINE HEAT-UP IN TRANSVERSE GAPS (LOCATION K)

(CONTOURED, BUTT, BUTT-STEP JOINTS)



- MSC 10 MW ARC TUNNEL
- HCR ORBITER AREA 2P HEATING ENVIRONMENT
- TEMPERATURE MEASURED AT BONDLINE
- 0.127 cm (0.050 in.) Ti MOUNTING AND BASE PLATES

H = 0.381 cm (0.15 in.)
PARALLEL GAP = 0.127 cm (0.05 in.)

Figure 10

TEMPERATURE RESPONSE IN PARALLEL GAP OF 3.18 CM (1.25 INCH)
BUTT AND CONTOURED JOINTS

(Figure 11)

The same trend holds for the parallel gap--for large gaps the contoured gap provides improved heat protection over a butt joint. Another conclusion that can be drawn from these data is that small gaps are necessary to limit convective heating in the gaps.

TEMPERATURE RESPONSE IN PARALLEL GAP OF 3.18 cm (1.25 in) BUTT AND CONTOURED JOINTS

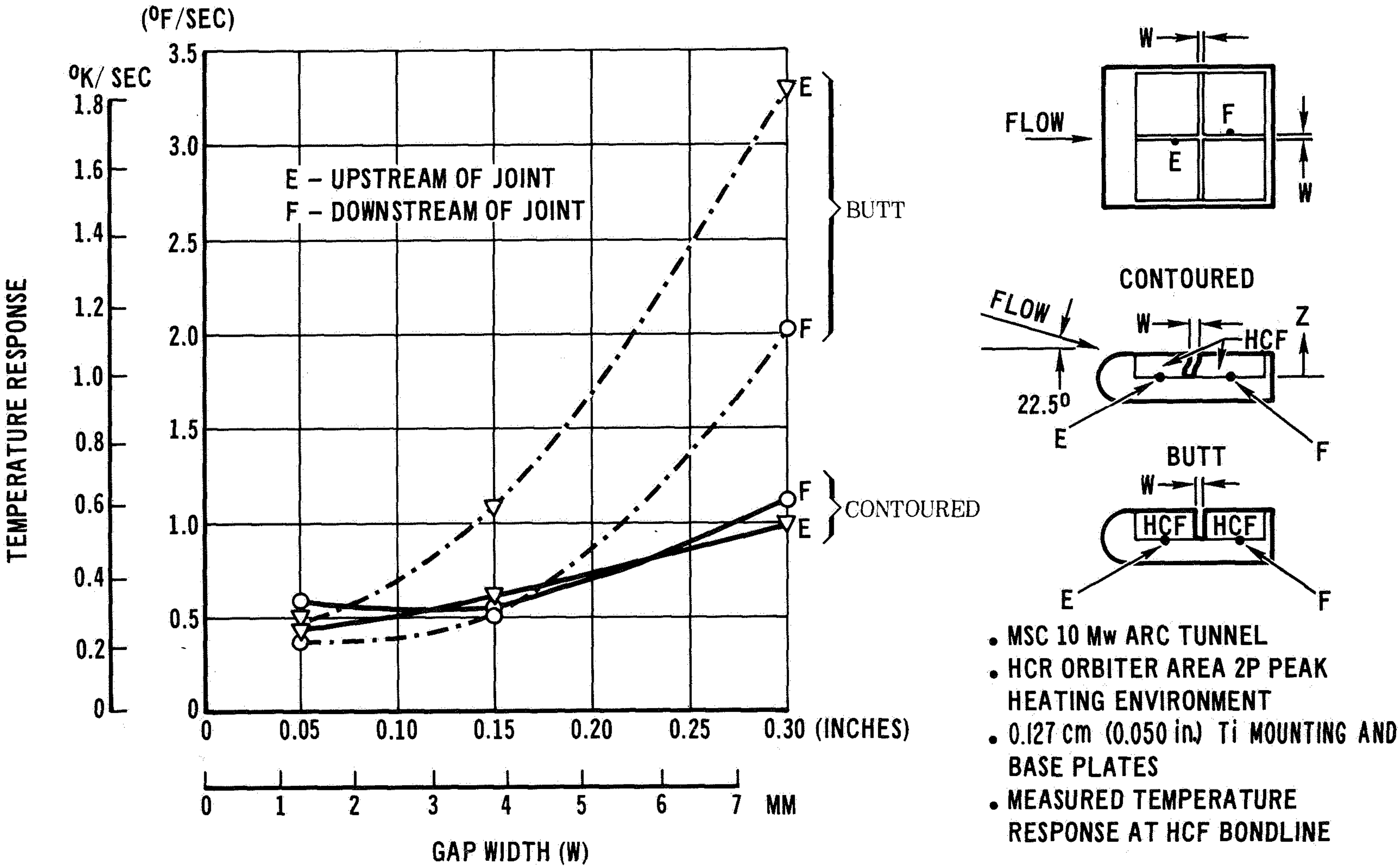


Figure 11

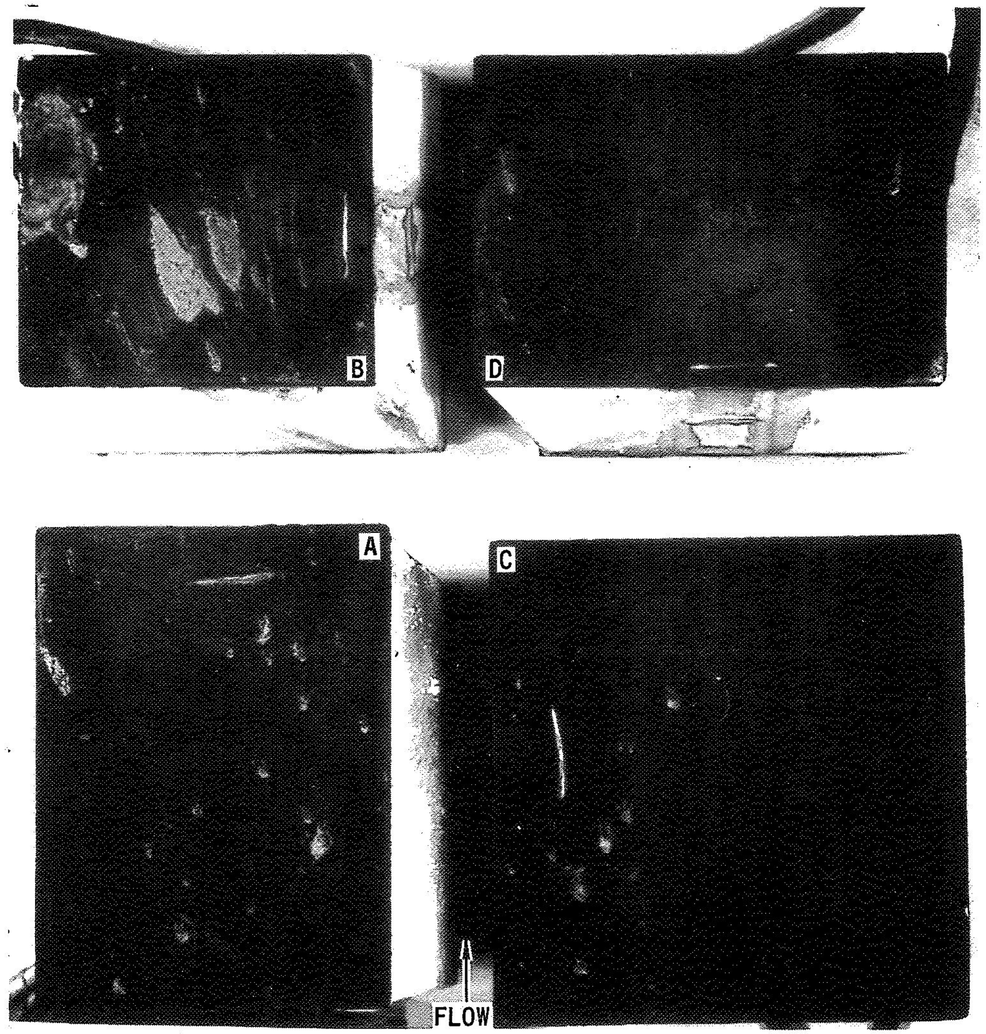
PLASMA WEDGE SPECIMENS - CONTOURED JOINT

(Figure 12)

Photographs of the joint models are very valuable in understanding the flow in the gaps. Residue from the Arc tunnel flow field deposited on the tiles and provides a visual picture of the flow in the gap and across the surface of the wedge. It appears that flow in the transverse gap emanates from the intersection of the tiles and that there was a slight diverging of the flow over the wedge.

PLASMA WEDGE SPECIMENS - CONTOURED JOINT

(HCF JOINT TESTING)



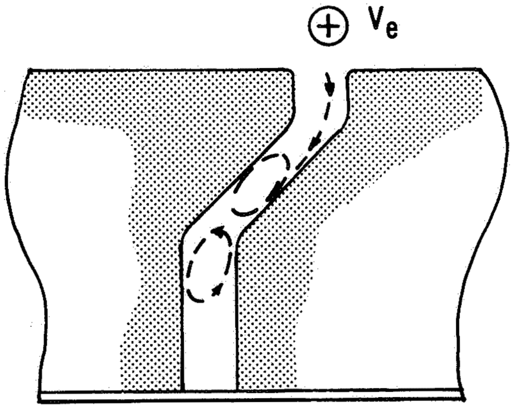
5.08 cm (2.00 in.) TILE THICKNESS

SCHEMATIC OF FLOW WITHIN CONTOURED JOINT

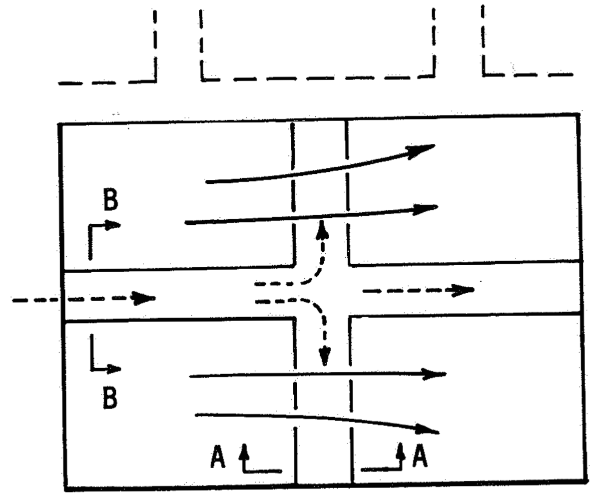
(Figure 13)

The flow field within the RSI joint, especially at the intersection of tiles, is complex. As depicted in figure 13, boundary layer flow tends to penetrate the parallel gap, setting up recirculation patterns. At the tile intersection, flow in the transverse gap is initiated, adding to the recirculation in the transverse gap. The gas outflow in the transverse gap is also caused by the diverging flow over the wedge. The test configuration is also representative of the staggered tile pattern in that the ends of the gaps are blocked.

SCHEMATIC OF FLOW WITHIN CONTOURED JOINT

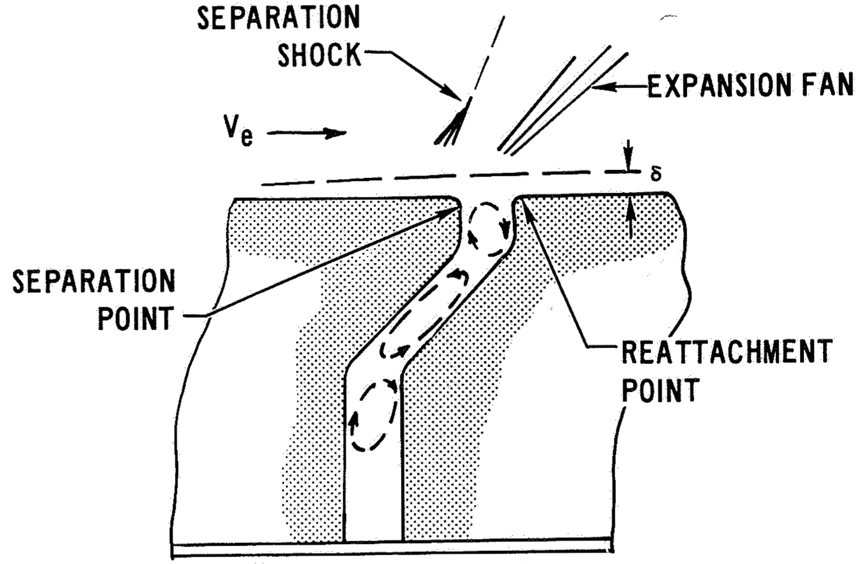


PARALLEL GAP (B–B)



PLAN VIEW

- 3–D RECIRCULATION AT LOWER VERTICAL FACE OF CONTOURED JOINT
- FLOW IN TRANSVERSE GAP INITIATED AT TILE INTERSECTION



TRANSVERSE GAP (A–A)

Figure 13

ANALYSIS OF GAP HEATING TESTS

(Figure 14)

Convective heating rates down the sides of the tiles were derived by constructing thermal models of the joint and feeding the measured temperature responses into the MDAC-E General Heat Transfer computer program. The inorganic coating on the HCF, the HCF, adhesive and carrier plate for opposing tiles were divided into thermal nodes. Heat storage and conduction links were defined for each node. In addition to radiative exchange with space, an automated view factor calculation was used to describe radiative exchange between tiles. Temperature responses of each thermocouple were recorded on magnetic tape during the tests at MSC and then fed directly into our computer for the heating calculation. Heating distributions have been calculated for the contoured, butt, and butt step joints and will be discussed in the next several figures. The effect of these heating distributions in upstream parallel gaps, downstream parallel gaps, and transverse gaps is assessed next, followed by a comparison with several analytical prediction methods.

ANALYSIS OF GAP HEATING TESTS

- THERMAL MODEL OF JOINT (2–D)
  - 84 NODE FINITE ELEMENT
  - THERMAL CONDUCTION AND HEAT STORAGE
  - RADIATION EXCHANGE BETWEEN FACES OF JOINT AND TO SPACE
  - AUTOMATICALLY PROCESSED MEASURED TEMPERATURES FROM MAGNETIC TAPE INTO TRANSIENT COMPUTER PROGRAM
  - INVERSE SOLUTION TO OBTAIN HEATING RATES ON FACES OF TILES
- DATA ANALYZED

  5.1 cm (2.0 in.) CONTOURED JOINT
  - THREE GAP SETTINGS
  - GAP PARALLEL TO FLOW – UPSTREAM
  - GAP PARALLEL TO FLOW – DOWNSTREAM
  - TRANSVERSE GAP

    3.18 cm (1.25 in.) BUTT AND 5.1 cm (2.0 in.) BUTT WITH FWD STEP
- COMPARISON OF DERIVED HEATING DISTRIBUTION WITH SEVERAL THEORIES

Figure 14

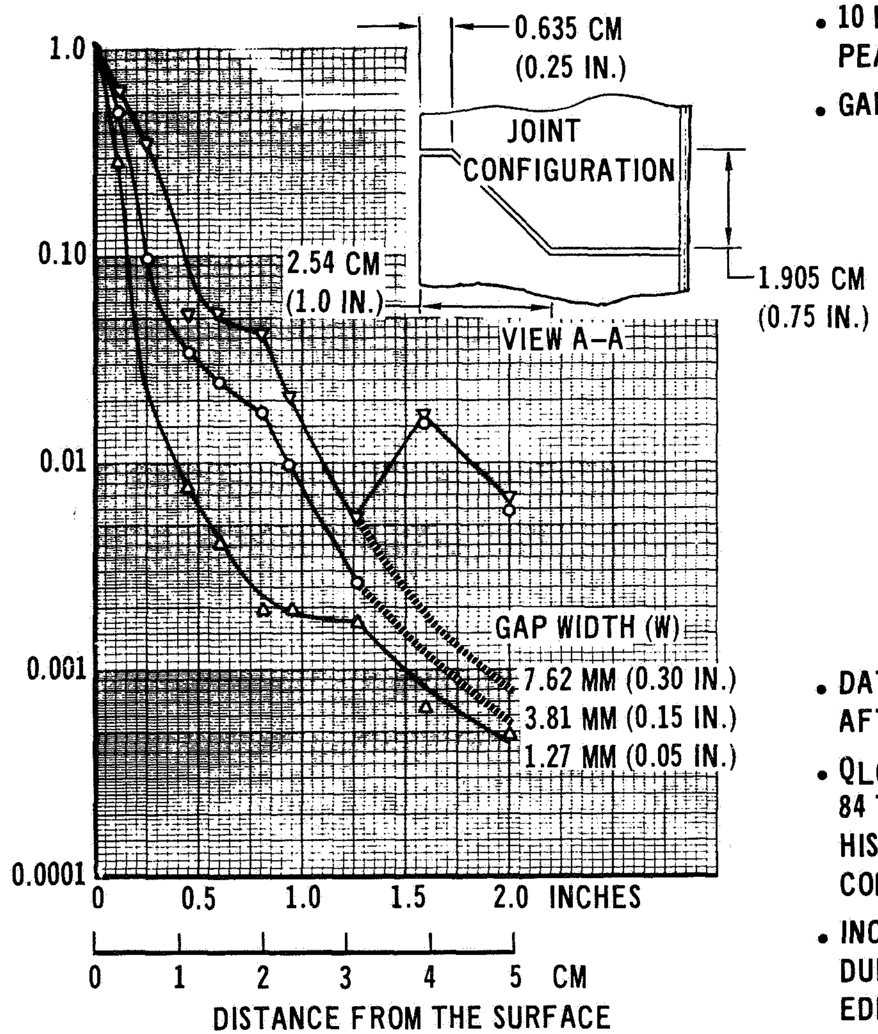
CONVECTIVE HEATING IN UPSTREAM GAP

(Figure 15)

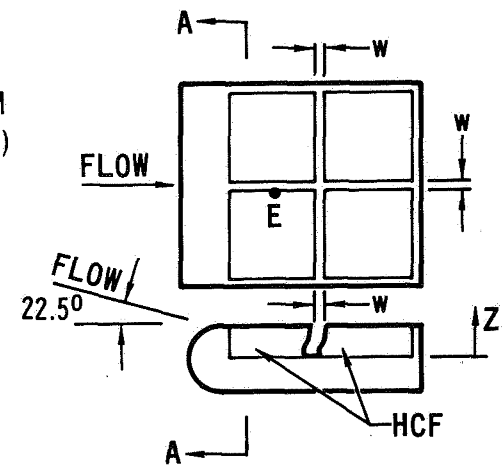
The heating distribution in the upstream parallel gap is presented in figure 15.

At location E, the heating distribution for gap settings of 0.127, 0.381, and 0.762 cm (0.05, 0.15, and 0.30 inch) gaps are shown. There is a considerable difference in heating in the first half inch down into the gap for the various gaps tested. The heating deep into the gap is very low and indicates a recirculating flow field.

CONVECTIVE HEATING IN UPSTREAM GAP
(LOCATION E)



- 5 CM (2.0 IN.) CONTOURED HCF JOINT
- 10 MW ARC TUNNEL, HCR ORBITER PEAK HEATING CONDITIONS
- GAP ANALYZED: PARALLEL TO FLOW AT LOCATION E



- DATA FOR TEST TIME IMMEDIATELY AFTER EXPOSURE TO PLASMA STREAM
- Q_{LOCAL} SOLVED FOR BY INVERSE SOLUTION, 84 THERMAL NODE, MEASURED TEMPERATURE HISTORIES ON GENERAL HEAT TRANSFER COMPUTER PROGRAM
- INCREASE IN HEATING DOWN IN GAP MAY BE DUE TO A SECOND RECIRCULATION OR EDDY FLOW.

Figure 15

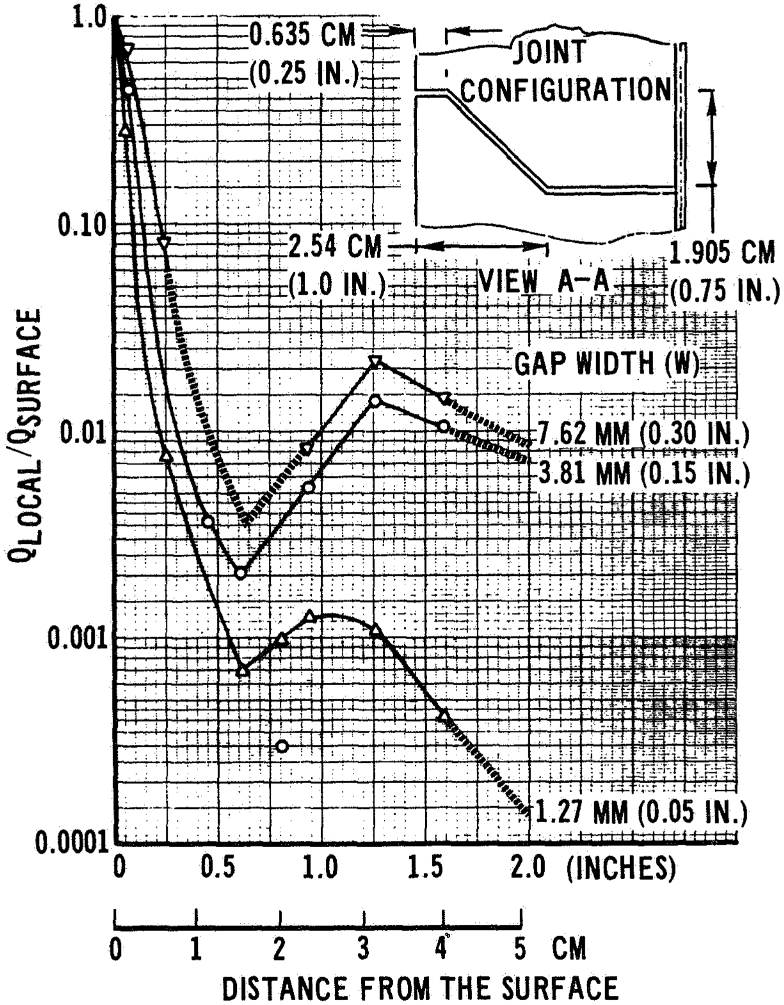
CONVECTIVE HEATING IN DOWNSTREAM GAP

(Figure 16)

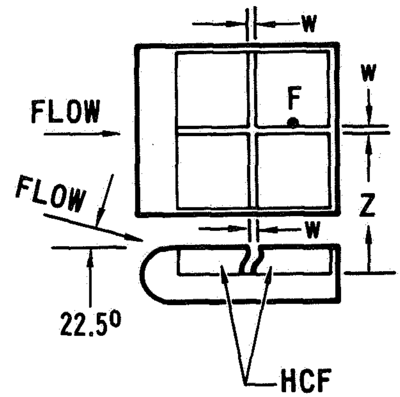
The heating distributions in the downstream parallel gap are similar to the upstream gap but drop off more sharply. This may be due to the slowing of the flow because of the close-out of the cavity downstream and the diverting of flow into the transverse gap. These heating distributions also show the effects of recirculation.

CONVECTIVE HEATING IN DOWNSTREAM GAP

(LOCATION F)



- 5.1 cm (2.0 in.) CONTOURED HCF JOINT
- 10 MW ARC TUNNEL, HCR ORBITER PEAK HEATING CONDITIONS
- GAP ANALYZED: PARALLEL TO FLOW AT LOCATION F



- Q_{LOCAL} SOLVED FOR BY INVERSE SOLUTION, 84 THERMAL NODE, MEASURED TEMPERATURE HISTORIES ON GENERAL HEAT TRANSFER COMPUTER PROGRAM.

Figure 16

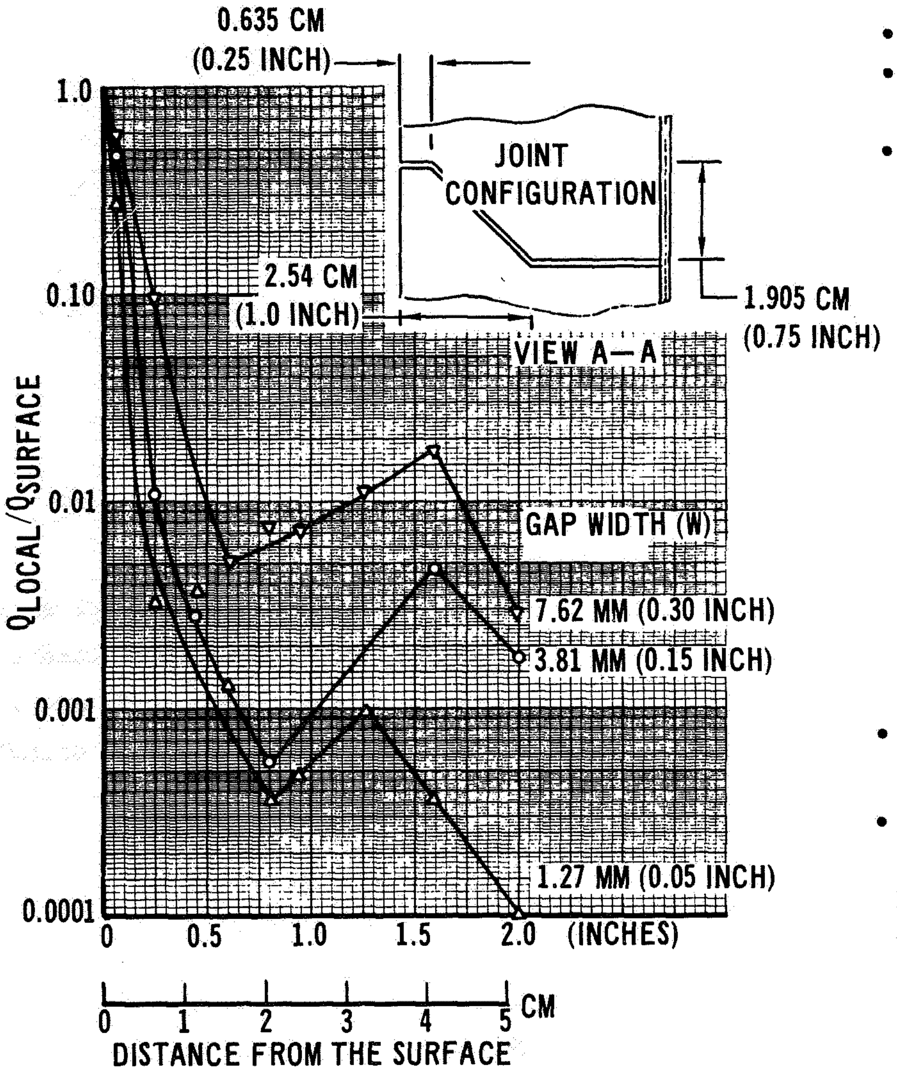
CONVECTIVE HEATING IN TRANSVERSE GAP

(Figure 17)

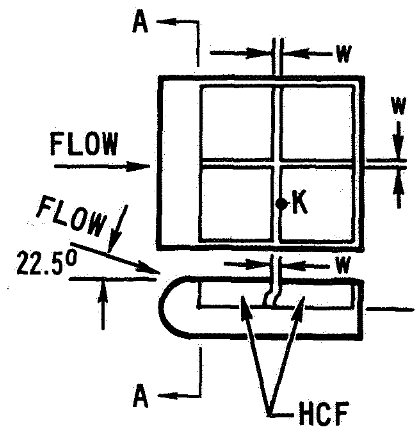
In the transverse gap, recirculation is also evident and the heating is only lower for the thin gaps 0.127 and 0.381 cm (0.05 and 0.15 inch) as compared with the parallel gap.

CONVECTIVE HEATING IN TRANSVERSE GAP

(LOCATION K)



- 5 CM (2.0 IN.) CONTOURED HCF JOINT
- 10 MW ARC TUNNEL, HCR ORBITER PEAK HEATING CONDITIONS
- GAP ANALYZED: TRANSVERSE TO FLOW AT LOCATION K



- DATA FOR TEST TIME IMMEDIATELY AFTER EXPOSURE TO PLASMA STREAM
- Q_{LOCAL} SOLVED FOR BY INVERSE SOLUTION, 84 THERMAL NODE, MEASURED TEMPERATURE HISTORIES ON GENERAL HEAT TRANSFER COMPUTER PROGRAM.

Figure 17

CONVECTIVE HEATING DISTRIBUTIONS IN TRANSVERSE GAPS OF 3.18 CM (1.25 INCH) BUTT JOINT MODEL

(Figure 18)

The heating distributions for the butt and butt with a forward facing step are shown in figures 18 and 19. These heating distributions do not indicate as strong a recirculation effect as for the contoured joint. The heating distribution for the upstream and downstream faces of the transverse gap are quite similar. It should be noted that these data are for 3.18 cm (1.25 inch) thick tiles.

CONVECTIVE HEATING DISTRIBUTIONS IN TRANSVERSE GAP OF 3.18cm (1.25 in.) BUTT JOINT MODEL

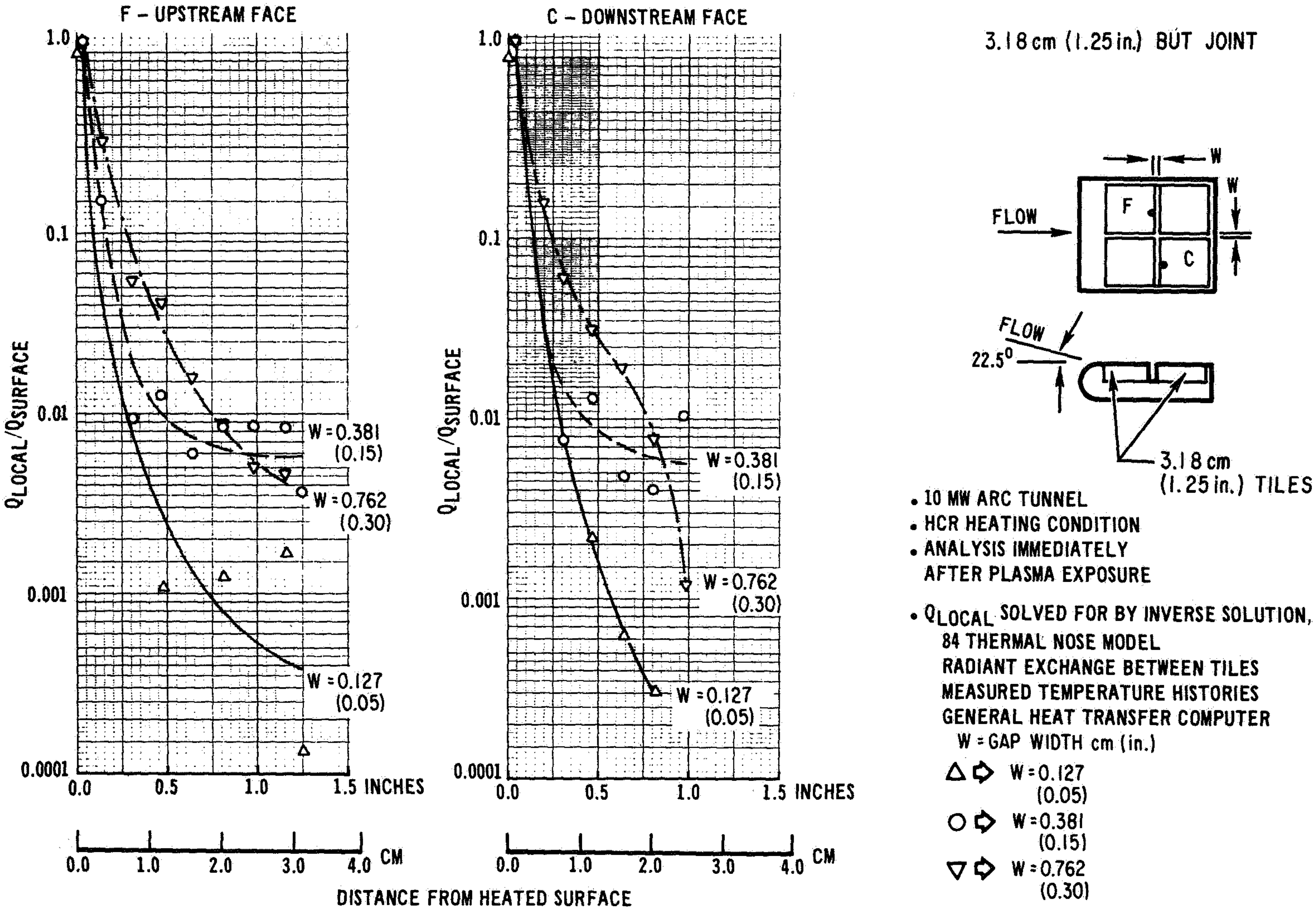


Figure 18

CONVECTIVE HEATING DISTRIBUTIONS IN TRANSVERSE GAP OF BUTT-STEP MODEL

(Figure 19)

The effect of a forward facing step on the heating distribution in the transverse gap are shown in figure 19. The model tested was a 5.1 cm (2.00 inch) tile with a 0.381 cm (0.15 inch) forward facing step. The parallel gap was held at a constant 0.127 cm (0.05 inch) on this model. The heating on the downstream face was slightly higher than on the upstream (or shadowed) face of the joint. The heat distributions deep within the gap show a slight upturn and this may or may not be a real effect. The drop-off in heating rate in the gap has somewhat of a similar shape as hypothesized for a 2-D recirculation pattern.

Sensitivity studies were performed on the heating calculations to determine the effect of thermocouple location and changes in HCF thermal conductivity. A random 0.076 cm (± 0.03 inch) relocation of thermocouples and a ± 5% change in HCF conductivity caused less than a 10% shift in heating near the surface and less than 50% shift deep within the joint. This magnitude of accuracy on heating rates is well within normal experiented tolerances.

CONVECTIVE HEATING DISTRIBUTIONS IN TRANSVERSE GAP OF BUTT-STEP MODEL

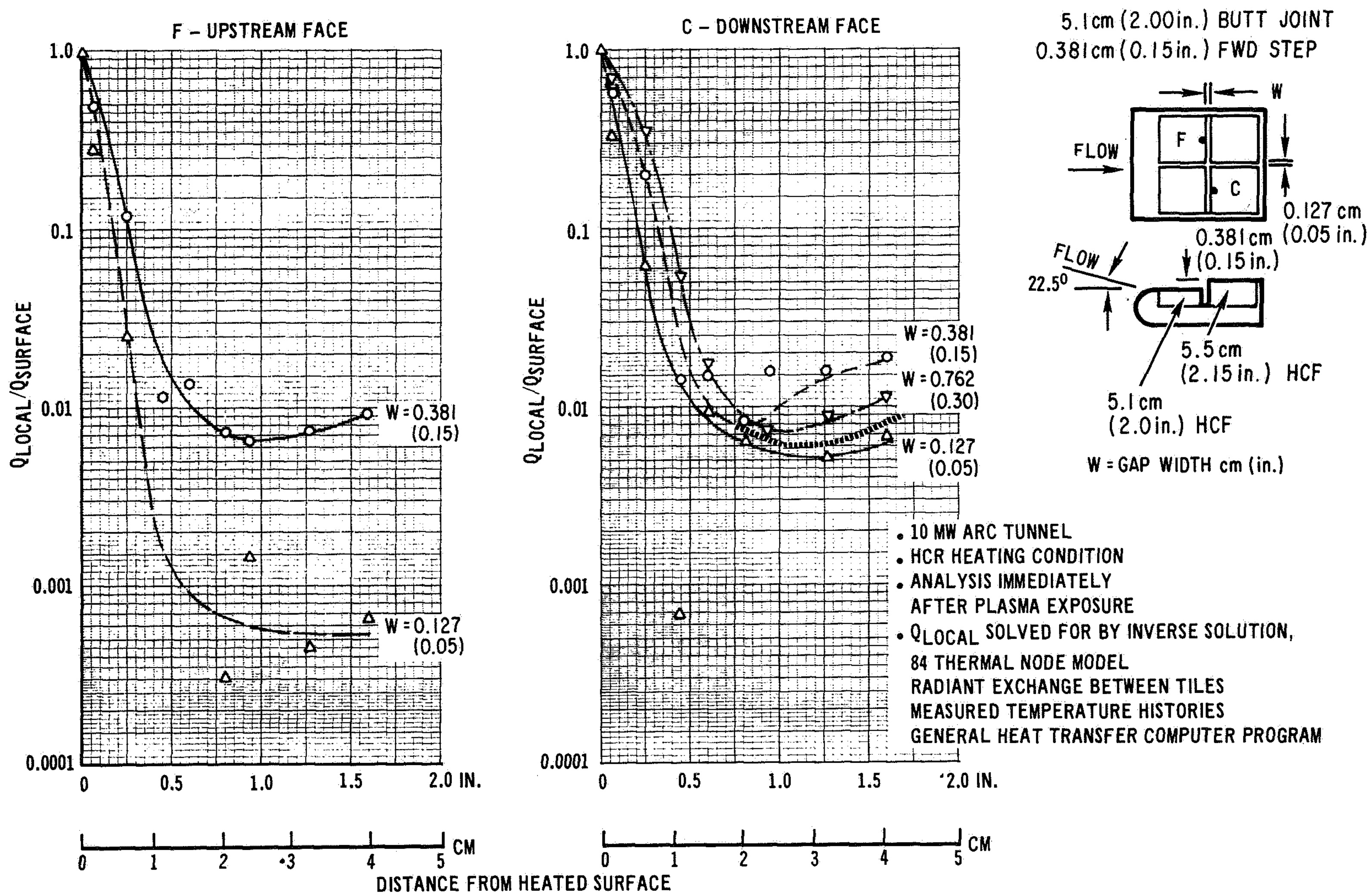


Figure 19

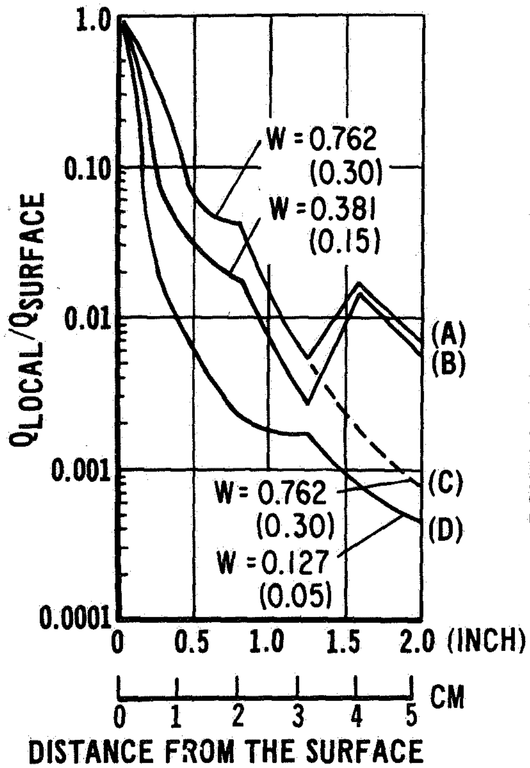
SENSITIVITY OF TPS HEAT-UP TO GAP HEATING DISTRIBUTIONS DERIVED FROM ARC TUNNEL TESTS

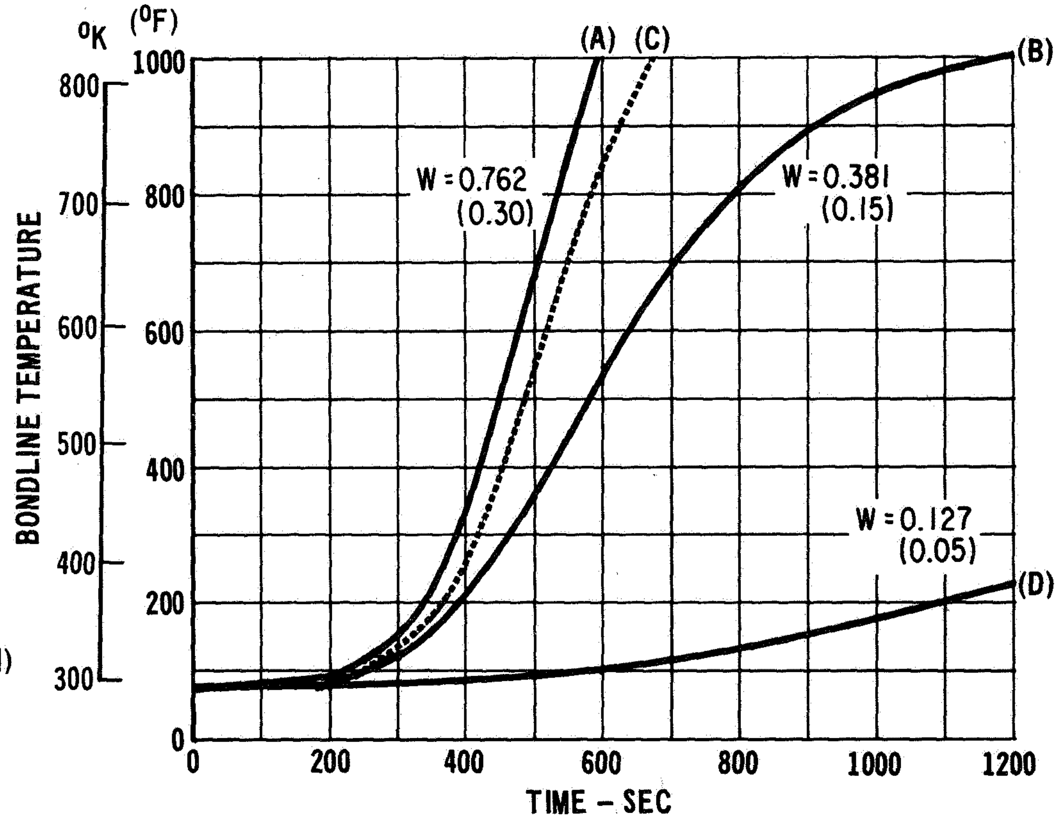
(Figure 20)

The data in figure 20 were computed to obtain a feel for the effects of the derived heating distributions on bondline temperature response for an orbiter entry. The high cross range 2P-1530°K (2300°F) maximum surface heat pulse was applied to the thermal model of a 5.1 cm (2.0 inch) HCF-TPS with a contoured joint with the heating distributions we have derived. As can be seen for the 0.127 cm (0.05 inch) gap heating distribution, the bondline at the base of the joint did not experience an excessive temperature rise. The 0.381 cm (0.15 inch) gap resulted in a very hot condition and the 0.762 cm (0.3 inch) gap was catastrophic. The differences in the heating magnitudes within the first 1.27 cm (0.5 inch) down the gap attributes to the difference in bondline response. The effect of the recirculation deep within the joint is minimal as can be seen by comparing temperatures for curves (A) and (C).

It should be noted that the temperature response shown in figure 20 is a result of radiation transport from the faces of the tiles to the bottom of the gap as well as convective heating.

SENSITIVITY OF TPS HEAT-UP TO GAP HEATING DISTRIBUTIONS DERIVED FROM ARC TUNNEL TESTS





W = GAP WIDTH cm (in.)

1) HEATING DESTRIBUTION OBTAINED FROM 5.1 cm (2.0 in.) CONTOURED HCF TILE TESTS
2) AREA 2P – 1530° K (2300° F) HEAT PULSE

3)

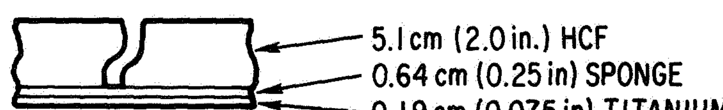


Figure 20

COMPARISON OF DERIVED HEATING DISTRIBUTIONS WITH SEVERAL THEORIES

(Figure 21)

Four analytical methods for predicting heating within the gap (primarily the transverse gap) were applied to the Arc tunnel test conditions.

The method by Hanner[1] as we applied it considers gap width to depth ratio and the effects of boundary displacement thickness. The computed heating rate in the gap is also only applied one gap width down into the gap. The Hanner predictions tend to be greater than a heating ratio of unity.

The method by Hodgson[2] is for a laminar boundary layer and involves reattachment lengths as well as velocity distributions and a derived Stanton Number-Reynolds Number heating distribution. The calculations using the method of Hodgson produced a heating distribution in the gap but the heating did not drop off as rapidly as was measured.

The method by Brewer et al.[3] considers the energy flux across the gap opening as compared with energy flux for attached flow and the gap width to height ratio to obtain heating at the bottom of the gap.

Burggraf's[4] method was also examined but it is only applicable for high Reynolds Number, according to Burggraf.

From these comparisons, it is evident that a refined prediction procedure is needed.

COMPARISON OF DERIVED HEATING DISTRIBUTIONS WITH SEVERAL THEORIES

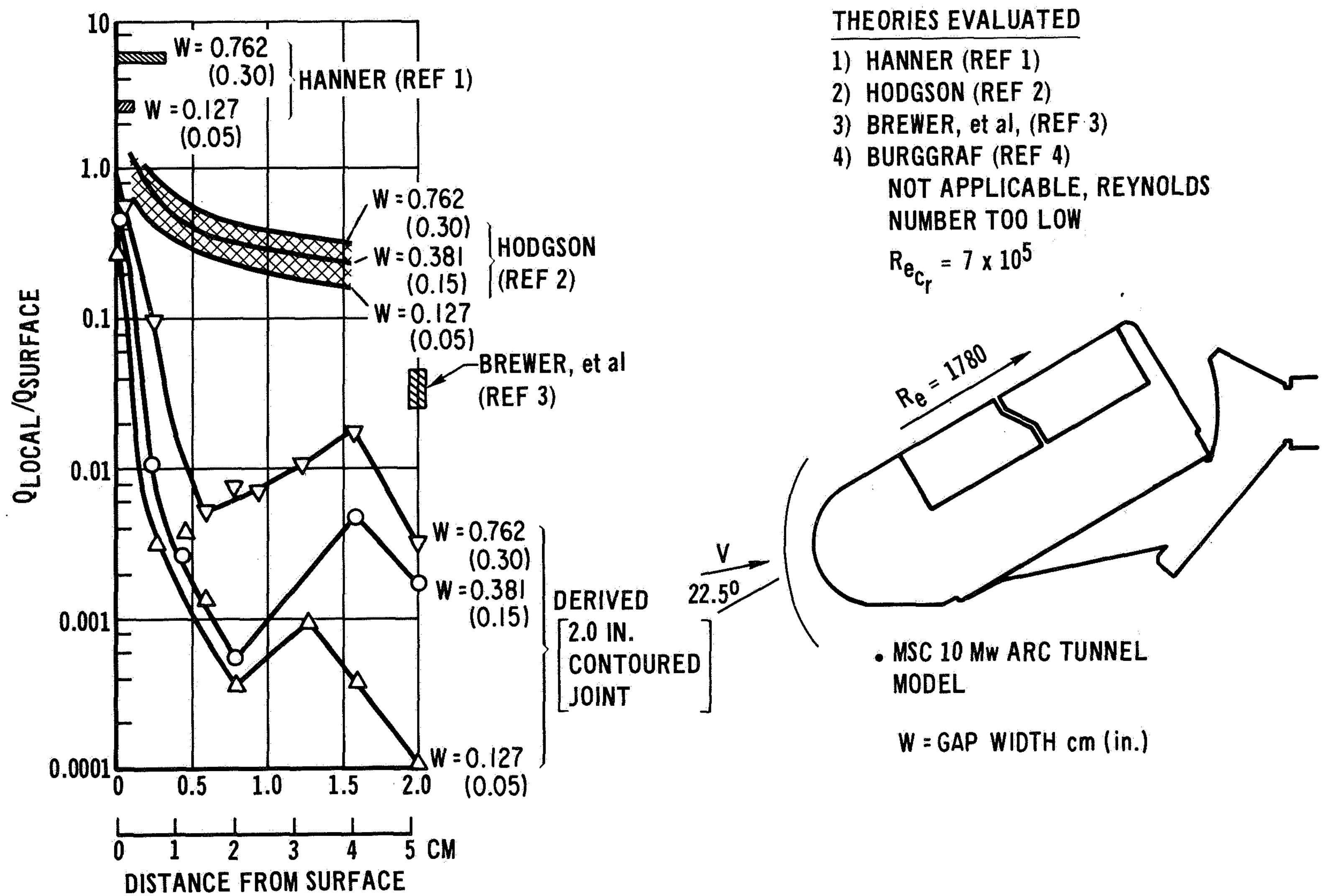


Figure 21

SIDE VIEW OF MSC CHANNEL NOZZLE WITH MDAC-E RSI JOINT
CONTAINER AND ADAPTER

(Figure 22)

In the next series of Arc tunnel tests at NASA-MSC, the channel nozzle will be used because it produces a more uniform heating distribution on the panel than can be obtained with a wedge. The channel nozzle produces a Mach 4 laminar flow with an approximate 0.64 cm (1/4 inch) thick boundary layer. An adapter was fabricated for the nozzle to house the joint test container used in the wedge test setup. The adapter has quick disconnects for thermocouples and pressure transducers (for measuring pressure gradients at the bottom of the joint). Air lines are provided to cool the model to room temperatures between tunnel runs which reduces dead time.

The adapter also contains access ports for setting the gaps between tunnel runs. This also improves test efficiency.

SIDE VIEW OF MSC CHANNEL NOZZLE WITH MDAC- E RSI JOINT CONTAINER AND ADAPT R

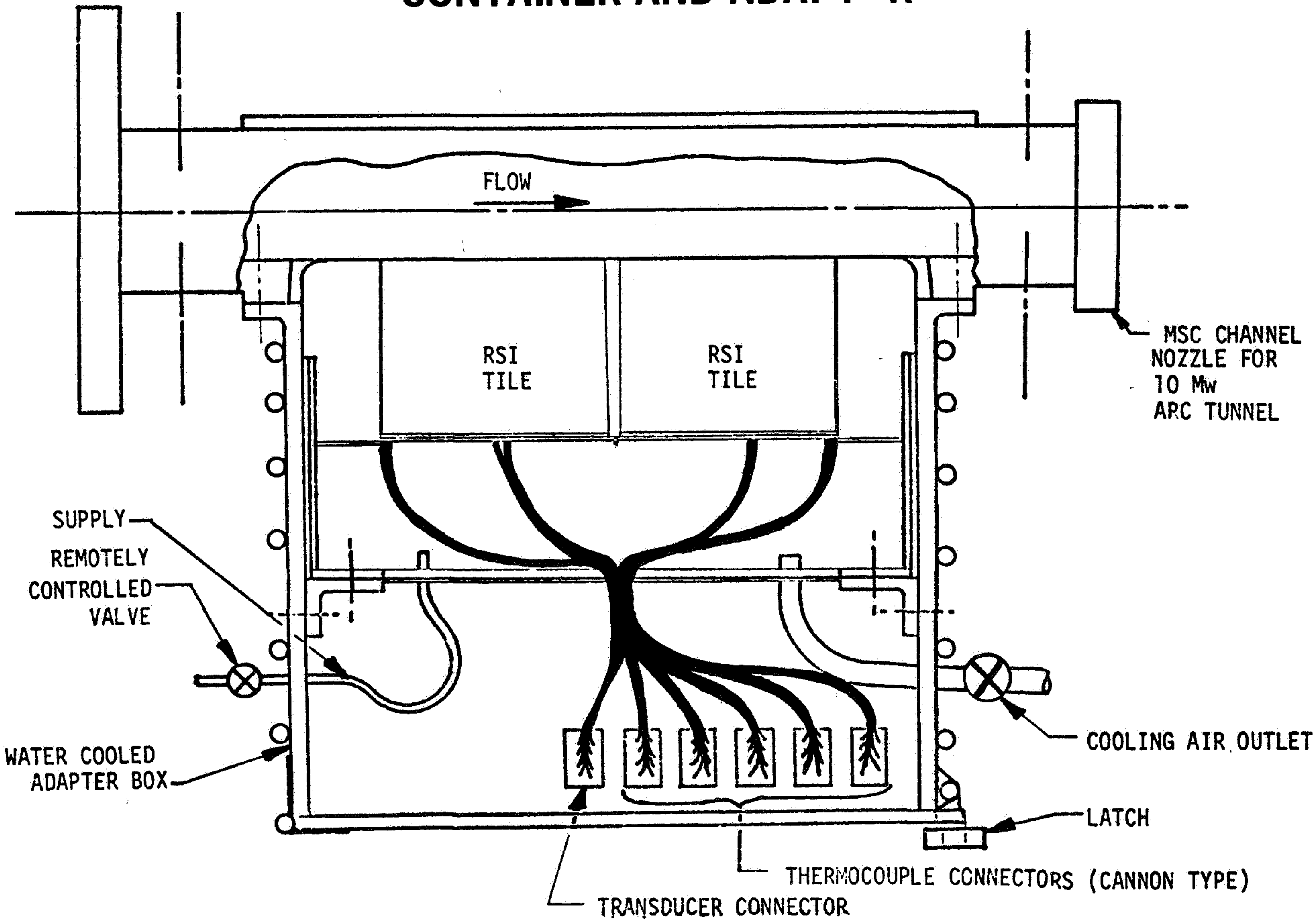


Figure 22

ADAPTER FIXTURE FOR MSC 10 MW CHANNEL NOZZLE

(Figure 23)

The adapter also contains accessports for setting the gaps between tunnel runs. This also improves test efficiency.

ADAPTER FIXTURE FOR MSC 10 MW CHANNEL NOZZLE

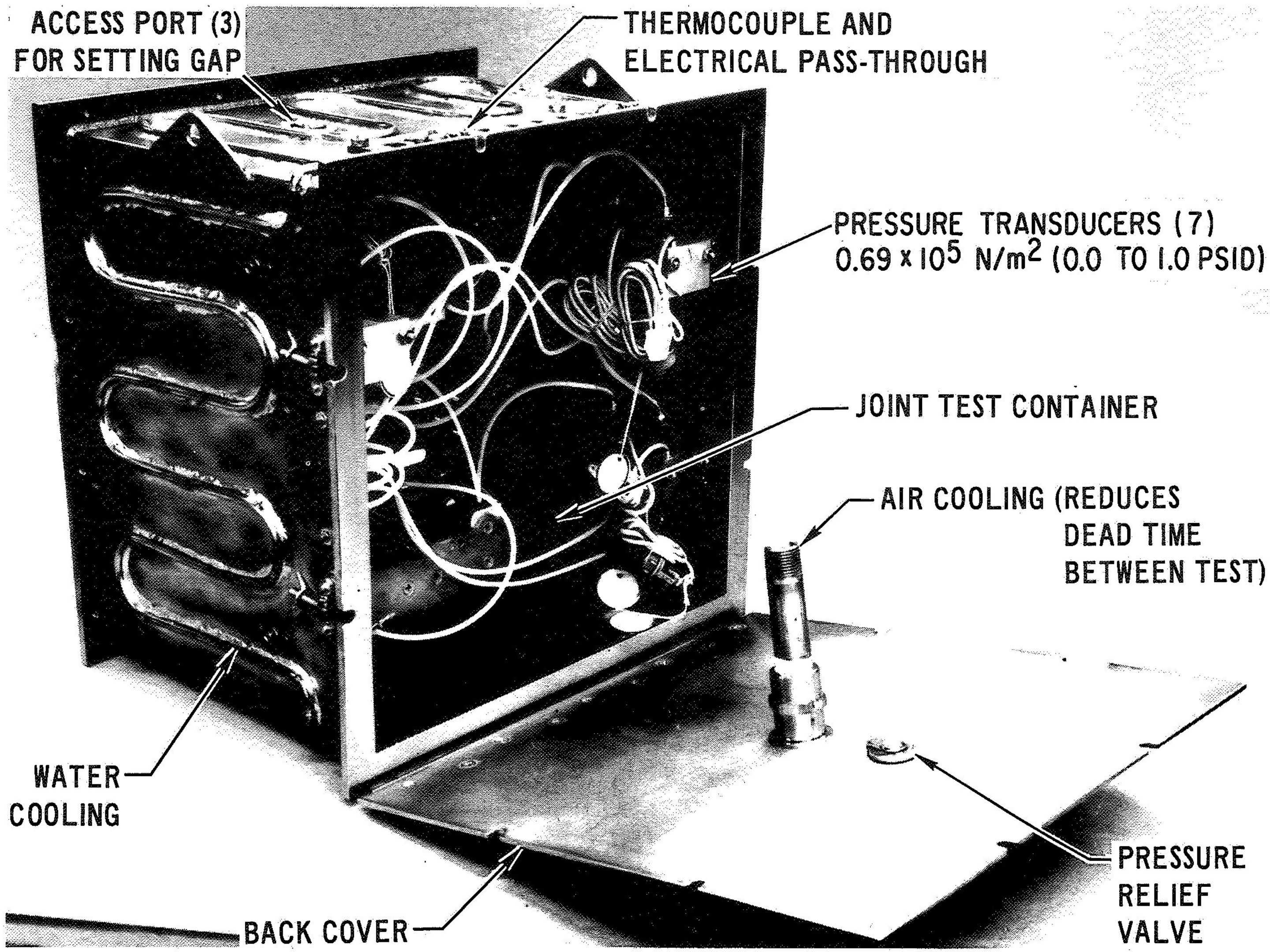


Figure 23

ADAPTER, HCF GUARDS, AND TILE SET (11) FOR MSC 10 MW ARC TUNNEL TESTS

(Figure 24)

Figure 24 is a view of the adapter as would be seen "so to speak" by the flow in the channel nozzle. There are four guards surrounding a tile set and as with the previous test configurations the tile sets are interchangeable.

ADAPTER, HCF GUARDS, AND TILE SET (11) FOR MSC 10 MW ARC TUNNEL TESTS

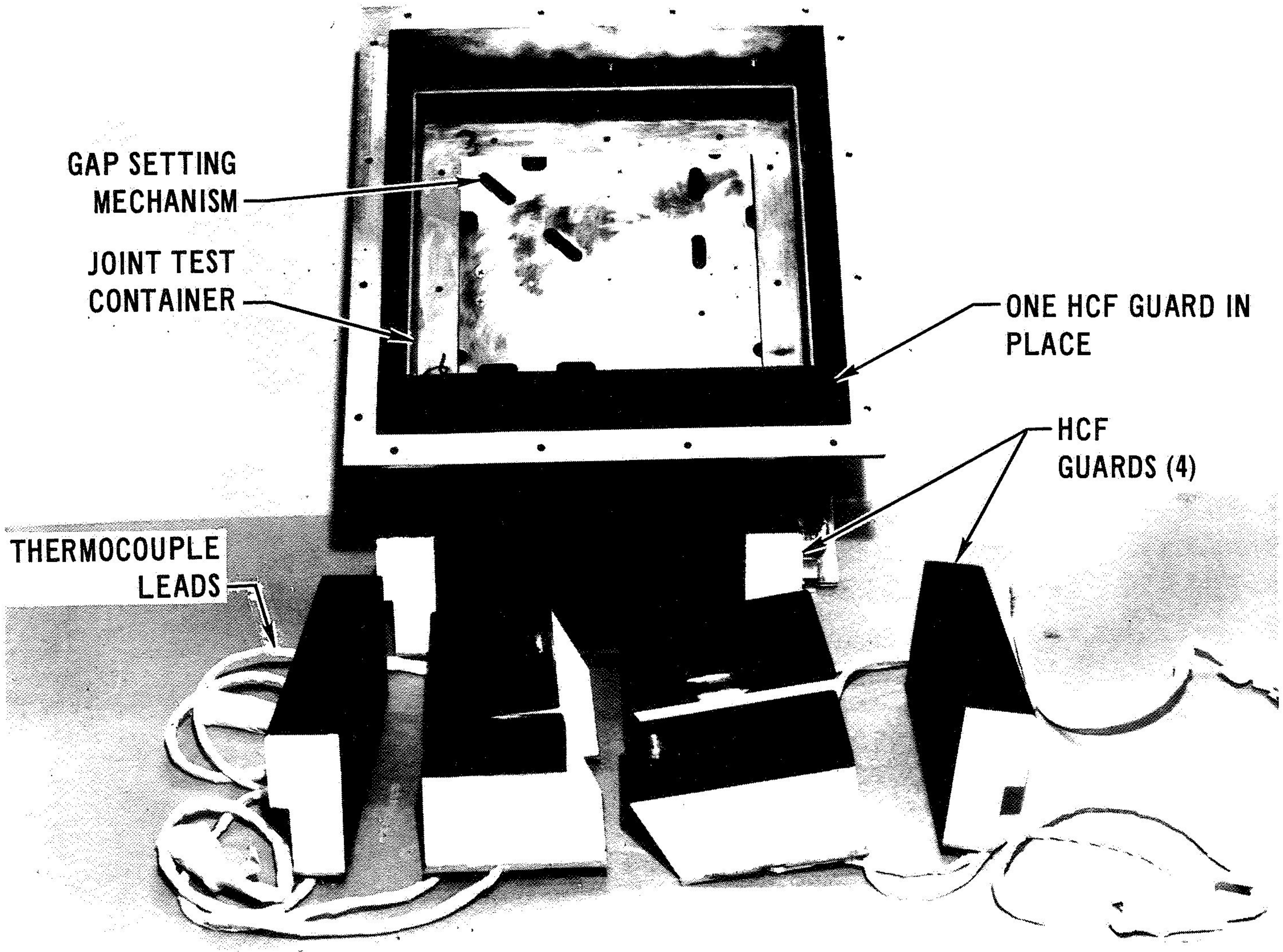


Figure 24

RSI-TPS WIND TUNNEL CONFIGURATION (CFHT AT LaRC)

(Figure 25)

To complement the Arc tunnel data, a wind tunnel test program will be conducted in Langley's CFHT Mach 10 facility. The purpose of these tests is to study the heating on the faces of a tile for a thick boundary layer as a function of gap width, tile mismatch, and flow orientation. The center tile is a heavily instrumented thin skin model being fabricated at LaRC. Tests will be performed on the side wall of the tunnel which has a boundary layer thickness of 5.1 to 10.2 cm (2 to 4 inches). The panel can also be tested in the Unitary Plan tunnel at LaRC providing an adapter to one of their tunnel doors can be made available. Testing in the Unitary tunnel would provide data at lower Mach numbers and variation in Reynolds number.

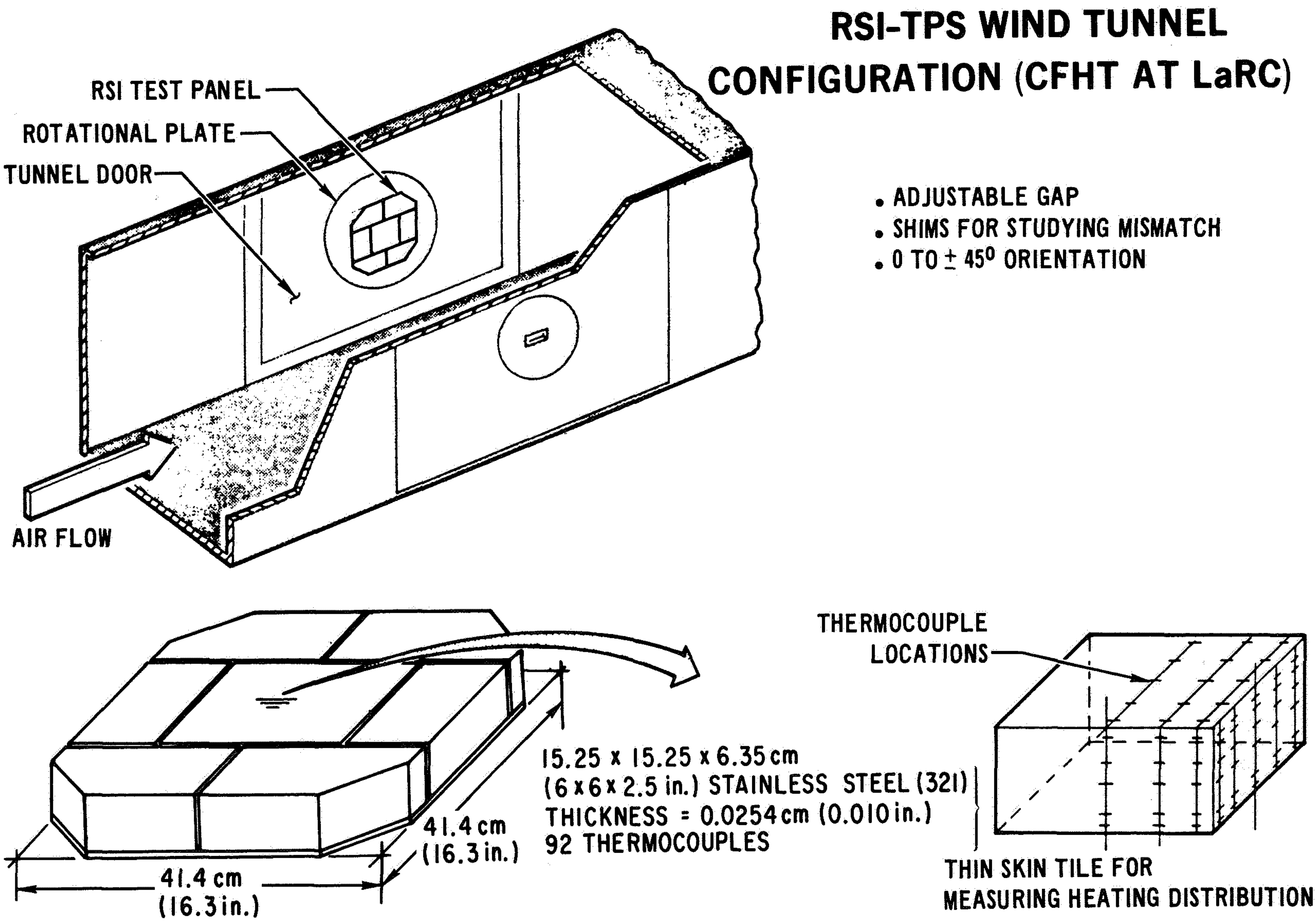

RSI-TPS WIND TUNNEL CONFIGURATION (CFHT AT LaRC)
RSI TEST PANEL
ROTATIONAL PLATE
TUNNEL DOOR
AIR FLOW
• ADJUSTABLE GAP
• SHIMS FOR STUDYING MISMATCH
• 0 TO ± 45⁰ ORIENTATION
THERMOCOUPLE LOCATIONS
15.25 x 15.25 x 6.35 cm (6 x 6 x 2.5 in.) STAINLESS STEEL (321)
THICKNESS = 0.0254 cm (0.010 in.)
92 THERMOCOUPLES
41.4 cm (16.3 in.)
41.4 cm (16.3 in.)
THIN SKIN TILE FOR MEASURING HEATING DISTRIBUTION

Figure 25

METALLIC COMPONENTS FOR THE WIND TUNNEL TESTS OF RSI-TPS

(Figure 26)

The metallic components (minus the thin skin tile) are shown in figure 26. Tile height adjustment is accomplished by shims and each tile is mechanically attached to the adapter. Spacers for the edge of the adapter are used to maintain uniform gap over the entire panel. Tests will be performed at four gap settings.

METALLIC COMPONENTS FOR THE WIND TUNNEL TESTS OF RSI-TPS

(MACH 10 CONTINUOUS FLOW HYPERSONIC TUNNEL)

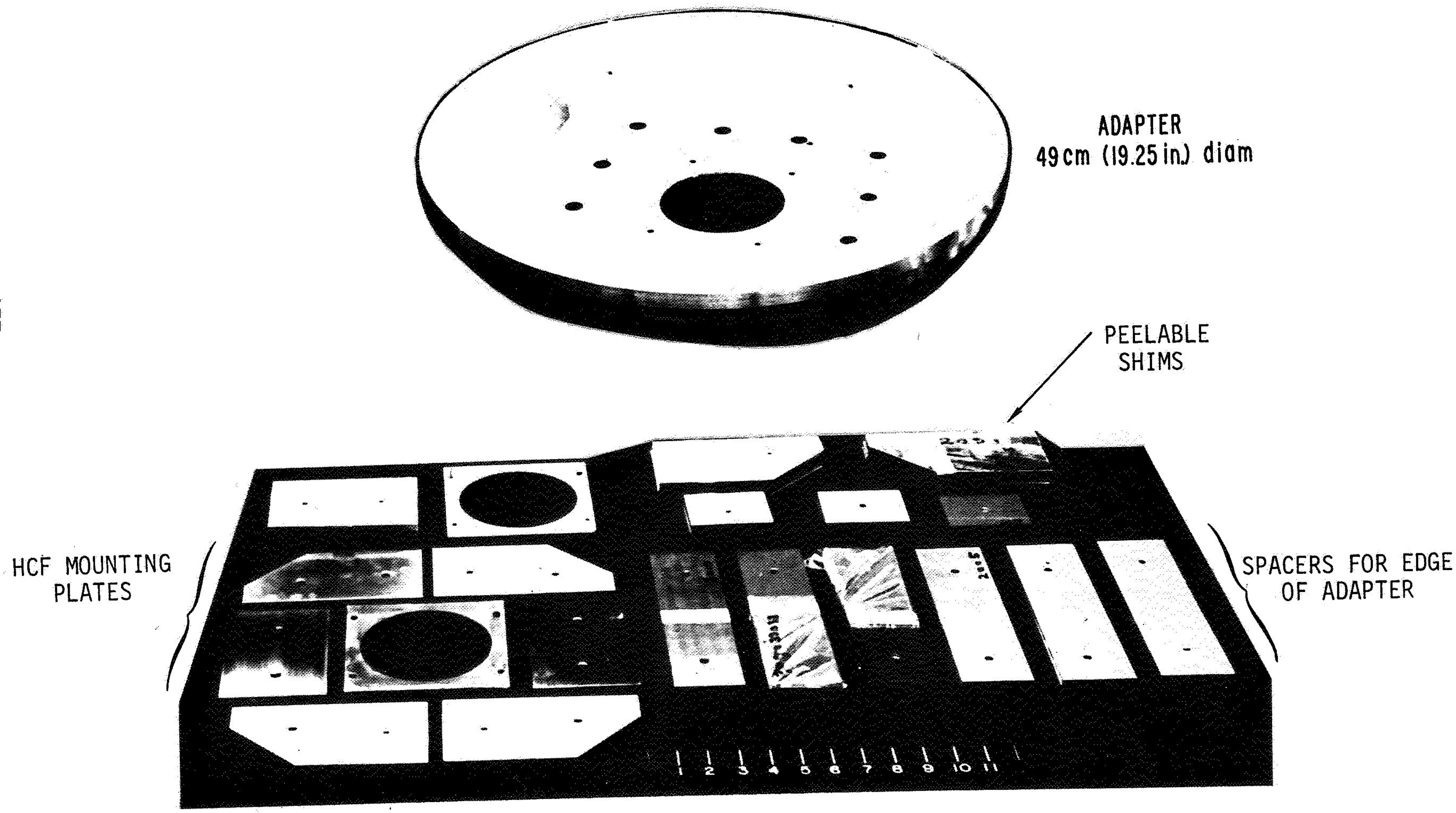


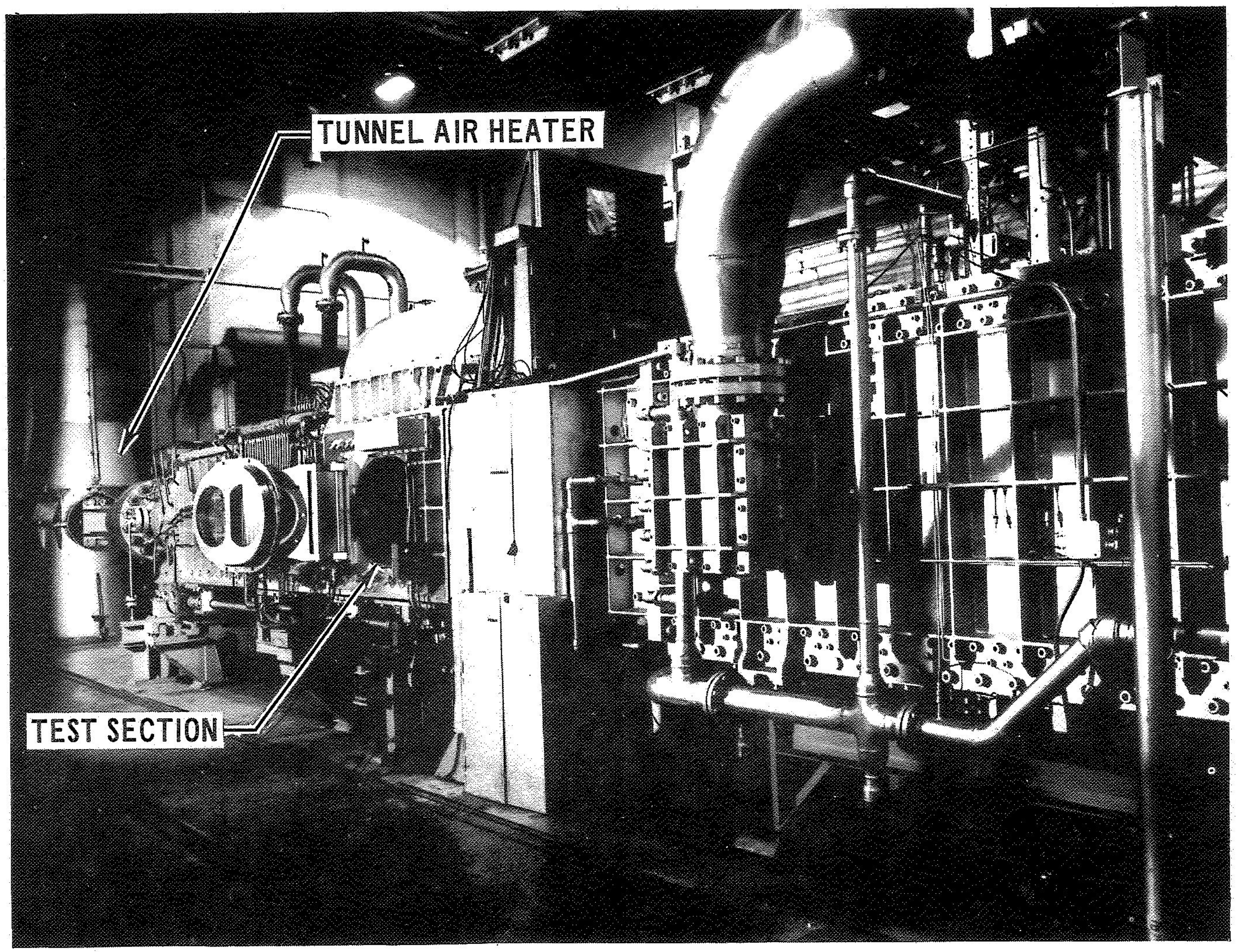
Figure 26

CONTINUOUS FLOW HYPERSONIC TUNNEL (CFHT) NASA-LaRC

(Figure 27)

Testing of the panel will be performed in the CFHT and the heating measurements will be made by injecting the panel to the test position and recording thermocouple responses for the thin skin tile. This is a normal operation procedure for testing wind tunnel models.

CONTINUOUS FLOW HYPERSONIC TUNNEL (CFHT) NASA - LaRC
(MACH 10)



FLOW IS FROM LEFT TO RIGHT

Figure 27

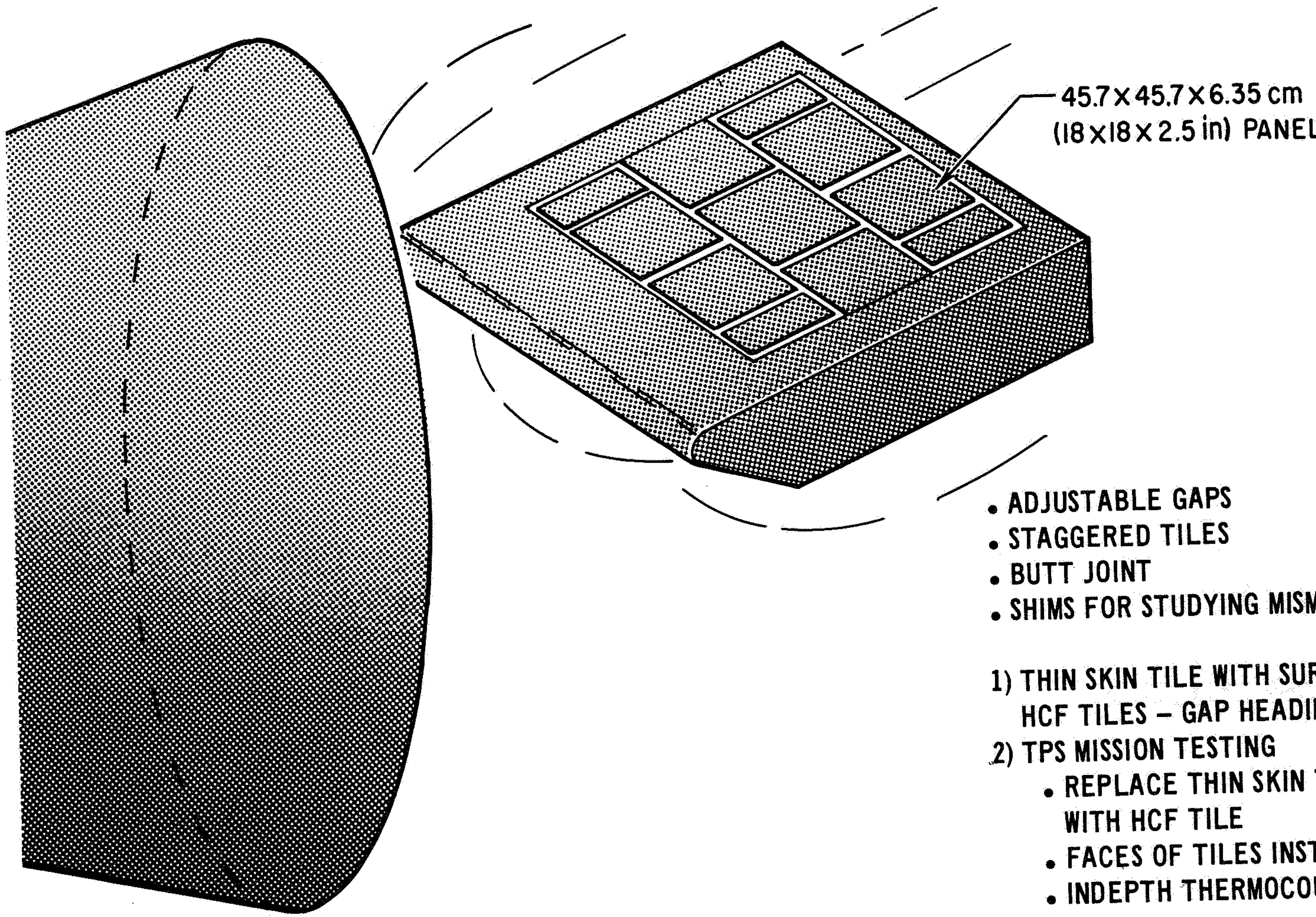
ARC TUNNEL TESTS AT 50 MW (WRIGHT FIELD)

(Figure 28)

Tentative plans are being formulated to perform tests in the 50 MW Arc tunnel at Wright Field using a larger [45.7 x 45.7 x 6.35 cm (18 x 18 x 2.5 inch)] HCF panel to study the heating in the gaps. The panel design is similar to that of the other panels used to study gap heating. This panel will be used to perform tests corresponding to MSC's arc tunnel tests and to tests in the wind tunnel. Hopefully, this will provide a basis for correlating results for all three test programs.

ARC TUNNEL TESTS AT 50 Mw (WRIGHT FIELD)

(TENTATIVE)



- ADJUSTABLE GAPS
- STAGGERED TILES
- BUTT JOINT
- SHIMS FOR STUDYING MISMATCH

1) THIN SKIN TILE WITH SURROUNDING HCF TILES – GAP HEADING
2) TPS MISSION TESTING
   - REPLACE THIN SKIN TILE WITH HCF TILE
   - FACES OF TILES INSTRUMENTED
   - INDEPTH THERMOCOUPLE

Figure 28

CONCLUSIONS

ARC TUNNEL FINDINGS

- EXCESSIVELY WIDE GAPS EXPERIENCE SIGNIFICANT CONVECTIVE HEATING AND MAY RESULT IN A BONDLINE OVERHEAT
- INCREASED HEAT PROTECTION IS AFFORDED BY CONTOURED JOINT AS COMPARED TO A BUTT JOINT
- 3–D RECIRCULATION EVIDENT AT INTERSECTION OF RSI TILES
  - OUT FLOW EMANATES FROM TILE INTERSECTION
- HEATING DISTRIBUTIONS IN GAPS WERE OBTAINED
  - CONTOURED JOINT
  - BUTT JOINT
  - BUTT/STEP MODEL
- ANALYTICAL MODEL FOR HEATING IN GAPS NEEDS TO BE DEVELOPED

ADDITIONAL TESTING

- ARC TUNNEL – USING CHANNEL NOZZLE, NASA MSC
- THICK BOUNDARY LAYER EFFECTS – LANGLEY'S CFHT
- WEDGE 45.7 X 45.7 cm (18 X 18 in) TEST – WRIGHT FIELD'S 50 MW (TENTATIVE)

REFERENCES

1. Hanner, O.M., Jr., "Aerodynamic, Gap Heating for Booster Entry, " SSD-71-247, March 1971.

2. Hodgson, J.W., "Heat Transfer in Separated Laminar Hypersonic Flow," AIAA J. Vol. 8, No. 12, December 1970.

3. Brewer, R.A.; Saydah, A.R.; Nestler, D.E.; and Florence, D.E., "Thermal Performance Evaluation of REI Panel Steps and Gaps for Space Shuttle Thermal Protection System," AIAA Paper No. 72-388, April 10, 1972.

4. Odus, R. Burggraf, "A Model of Steady Separated Flow in Rectangular Cavities at High Reynolds Number," Proceedings of the 1965 Heat Transfer and Fluid Mechanics Institute, Andrew F. Charwatt ed Stanford University Press, 1965, pp. 190-229.