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SILICA
HEAT SHIELD SIZING

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FINAL REPORT

4 MARCH 1975 TO 24 JULY 1975

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FOREWORD

This report summarizes the work conducted by McDonnell Douglas Astronautics Company-East (MDAC-E) in St. Louis, Missouri for the NASA Ames Research Center (NASA-Ames) under Contract NAS2-7897 (Rev 4), "Silica Heat Shield Sizing." The period of performance was from 4 March 1975 thru 24 July 1975.

This study was performed under the direction of H. K. Larson of NASA-Ames. Significant contributions to this study were made by H. J. Fivel and T. W. Parkinson of MDAC-E.

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1.0 INTRODUCTION AND SUMMARY

The high temperature reusable surface insulation (HRSI) thermal protection system (TPS) for Space Shuttle requires gaps at HRSI joints to accommodate structural deflection resulting from loads and thermal expansion. In addition, allowance must be made for manufacturing and assembly tolerances. At room temperature, gap widths under current consideration range from 0.05 inch to 0.10 inch. In orbital operation, these gaps may shrink to near zero during cold soak and then grow by as much as 25% during reentry. Candidate tile edge radii range from 0.03 inch to 0.10 inch.

The successful application of HRSI material for Shuttle thermal protection is significantly affected by heating in the gaps between HRSI tiles during entry into the earth's atmosphere. Gap width, gap depth, tile edge radius, gap cross section geometry, gap orientation, waterproof coating thickness, emittance of this coating, substructure, boundary layer state and surface mismatch are all known to affect convective heating within the gap and heat leakage to the protected substructure.

The objective of this study was to determine the sensitivity of silica heat shield requirements to gap width, tile edge radius and heat transfer distributions within tile gaps using representative correlations contained in References 1 and 2. Other information pertinent to the study was supplied by NASA Ames. For purposes of sensitivity studies the nominal configuration was specified to be a 6" x 6" tile with a .10 inch gap between tiles. Tile edge radius was specified to be .06 inches. The two-dimensional thermal model prepared for Reference 1 was modified and used to determine the effect of two-dimensional heat transfer distributions at HRSI edges on Shuttle TPS requirements. For the Rockwell baseline gap heating distribution the HRSI thickness requirements may be increased approximately 30% above the thickness required for a TPS with no gaps in regions of high heating on the orbiter lower surface.

This report also describes the sensitivity of TPS requirements to coating thickness, emissivity, substructure thickness and changes in gap heating for several locations on Shuttle.

In order to better understand the effect of tile edge radius on TPS requirements, an inverse solution technique was applied to temperature data obtained in the Ames 20 MW turbulent duct. The derived heating values were then used to predict TPS requirements. The results of this analysis, summarized in Section 6.0, show that increasing tile radius reduces TPS requirements.

2.0 THERMAL MODELS

The Shuttle thermal protection system (TPS) consists of 6 in x 6 in tiles of LI-900 silica High Temperature Reusable Surface Insulation (HRSI). The tiles are bonded to a thin strain isolator pad (SIP) which is in turn bonded to the primary aluminum structure. The tile thickness on Shuttle varies with location; the thickness being designed to limit the primary structure to 350°F. The aluminum structure reaches maximum temperature after entry, during the period of heat soak. The nominal TPS configuration employs tiles with corner edge radii of 0.06 in. and a gap width of 0.10 in. between tiles. The LI-900 HRSI has a density of 9 PCF and is covered with a silicon carbide waterproof coating.

TPS thickness requirements were computed for Shuttle entry trajectory 14414 at four locations designated as Body Point 1, Body Point 2, Body Point 3 and the Body Flap. Body Point 1 corresponds to body station 1040 which is located near the nose and reaches a radiation equilibrium temperature of 2335°F. Body Point 2 represents conditions at the fuselage midpoint (body station 1070) which reaches a radiation temperature of 1815°F. Body Point 3 is typical for aft fuselage (body station 1157) and reaches a radiation equilibrium temperature of 1180°F. The Body Flap (body station 212) reaches a 2675°F radiation equilibrium temperature. Transient temperature analyses for the complete trajectory were performed using the two dimensional thermal model as shown on Figure 1. Computations were performed for each set of conditions until the aluminum structure reached its maximum temperature. The model uses hallmark dimensions such as V(2) to define key dimensions from which the remaining node dimensions are computed. The baseline configuration is shown in Figure 1.

To determine the temperature response resulting from a complete absence of gaps, a one dimensional model was constructed. This model is shown on Figure 2.

Consideration was given to the need for assessing three dimensional heat transfer effects. Since the available resources precluded analysis using a detailed three dimensional finite difference computer model, the two dimensional model was converted to a pseudo three dimensional model as shown on Figure 3. This method assumes that the heating conditions over the top of the tile was uniform and heating in the gap was two dimensional and isometric. The heat storage terms were modified as indicated in the Figure.

The influence of thermal models on TPS requirements is shown on Figure 4. TPS thickness requirements for a two dimensional model which includes gap heating are

15% greater than the one dimensional requirements whereas the three dimensional model requirements are 30% greater. The heating environment, SIP and structure at body station 1040 was used for this analysis. The effect of thermal model differences on the body flap (B.P. 212) TPS thickness requirements, Figure 5, is lower than for body station 1040. The thickness increments are 4.3% and 8.2% for the two dimensional and three dimensional models respectively. Figure 6 shows the variation of maximum structural temperature with HRSI thickness for the one, two and three dimensional models at body station 1040. In spite of the significant difference between the two dimensional and three dimensional predictions of HRSI thickness requirements, differences in surface temperature between the two models are shown in Figure 7 to be generally less than 10°F. Figure 8 shows the rapid decrease of computed TPS thickness requirements with increasing width of the two dimensional model. Also shown is the thickness requirement for a 6 in. x 6 in. tile computed using the Pseudo three dimensional model. The figure indicates that three dimensional effects are important and that the TPS thickness is a strong function of the ratio of gap length to tile surface area. It is also evident that the required tile thickness (hence TPS weight) could be reduced by increasing tile size.

The majority of the analysis contained in the report employ the two-dimensional model as a consistent basis to show sensitivities.

3.0 ENTRY ENVIRONMENT

A current Shuttle baseline reference heating rate history is shown on Figure 9 for Shuttle entry trajectory 14414 (Reference 2). Heating rates for each of the body points analyzed in this study were computed by multiplying the reference heating rate history by a constant ratio of local-to-reference heating rate ($\dot{q}_L/\dot{q}_{REF}$). The local heating rate was imposed on the top of the tile with the gap heating distribution applied to the gap walls. The local pressure, Figure 10, on the Shuttle lower surface was used to obtain the proper thermal conductivity of LI-900 which is a function of both pressure and temperature.

4.0 INFLUENCE OF HEATING DISTRIBUTION IN THE GAP

Extensive arc and wind tunnel tests of instrumented panels of tiles have been performed in order to quantitize the heating distribution on the faces of the tiles. Various correlations have been developed to describe the distributions in the gap. Three general correlations were already developed at the start of this study and a fourth was developed by this study (see Section 6.0). The characteristics of the first three correlations and the resulting impact on TPS requirements and thermal responses are contained in the following subsections.

4.1 Heating Distributions in the Gap - Comparisons were performed using the "R.I. Baseline Heating Distribution", the "Gap Heating Correlation, Equation 4-17" and the "Marssdorf Curves".

4.1.1 R.I. Baseline Heating Correlation - At the outset, TPS requirements were computed using only the Rockwell International baseline (R.I. B/L) heating distribution in transverse gaps as shown on page 16 of Reference 2 and shown here as Figure 11. This curve was originally developed for a gap width of 0.10 inch and a tile edge radius of 0.06 inch. However, to determine the effect of varying gap width and edge radius, this distribution was used for several combinations of width and radii. When using this curve the results show a slight increase in requirements with increasing gap width, and a decrease in TPS requirements with increasing edge radius.

4.1.2 Gap Heating Correlation, Equation 4-17 - A gap heating correlation (Eq. 4-17) for a transverse gap, was developed from data measured on thin skin tiles with various edge radii and gap width settings. The model was tested in a wedge in the JSC 10 MW Arc Tunnel. The data analysis and correlation are reported in Reference 1. Figure 12 summarizes the heating data obtained in transverse gaps with superimposed plots of the resulting correlation equations. The correlating equation is presented in Figure 13 together with the regression correlation coefficient, standard error of estimate, minimum and maximum heating for both the measured data and the derived function.

As can be seen from Figure 12, the heating data do not extend deep into the gap. Figure 14 shows the method of extrapolating the correlation curve toward the bondline. In the gap near the upper surface a second order curve was fit tangent to Equation 4-17 and passing through $\ell n(q/q_{FP}) = 1.0$ at the tangency point of the edge radius and tile flat surface (S=0.0). (The extensions of Equation 4-17 used in the vicinity of the tile corner are shown in Figure 12.) The technique of extending the correlation curves is described in Section 6.0 of Reference 1.

4.1.3 Effect of Gap Heat Load - Figure 15 contains transverse gap heating distributions for a tile with an edge radius of 0.06 inches and a gap width of 0.10 inch between tiles based upon several computational methods. Method 1 is the R.I. baseline heating distribution. This distribution requires 3.32 inches of HRSI in order to limit structure temperatures to 350°F. Computer runs were made using 3.32 inches of HRSI in order to determine how the other methods would affect the maximum structural temperature. The temperatures ranged from 354°F to 427°F. Also the TPS thicknesses required for each heating distribution to satisfy the 350°F limit were computed. Figure 16 shows the effect of integrated gap heat load on HRSI requirements for a 6.0 x 6.0 inch tile. Method 3A requires approximately 31% more HRSI than Method 1. Comparison of HRSI requirements from Methods 3 and 3A, Figure 16, show that the lack of accurate definition of heating at $q/q_{REF} \leq 0.1$, which occurs deep within the gap, can significantly affect the TPS thickness. Sensitivity to heat load on the body flap is also shown on Figure 17. Method 3 requirements for the flap are approximately 16% greater than Method 1.

4.1.4 Marssdorf Gap Heating Curves - Heating distribution curves for a transverse gap developed by J. Marssdorf of Rockwell International were furnished by F. J. Centolanzi of NASA-Ames. These curves were derived from tests using thin skin tiles having a 0.10 inch gap and 3 different edge radii. The heating curves were derived accounting for thermal conduction effects. The tests were conducted in the JSC 10 MW Arc Tunnel.

The curves of Marssdorf are plotted in Figure 18 as a function of "Z" (distance into the gap measured from the tile top surface). This figure shows a significant affect of tile edge radius on gap heating distribution. Analyses employing the Marssdorf curves are contained in subsequent sections.

4.2 Comparison of Heating Distributions and Gap Temperatures - Figure 19 shows additional heating distributions for a .10 inch transverse gap with tiles having an edge radius of 0.06 inches. The curve labeled Equation 4-17 here and on Figures 20 and 21 was used for obtaining the effects of edge radius and gap widths on TPS sizing. The Marssdorf curves and the revised R.I. Baseline (data from Ames Aero Heating Test No. 158) heating distribution prepared by Marssdorf are shown for comparison. A table of Figure 19 shows the percent change compared to the R.I. Baseline. Figures 20 and 21 show the comparison of MDAC Equation 4-17 and Marssdorf curves for tile edge radius of .12 and .25 inch respectively. The two heating distributions for a tile having a large (0.25 inch) radius are very similar.

The heating distributions for various edge radii computed using the MDAC Equation 4-17 are compared in Figure 22. A similar comparison is made in Figure 18 using the curve fits obtained by Marssdorf. The level of heating increases when increasing the edge radius on both figures. Figure 18 shows a greater spread for edge radius range than does Figure 22. Even though the heating increases with increasing edge radius, the temperatures within the gap decrease with increasing edge radius for Equation 4-17 as is shown in Figure 23. With large edge radius more surface is available for radiation to space (T = 0^{o}R), thus increasing the heat rejected. However, as shown in Figure 24, the Marssdorf distribution results in increasing gap temperature with increasing edge radius. In this case there is a sufficiently large increase in gap heating with increasing edge radius that the convective heating out weighs the radiation effect. Figure 25 shows the temperatures for the Rockwell International baseline heating curve and the Marssdorf revision to that heating curve.

4.3 Tile Thermal Responses - Typical temperature-time history plots in Figures 26, 27, and 28 show the response of the tile, the coating on the tile top and gap wall, and in-depth temperature near the center of the tile. Temperature-time plots are presented for 17 priority cases in Appendix B. Figure 29 is a typical temperature isotherm plot at the time of peak heating showing that the in-depth temperatures of the coating in the gap and temperatures in the HRSI adjacent to the gap coating are hotter than the in-depth temperature of the HRSI toward the center of the tile. This figure shows the extent of the effect of gap heating on temperature.

The sensitivity of aluminum temperature to tile thickness is shown in Figure 30 for a nominal gap width of 0.10-inch and an inner edge radius of 0.06 inch. For reference purposes, a one dimensional thermal analysis at the same vehicle location, indicates a requirement of 2.88 inches of HRSI. Information from the previous figure is also presented in Figure 31 in terms of an increase over the one dimensional value. Using the heating distribution of Equation 4-17, approximately 33% more HRSI is needed considering a nominal gap and a maximum aluminum temperature of 350^{o}F. By referring to Figure 31 and choosing other maximum aluminum temperatures the percentage change over a 1-D model is easily obtained.

5.0 INFLUENCE OF TPS CONFIGURATION VARIABLES

In addition to convective heating, the TPS requirements are governed by heat transfer characteristics of: the HRSI, the SIP, the tile coating and the primary structure. Gap width and tile edge radius also enter into determining TPS requirements. The sensitivity of TPS requirements to configuration variables are analyzed in the following subsections.

5.1 Tile Coating and Primary Structure Effects - The effect of HRSI coating emissivity and aluminum structure thickness can be seen on Figure 32. The one dimensional thermal model has coating on the HRSI surface only, while the two dimensional model has the coating on the gap walls as well as on the surface. For the emissivities and thicknesses used for this figure, the ratio of 2-D to 1-D model TPS requirements change only slightly. Changing the aluminum structure thickness from 0.08 inches to 0.12 inches reduces the 2-D TPS requirement by approximately 17 percent.

The HRSI coating thickness also affects TPS requirements. Figure 33 shows that changing the coating thickness from 0.005 inch to 0.025 inch increases the 2-D requirements by three percent. This increase is minor compared to the gap width and edge radius effects. The coating has an order of magnitude higher conductivity than the HRSI.

5.2 Gap Width Effects- The effect of gap width on aluminum structure temperature, using the heating distribution curve of Figure 11 is shown on Figure 34. A more realistic effect of gap width is shown on Figure 35 which was derived by using MDAC correlation Equation 4-17 (Reference 1). This figure shows the effect on TPS requirements for various gap widths and edge radii. Figure 35 shows that increasing the gap width from 0.10 inch to 0.20 inch results in a tile thickness increase of seven percent for a tile with an edge radius of 0.06 inches. Figure 36 shows the same information normalized to the 1-D thermal model requirements.

5.3 Tile Edge Radius Effects- The tile edge radius also has an effect on TPS requirements as shown on Figure 37. First, analysis were performed assuming that the heating distribution with respect to (Z) did not change and only varies with the geometry of the tile edge. The heating curve in Figure 11 was used. The TPS requirements drop for increased edge radii for all three body points (See Figure 37). Analysis were also performed using the MDAC correlation Equation 4-17 which accounts for edge radius (See Figure 38). Increasing the tile inner edge radius from 0.06 inch to 0.12 inches reduces the required HRSI thickness by about 0.2

inches (or five percent) for a gap width of 0.10 inch. Figure 39 shows this same information normalized to the 1-D thermal model requirements.

Three other gap heating distributions were investigated to determine edge radius effects on TPS requirements. They are shown on Figure 40. Using the Marssdorf heating distribution curves indicates the TPS requirements increase with increasing the edge radius. Heating distributions were also obtained for HRSI tiles (0.06 and 0.25 inch edge radius) tested in the Ames 20 MW Turbulent Duct. Using the data from the Ames 20 MW Turbulent Duct Facility for tiles with a 0.06 inch and 0.25 inch edge radius and having a 0.10 inch gap width, the 2-D requirements increase by approximately 25 percent and 9 percent respectively over the 1-D thermal model requirements but are less than that required using the other distributions. These results show the same trend as Equation 4-17 heating distribution when varying edge radius.

6.0 ANALYSIS OF 0.157 CM RADIUS HRSI TILES TESTED IN THE AMES 20 MW TURBULENT DUCT

During the course of this contract, thermal response data for a series of Arc Tunnel tests of 0.157 cm radius silica HRSI tiles tested in the Ames 20 MW Turbulent Duct were received. The test panel consisted of an upstream tile and a downstream tile positioned to form a transverse gap tested in the wall of a duct through which turbulent air flowed from an Ames 20 MW Arc Heater. A series of six tests were performed which were a companion test program to that performed on a set of 0.635 cm radiused tiles reported in Reference 1.

The 0.157 cm radius tiles were instrumented with thermocouples on the top of the tile, down both faces of the transverse gap and also in-depth. Tests were conducted with each tile being in the upstream position so as to get comparative data to ascertain the effect of tile instrumentation on derived gap heating. Heating rates were calculated by the "Inverse Solution Technique" (described in Reference 3). This technique utilizes a detailed thermal model of the tile test panel and the measured temperature histories in a transient analysis to determine heating rates.

Derived Gap Heating Distribution for 0.157 cm Tile Tests - Heating distributions were calculated for the downstream wall of the transverse gap for three gap widths (0.127, 0.254 and 0.381 cm) with thermocouple (T/C 1) being in the upstream and in the downstream position. The calculated heating distributions are contained in Figure 41. The spread in heating value attributed to instrumentation and test conditions is reasonable as evident upon examination of this figure. Data fairing was used to obtain an experimentally derived heating distribution for each gap width and the effect of gap width is evident in Figure 42. The convective heating drops off with distance into the gap and the heating intensity increases with the gap width. The shape of the heating distribution should be noted, because of a slight plateau near the top of the gap. Uncertainties in coating thickness, surface emittance and coating conduction effects become significant below a depth of 0.7 cm where the convective heating becomes negligible. The heating ratio measured near the top of the gap(for a gap of 0.254 cm)is comparable to what was obtained in the LaRC CFHT facility. The results for the narrower gap (0.127 cm) are comparable for 0.178 cm gap tested in the LaRC 8 Foot HTST. These other facilities also produced turbulent flow and the referenced heating distribution are contained in Figure 161 of Reference 1.

The heating distributions obtained for the 0.157 cm and 0.635 cm radiused HRSI tiles are compared in Figure 43. As can be noted from the figure, increasing the edge radius significantly reduces the convective heating within a transverse gap. Also the required tile thickness is also significantly reduced by increasing the edge radius (See Section 5.3, Figure 40).

7.0 CONCLUSIONS AND RECOMMENDATIONS

In this study the sensitivity of the Shuttle HRSI thickness to various design parameters has been investigated. The design parameters which were investigated include tile edge radius, gap width, gap convective heating profiles, aluminum substructure thickness, and tile coating thickness. Figure 44 summarizes these results which are predicated on limiting structural maximum temperature to 350°F. Heating distributions were derived for the 0.157 cm radiused HRSI tiles tested in the Ames 20 MW Turbulent Duct Facility.

Following are some of the major conclusions derived from this study:

1. Based on HRSI Turbulent Duct Tests, increasing tile edge decreases convective heating in a transverse gap. This finding is in contrast to results obtained from thin skin model tests conducted under laminar flow conditions where convective heating increased slightly with edge radius.
2. Increasing tile edge radius appears to reduce HRSI thickness requirements. This conclusion is sensitive to the manner in which existing experimental heat transfer data are interpreted, and using other investigator's heating distribution results in contradictory conclusions.
3. A significant decrease in TPS thickness (as well as a reduction in tile inventory) would result from increasing HRSI tile size.
4. Increasing gap width from .10 to .20 inch increases the HRSI thickness requirement by 7%, principally as the result of increased gap convective heating.
5. The HRSI thickness requirements decrease as the aluminum structure thickness (or heat capacity) increase. For example, a change in aluminum thickness of 50%, from 0.08 inch to 0.12 inch, results in a 17% reduction in required HRSI. However, such a change actually results in a 4% combined weight increase.
6. Coating thickness has a minor effect on HRSI thickness required compared with the effect of other parameters. A 3% increase in HRSI thickness requirement results from increasing coating thickness from 0.005 inch to 0.025 inch. The increased HRSI thickness occurs because the coating thermal conductivity is an order of magnitude higher than that of the HRSI.
7. The precision (or lack of precision) to which the convective heating distribution down the face of a gap is known, directly influences the required amount of HRSI. Even the low convective heating ($0.01 \leq q/q_{Ref} \leq 0.1$) which occur deep within the gap result in direct heating of the lower portions of the gap and hence increase TPS requirements.

8. Temperature in the coating at the HRSI/RTV bondline near the tile edge can be approximately 30°F greater than the HRSI/RTV bondline at the center of the tile. This increase in temperature is a combination of the higher conductivity in the coating and convective heating in the gap.
9. Temperatures on the 0.060 inch radius portion of the tile may exceed smooth surface temperatures by as much as 129°F.
10. The HRSI thickness for a 350°F bondline (using the R.I. baseline heating distribution for a 0.06 in. radius tile with a 0.10 in. gap) is 15 percent greater for a two-dimensional model and 30 percent greater for a pseudo three-dimensional model over the one-dimensional model requirements.

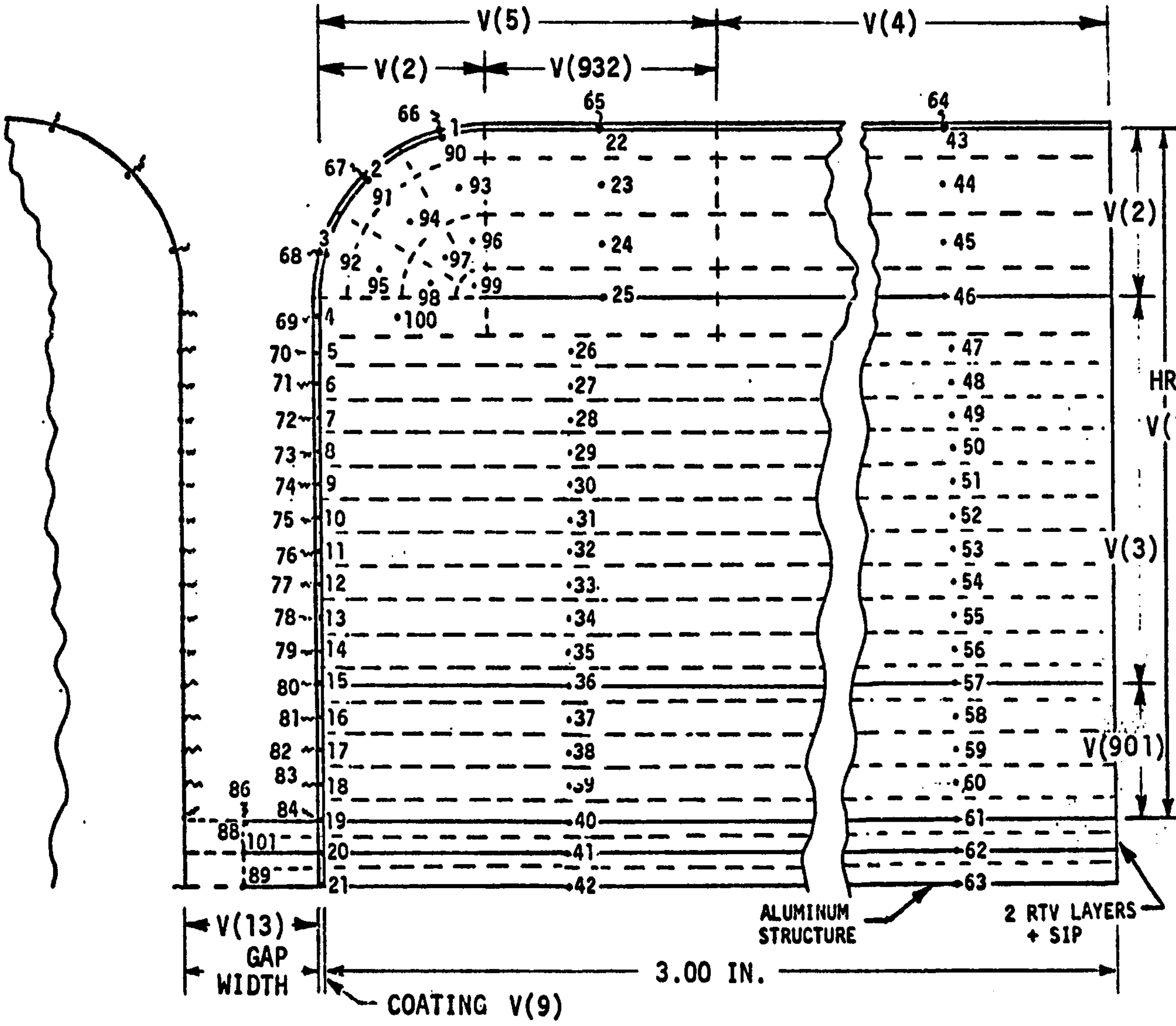
The following additional effort is recommended to maximize confidence in the TPS design:

1. A significant portion of the Shuttle TPS employs tiles orientated at 45°. Consequently Arc Tunnel Test (both laminar and turbulent) of radiused HRSI tiles should be conducted at several gap orientations to determine heating patterns that can be expected during flight and to study optimum tile configuration. These tiles should be extensively instrumented in the upper regions of the gap and on the radiused region.
2. Analysis of the additional tests to obtain convective heating rate distributions. These convective heating rate distributions should be compared with prior work to evaluate the consistency of the test results.

8.0 REFERENCES

1. "Data Correlation and Analysis of Arc Tunnel and Wind Tunnel Tests of RSI Joints and Gaps," Phase II Final Report, MDC E1248, 19 May 1975.
2. "Gap Heating Study Matrix," supplied by H. K. Larson, NASA Ames, March 1975.
3. "Heating in Shuttle RSI Gaps Derived from an Inverse Heat Transfer Solution," H. E. Christensen and H. W. Kipp, ASME Paper 75-ENAS-15, July 24, 1975.

TWO-DIMENSIONAL THERMAL MODEL OF AN HRSI TILE JOINT WITH EDGE RADIUS



BASELINE CONFIGURATION:

1. HEATING DISTRIBUTION IN GAP (R.I. BASELINE)
2. MODEL WIDTH = 3.0 INCH
3. INNER EDGE RADIUS (E_1) = 0.06 INCH
4. GAP WIDTH (W) = 0.10 INCH
5. COATING EMISSIVITY (ε) = 0.80
6. COATING THICKNESS (δc) = 0.015 INCH
7. ALUMINUM STRUCTURE (t) = 0.080 INCH
8. SIP PLUS RTV ADHESIVE = 0.175

FIGURE 1

ONE-DIMENSIONAL THERMAL MODEL OF AN HRSI TILE

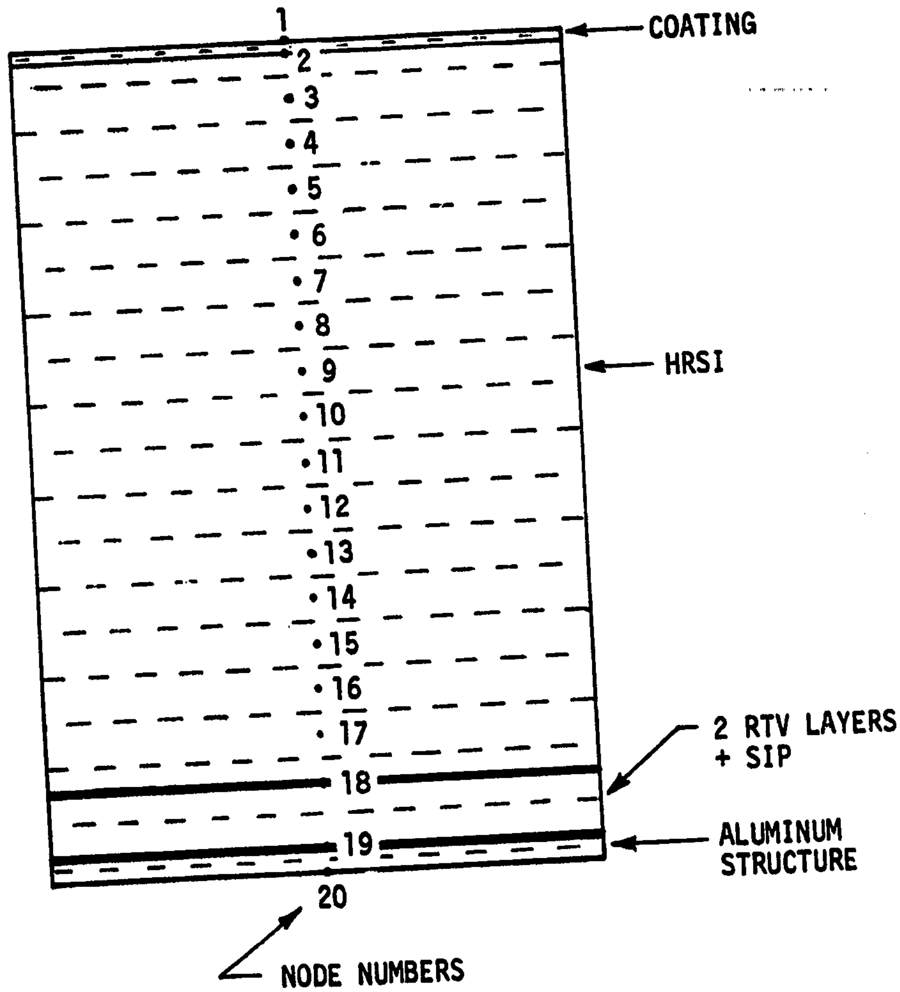
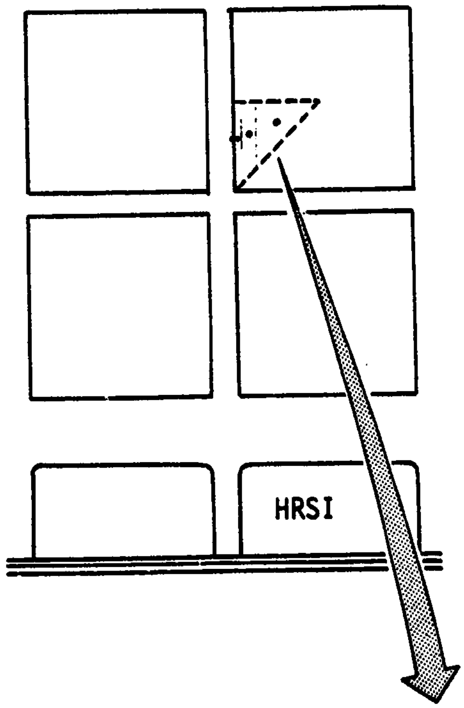


FIGURE 2

PSEUDO 3-D THERMAL MODEL OF BUTT JOINT



- o 101 THERMAL NODES
- o CONVECTIVE HEATING TO SURFACE NODES
- o RADIOSITY NETWORK, RADIATION FROM SURFACE NODES
- o HEAT STORAGE AT NODES
- o CONDUCTION LINKS BETWEEN NODES

- o SURFACE NODES (43,22,1 TO 19)
- o CENTRAL STACK (NODES 43 TO 63)
- o INTERNAL NODES AT EDGE (NODES 90 TO 101)
- o NODES 22 TO 40, INTERNAL NODES
- o SIP NODES 88,101,19,20,40,41,61,62
- o STRUCTURE NODES 101,89,20,21,41,42,62,63

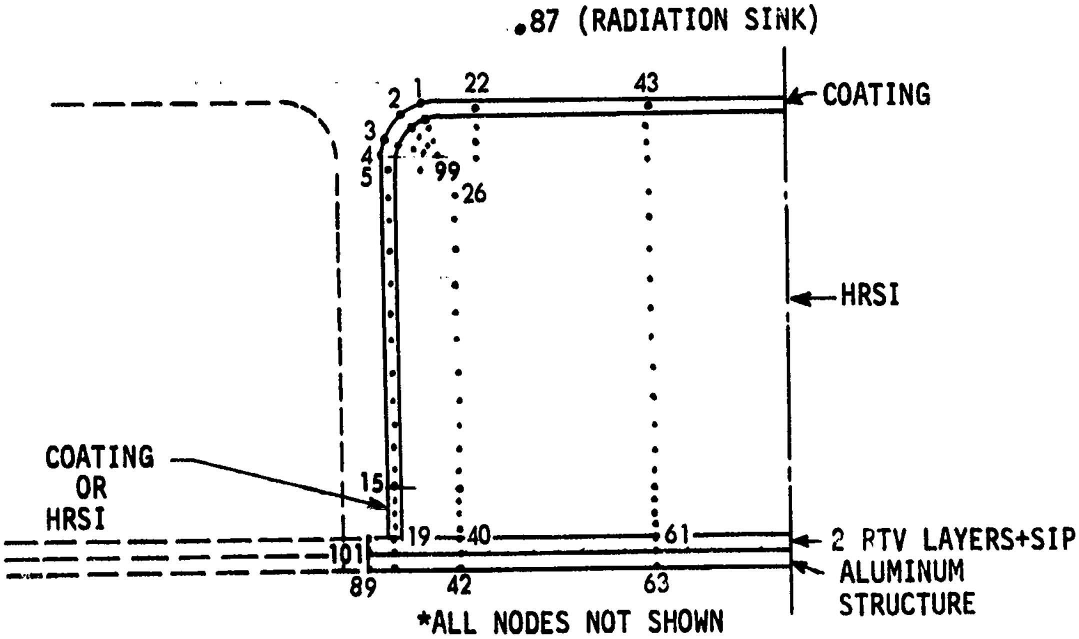


FIGURE 3

INFLUENCE OF THERMAL MODEL ON TPS REQUIREMENTS

- BODY POINT 1
- R.I. BASELINE GAP HEATING DISTRIBUTION
- TRAJECTORY 14414

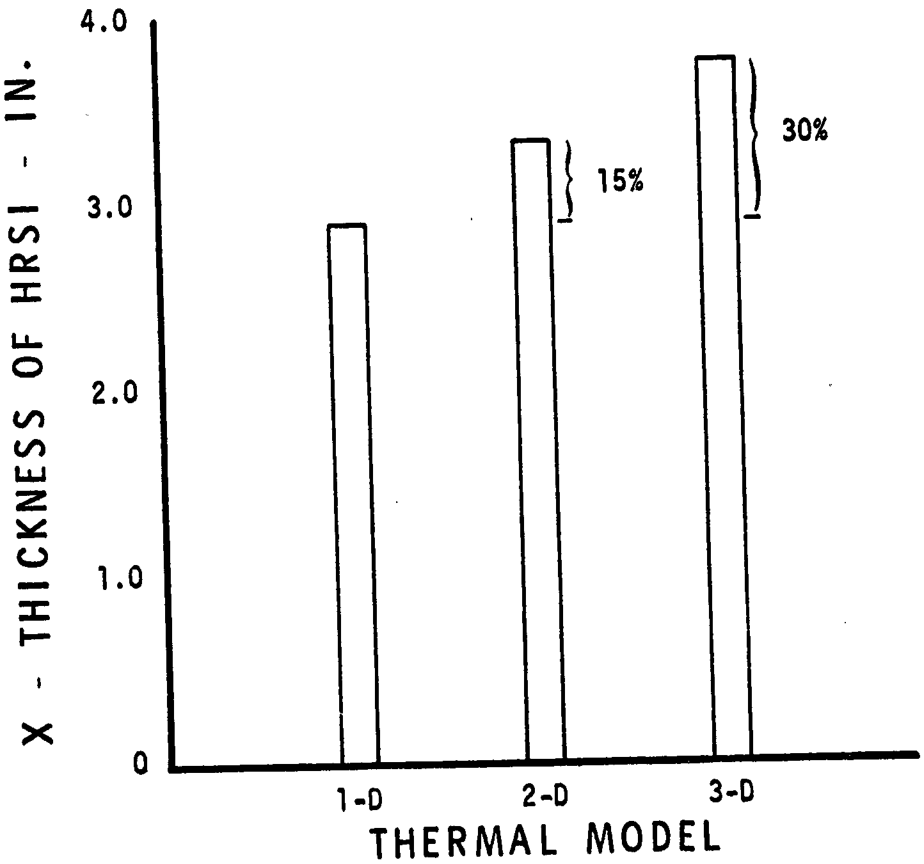


FIGURE 4

INFLUENCE OF THERMAL MODEL ON TPS REQUIREMENTS

- FLAP (BODY POINT 212)
- R.I. BASELINE GAP HEATING DISTRIBUTION
- TRAJECTORY 14414

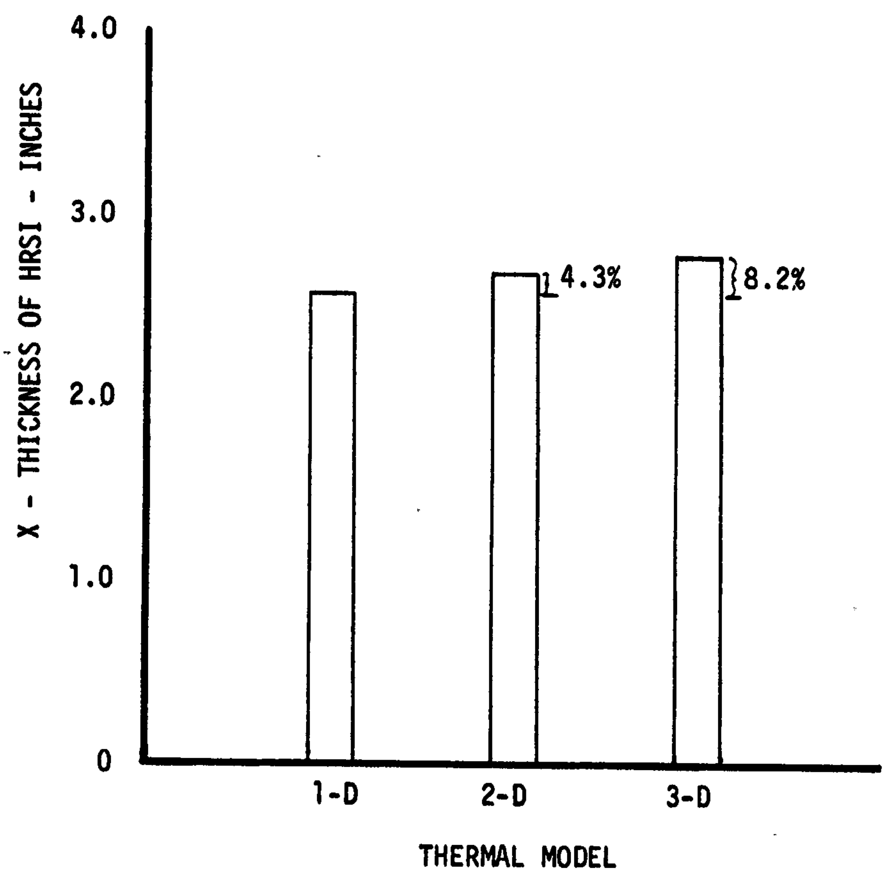


FIGURE 5

THERMAL MODEL INFLUENCE ON TEMPERATURE AND TPS REQUIREMENT SHUTTLE BODY POINT 1 TRAJECTORY 14414

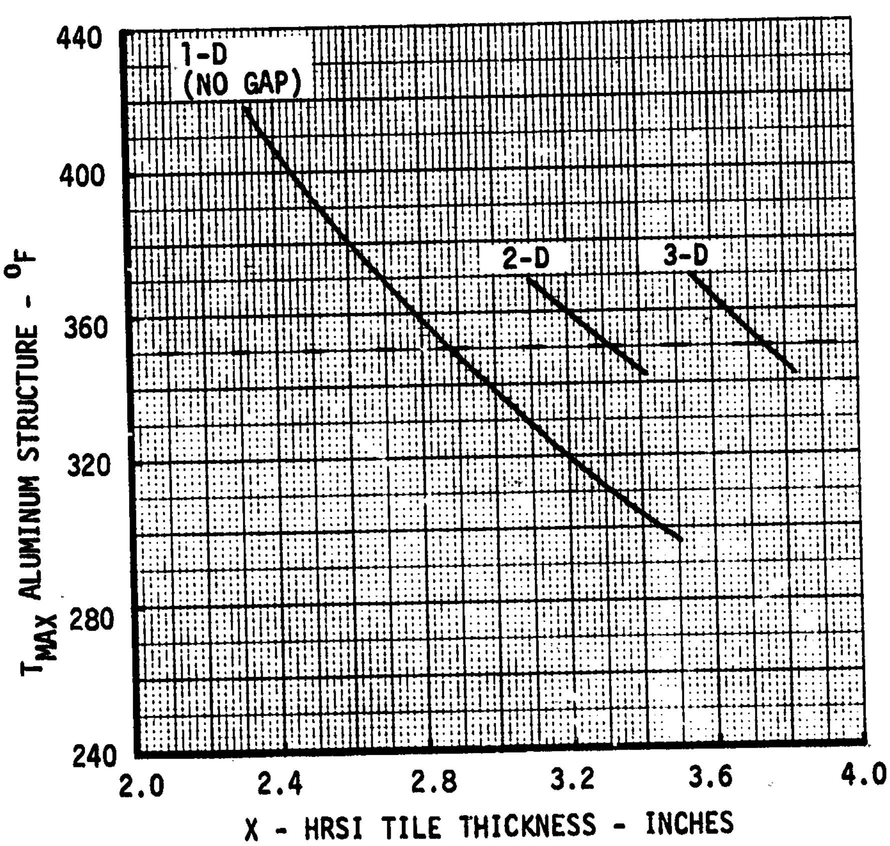
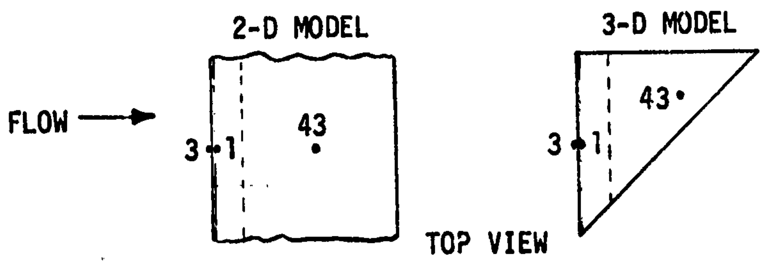


FIGURE 6

TEMPERATURE DIFFERENCES BETWEEN 2-D AND 3-D THERMAL MODELS

- BODY POINT 1
- 0.10 IN. GAP HEATING DISTRIBUTION (R.I. BASELINE)
- TRAJECTORY 14414
- 0.06 IN. EDGE RADIUS
- MAXIMUM ALUMINUM TEMPERATURE = 350°F



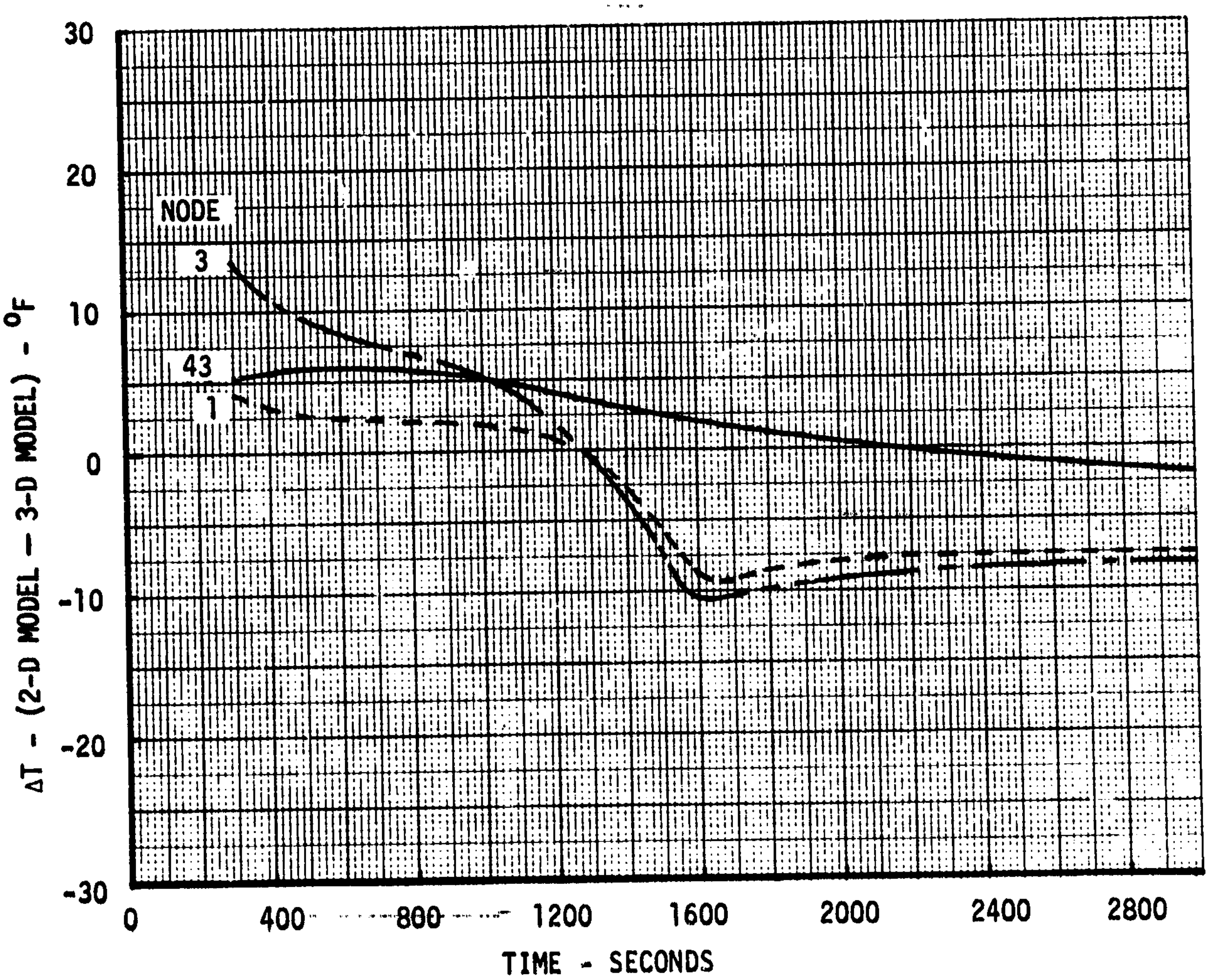


FIGURE 7

SENSITIVITY OF TPS REQUIREMENTS TO TILE THERMAL MODEL WIDTH

- BODY POINT 1
- TRAJECTORY 14414
- R.I. BASELINE HEATING DISTRIBUTION
- GAP WIDTH = 0.10"
- INNER EDGE RADIUS = 0.06"
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- BASELINE TILE HALF WIDTH = 3.0" FOR 6" x 6" TILE

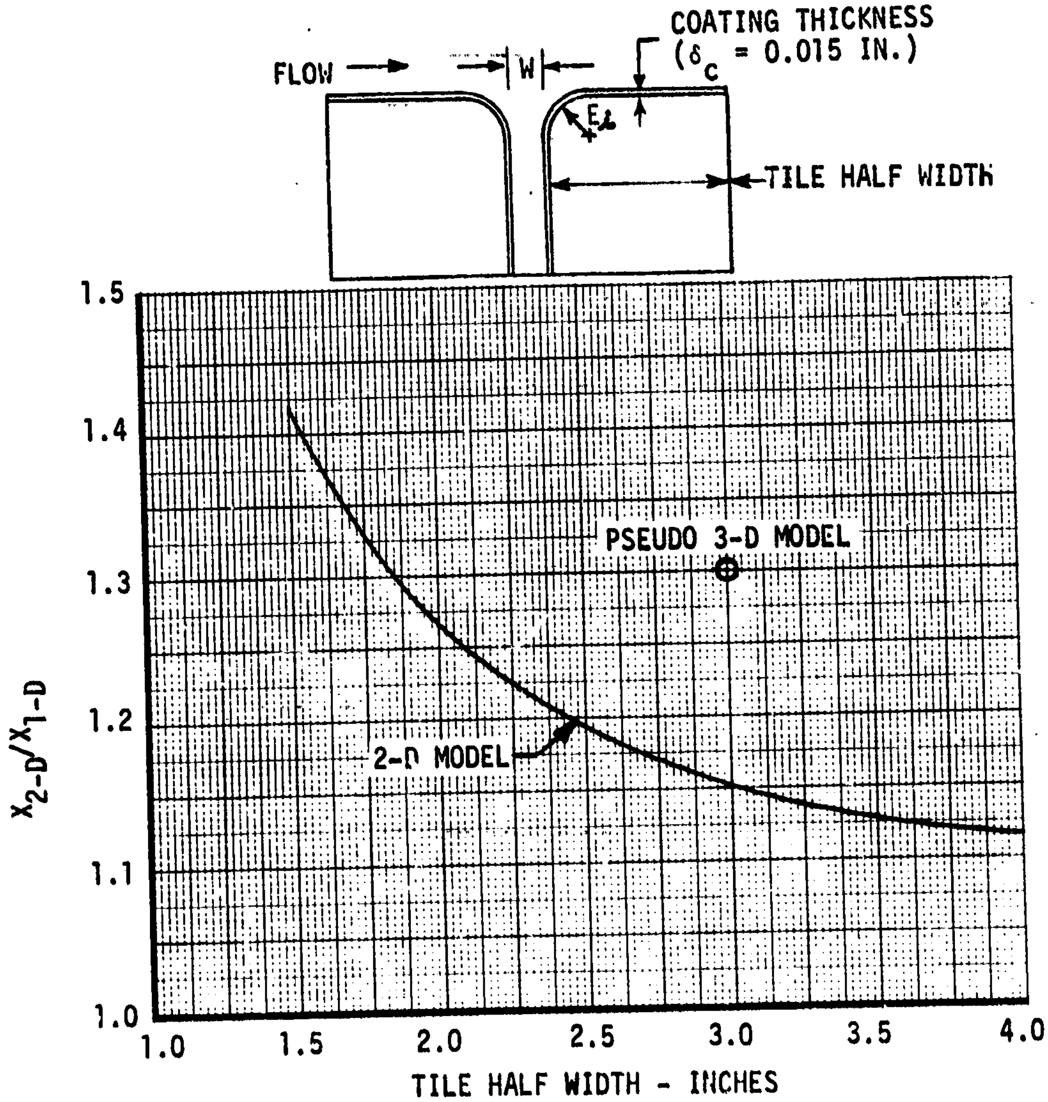


FIGURE 8

REFERENCE HEATING RATE

- TRAJECTORY 14414 (REFERENCE 2)

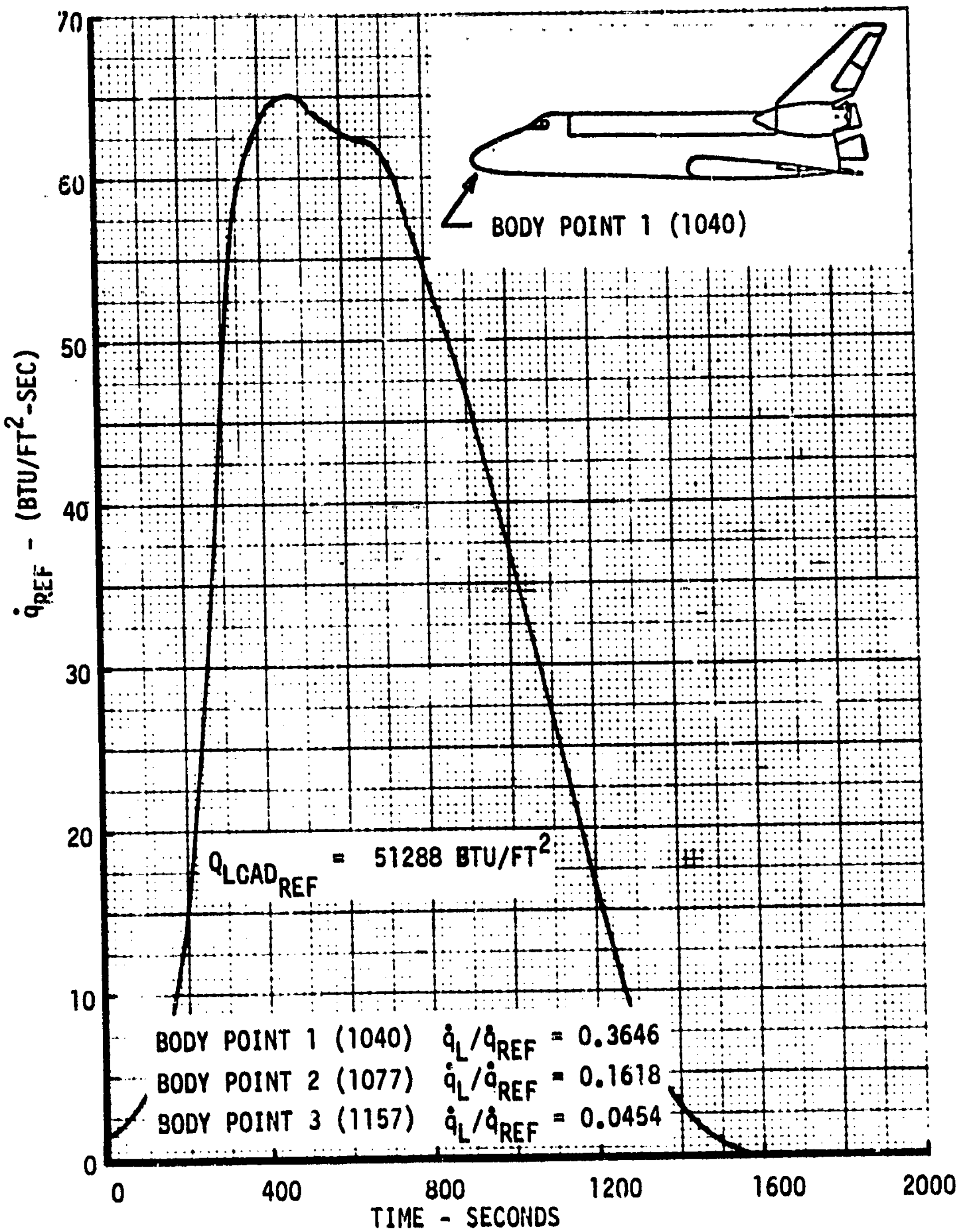


FIGURE 9

LOCAL PRESSURE ON LOWER SURFACE OF SHUTTLE DURING ENTRY

TRAJECTORY 14414
(REFERENCE 2)

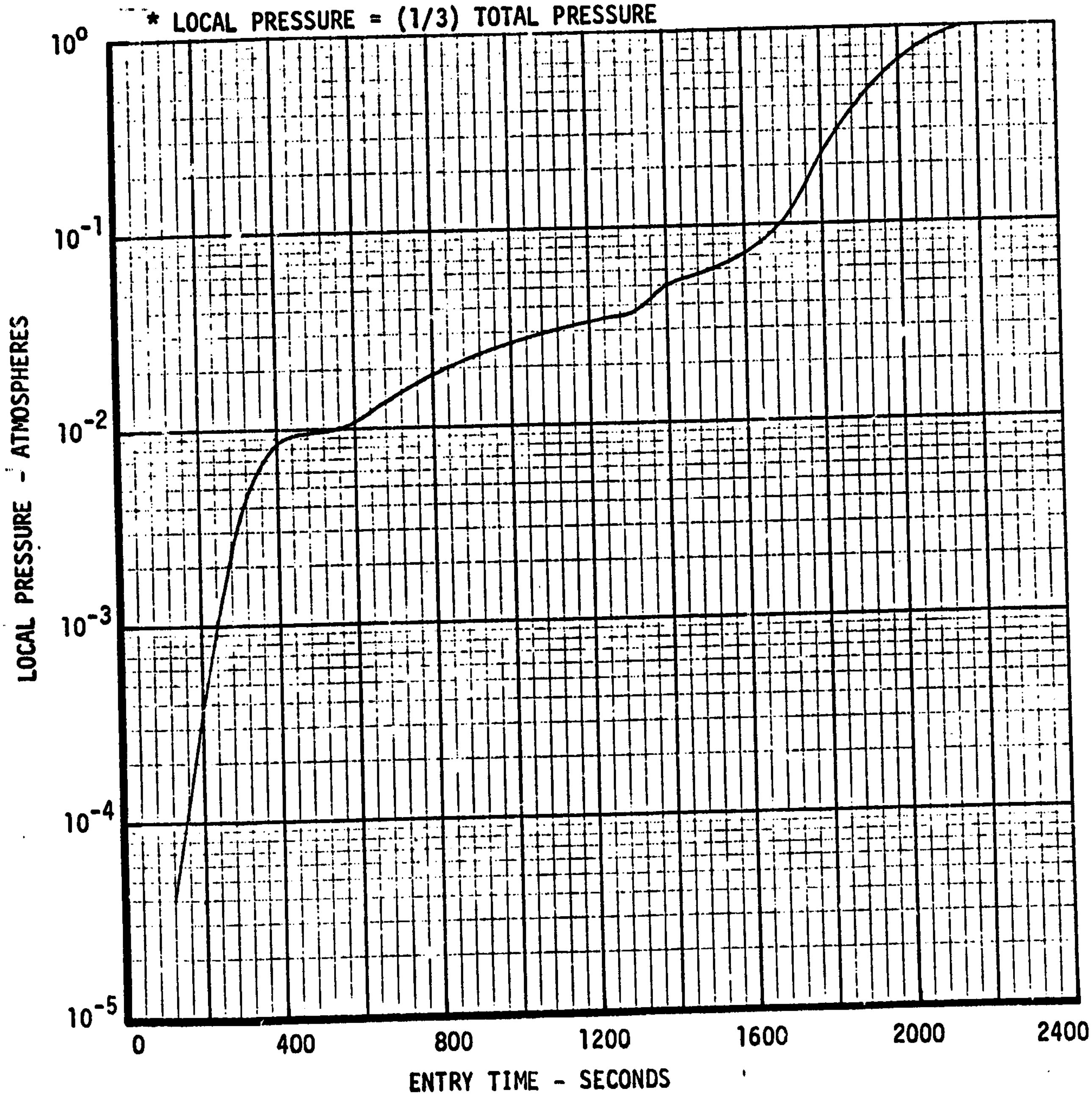


FIGURE 10

TRANSVERSE GAP HEATING DISTRIBUTION
ROCKWELL INTERNATIONAL BASELINE
0.06 INCH EDGE RADIUS-0.10 INCH GAP WIDTH

REF: AERO HEATING TEST NO. 158
AMES 3.5 FOOT WIND TUNNEL,
CONDUCTION CORRECTED DATA

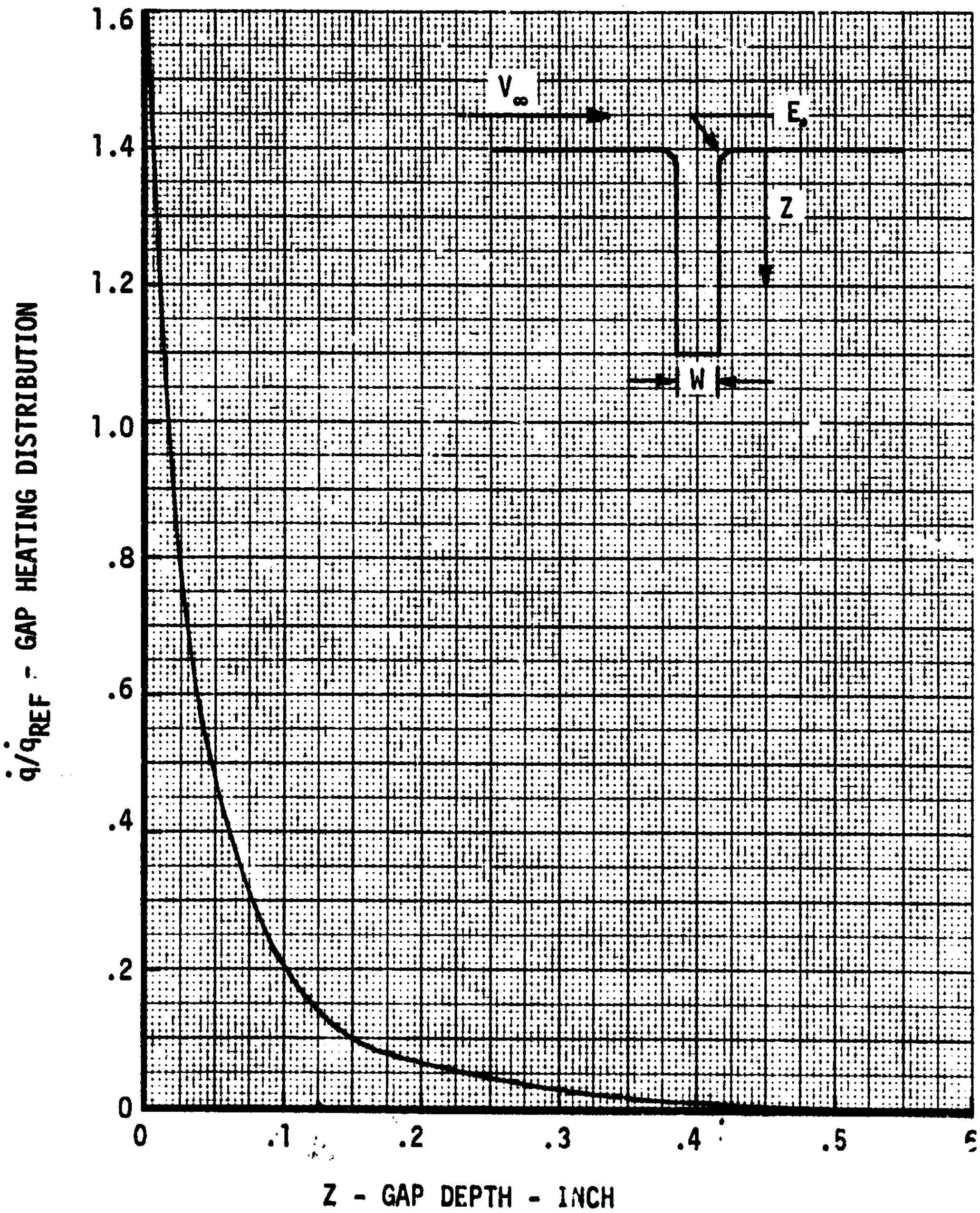


FIGURE 11

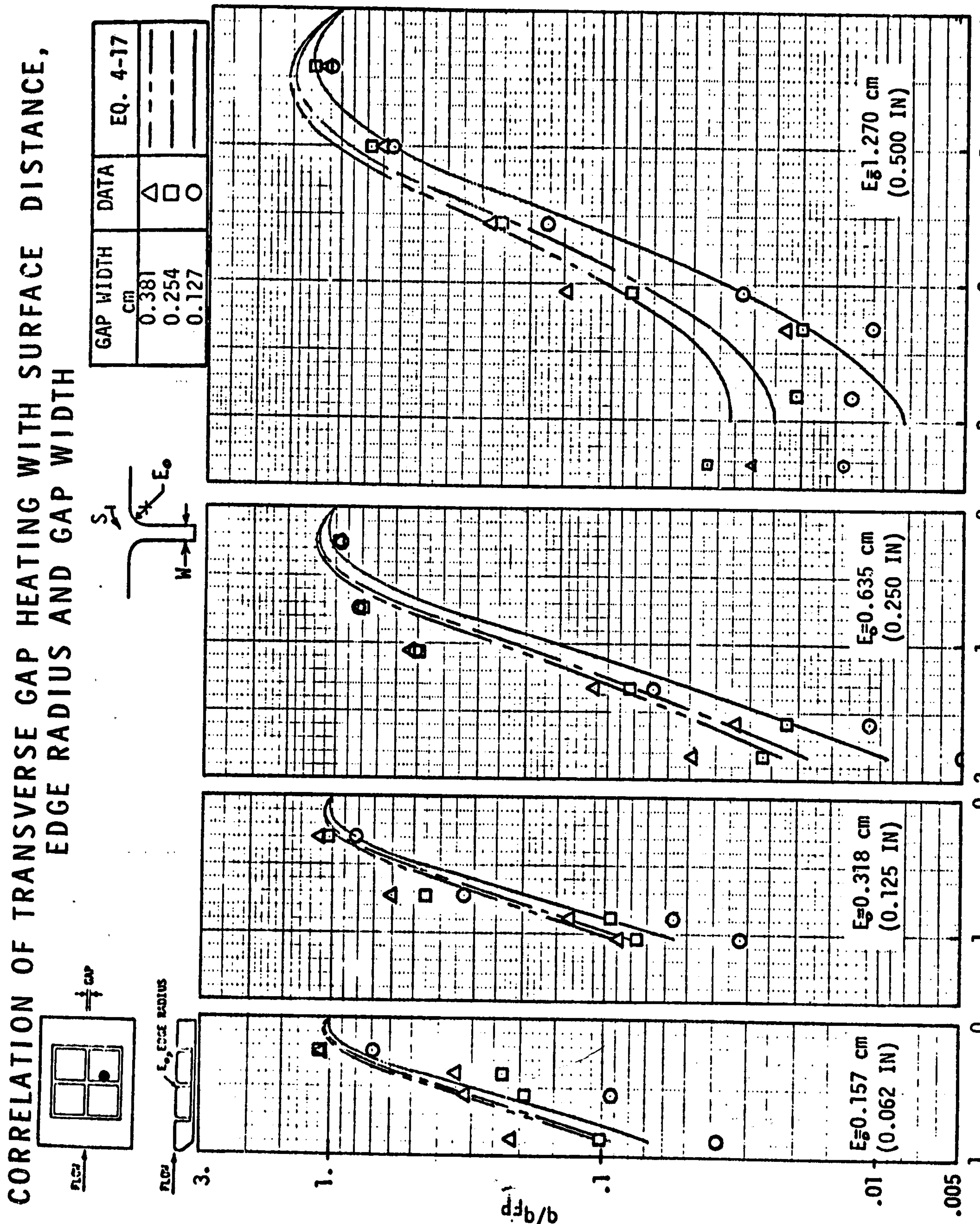
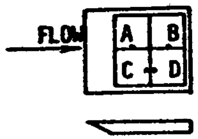

CORRELATION OF TRANSVERSE GAP HEATING WITH SURFACE DISTANCE, EDGE RADIUS AND GAP WIDTH
GAP WIDTH cm
0.381
0.254
0.127
DATA
EQ. 4-17
FLOW
GAP
EDGE RADIUS
S
W
q/q_FP
S(cm)
E₀=0.157 cm (0.062 IN)
E₀=0.318 cm (0.125 IN)
E₀=0.635 cm (0.250 IN)
E₀=1.270 cm (0.500 IN)

FIGURE 12



CORRELATION FUNCTIONS FOR GAPS WITH EDGE RADIUS
(EDGE AND WALL)

LOCATION	EQ.NO.	FUNCTION	NO. OF POINTS	R	S	RANGE IN q/q_{FP} (CARTESIAN) MEASURED MIN	MEASURED MAX	FUNCTION MIN	FUNCTION MAX	S^{∇}
D TRANS-DN	4-17	$\ln(q/q_{FP}) = 0.59775 - 3.67827S + 0.14962S^3 + 3.05060E - 0.09307(S/W) - 0.27898(E/S)^2$	61	.9440	.5298	.005	1.240	.009	1.376	.1643

$E_\circ$ = EDGE RADIUS (cm)
Z = DISTANCE INTO GAP (cm)
W = GAP WIDTH (cm)
S = SURFACE DISTANCE (cm)

JSC 10MW ARC TUNNEL TESTS (C. D. SCOTT)

E = 0.157, 0.3175, 0.635 AND 1.27 cm
W = 0.127, 0.254, AND 0.381 cm

R = REGRESSION CORRELATION COEFFICIENT BASED ON NATURAL LOGARITHM

S = STANDARD ERROR OF ESTIMATE BASED ON NATURAL LOGARITHM

S^{∇} = STANDARD ERROR OF ESTIMATE BASED ON CARTESIAN VALUES

SET 2 PARAMETERS USED IN ABOVE CORRELATIONS

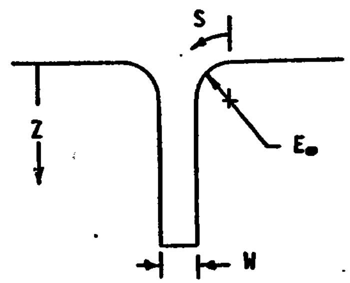
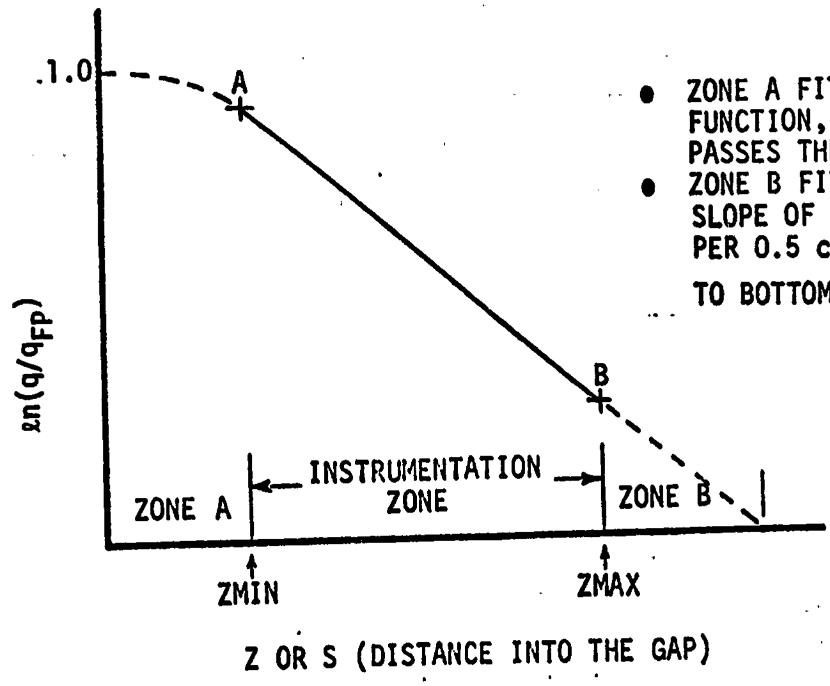


FIGURE 13

TECHNIQUE FOR EXTRAPOLATING CORRELATION FUNCTIONS



- ZONE A FIT WITH 2ND ORDER FUNCTION, TANGENT AT A AND PASSES THROUGH 1.
- ZONE B FIT SLOPE OF 1 CYCLE PER 0.5 cm FROM Z_{MAX} TO BOTTOM OF GAP

TRANSVERSE GAP HEATING DISTRIBUTION

METHOD	SYMBOL	SOURCE	
1	— - —	ROCKWELL,	$S<0$, $q/q_{FP} = 1$ $S>0$, SPECIFIED CURVE
2	- - - - -	C. SCOTT, JSC	$S<.66$, $q/q = .965-0.035\cos\pi\left(\frac{S-.06}{2.88}\right)$ $S>.56$, q/q TABLE
3A	———	MDAC-E, CORRELATION OF C. SCOTT DATA (EQ. 4-12)	$S<0$, $q/q_{FP} = 1$ $0<S<0.22$, LINEAR BETWEEN $q/q=1$ AND EQ 4-12 $0.22<S<0.92$, EQ. 4-12 $0.92<S<$ BOTTOM OF GAP WHERE q/q SET EQUAL TO 10^{-5}
3	·		$0.92<S<$ BOTTOM OF GAP WHERE $\ln q/q$ HAS SAME SLOPE AS EQ. 4-12

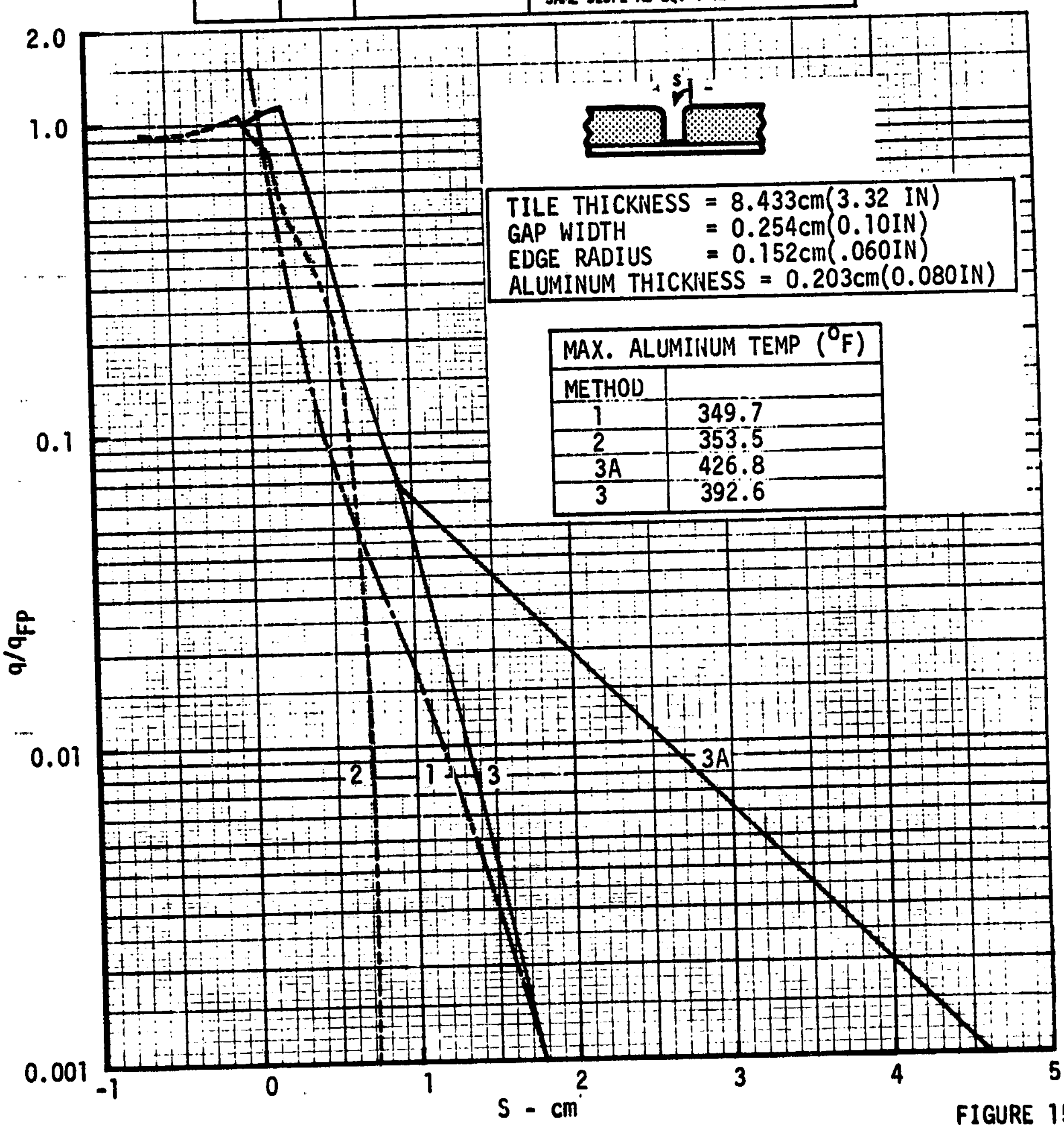


FIGURE 15

SENSITIVITY OF HRSI REQUIREMENT TO GAP HEAT LOAD, 2-D MODEL

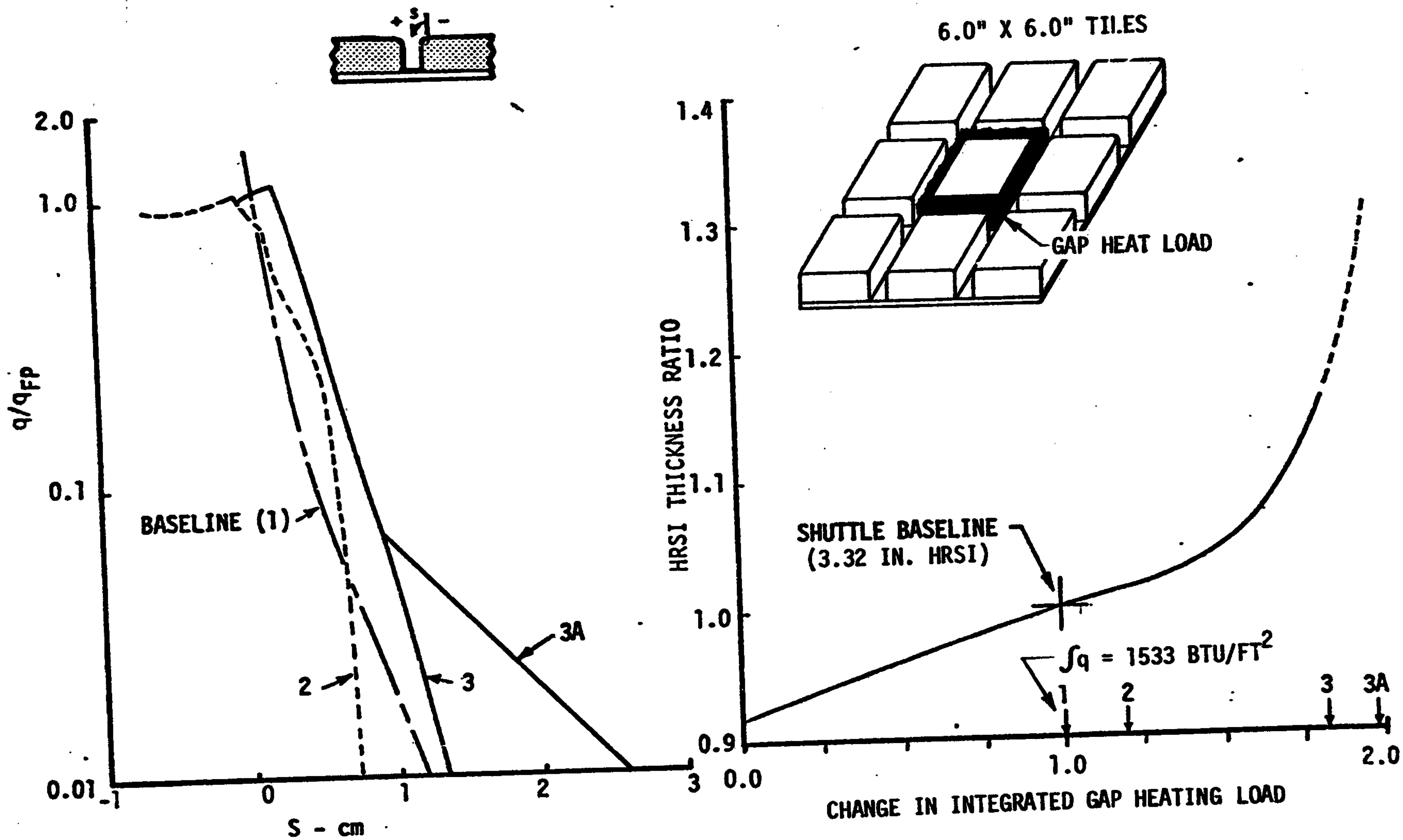
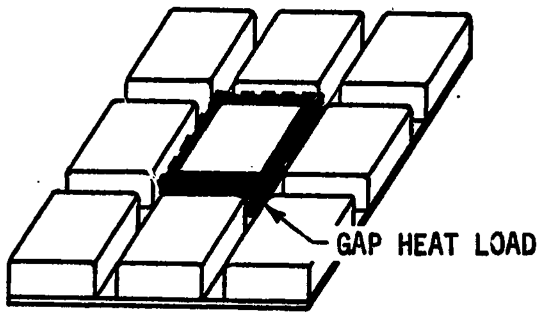


FIGURE 16

EFFECT OF GAP "EAT LOAD ON B^DY FLAP TPS REQUIREMENT

- FLAP (BODY POINT 212)
- TRAJECTORY 14414
- GAP WIDTH = 0.10 IN.
- INNER EDGE RADIUS = 0.06"
- MAXIMUM ALUMINUM TEMPERATURE = 350°F

6.0"X 6.0" TILES



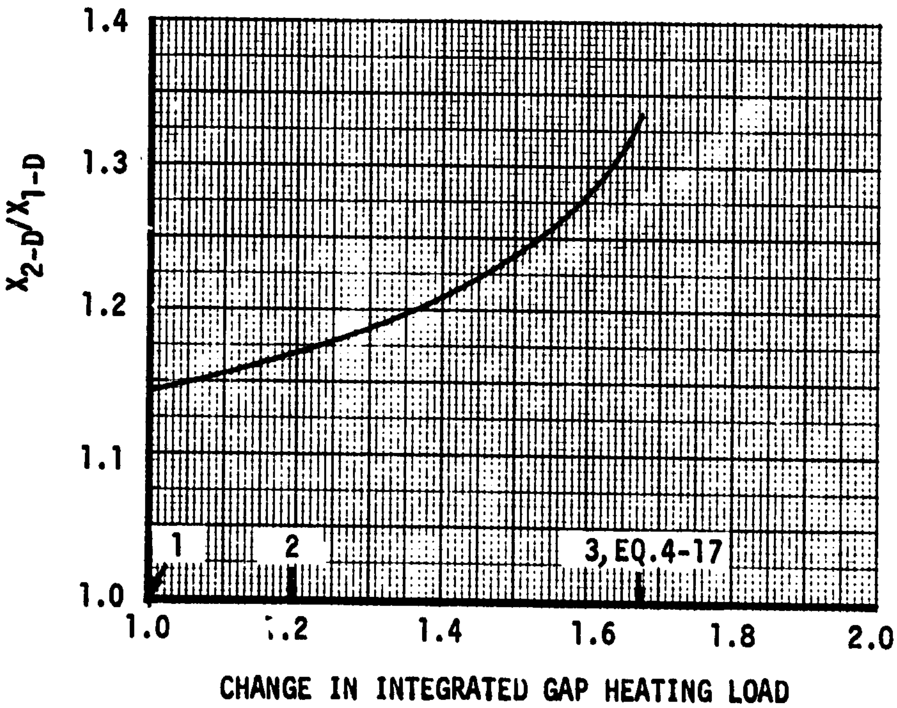


FIGURE 17

TRANSVERSE GAP HEATING DISTRIBUTION USED FOR TPS SIZING

- J. MARSSDORF/R.I. CURVE FIT
- C. SCOTT TEST DATA, JSC 10 MW TUNNEL
- GAP WIDTH = 0.10 IN.

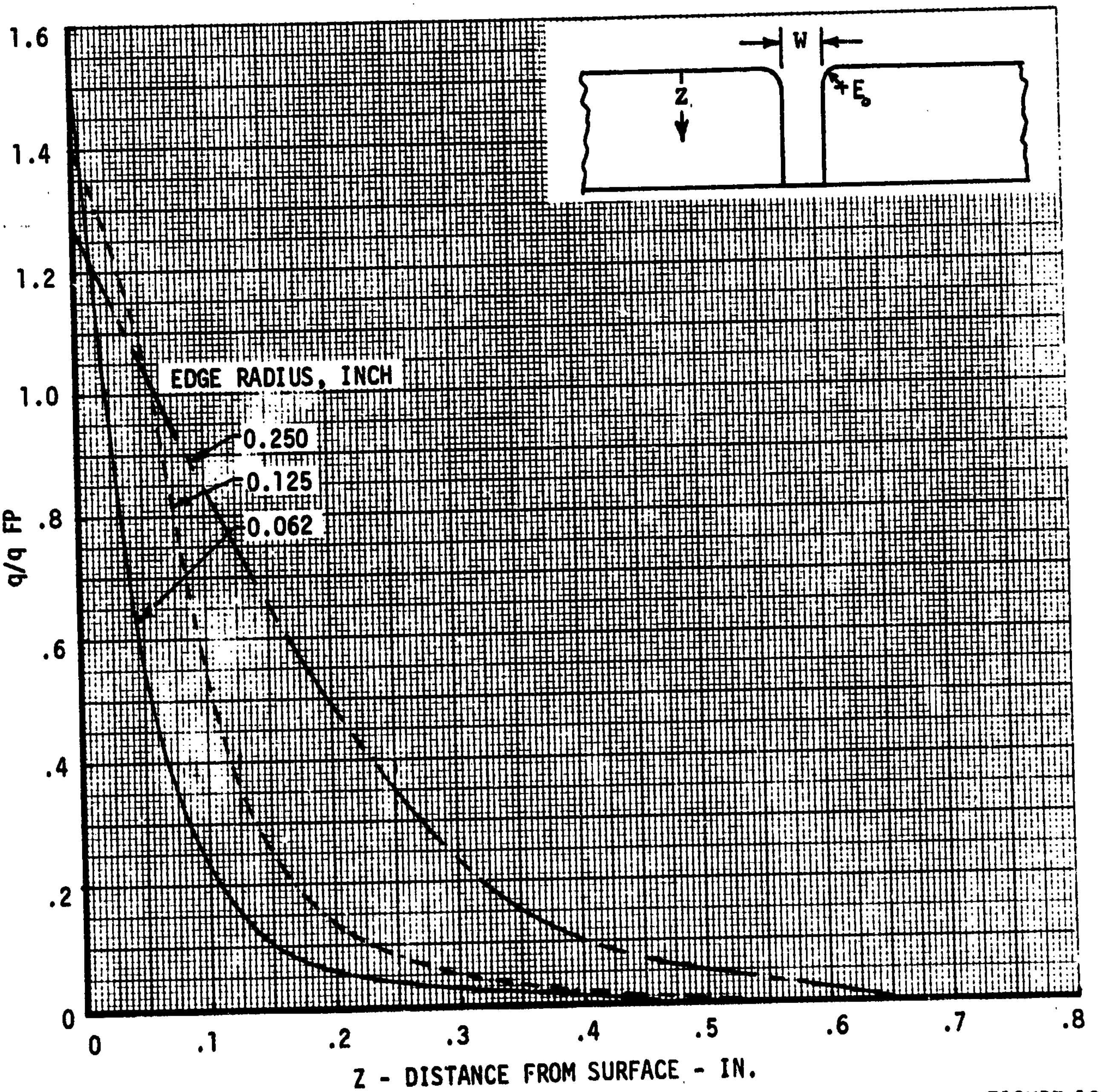
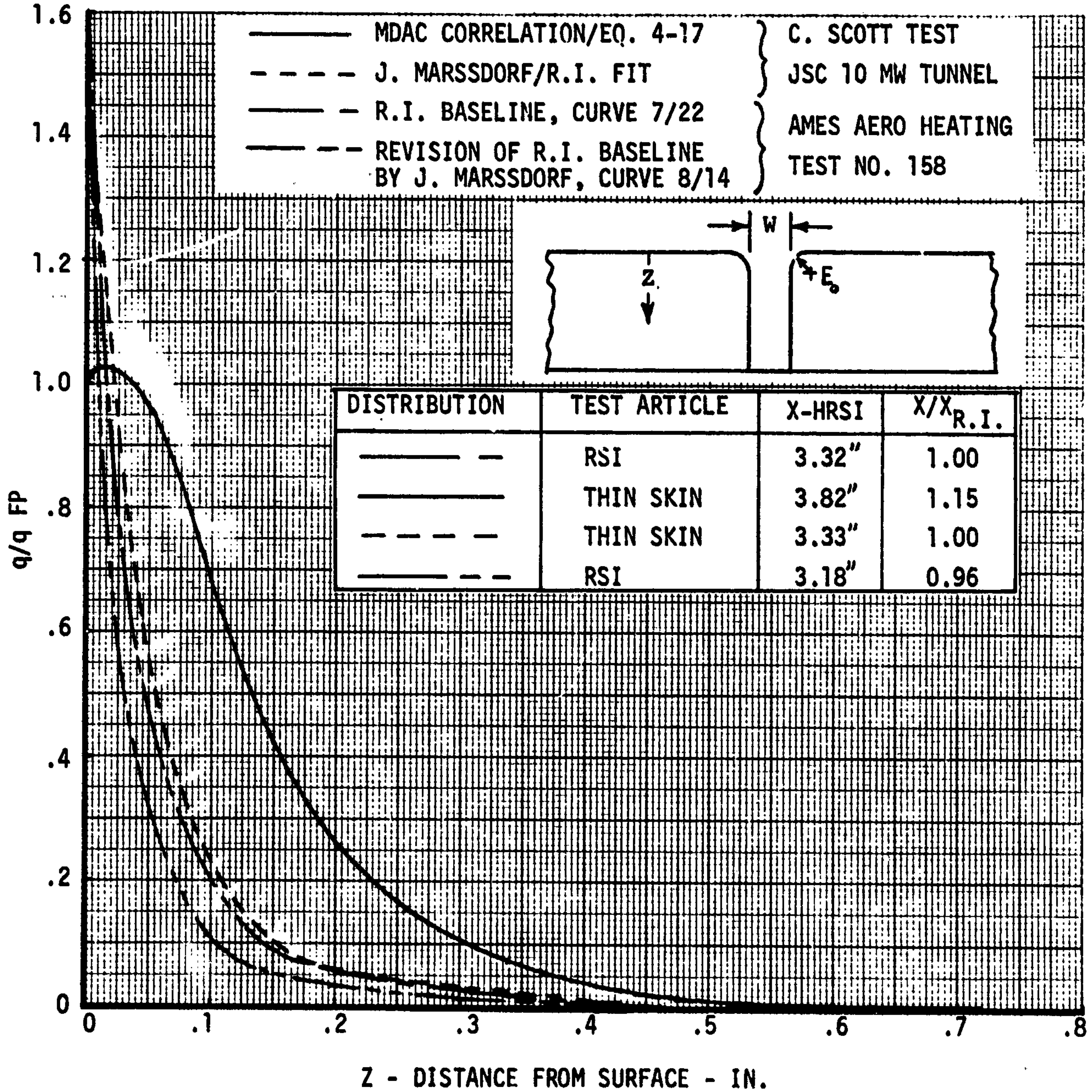


FIGURE 18

GAP HEATING DISTRIBUTION COMPARISON

- 0.10 IN. TRANSVERSE GAP
- 0.06 IN. EDGE RADIUS



DISTRIBUTION	TEST ARTICLE	X-HRSI	$X/X_{R.I.}$
——— —	RSI	3.32"	1.00
———	THIN SKIN	3.82"	1.15
— — — —	THIN SKIN	3.33"	1.00
——— — —	RSI	3.18"	0.96

FIGURE 19

GAP HEATING DISTRIBUTION COMPARISON

- C. SCOTT TEST DATA, JSC 10 MW TUNNEL
- 0.10 IN. TRANSVERSE GAP
- 0.12 IN. EDGE RADIUS

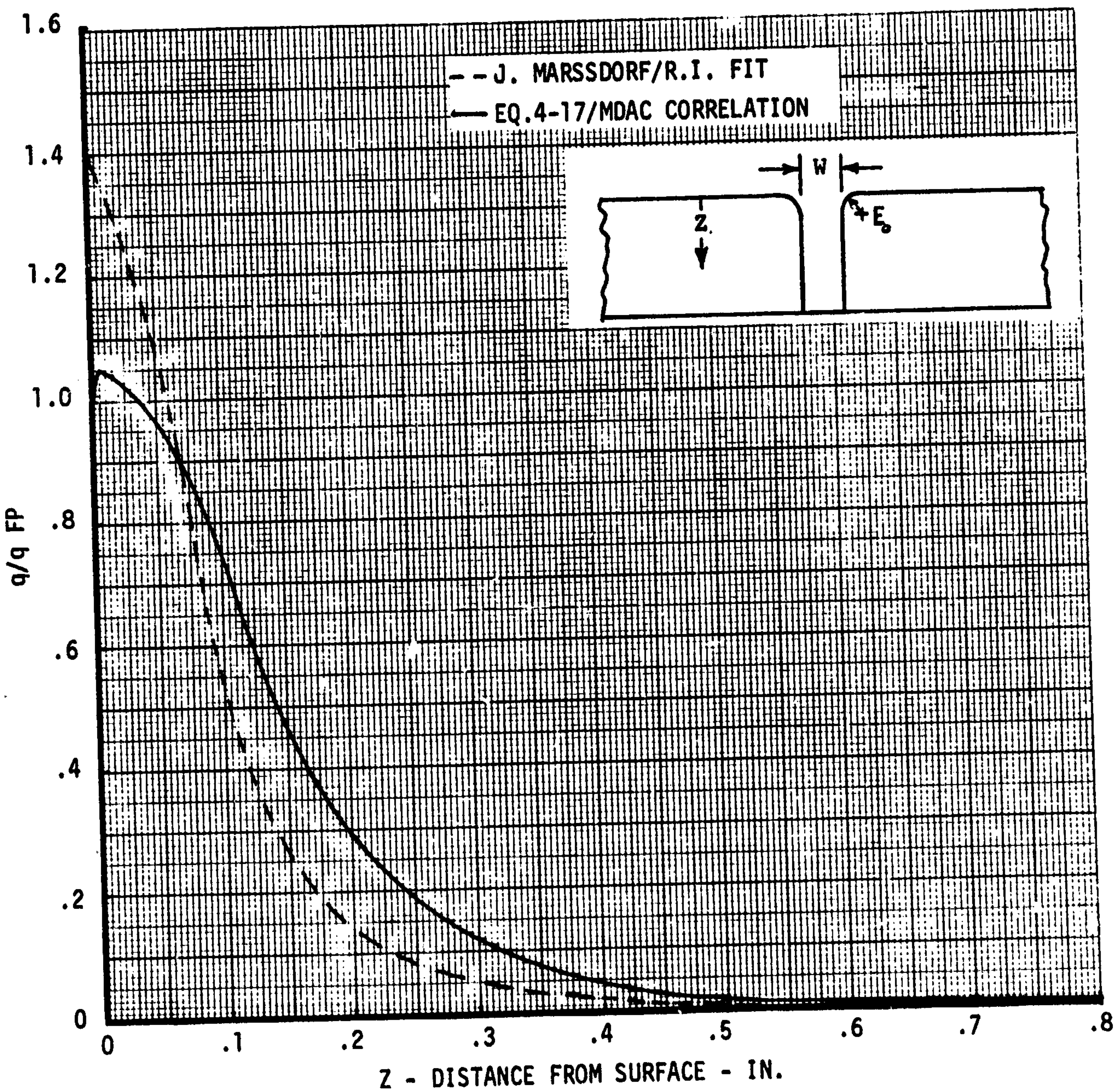


FIGURE 20

GAP HEATING DISTRIBUTION COMPARISON

- C. SCOTT TEST DATA, JSC 10 MW TUNNEL
- 0.10 IN. TRANSVERSE GAP
- 0.25 IN. EDGE RADIUS

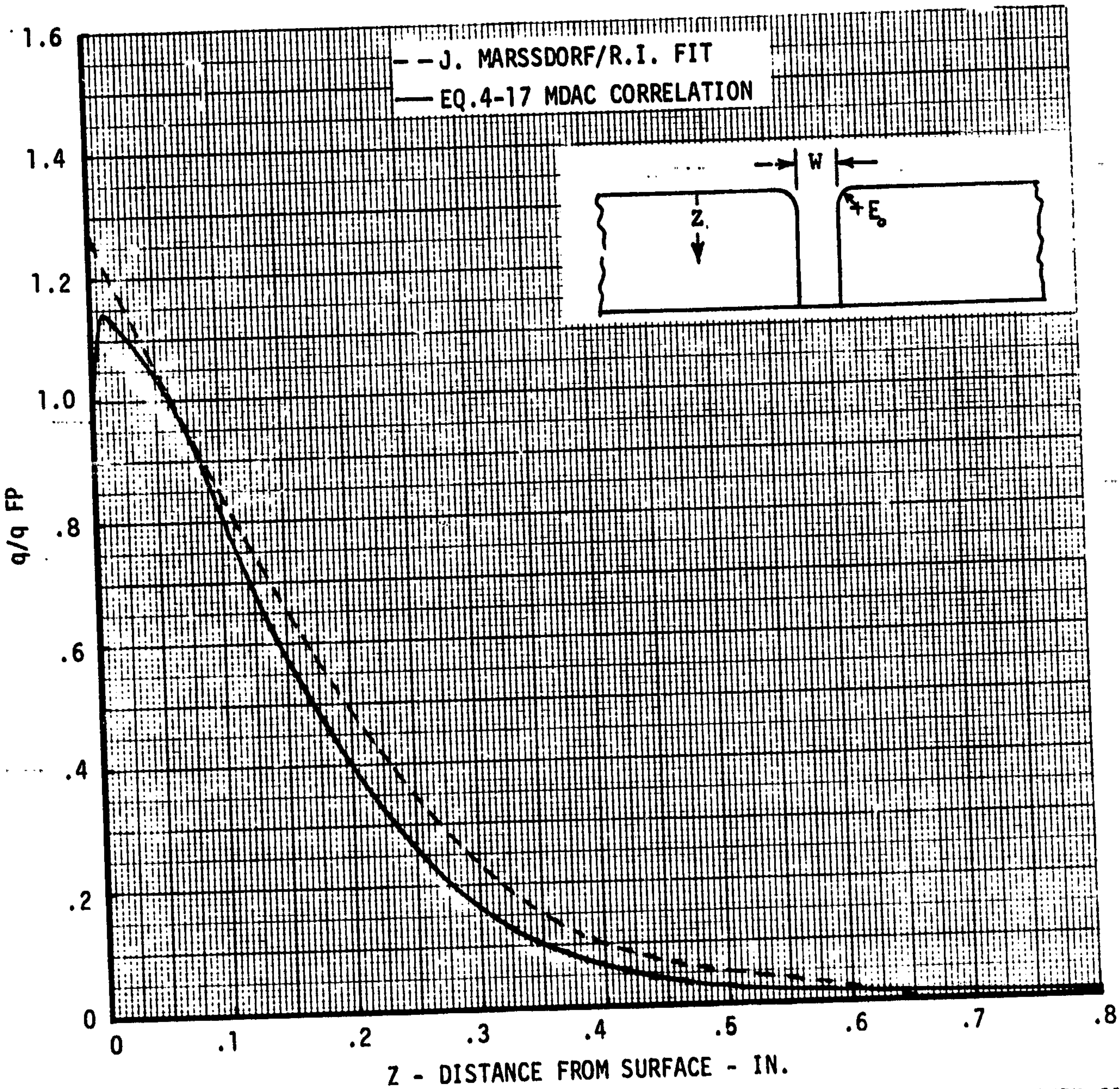


FIGURE 21

TRANSVERSE GAP HEATING DISTRIBUTION USED FOR TPS SIZING

- MDAC CORRELATION EQUATION 4-17
- C. SCOTT TEST DATA, JSC 10 MW TUNNEL
- GAP WIDTH = 0.10 IN.

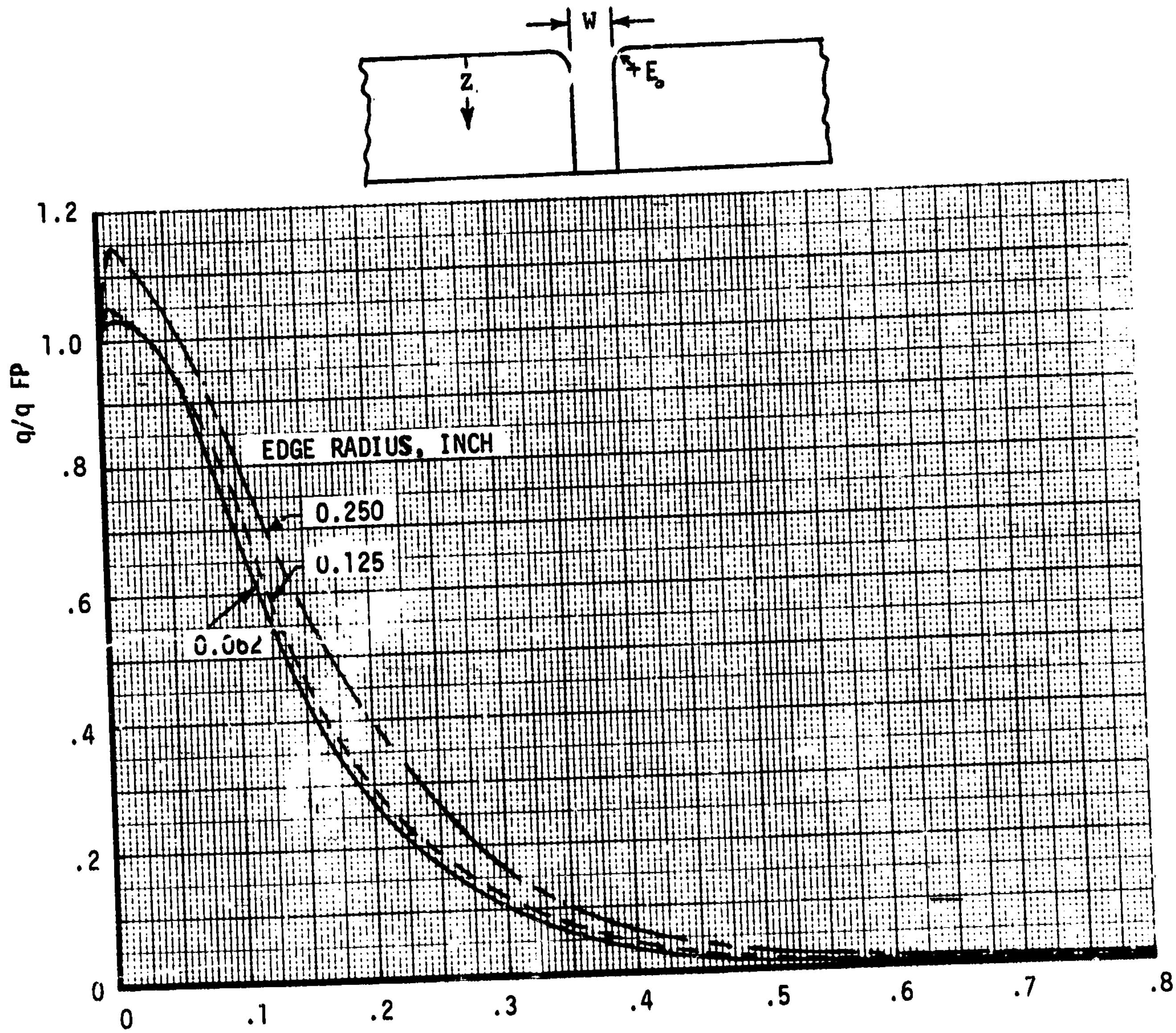


FIGURE 22

TEMPERATURE DISTRIBUTION DOWN GAP

- MDAC CORRELATION, EQ. 4-17
- BODY POINT 1, TRAJECTORY 14414
- GAP WIDTH = 0.10 INCH
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- TIME = 500 SECONDS (MAXIMUM HEATING)

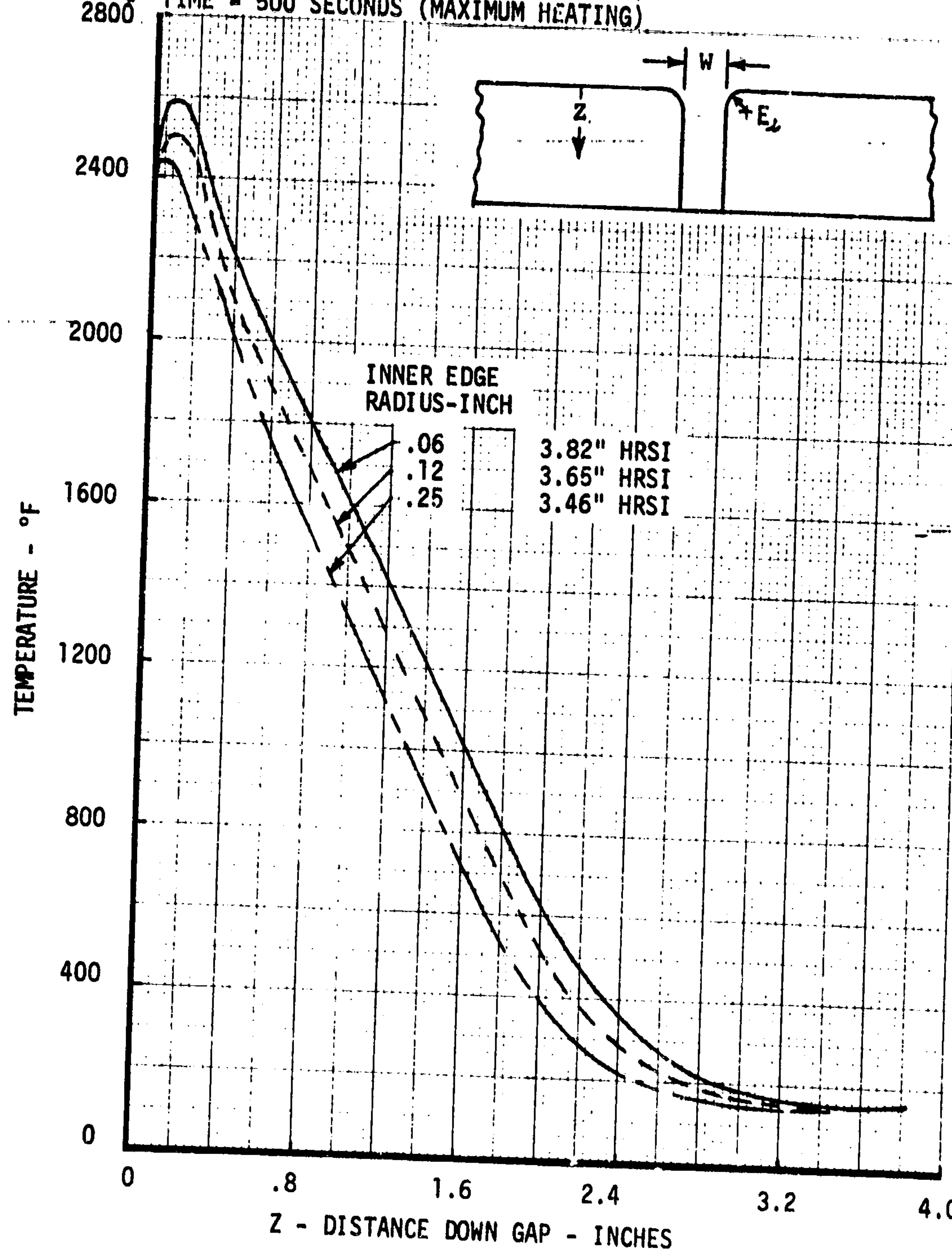


FIGURE 23

TEMPERATURE DISTRIBUTION DOWN GAP

- J. MARSSDORF/R.I. CURVE FIT
- BODY POINT 1, TRAJECTORY 14414
- GAP WIDTH = 0.10 INCH
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- TIME = 500 SECONDS (MAXIMUM HEATING)

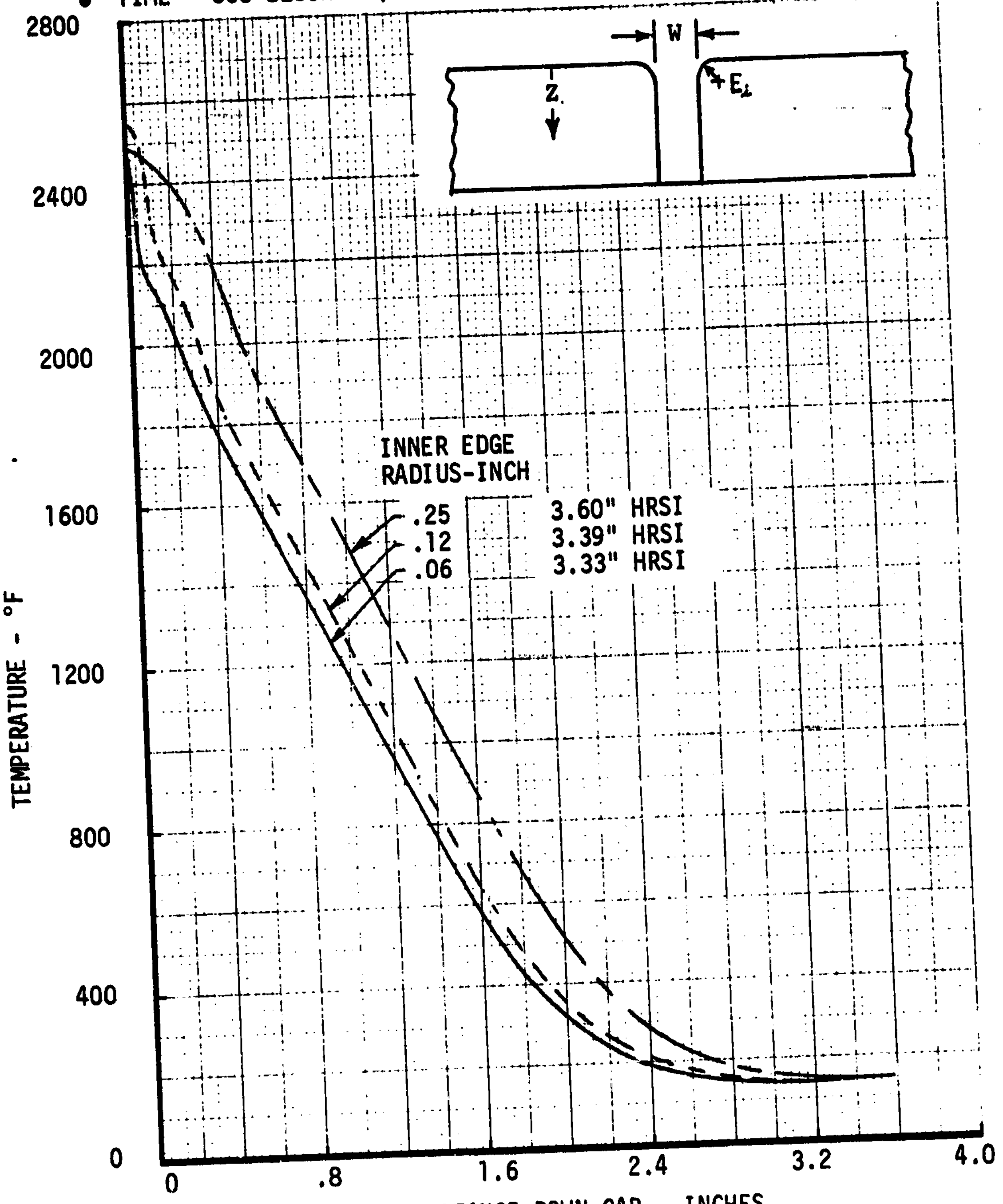


FIGURE 24

TEMPERATURE DISTRIBUTION DOWN GAP

- BODY POINT 1, TRAJECTORY 14414
- GAP WIDTH = 0.10 INCH
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- TIME = 500 SECONDS (MAXIMUM HEATING)

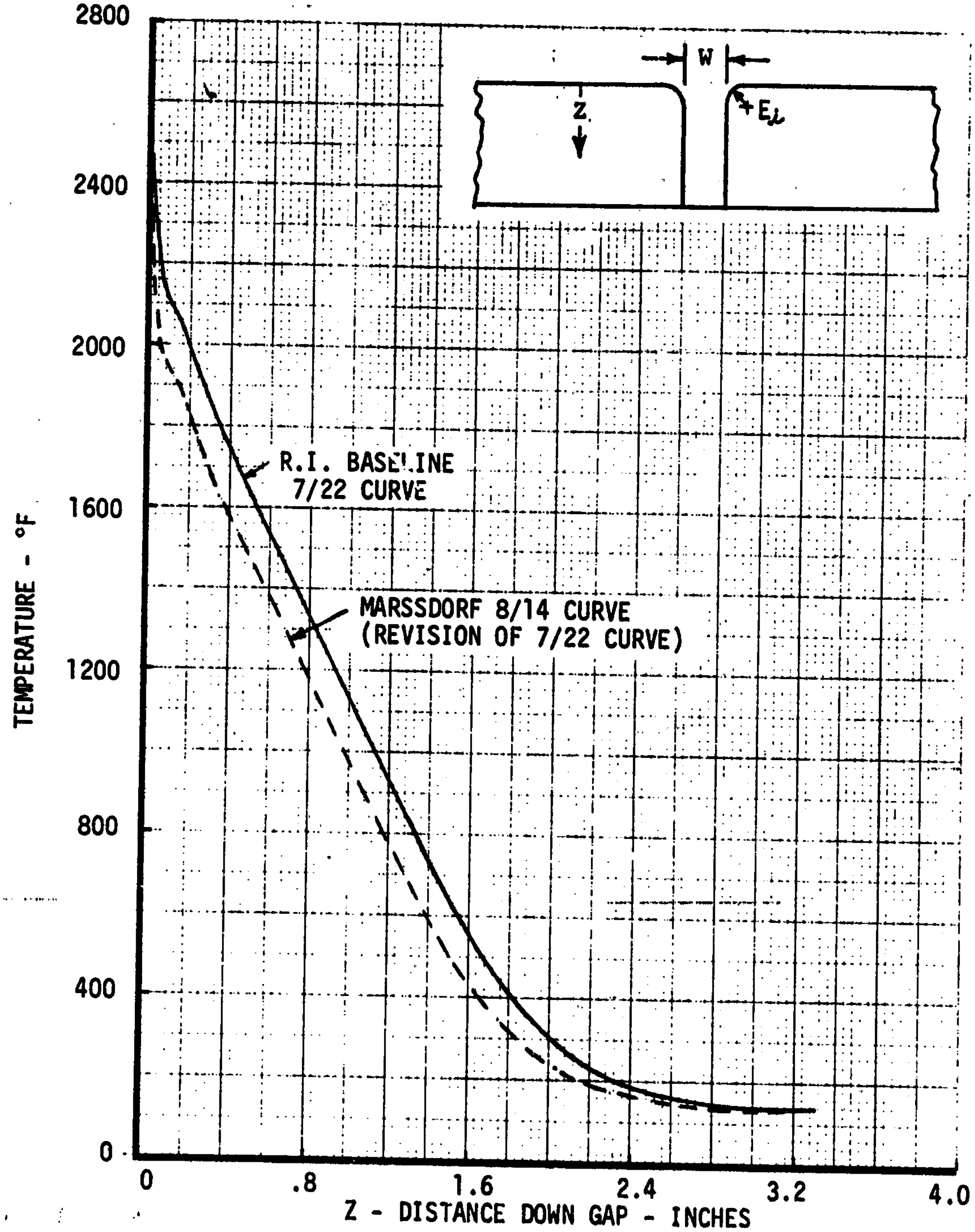


FIGURE 25

SURFACE, EDGE RADIUS AND ALUMINUM STRUCTURE TEMPERATURES

- BODY POINT 1
- TRAJECTORY 14414
- GAP WIDTH = 0.10 IN
- INNER EDGE RADIUS = 0.06 IN

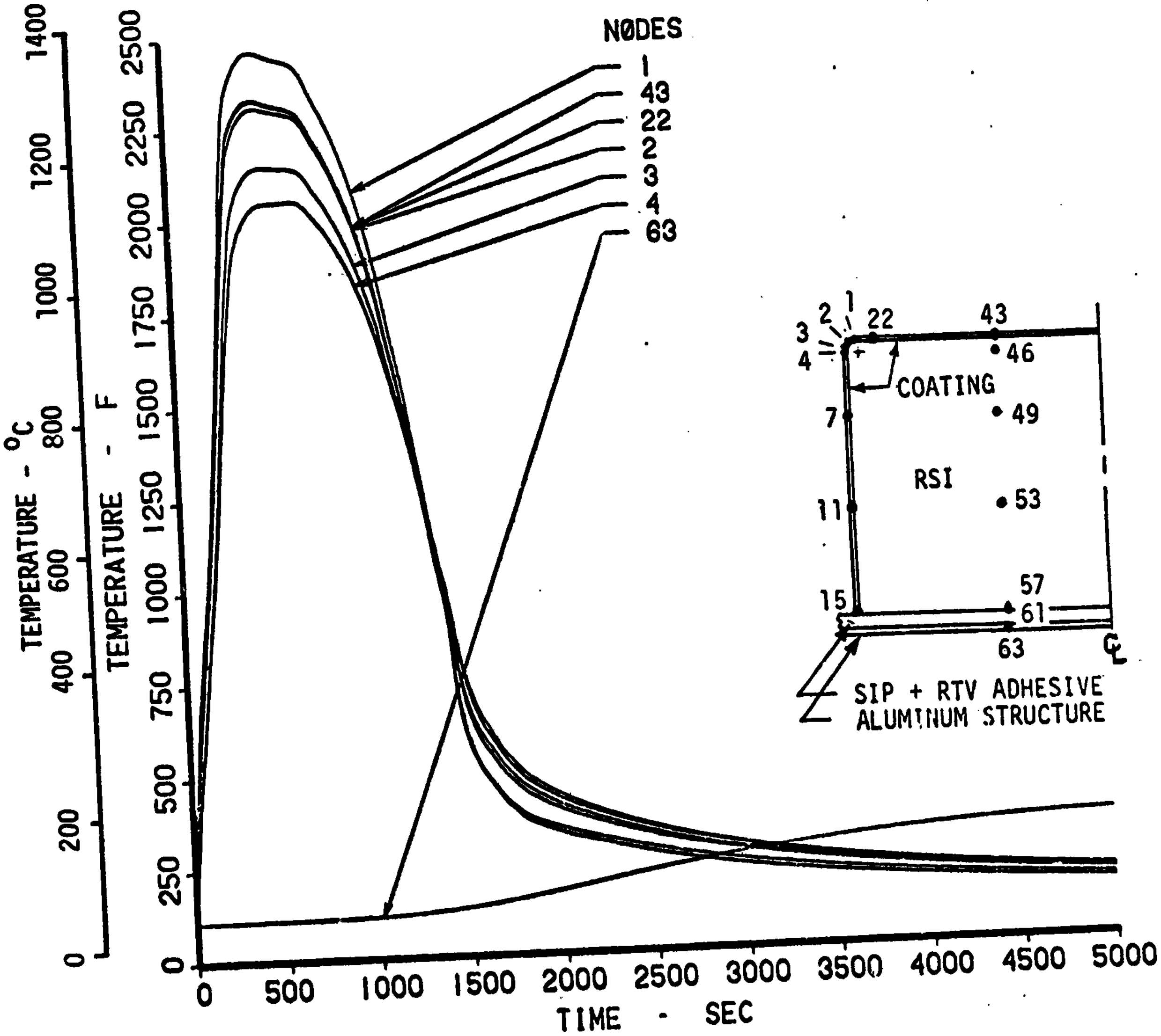


FIGURE 26

TILE TOP AND GAP WALL COATING TEMPERATURES

- BODY POINT 1
- TRAJECTORY 14414
- GAP WIDTH = 0.10 IN
- INNER EDGE RADIUS = 0.06 IN

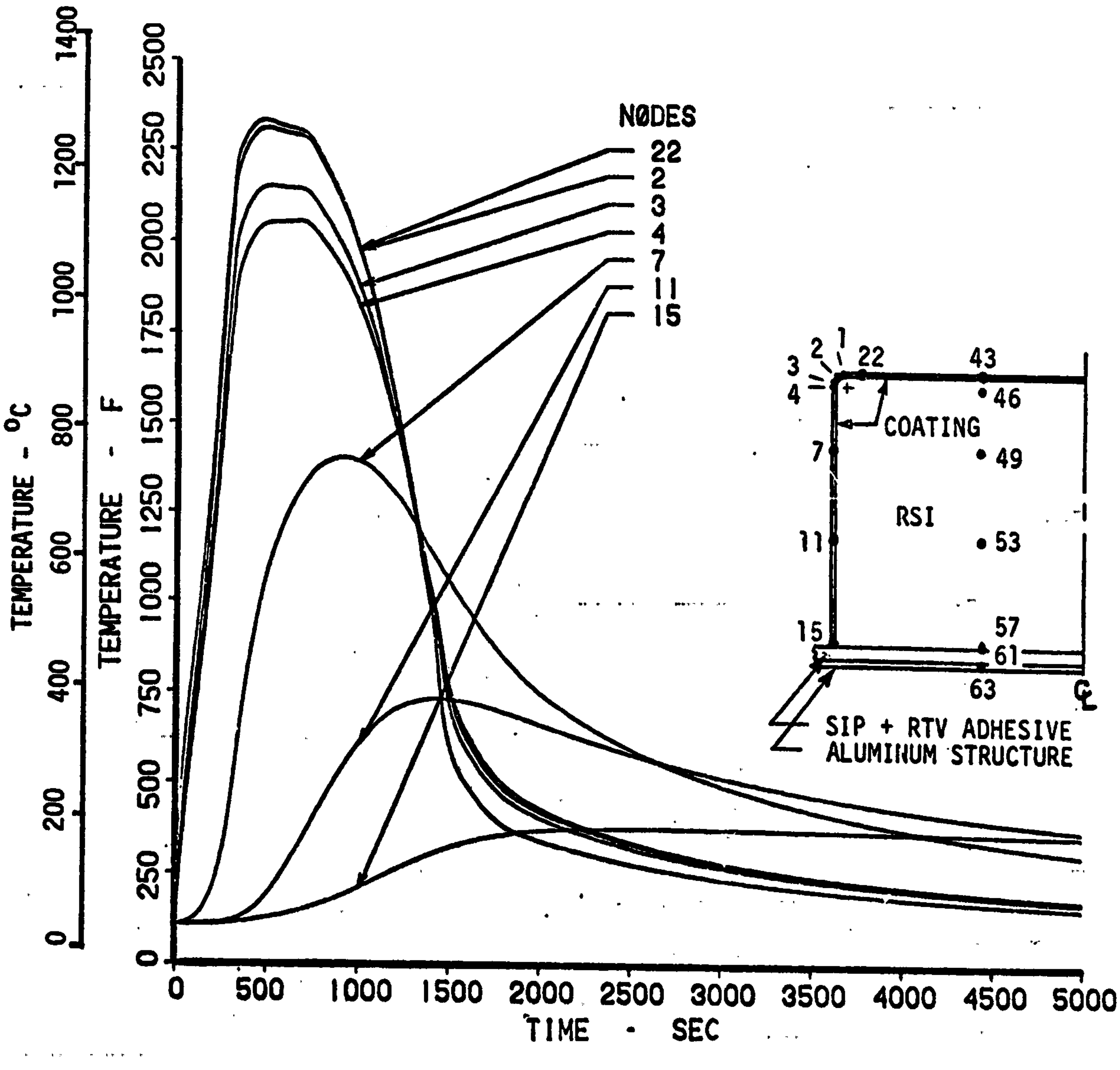


FIGURE 27

RSI IN-DEPTH TEMPERATURES NEAR CENTER OF TILE

- BODY POINT 1
- TRAJECTORY 14414
- GAP WIDTH = 0.10 IN
- INNER EDGE RADIUS = 0.06 IN

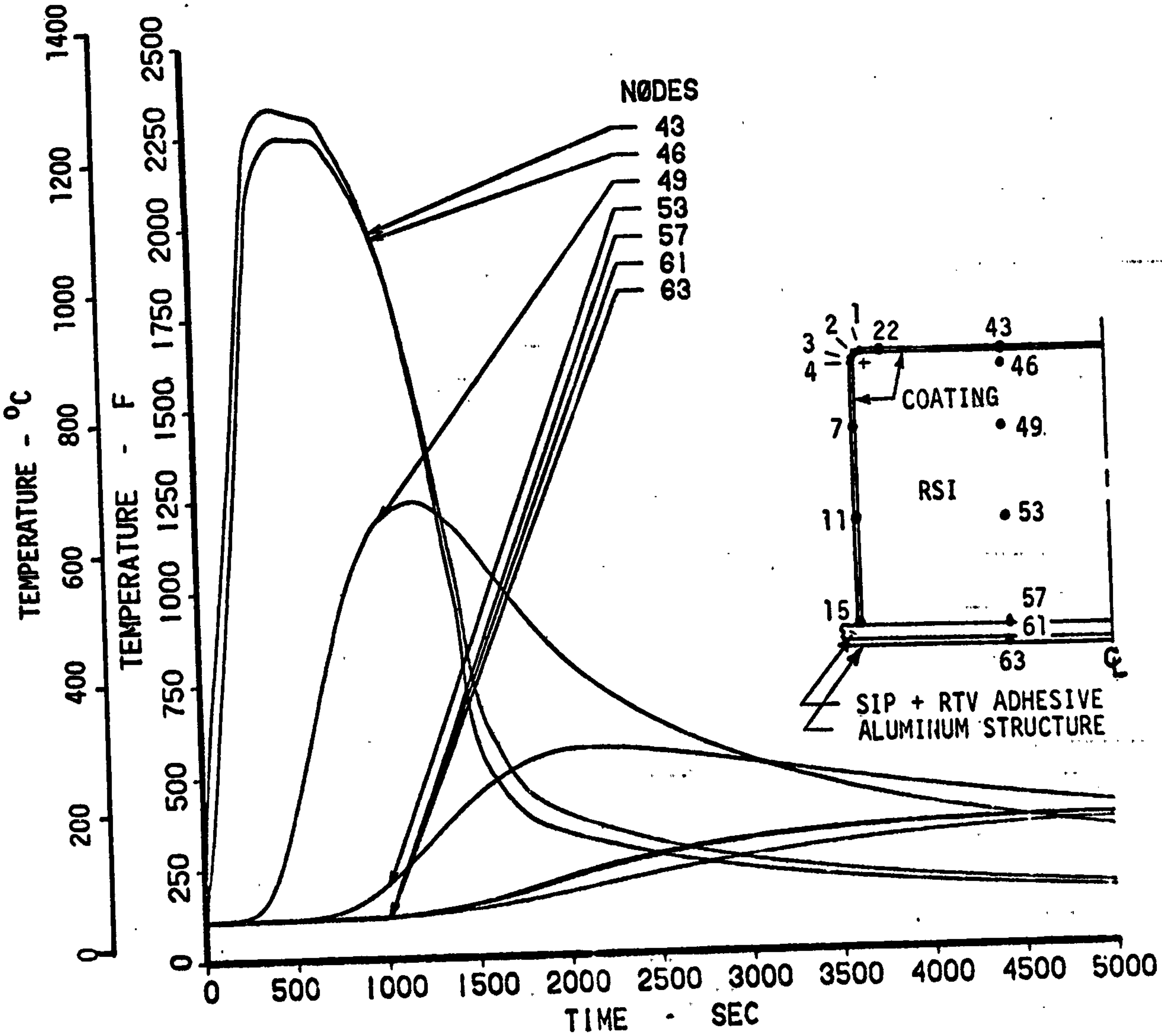


FIGURE 28

TEMPERATURE ISOTHERMS THROUGH HRSI TILE

- MAXIMUM HEATING (t = 500 SEC)
- BODY POINT 1
- 0.10" GAP HEATING DISTRIBUTION*
- TRAJECTORY 14414
- 3.32 IN. HRSI
- 0.06 IN. EDGE RADIUS
- 2-D MODEL

* R.I. BASELINE

PRIORITY CASE 7

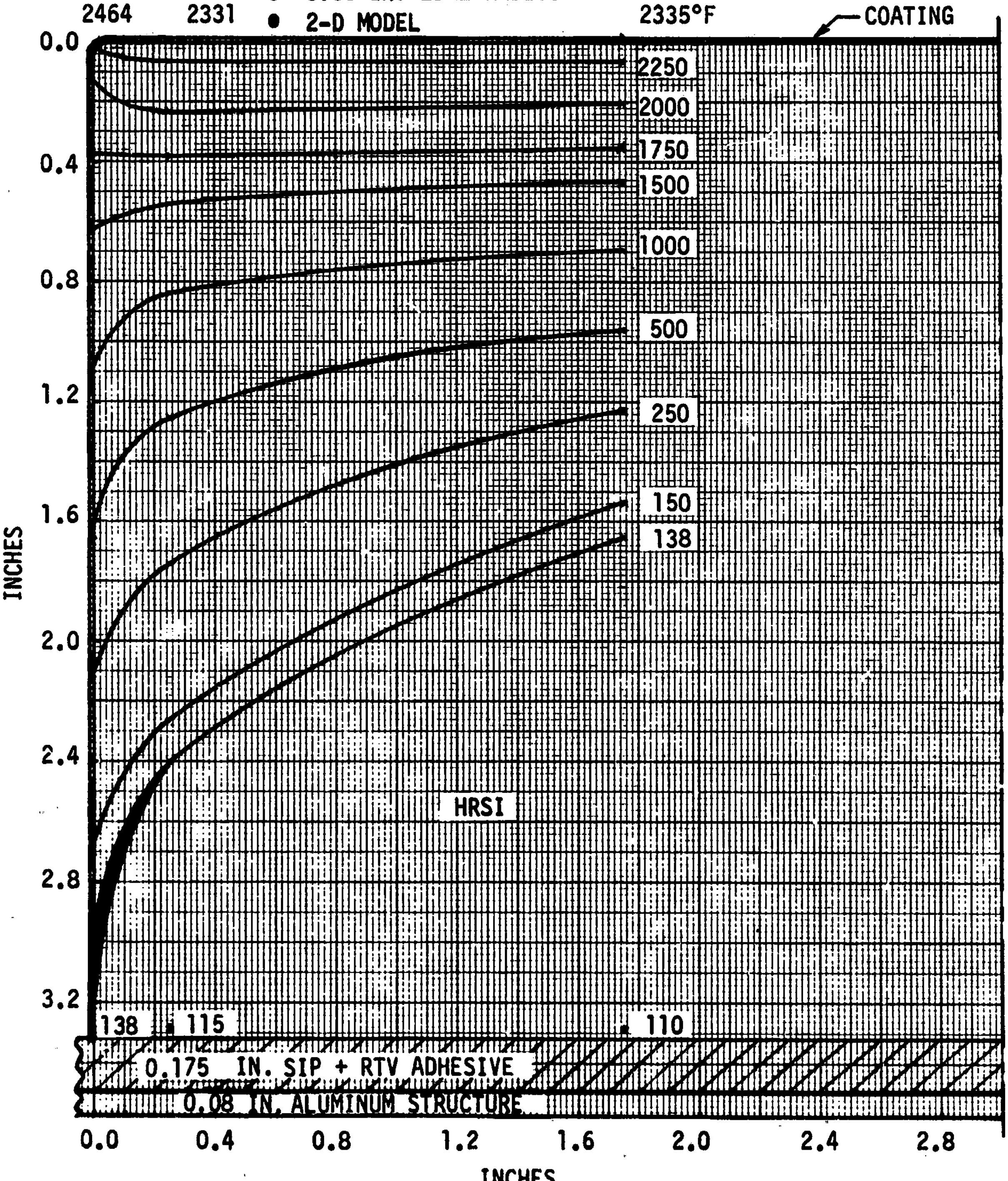
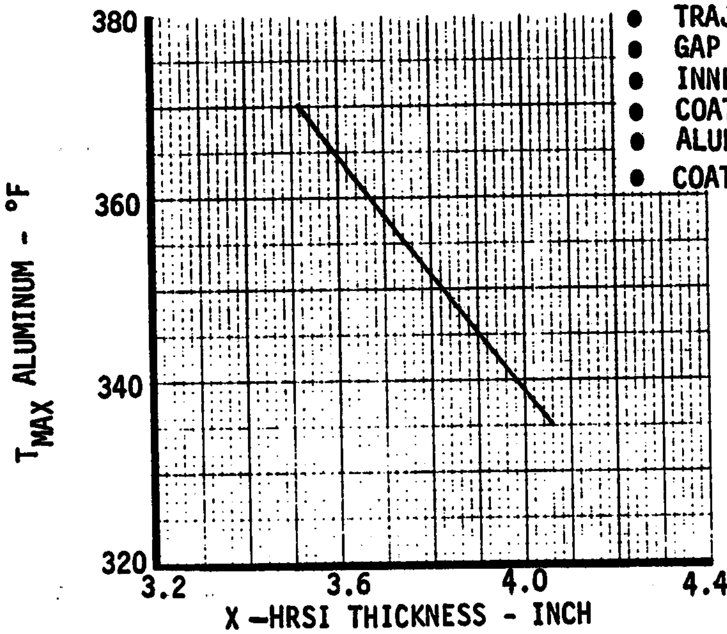


FIGURE 29

ALUMINUM STRUCTURE MAXIMUM TEMPERATURE VS. HRSI TILE THICKNESS

- MDAC EQ. 4-17
- 2-D MODEL
- BODY POINT 1
- TRAJECTORY 14414
- GAP WIDTH = 0.10 INCH
- INNER EDGE RADIUS = 0.06 INCH
- COATING THICKNESS = 0.015 INCH
- ALUMINUM THICKNESS = 0.203 cm
- COATING EMISSIVITY = 0.8



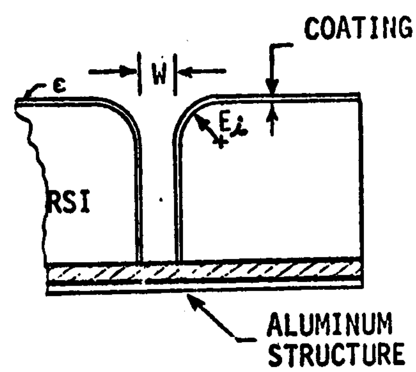


FIGURE 30

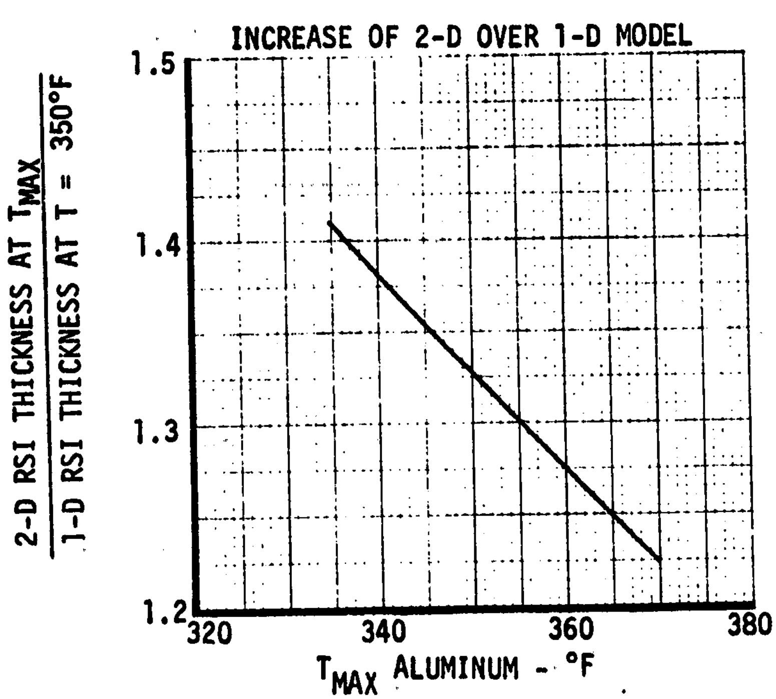
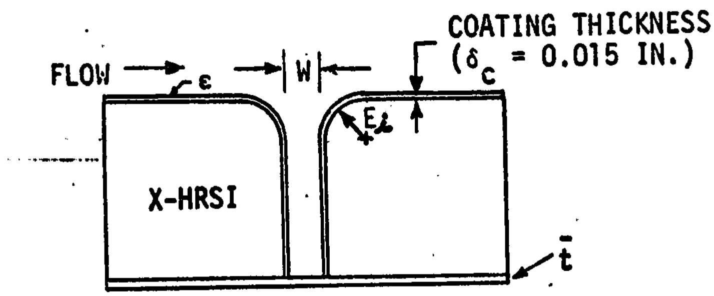


FIGURE 31

EFFECT OF COATING EMISSIVITY AND ALUMINUM STRUCTURE THICKNESS ON THE RATIO OF 2-D TO 1-D MODEL TPS REQUIREMENTS

- BODY POINT 1
- TRAJECTORY 14414
- R.I. BASELINE HEATING DISTRIB. } 2-D MODEL
- GAP WIDTH = 0.10" } 2-D MODEL
- INNER EDGE RADIUS = 0.06" } 2-D MODEL
- MAXIMUM ALUMINUM TEMPERATURE = 350°F

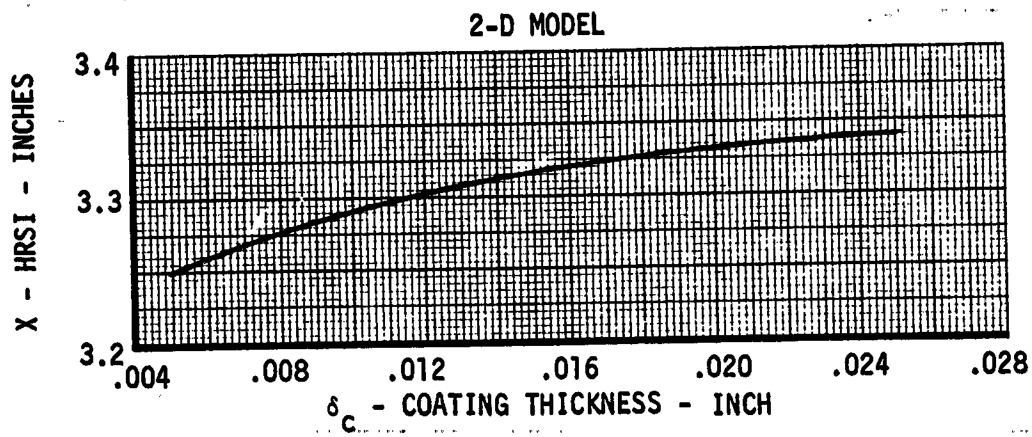


ε COATING EMISSIVITY	$\bar{t}$ ALUMINUM STRUCTURE	X-HRSI 1-D MODEL	X-HRSI 2-D MODEL	X_{2-D}/X_{1-D}
0.80	0.08	2.88	3.32	1.153
0.85	0.10	2.53	2.91	1.150
0.80	0.12	2.38	2.76	1.160

FIGURE 32

EFFECT OF COATING THICKNESS ON TPS REQUIREMENTS

- BODY POINT 1
- TRAJECTORY 14414
- R.I. BASELINE HEATING DISTRIBUTION
- GAP WIDTH = 0.10 IN.
- INNER EDGE RADIUS = 0.06"
- MAXIMUM ALUMINUM TEMPERATURE = 350°F



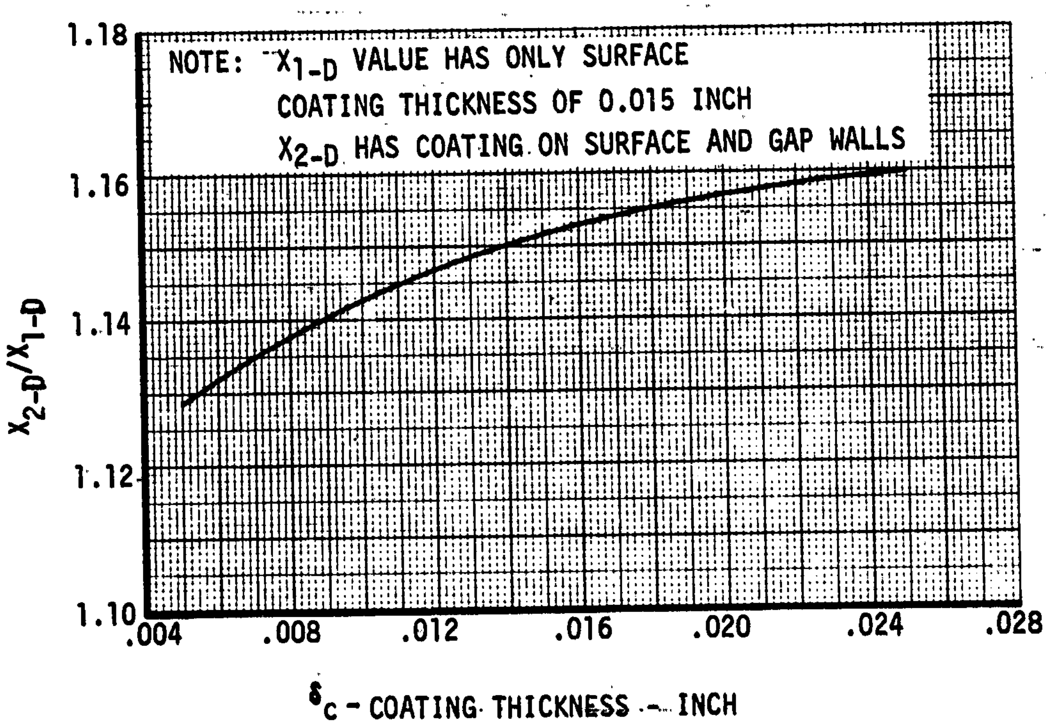
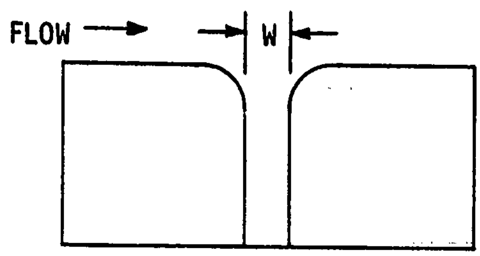


FIGURE 33

EFFECT OF GAP WIDTH ON TEMPERATURE OF ALUMINUM STRUCTURE

- BODY POINT 1
- TRAJECTORY 14414
- GAP HEATING DISTRIBUTION SAME FOR ALL GAP WIDTHS
- 3.32 IN. HRSI
- 0.06 IN. EDGE RADIUS



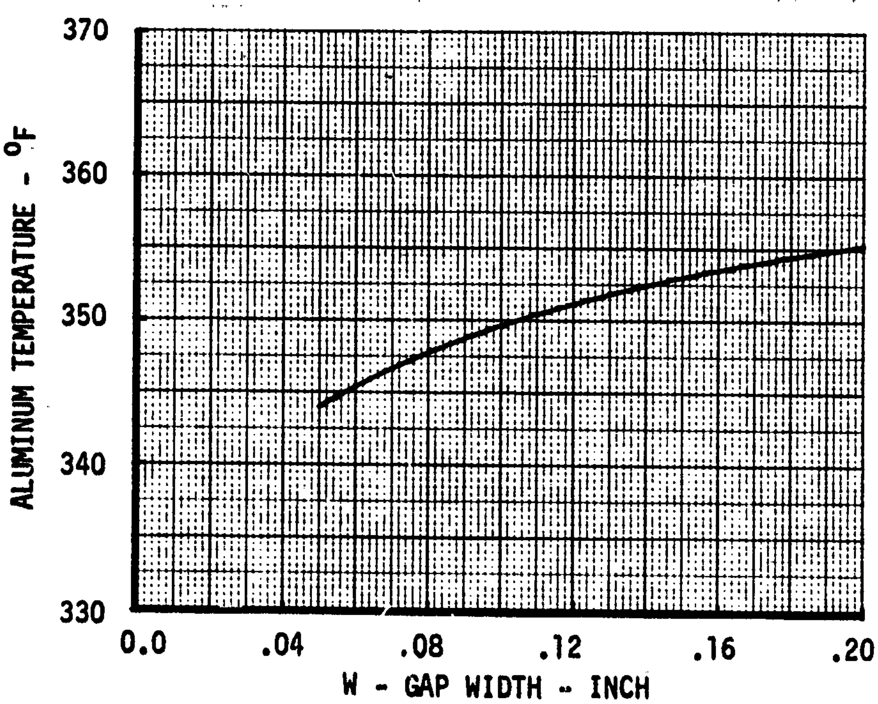
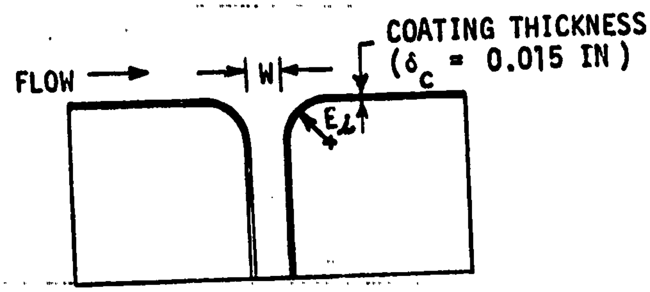


FIGURE 34

GAP WIDTH EFFECT ON TPS REQUIREMENTS

- 2-D MODEL
- BODY POINT 1
- TRAJECTORY 14414
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- MDAC EQ. 4-17 HEATING DISTRIBUTION



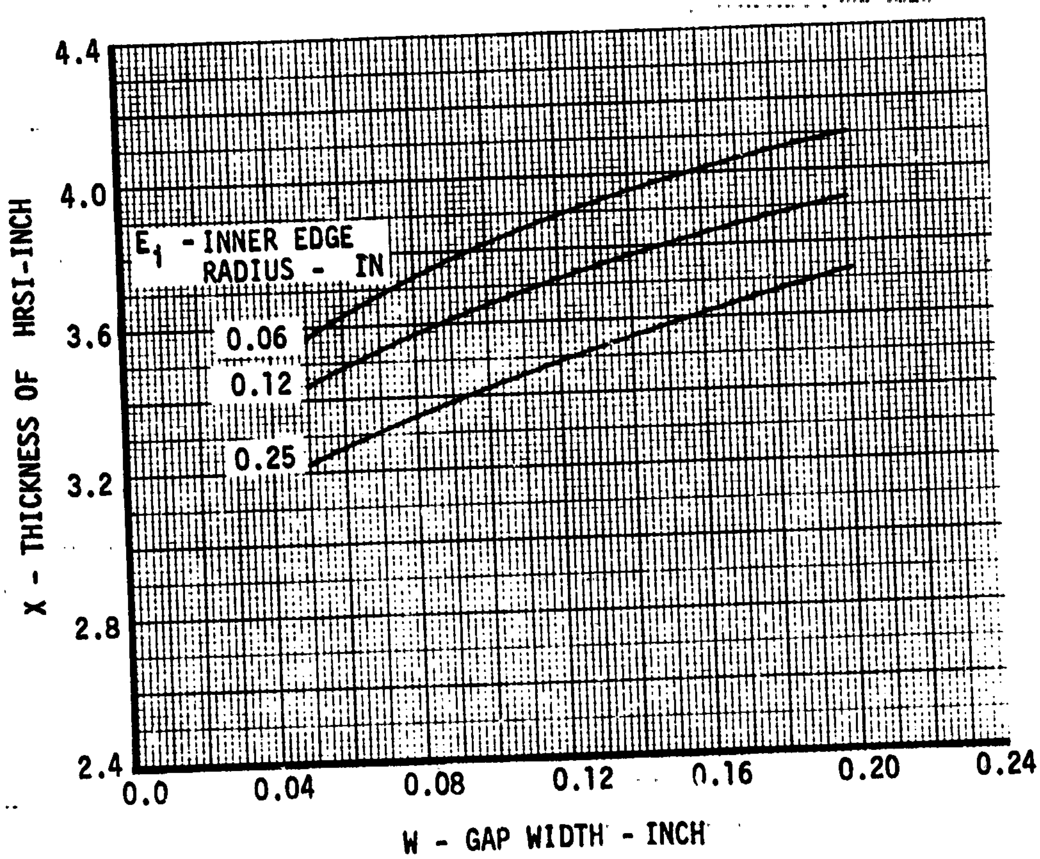


FIGURE 35

GAP WIDTH EFFECT ON TPS REQUIREMENTS

- BODY POINT 1
- TRAJECTORY 14414
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- MDAC CORRELATION, EQ. 4-17

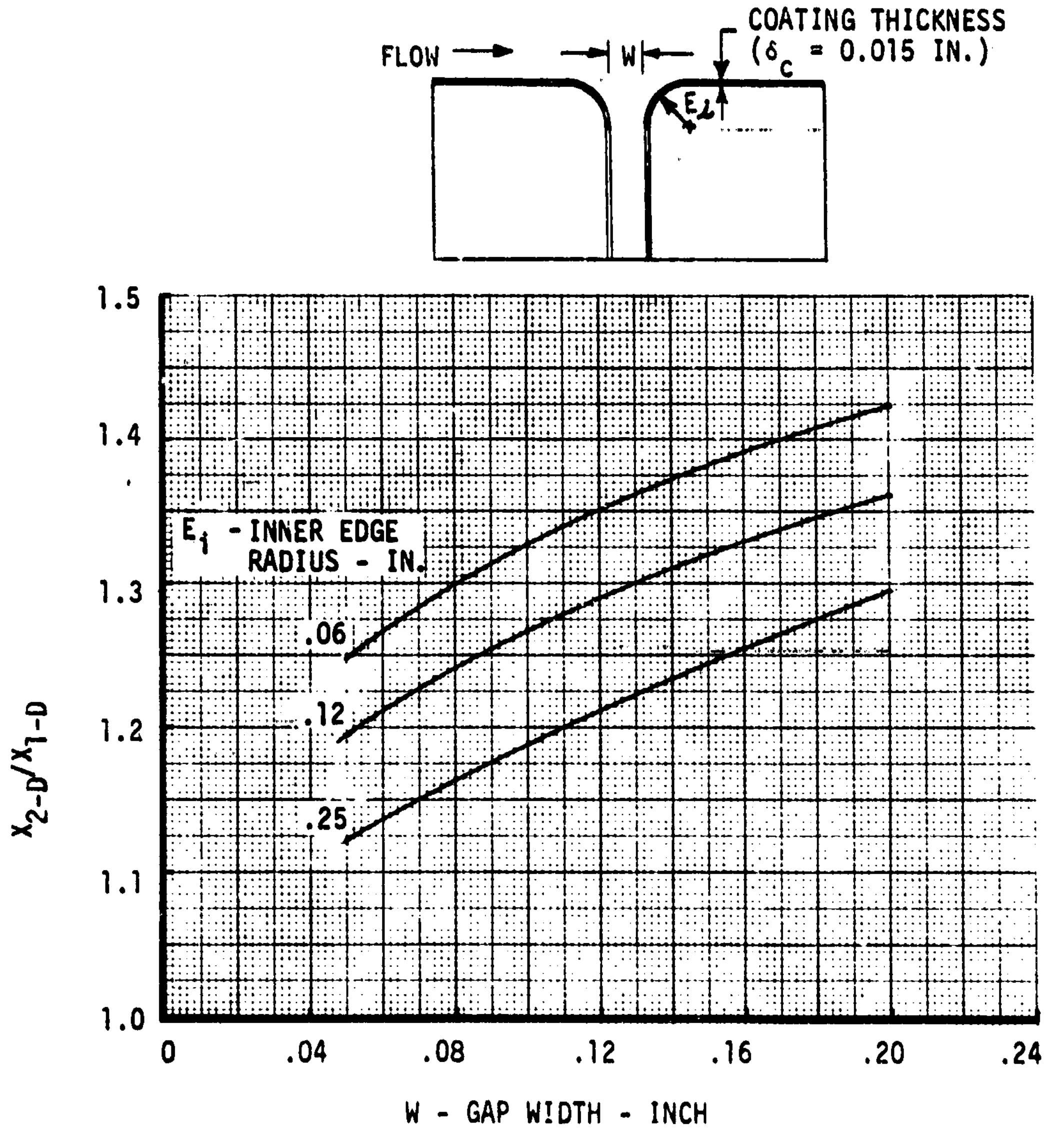


FIGURE 36

INCREASING EDGE RADIUS REDUCES TPS REQUIREMENTS
R.I. BASELINE HEATING DISTRIBUTION

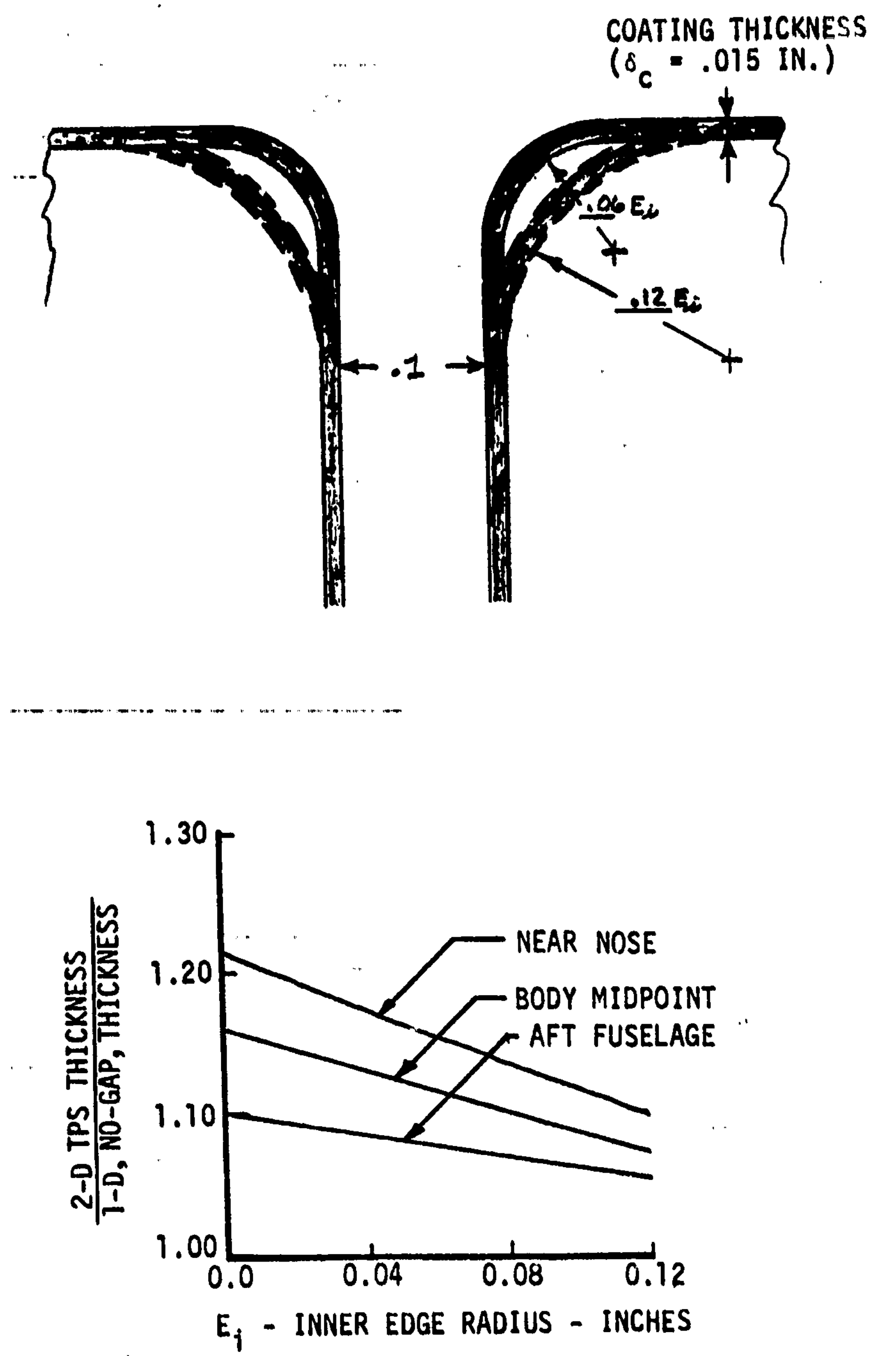
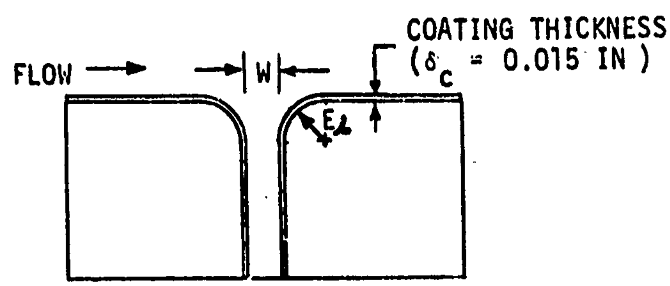


FIGURE 37

EDGE RADIUS EFFECT ON TPS REQUIRCMENTS

- 2-D MODEL
- BODY POINT 1
- TRAJECTORY 14414
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- MDAC EQ. 4-17 HEATING DISTRIBUTION



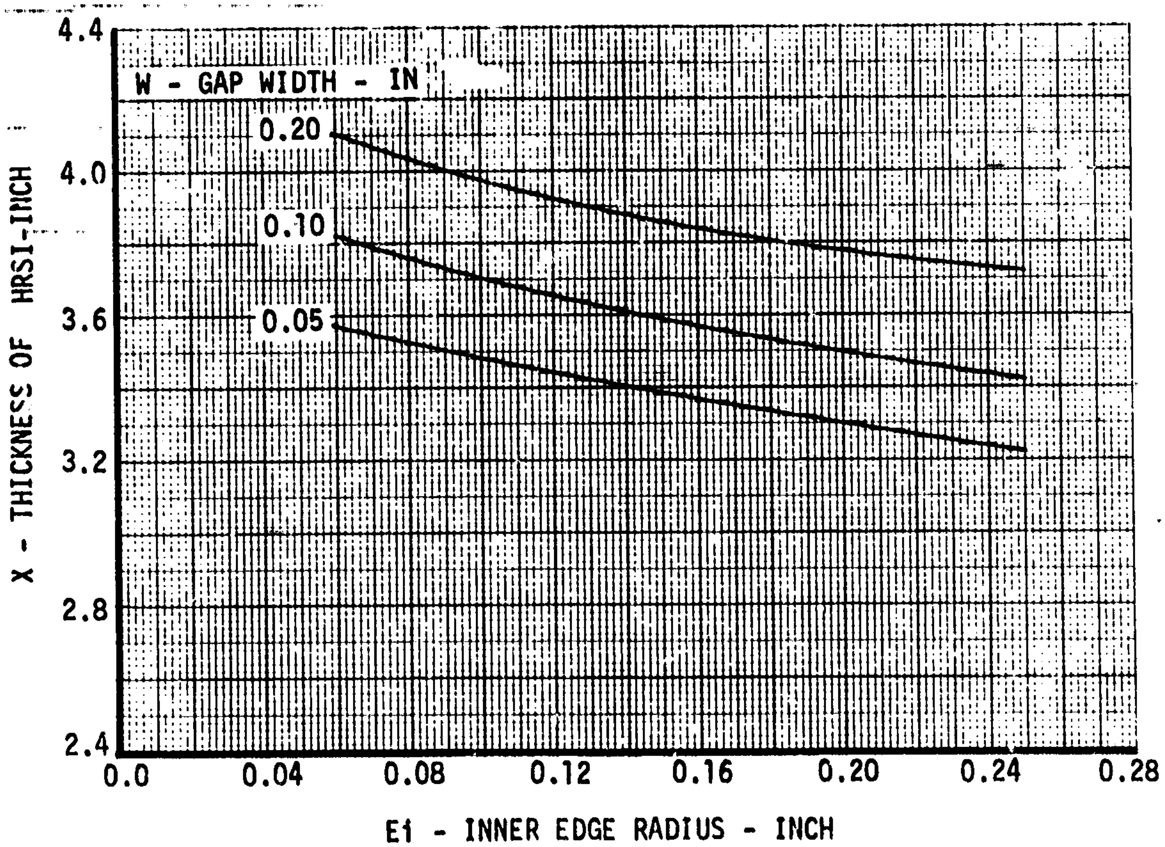


FIGURE 38

EDGE RADIUS EFFECT ON TPS REQUIREMENTS

- BODY POINT 1
- TRAJECTORY 14414
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- MDAC CORRELATION, EQ. 4-17

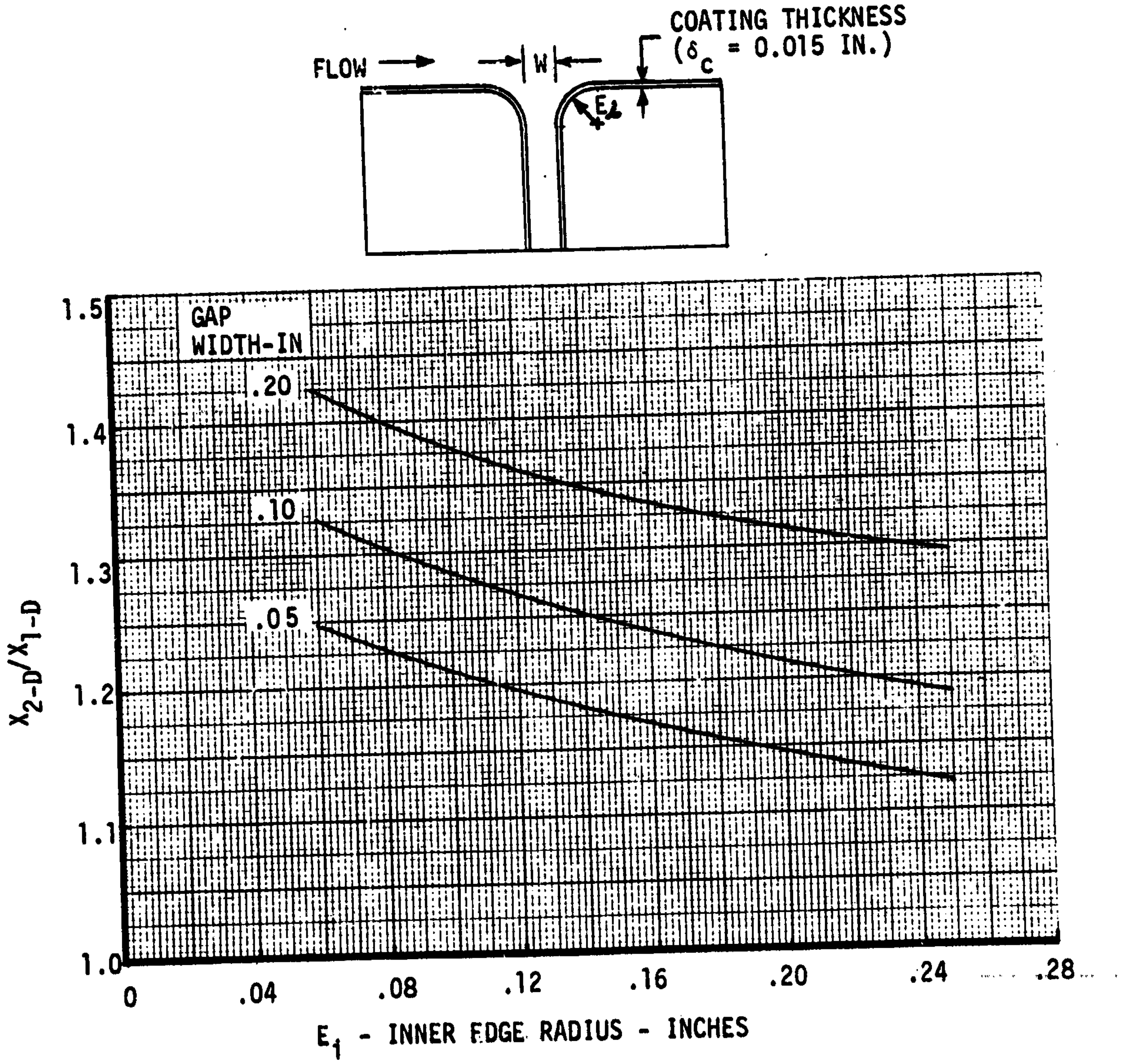
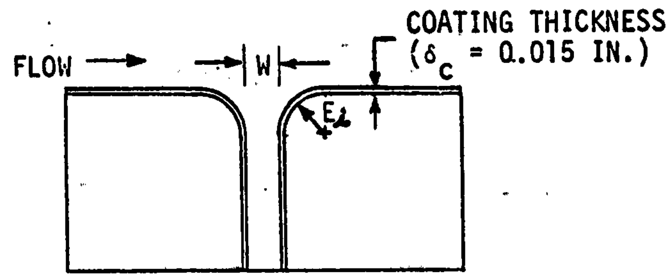


FIGURE 39

EDGE RADIUS EFFECT ON TPS REQUIREMENTS

- BODY POINT 1
- TRAJECTORY 14414
- MAXIMUM ALUMINUM TEMPERATURE = 350°F
- MDAC EQ. 4-17 HEATING DISTRIBUTION



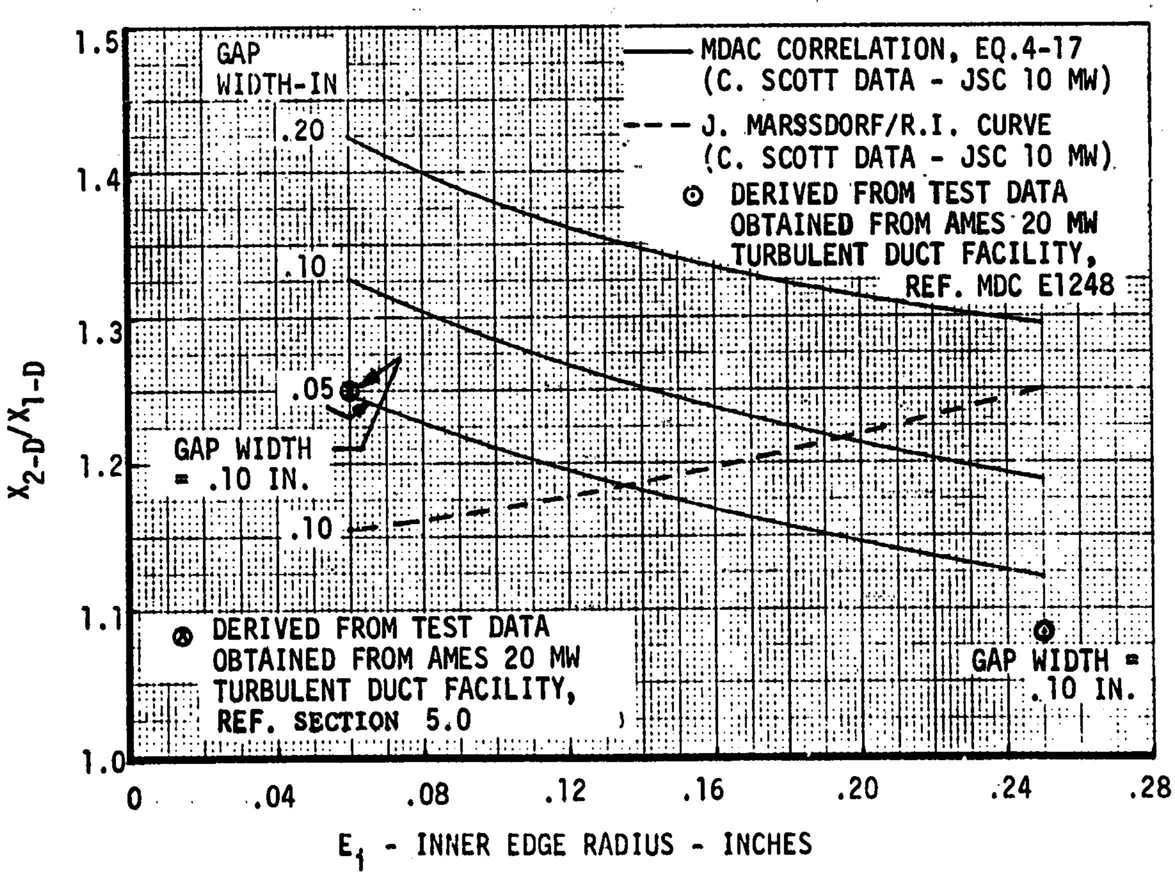
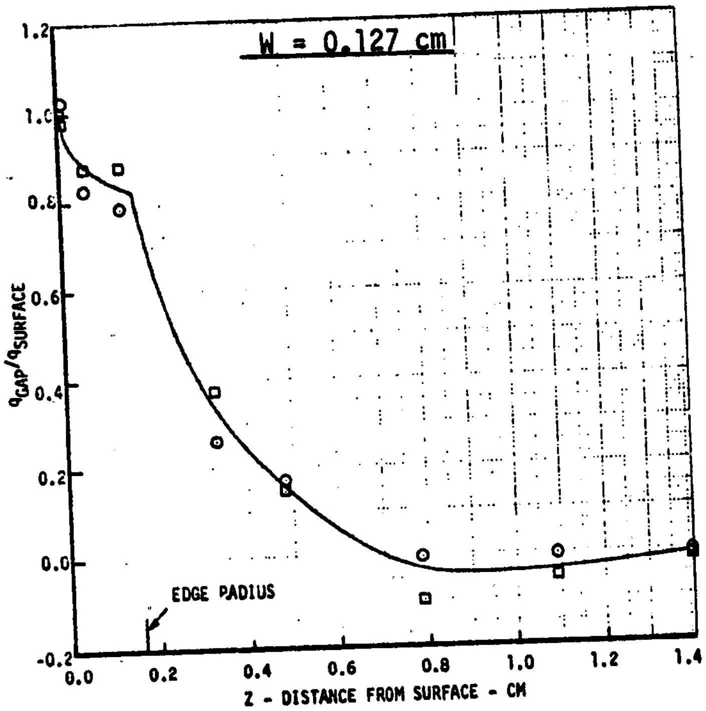
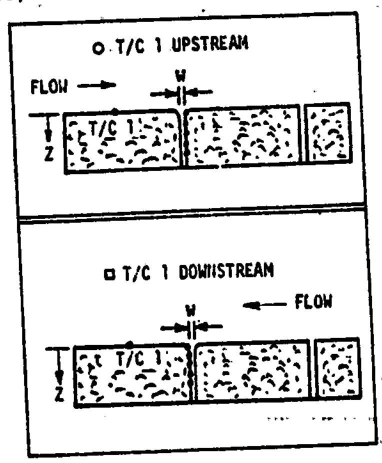


FIGURE 40

HEATING DISTRIBUTIONS FOR 0.157 CM EDGE RADIUS HRSI TILES



- Ames 20 MW 2 x 9 inch turbulent flow duct facility
- Downstream wall of transverse gap
- Distribution at 160 sec test time
- M_∞ = 3.5
- Re/m = 0.3 x 10^6



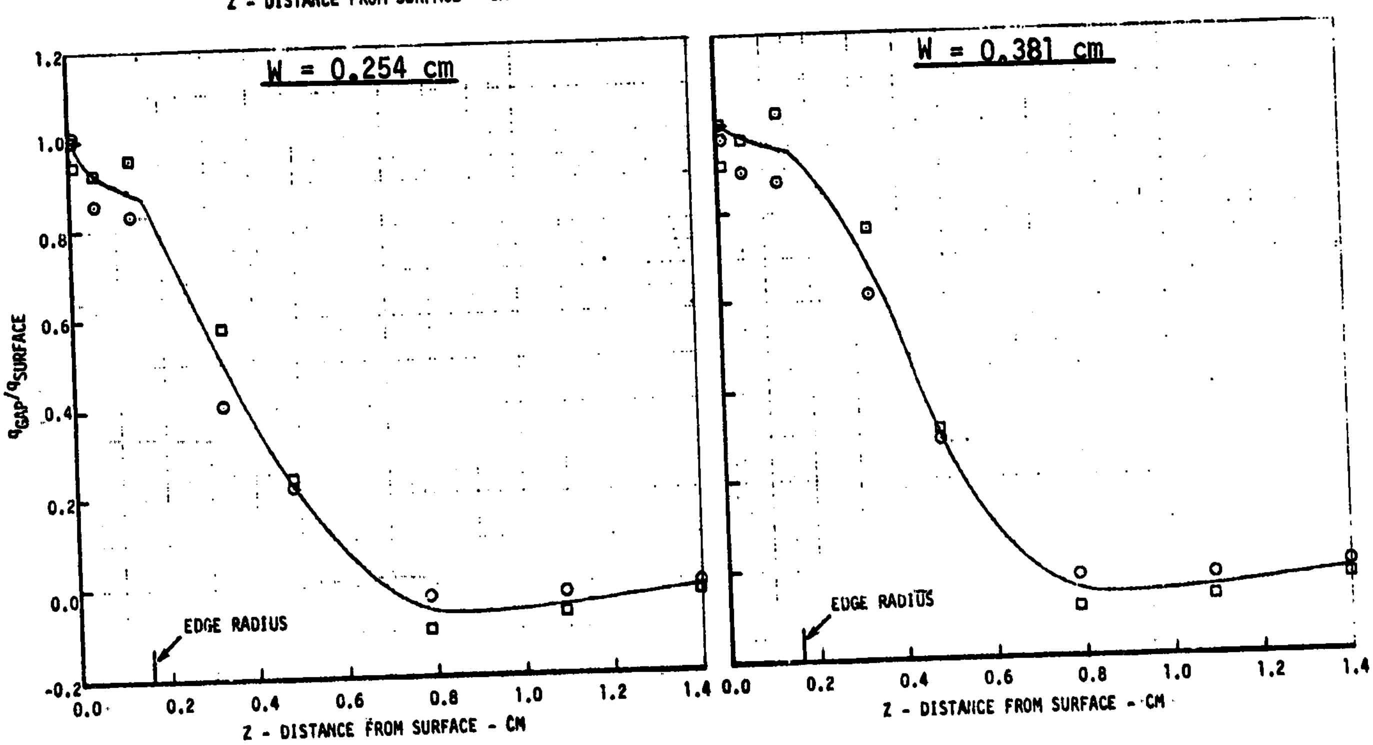


FIGURE 41

INFLUENCE OF GAP WIDTH ON HEATING IN TRANSVERSE GAPS 0.157 CM EDGE RADIUS

- AMES 20 MW 2-x 9 INCH TURBULENT FLOW DUCT FACILITY

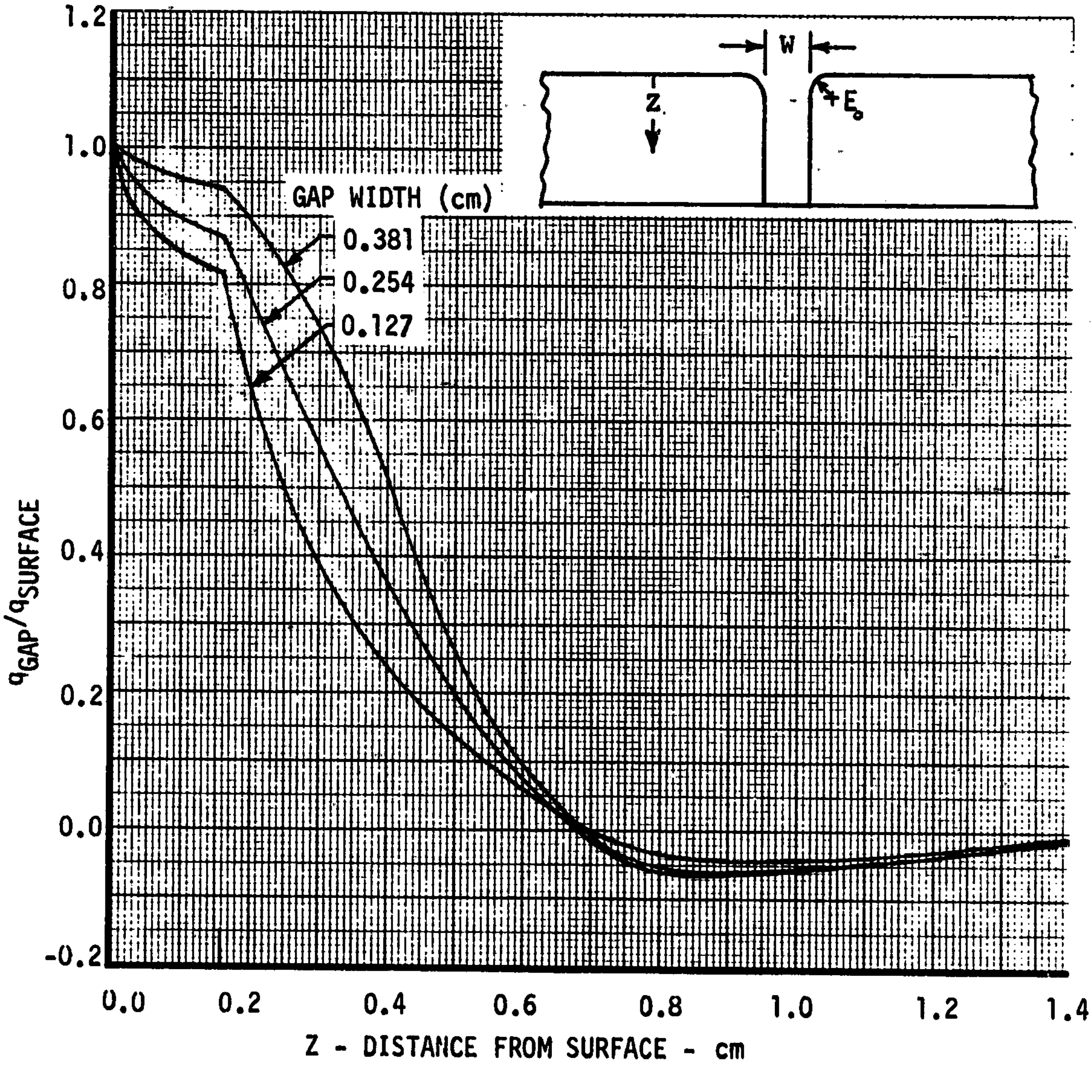


FIGURE 42

INFLUENCE OF EDGE RADIUS ON HEATING IN A TRANSVERSE GAP

• AMES 20 MW 2 x 9 INCH TURBULENT FLOW DUCT FACILITY

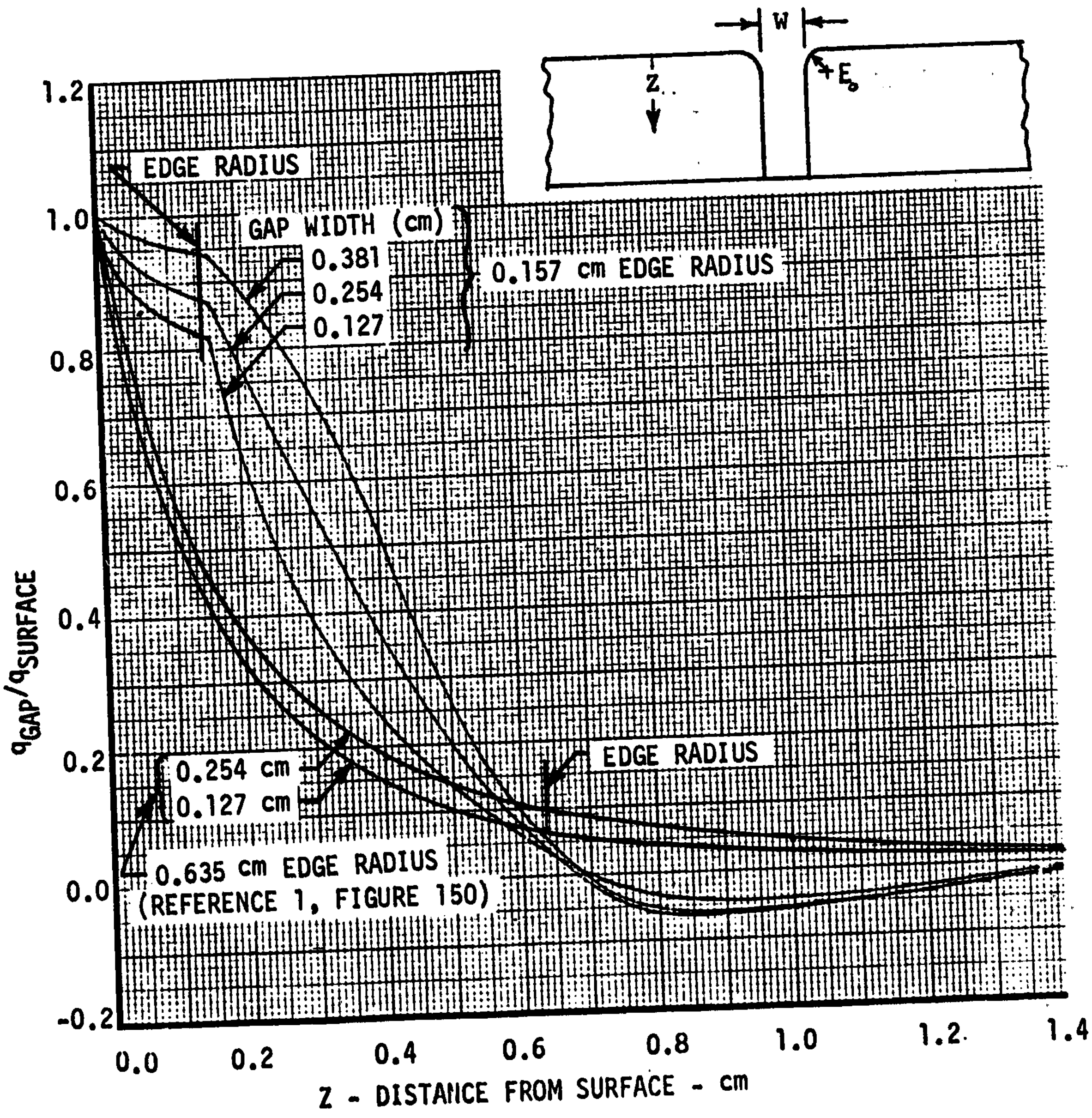


FIGURE 43

EFFECT OF TRANSVERSE GAP HEATING ON TPS REQUIREMENTS

(BODY POINT 1)

EDGE RADIUS (IN)	GAP WIDTH (IN)	X-HRSI (IN)	X2-D/X1-D
1-D MODEL	NO GAP	2.88	-
.06	.05	3.57	1.25
.12	.05	3.44	1.19
.25	.05	3.22	1.12
.06	.10	3.82	1.33
.12	.10	3.65	1.27
.25	.10	3.42	1.19
.06	.20	4.10	1.42
.12	.20	3.92	1.36
.25	.20	3.72	1.30

THE ABOVE RESULTS BASED ON EQUATION 4-17.

ALUMINUM t (IN)	COATING t (IN)	X-HRSI 1-D (IN)	X-RSI 2-D (IN)	X2-D/ X1-D	X3-D/ X1-D
.08	.015	2.88	3.32	1.15	1.30
.12	.015	2.38	2.76	1.16	--
.08	.005	2.88	3.25	1.13	--
.08	.015	2.88	3.32	1.15	--
.08	.025	2.88	4.61	1.60	--

HEAT LOAD	X-HRSI 2-D (IN)	THICKNESS RATIO
1.0	3.32	1.0
1.2	3.36	1.01
1.82	3.84	1.16
1.963	4.34	1.31

1) R.I. Baseline Heating
2) 0.10 inch gap
3) 0.06 inch inner edge radius

FIGURE 44

APPENDIX A PRIORITY CASE LIST

Seventy-two priority cases were run. A list describing the contents of each case, thickness of HRSI used, the associated temperatures and the required thicknesses to restrict the aluminum temperature to a peak of 350°F has been prepared. The baseline configuration being considered for the TPS is listed after priority Case 7. The majority of these cases consisted of two or more computer runs to reach the required thickness, totaling approximately 145 computer runs.

The HRSI thickness for some of the computer runs has been flagged with double asterisks. The thermal model used for these runs had some irregularities and was later revised to be more realistic. The thicknesses and temperatures associated with these runs should not be used as absolute values alone, but can be used to show sensitivities, i.e. varying gap heating distribution (priority cases 2, 3, 4, 5, and 5-1).

PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	$T_{MAX)AL}$ ^{o}F	X-HRSI @ $350^{o}F$ (INCHES)
1	B.P. 3 (1157), one dimensional model, coating emissivity = 0.8, aluminum t = 0.08 inch	1.50	261	
		1.00	333	0.91
		0.50	483	
2	B.P. 3, two dimensional model, baseline configuration*	1.50**	276	
		1.02**	348	1.01**
		1.00**	352	
		0.98	350	0.98
3	B.P. 3, baseline configuration except that smooth wall heating ($q_{GAP}/q_{SURFACE}$ = 1.0) is assumed to vertical tangency point of radius and zero heating below tangency point	1.20**	312	0.99**
		1.00**	347	
4	B.P. 3, baseline configuration except that smooth wall heating is assumed to vertical tangency point of radius and the gap is closed to prevent radiation transfer in the gap	1.00**	345	
		0.96**	353	0.975**
		0.90**	366	
		1.00	346	0.98
5	B.P. 3, baseline configuration except the coating terminated 0.5 inch from bottom of the gap	1.50**	275	1.0**
		1.00**	351	
5-1	B.P. 3, baseline configuration except the coating is removed to the vertical tangency point in the gap	1.02**	343	0.985**
6	B.P. 1 (1040), one dimensional model, coating emissivity = 0.8, aluminum t = 0.08 inch	3.50	297	
		3.00	338	2.88
		2.50	393	
7	B.P. 1, two dimensional model, baseline configuration	4.5**	293	
		3.6**	350	3.6**
		3.5**	358	
		3.20	360	3.32
		3.32	350	

*Baseline configuration:
1. Heating distribution in gap (R.I. Baseline)
2. Model width = 3.0 IN.
3. Inner edge radius (E_i) = 0.06 IN.
4. Gap width (W) = 0.10 IN
5. Coating emissivity (ϵ) = 0.80
6. Coating thickness (δ_c) = 0.015 IN.
7. Aluminum structure (t) = 0.08 IN.
8. SIP + RTV adhesive = 0.175 IN.

**Initial thermal model and assumptions.

PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	$T_{MAX})_{AL}$ °F	X-HRSI @ 350°F (INCHES)
8	B.P. 1, baseline configuration except that smooth wall heating (q/q = 1.0) is assumed to vertical tangency point of radius and zero heating below tangency point	3.32 3.24	343 349	3.23
9	B.P. 1, baseline configuration except that smooth wall heating is assumed to vertical tangency point of radius and the gap is closed to prevent radiation transfer in the gap	2.95 3.04	359 350	3.04
10	B.P. 1, baseline configuration except the coating terminated 0.5 inch from bottom of the gap	3.32 3.27	346 350	3.27
11	B.P. 1, baseline configuration except model width = 1.5 inches	4.5** 4.4** 3.6**	345 352 411	4.43**
12	B.P. 1, baseline configuration except model width = 4.0 inches	3.6**	334	3.49**
13	B.P. 3, baseline configuration except model width = 1.5 inches	1.02**	368	1.1**
14	B.P. 1, baseline configuration except inner edge radius = 0.001 inch	3.80 3.50	327 349	3.49
15	B.P. 1, baseline configuration except inner edge radius = 0.03 inch	3.50 3.41	343 350	3.41
16	B.P. 1, baseline configuration except inner edge radius = 0.09 inch	3.00 3.26	372 349	3.24
17	B.P. 1. baseline configuration except inner edge radius = 0.12 inch	2.85 3.20	381 349	3.17
18	B.P. 1, baseline configuration except no lateral conduction in SIP at gap	3.60**	349	
19	B.P. 1, baseline configuration except no conduction through SIP at gap	3.60**	347	
20	B.P. 1, baseline configuration except coating emissivity = 0.85, aluminum t = 0.10 inch	3.50** 3.20**	326 347	3.16** 2.91

PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	$T_{MAX)AL}$ ^{o}F	X-HRSI @ 350^{o}F (INCHES)
21	B.P. 1, baseline configuration except aluminum t = 0.12 inch	3.50** 3.00**	315 350	} 3.00** 2.76
22	B.P. 1, one dimensional model, coating emissivity = 0.85, aluminum t = 0.10 inch	3.50 2.50 2.00	272 352 420	2.53
22'	B.P. 1, one dimensional model, coating emissivity = 0.85, aluminum t = 0.08 inch	2.50 2.00	381 459	2.77
23	B.P. 1, one dimensional model coating emissivity = 0.80, aluminum t = 0.12 inch	3.50 3.00 2.50 2.00	264 295 338 400	2.38
24	B.P. 3, baseline configuration except inner edge radius = 0.001 inch	1.00	350	1.00
25	B.P. 2 (1077), baseline configuration except inner edge radius = 0.001 inch	2.20	350	2.20
25A	B.P. 2, one dimensional model, coating emissivity = 0.80, aluminum t = 0.08 inch	2.50 2.00 1.50	286 338 418	1.90
26	B.P. 2, baseline configuration	2.22 2.10	334 352	2.12
27	B.P. 2, baseline configuration except inner edge radius = 0.12 inch	2.08	345	2.04
28	B.P. 3, baseline configuration	1.01 0.98	344 350	0.98
29	B.P. 3, baseline configuration except inner edge radius = 0.12 inch	0.97	347	0.96
30	B.P. 1, three dimensional model, baseline configuration	3.75	349	3.74
31	B.P. 1, baseline configuration except gap width = 0.05 inch	3.32	344	3.24

PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	$T_{MAX)AL}$ ^oF	X-HRSI @ 350^{o}F (INCHES)
32	B.P. 1, baseline configuration except gap width = 0.15 inch	3.32	353	3.36
33	B.P. 1, baseline configuration except gap width = 0.20 inch	3.32	355	3.38
34	B.P.1, Baseline configuration using method 2 heating distribution (C. Scott, JSC, Tables)	3.32 3.36	353.5 350.4	3.36
35	B.P.1, Baseline configuration using method 3 heating distirubtion (MDAC correlation of Scott Data, EQ. 4-12)	3.32 3.86	392.6 348.8	3.84
36	B.P.1, Baseline configuration using method 3A distribution (MDAC Correlation Scott data, EQ. 4-12)	3.32	426.8	4.34
37	B.P.1, Baseline configuration using method 3AA heating distribution (MDAC correlation of Scott data, EQ. 4-12)	3.32	694.0	
38	B.P.1, Baseline configuration using method 1 heating distribution (R.I. baseline, Scott data), gap width = 0.20"	3.32 3.70 3.88	389.9 361.1 349.4	3.88
39	B.P.1, Baseline configuration using method 3 (EQ. 4-17) heating distribution (M-3, EQ.4-17 is MDAC correlation using 0.062" as edge radius for sharp corner data), gap width = 0.10", inner edge radius = 0.06"	3.84 3.82	348.9 350.2	3.82
40	B.P.1, Baseline configuration using method 3 EQ. 4-17 heating distribution, gap width = 0.20", inner edge radius = 0.06"	3.88 4.10	365.1 349.7	4.10
41	B.P.1, Baseline configuration using Method 3 EQ. 4-17 heating distribution, gap width = 0.20", inner edge radius = 0.25"	3.88 3.72	339.8 350.9	3.73
42	B.P.1, Baseline configuration using method 3 EQ. 4-17 heating distribution, gap width = 0.20", inner edge radius = 0.12"	3.88 3.92	353.0 350.3	3.92
43	B.P.1, Baseline configuration using method 3 EQ. 4-17 heating distribution, gap width = 0.10", inner edge radius = 0.12"	3.84 3.60 3.65	336.5 353.9 350.0	3.65

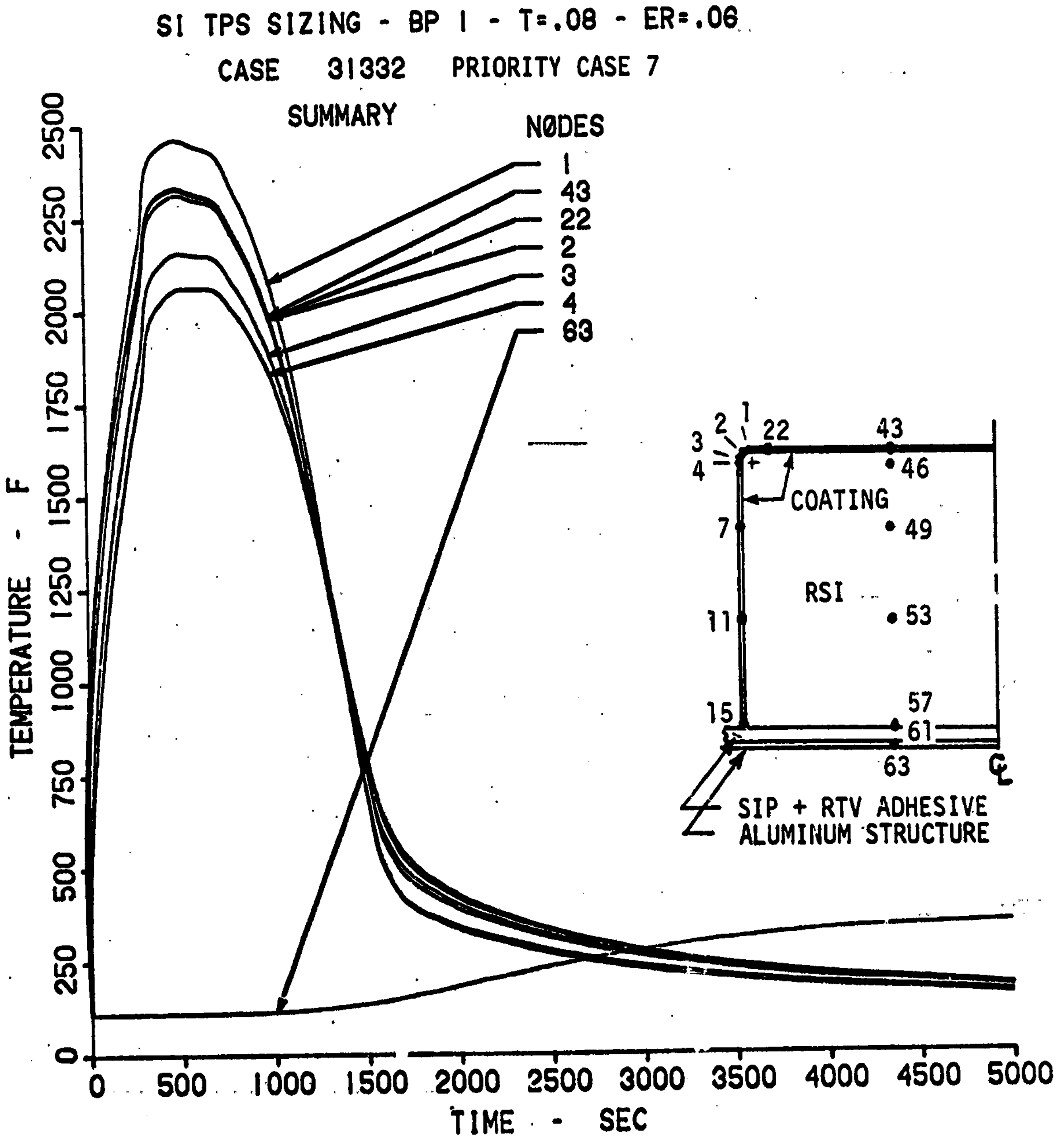
PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	T_{MAX})AL (^{o}F)	X-HRSI @ 350^{o}F (INCHES)
44	B.P.1, Baseline configuration using method 3 EQ. 4-17 heating distribution, gap width = 0.10", inner edge radius = 0.25"	3.73 3.46	327.5 347.0	3.42
45	FLAP (B.P.212), one dimensional model, coating emissivity = 0.8, aluminum t=0.08".	3.00 2.55 2.00	330.9 377.1 460.1	2.80
46	FLAP, Baseline configuration using method 3 EQ. 4-17 heating distribution.	3.62 3.75	358.5 348.8	3.74
47	FLAP, Baseline configuration using method 2 heating distribution.	3.62 3.29	325.4 348.4	3.27
48	FLAP, Baseline configuration using method 1 heating distribution.	3.62 3.23 3.20	319.4 347.9 350.4	3.20
49	B.P. 1, Baseline configuration using method 1 heating distribution (R.I. baseline, Scott data), coating thickness = 0.005".	3.32 3.24	344.6 351.2	3.25
50	B.P. 1, Baseline configuration using method 1 heating distribution, coating thickness = 0.025".	3.32 3.34	351.3 349.8	3.34
51	B.P. 1, Baseline configuration using method 1 heating distribution, coating thickness = 0.010".	3.32 3.29	346.6 349.0	3.29
52	Flap, one dimensional model, initial T=90^{o}F, coating emissivity = 0.85, aluminum t = 0.081".	3.00 2.80 2.55	307.3 325.6 352.1	2.57
53	B.P.1, 3-D Model, baseline configuration using method 3 Eq. 4-17 heating distribution.	3.75	418.1	
54	Flap, 2-D model, only external surface heating, gap and radius heating = 0.0, Gap width = 0.10", inner edge radius = 0.001", aluminum = 0.081", coating emissivity = 0.85, initial temperature = 90^{o}F	2.55 2.67	364.1 350.9	2.68
55	Flap, 3-D model, other data in P.C. #54	2.55 2.78	374.2 350.0	2.78

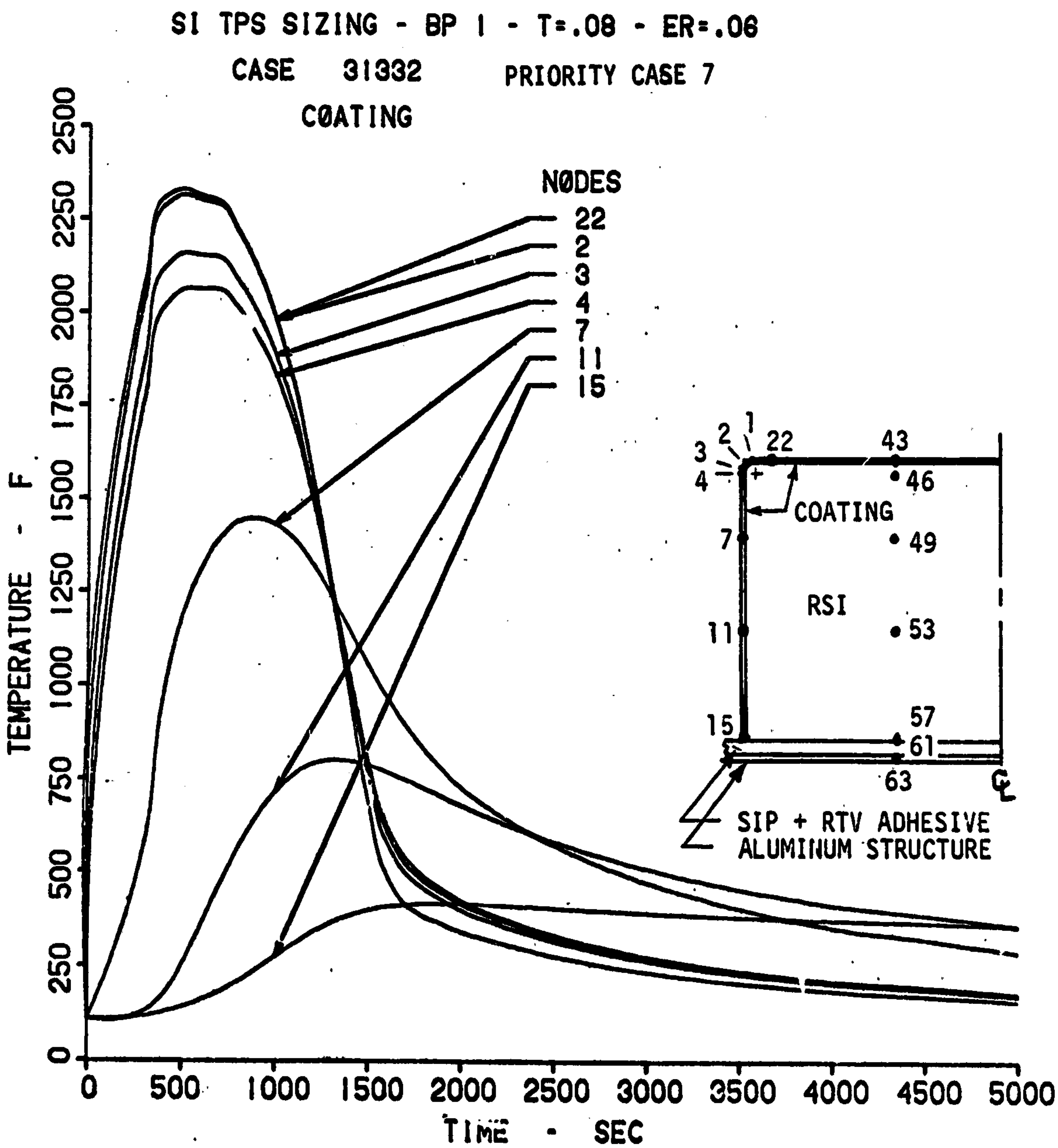
PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	$T_{MAX})AL$ (°F)	X-HRSI @ 350°F (INCHES)
56	B.P.1, Baseline configuration using method 1 heating distribution (R.I. test of HRSI tiles, task 28, Ref. MDAC TTN NO. E242-76) in-line gap.	2.88 3.32 3.30	389.9 348.1 349.9	3.30
57	B.P.2, Baseline configuration using method 1 task 28 heating distribution, in-line gap	1.90 2.12	376.8 348.9	2.11
58	B.P.1, Baseline configuration using method 3 Eq. 4-17 heating distribution, gap width = 0.05", inner edge radius = 0.06".	3.63 3.57	346.6 351.3	3.59
59	B.P.1, Baseline configuration using method 3 Eq. 4-17 heating distribution, gap width = 0.05", inner edge radius = 0.12"	3.46	349.0	3.44
60	B.P.1, Baseline configuration using method 3 Eq. 4-17 heating distribution, gap width - 0.05", inner edge radius = 0.25"	3.22	351.0	3.23
61	B.P.1, Baseline configuration using gap heating distribution by J. Marssdorf of R.I. (C. Scott Data-Trans. Gap) gap width = 0.10", inner edge radius = 0.06"	3.32 3.33	350.7 349.9	3.33
62	B.P.1, Baseline configuration using gap heating distribution by J. Marssdorf of R.I. (C. Scott data - Trans. gap) gap width = 0.10", inner edge radius = 0.125"	3.33 3.39	355.1 350.2	3.39
63	B.P.1, Baseline configuration using gap heating distribution by J. Marssdorf of R.I. (C. Scott data - Trans. gap) gap width = 0.10", inner edge radius = 0.25"	3.33 3.67 3.60	372.8 344.7 350.2	3.60
64	B.P.1, Baseline configuration using gap heating distribution by J. Marssdorf of R.I. (Curve labeled 8/14, a revision of R.I. Baseline) gap width = 0.10", inner edge radius = 0.06"	3.32 3.16	338.2 351.4	3.18

PRIORITY CASE #	CONTENTS	X-HRSI (INCHES)	$T_{MAX})_{AL}$ (^oF)	X-HRSI @350^{o}F (INCHES)
65	B.P.1, (Qe = 18700 BTU/FT^2) one dimensional model using initial temperature distribution, SIP properties and thickness of R.I., coating emissivity = 0.80, aluminum t = 0.10"	2.547	353.3	
65A	Same as 65, except coating emissivity = 0.85	2.547	343.9	
65B	Qe = 19115 (approx. BP 2110, Qe = 19117), one dimensional model using initial temperature distribution, SIP properties and thickness of R.I., coating emissivity = 0.85, aluminum t = 0.10"	2.547	347.0	
67	B.P.1, Baseline configuration using heating distribution from Ames Turb Duct Tests. Ref. MDC E1248 pg. 226, Inner Edge Radius = 0.25"	3.46 3.06 3.12	321.7 354.7 349.3	3.12
66	B.P.1, Baseline Configuration using Heating distribution from Ames Turb Duct Tests, inner edge radius = 0.06"	3.32 3.82 3.70	370.3 334.3 342.3	3.59

APPENDIX B TEMPERATURE-TIME PLOTS

The priority cases for which data have been plotted are: 7,8,9,10,14,17,30,38, 39,40,41,42,43,44,46,47 and 48. For the contents of the plotted cases refer to the preceeding Appendix. The temperature-time data for the unplotted cases are recorded in the form of computer tabulated output. This has been sent to Mr. H. K. Larson of NASA Ames.


SI TPS SIZING - BP I - T=.08 - ER=.06
CASE 31332 PRIORITY CASE 7
SUMMARY
NØDES
1
43
22
2
3
4
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME - SEC
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE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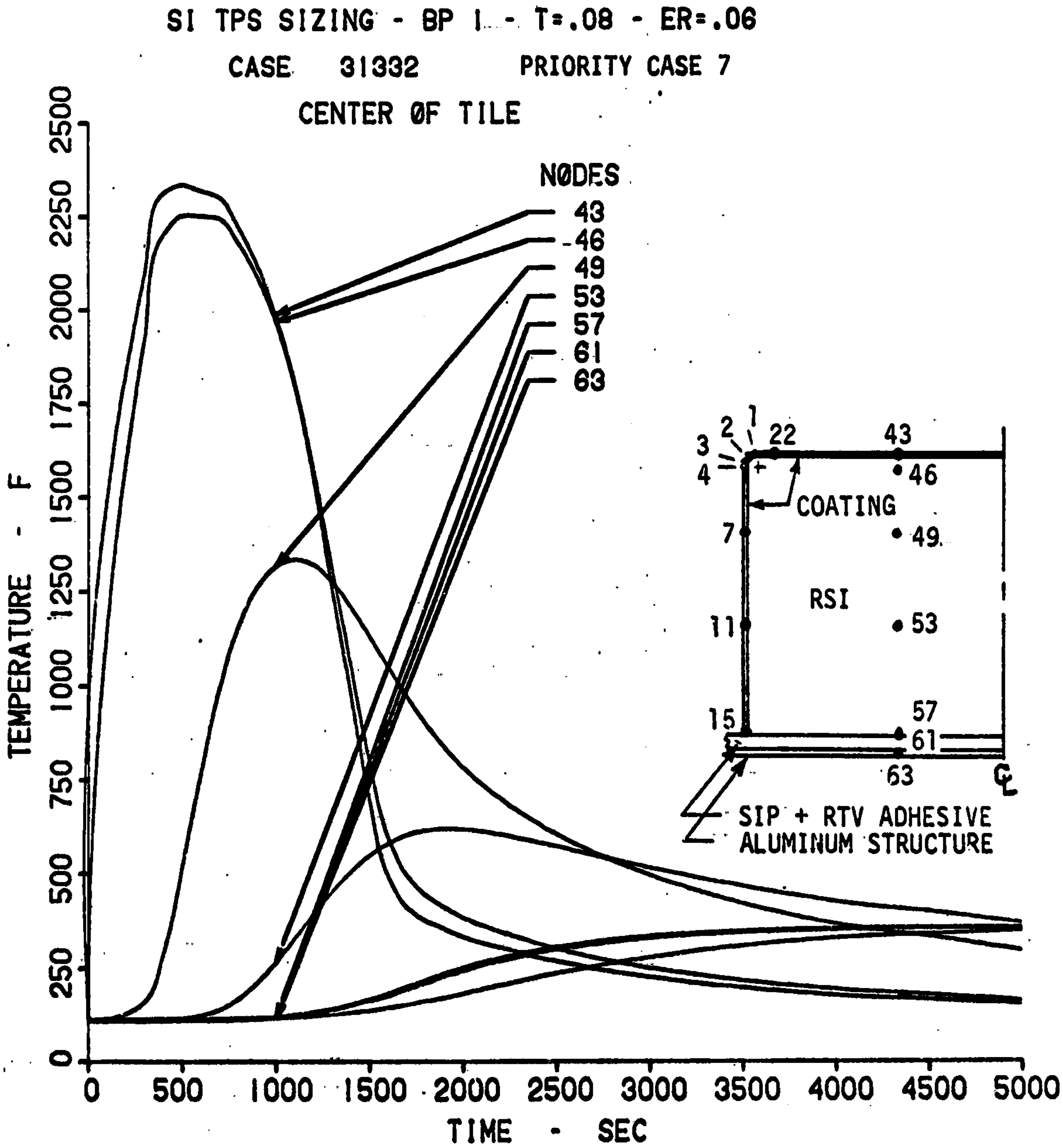
CASE 31332 PRIORITY CASE 7
CØATING
NØDES
22
2
3
4
7
11
15
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME - SEC
1
2
3
4
22
43
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE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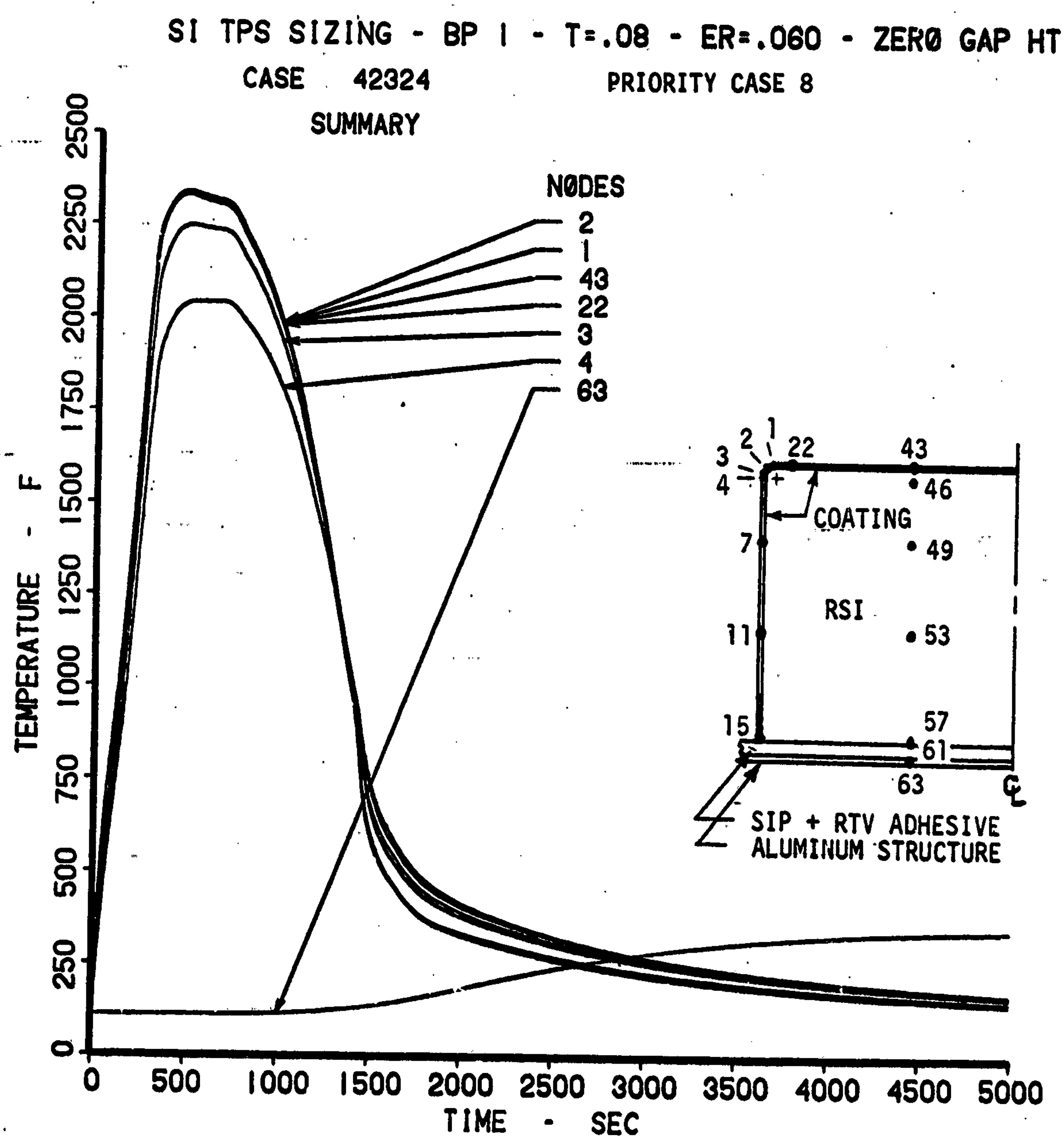
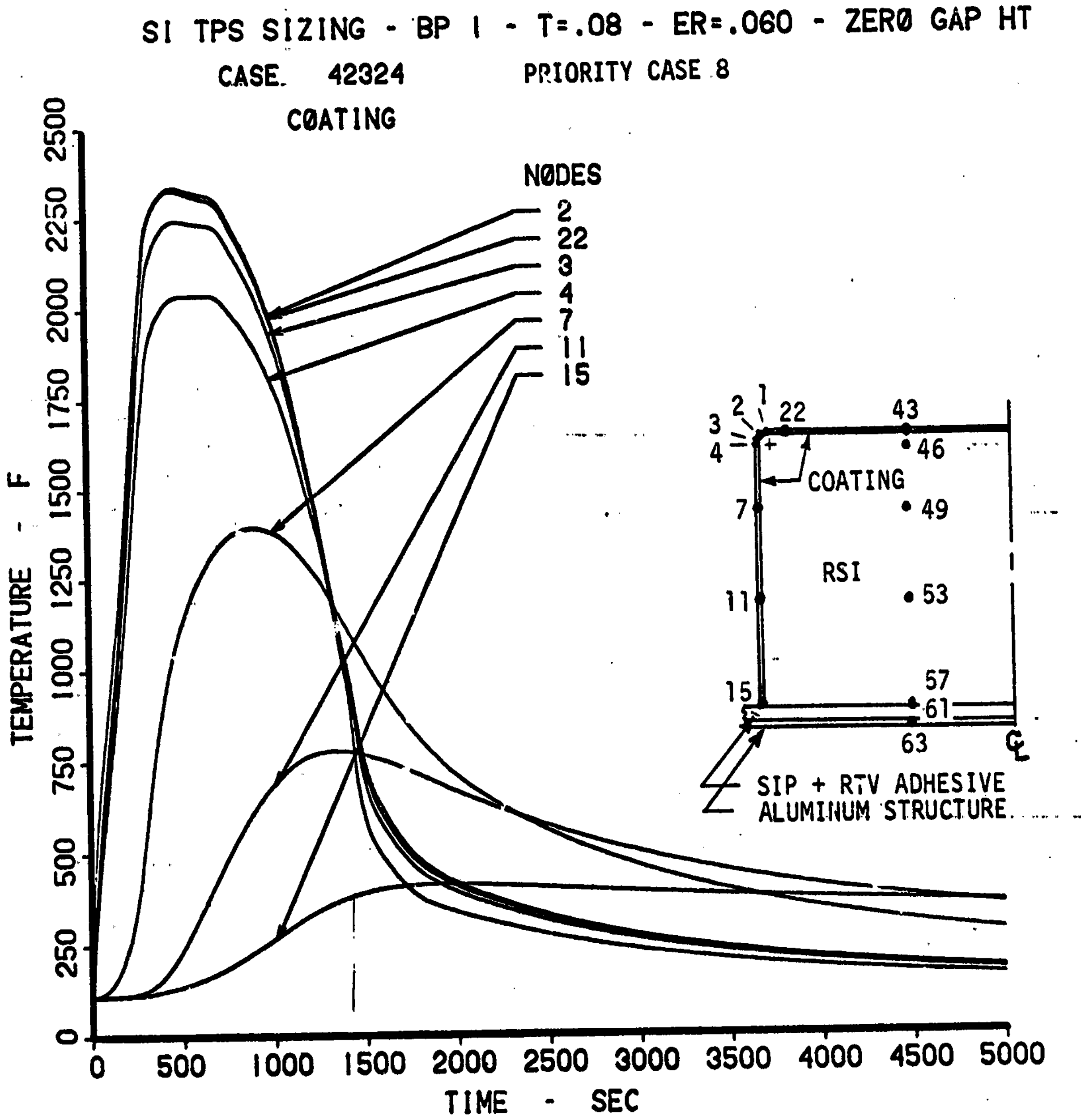
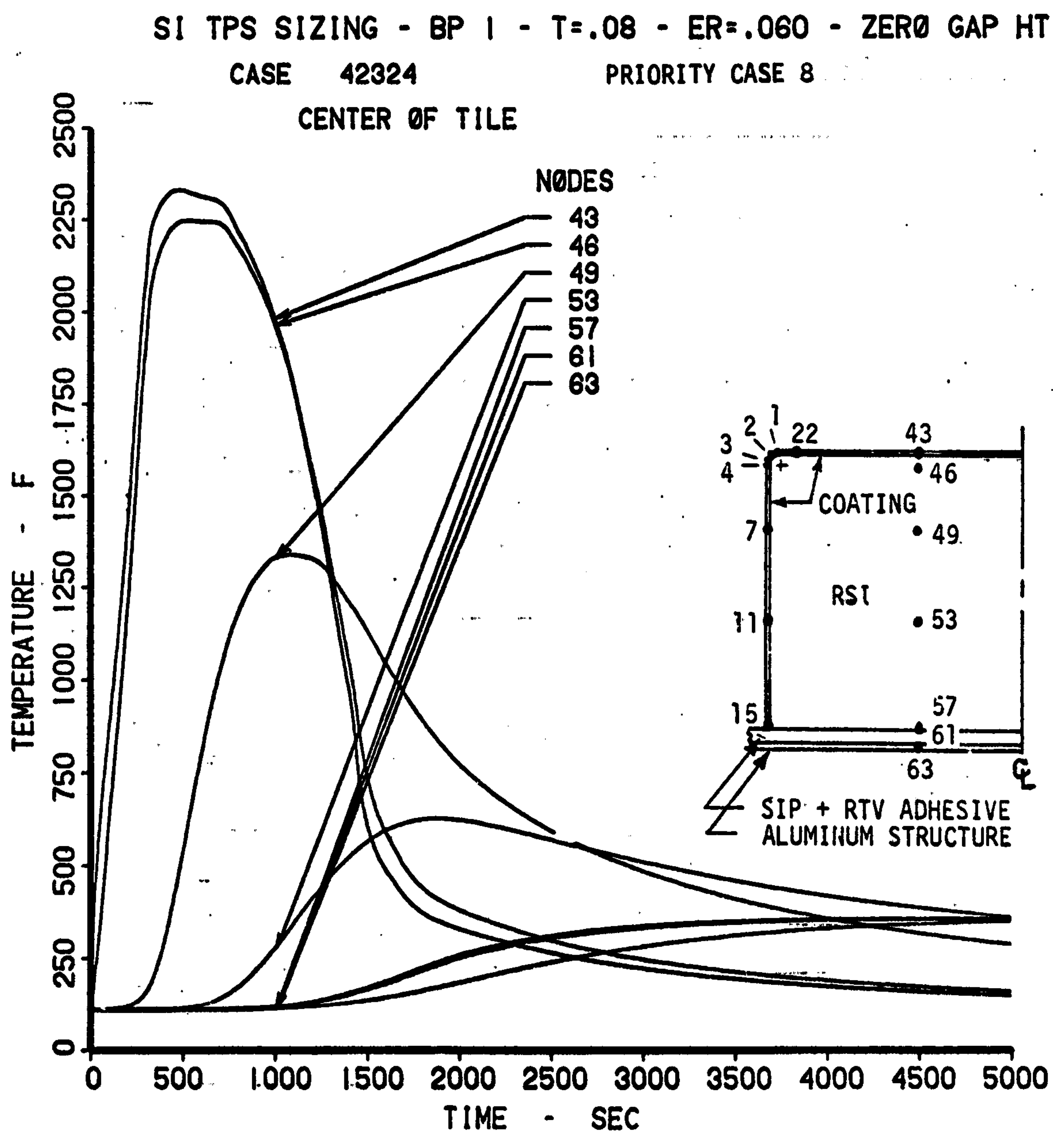
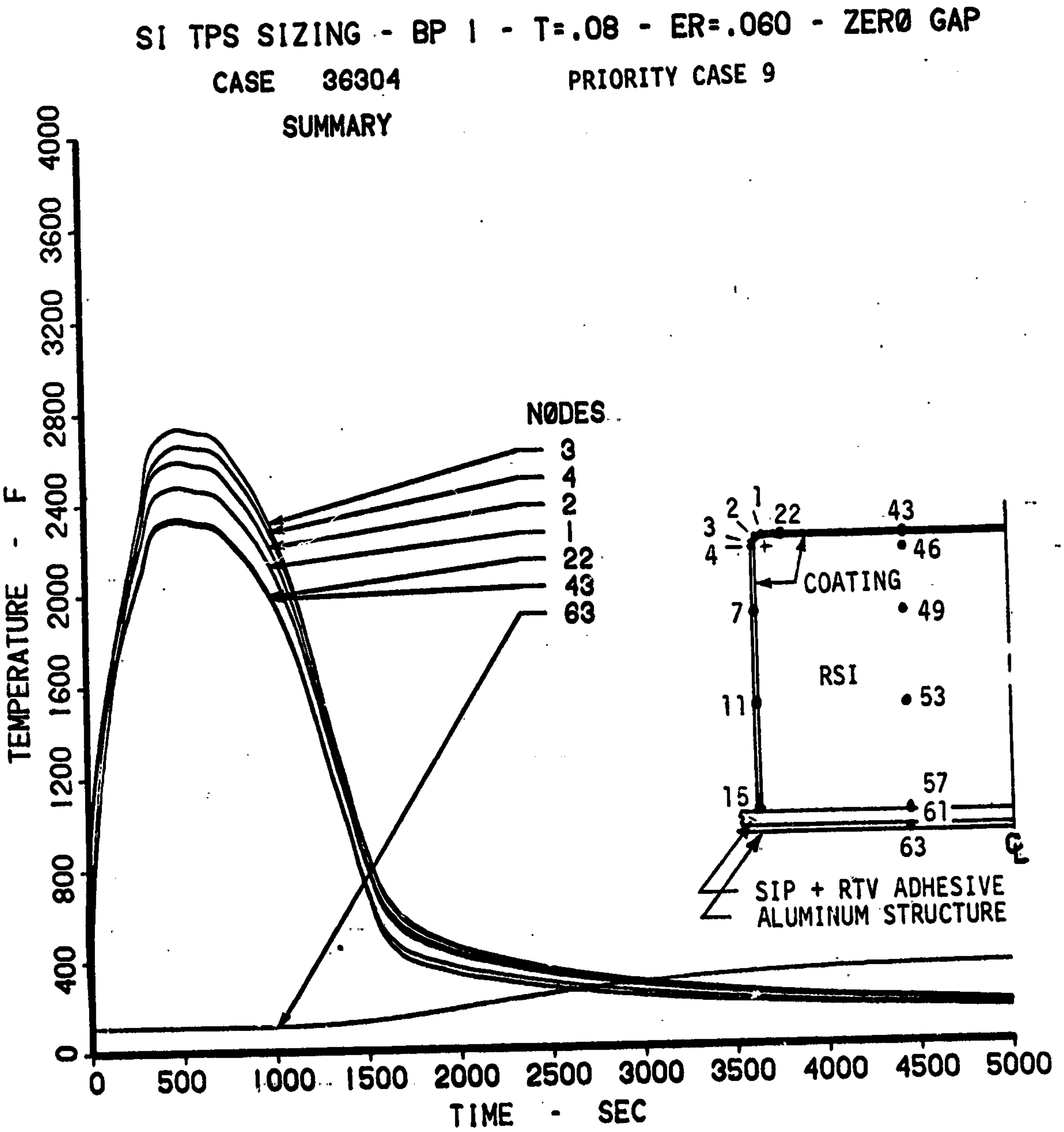
CASE 31332 PRIORITY CASE 7
CENTER ØF TILE
NØDES
43
46
49
53
57
61
63
TEMPERATURE - F
TIME - SEC
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP I - T=.08 - ER=.060 - ZERØ GAP HT
CASE 42324
PRIORITY CASE 8
SUMMARY
NØDES
2
1
43
22
3
4
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP I - T=.08 - ER=.060 - ZERØ GAP HT
CASE 42324
PRIORITY CASE 8
CØATING
NØDES
2
22
3
4
7
11
15
TEMPERATURE - F
TIME - SEC
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
2
1
22
43
3
4
46
COATING
7
49
RSI
11
53
57
15
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP I - T=.08 - ER=.060 - ZERØ GAP HT
CASE 42324
PRIORITY CASE 8
CENTER ØF TILE
NØDES
43
46
49
53
57
61
63
TEMPERATURE - F
TIME - SEC
COATING
RSI
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE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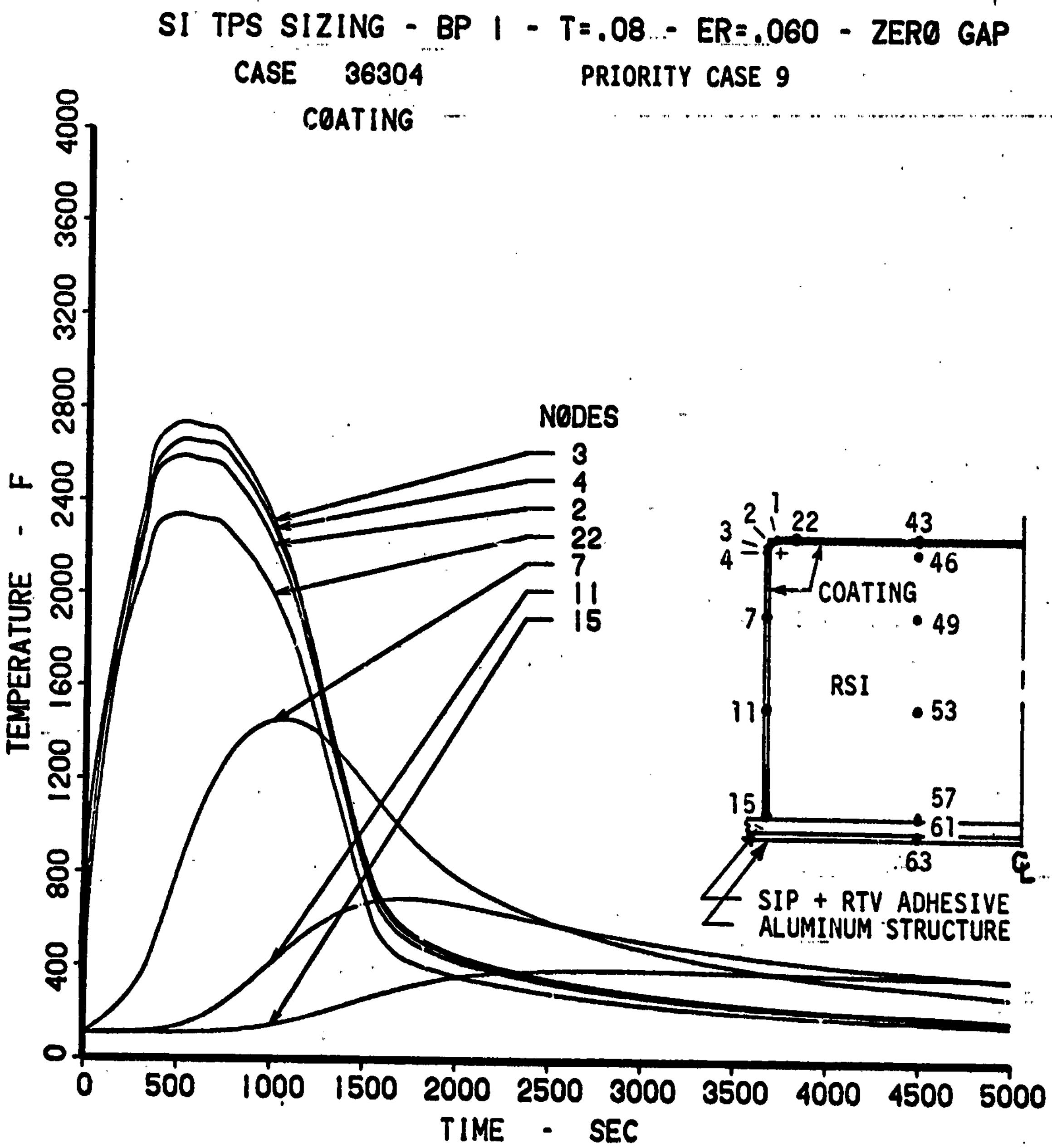
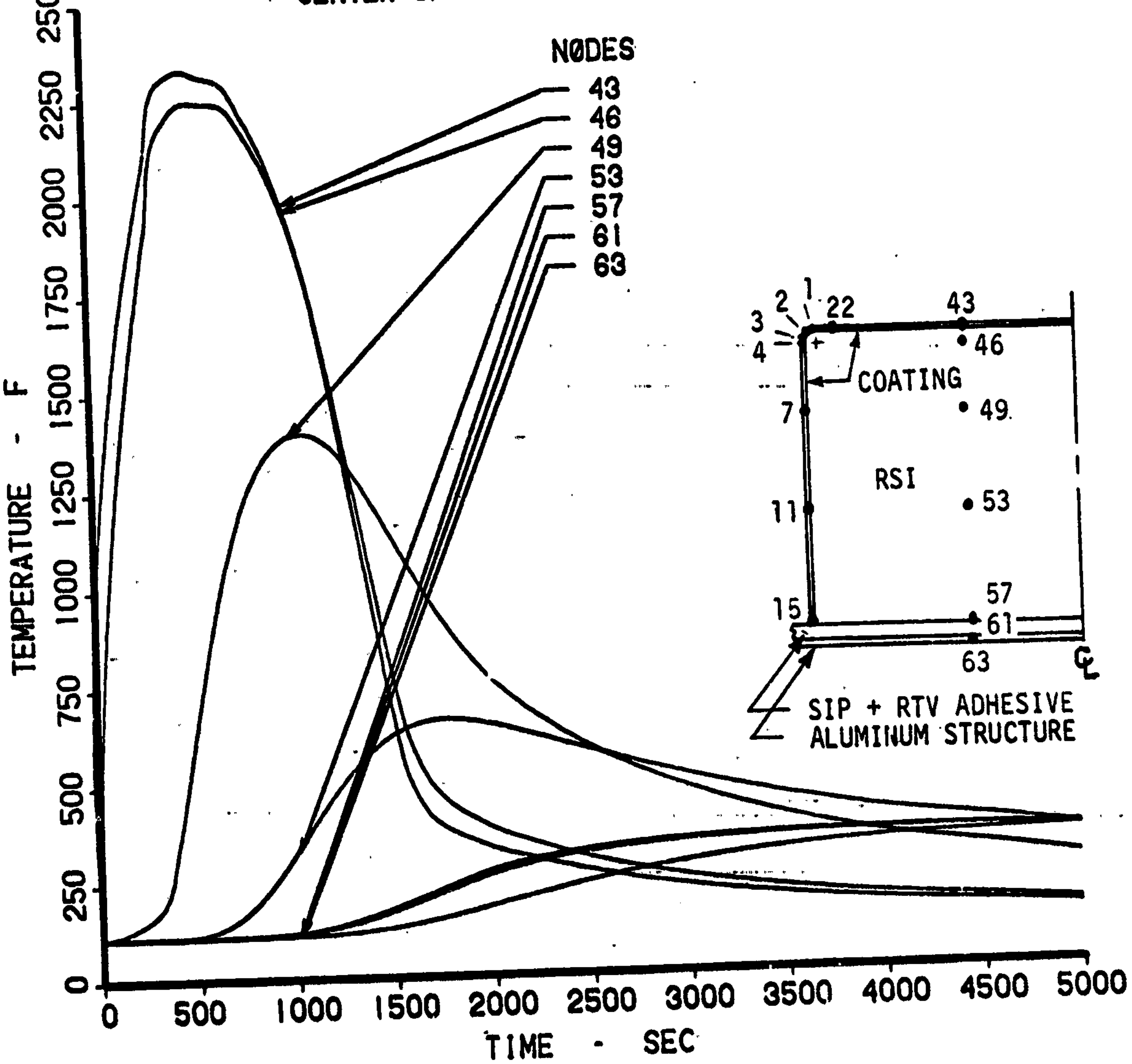
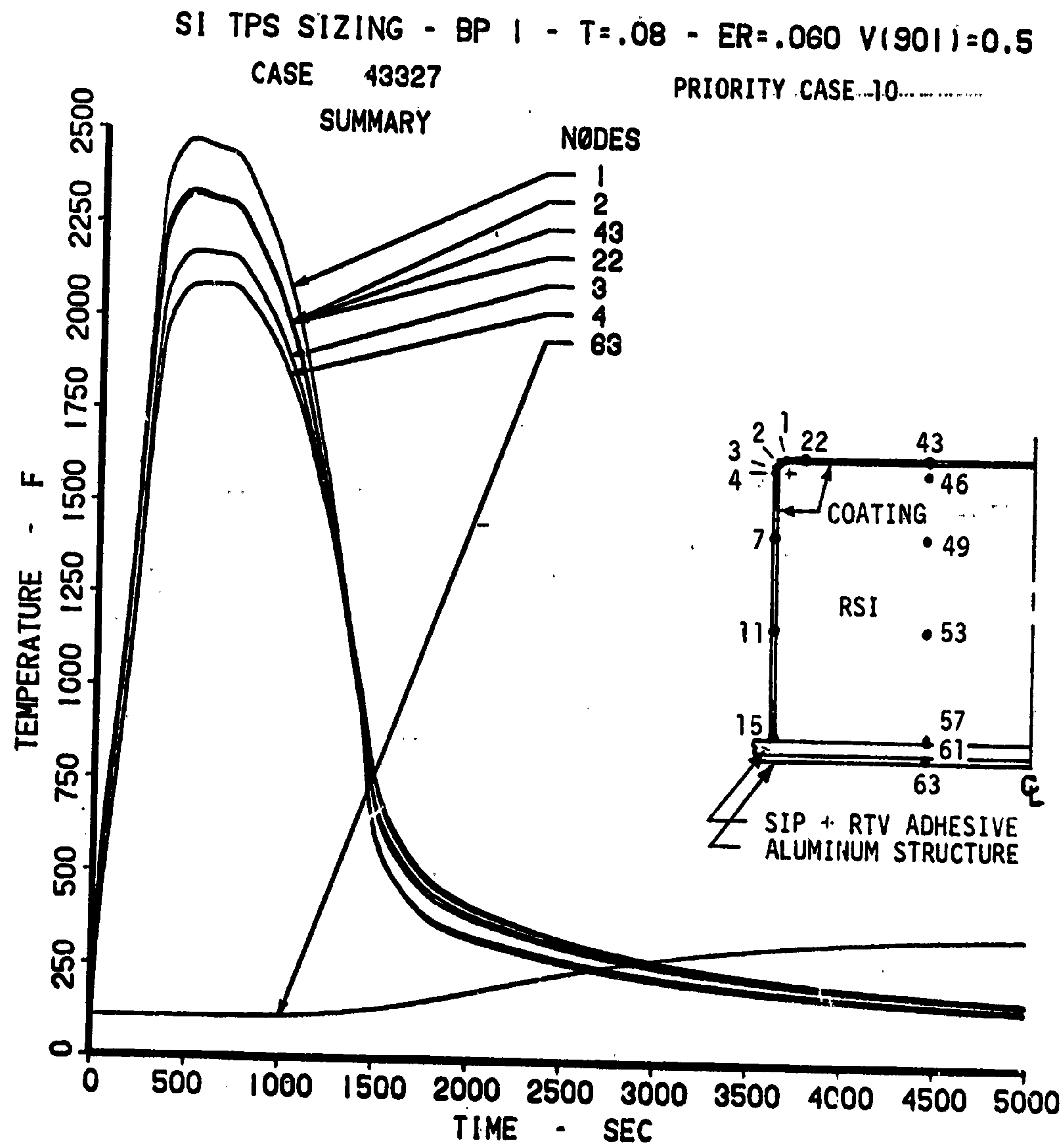
CASE 36304
PRIORITY CASE 9
SUMMARY
TEMPERATURE - F
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
NØDES
3
4
2
1
22
43
63
COATING
RSI
46
49
53
57
61
7
11
15
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP I - T=.08 - ER=.060 - ZERØ GAP
CASE 36304
PRIORITY CASE 9
CØATING
TEMPERATURE - F
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME - SEC
NØDES
3
4
2
22
7
11
15
1
43
46
COATING
49
RSI
53
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - BP I - T=.08 - ER=.060 - ZERØ GAP
CASE 36304 PRIORITY CASE 9
CENTER ØF TILE

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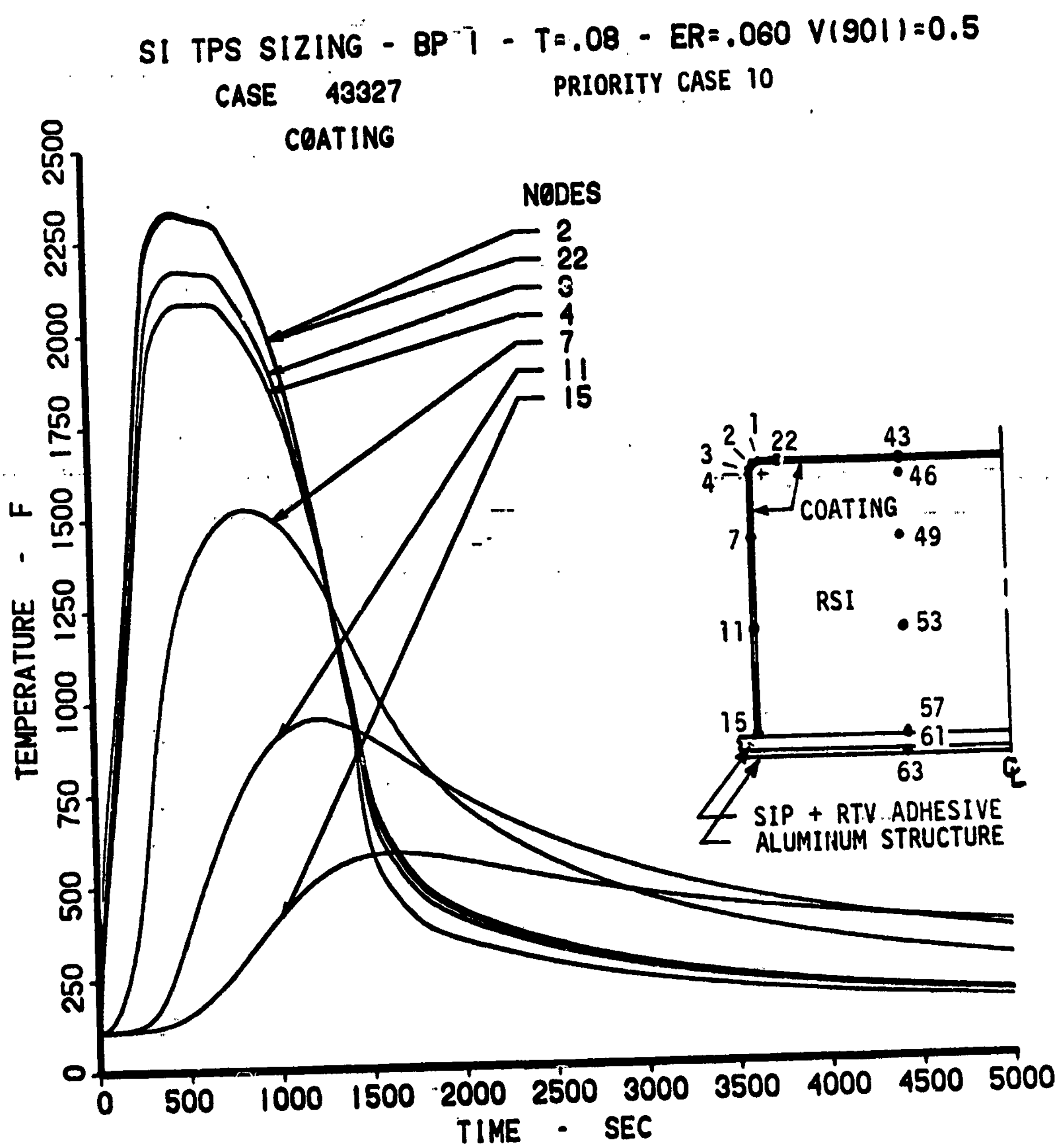
CASE 43327
PRIORITY CASE 10
SUMMARY
NØDES
1
2
43
22
3
4
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE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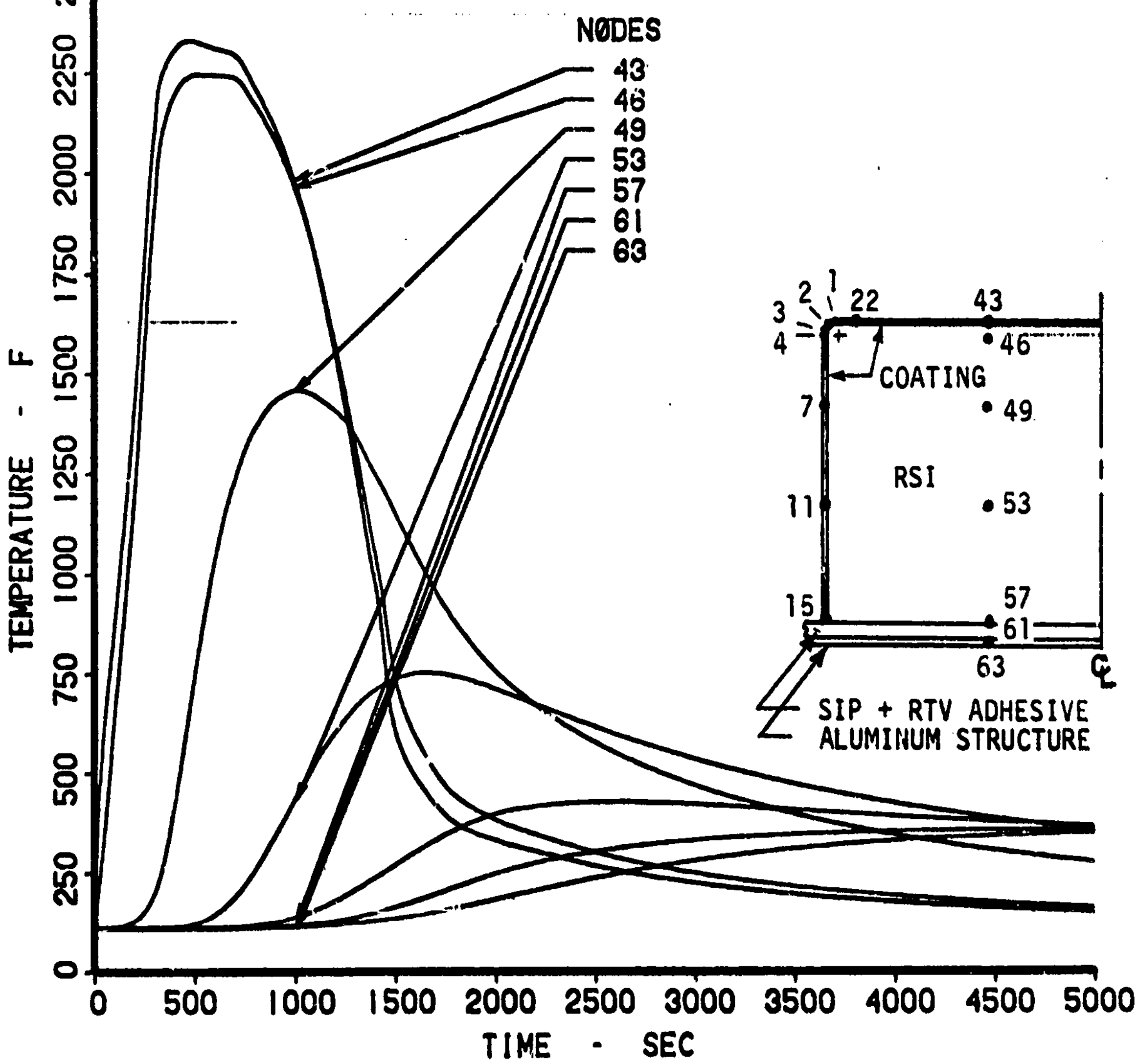
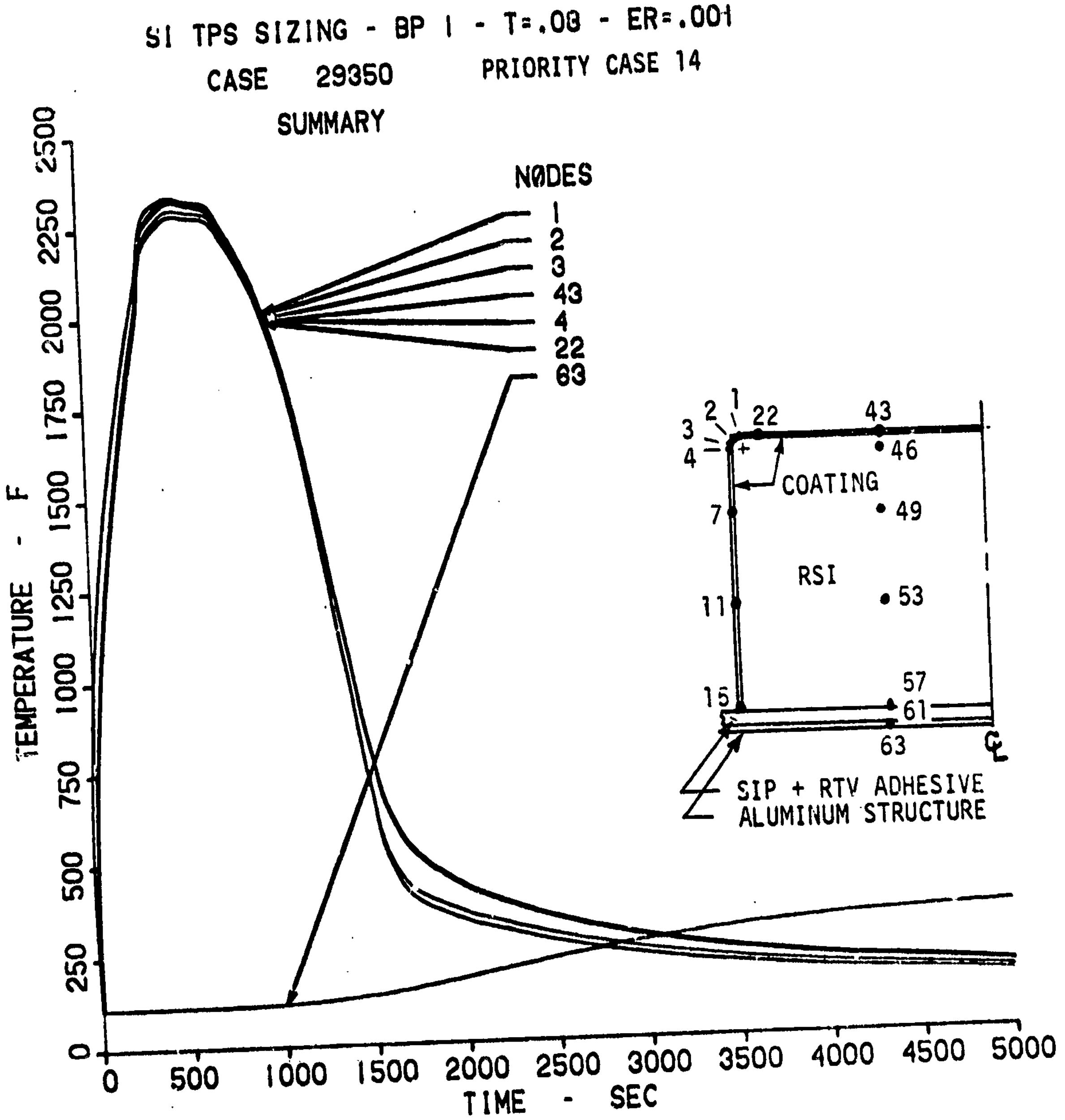
CASE 43327
PRIORITY CASE 10
COATING
NØDES
2
22
3
4
7
11
15
TEMPERATURE - F
TIME - SEC
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1
2
3
4
22
43
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - BP 1 - T=.08 - ER=.060 V(901)=0.5

CASE 43327 PRIORITY CASF 10

CENTER ØF TILE

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CASE 29350 PRIORITY CASE 14
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NØDES
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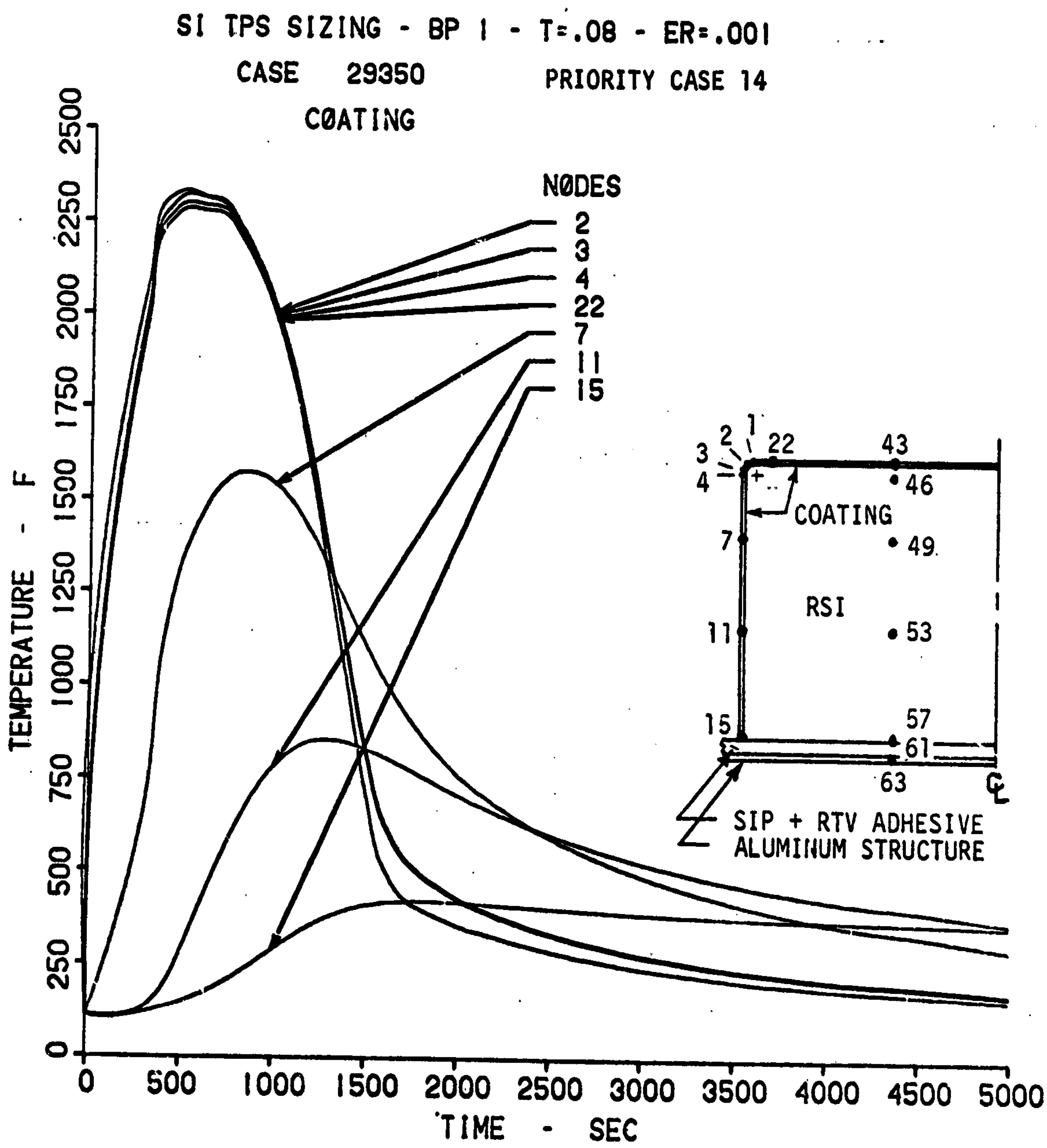
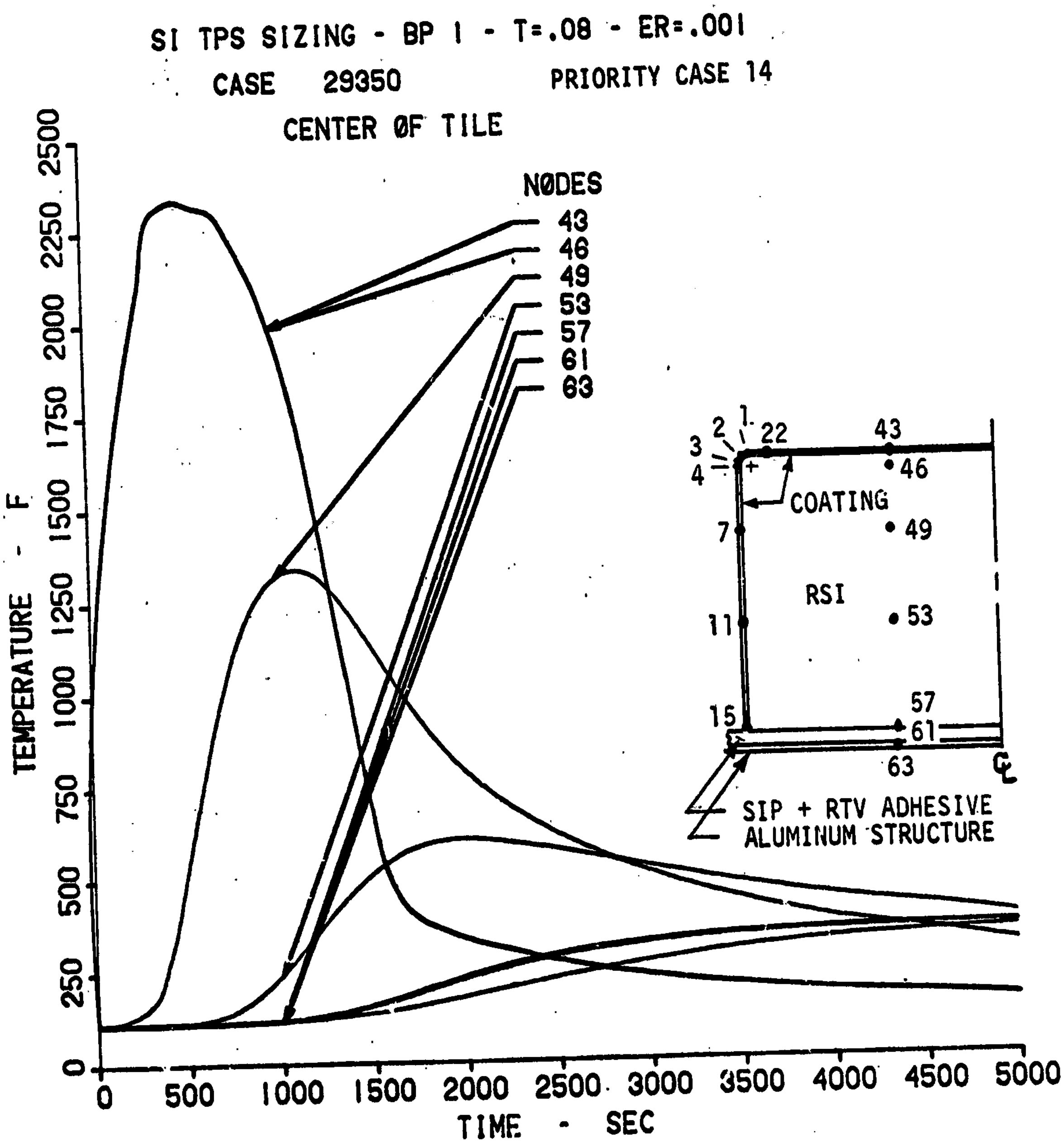
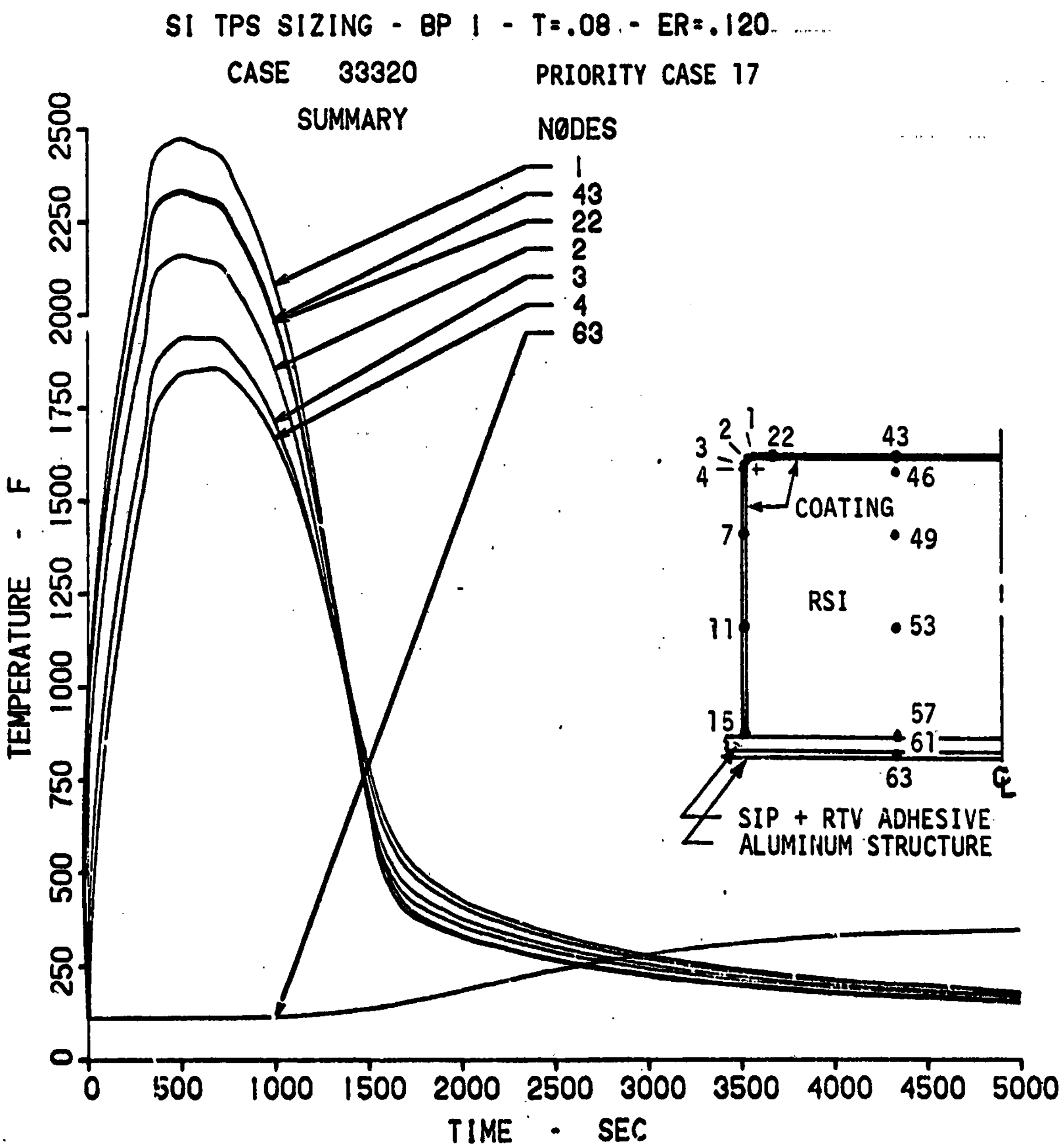
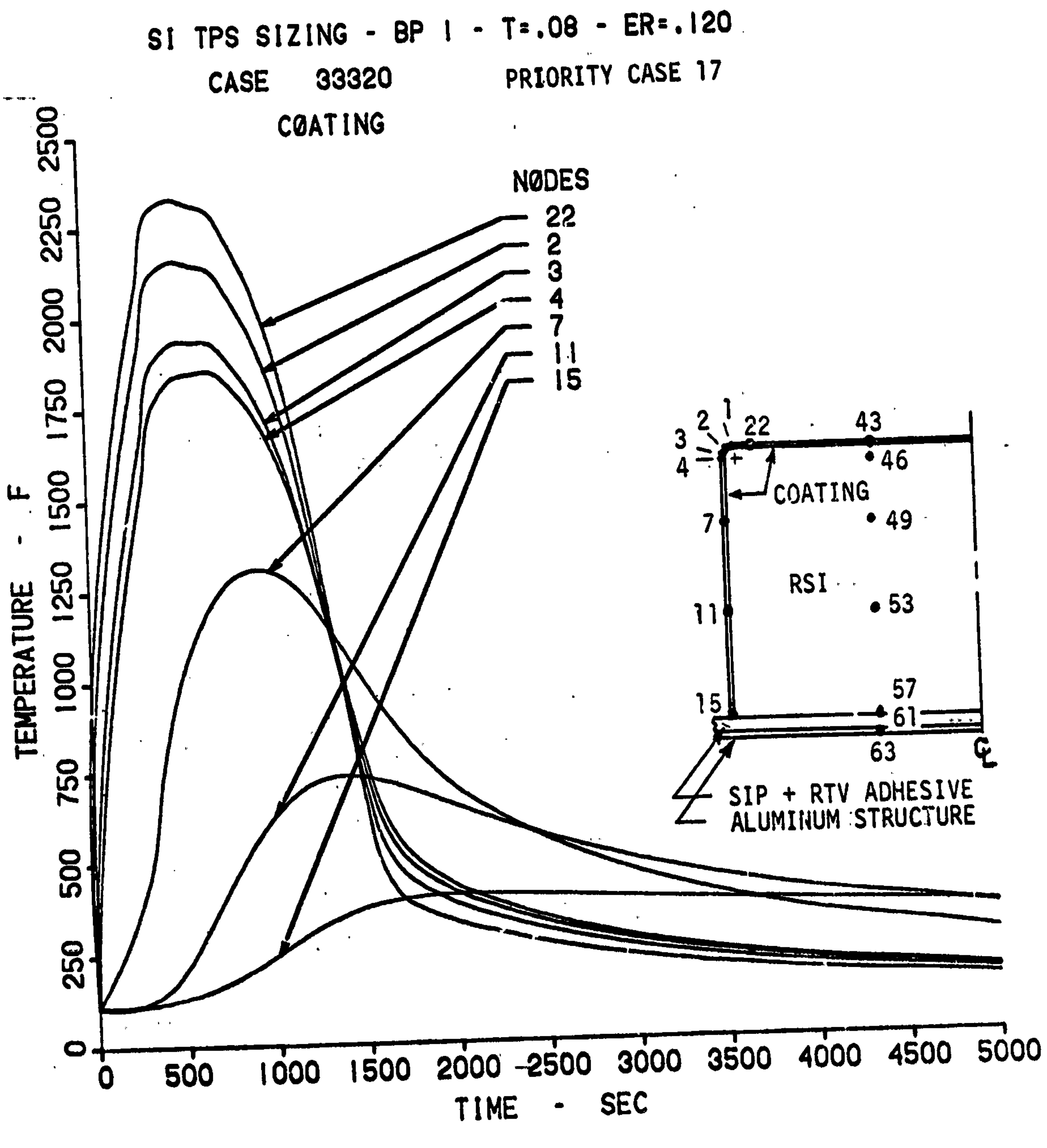
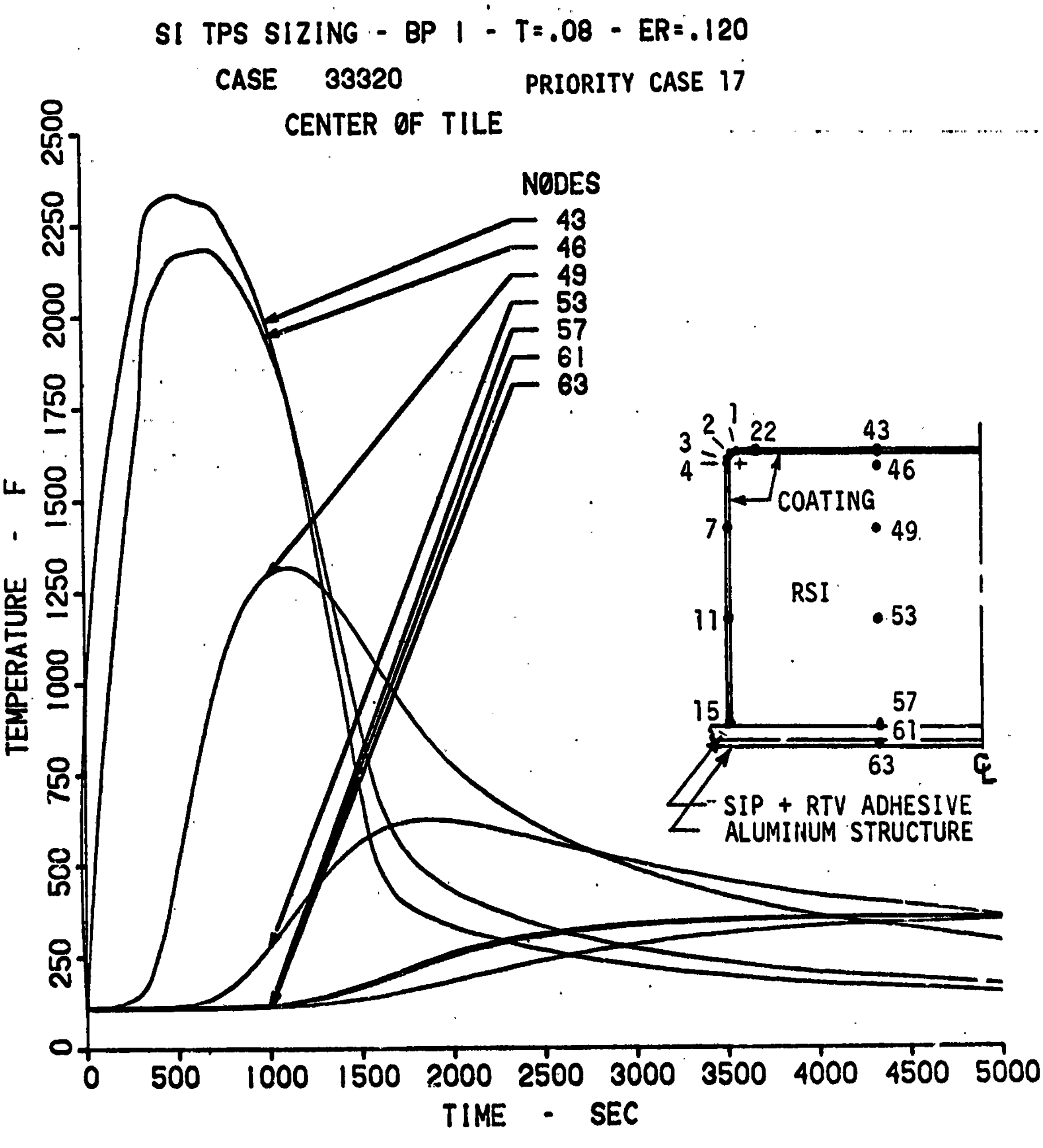
2
3
43
4
22
63
TEMPERATURE - F
TIME - SEC
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
2
1
22
43
3
4
46
COATING
7
49
RSI
11
53
57
15
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

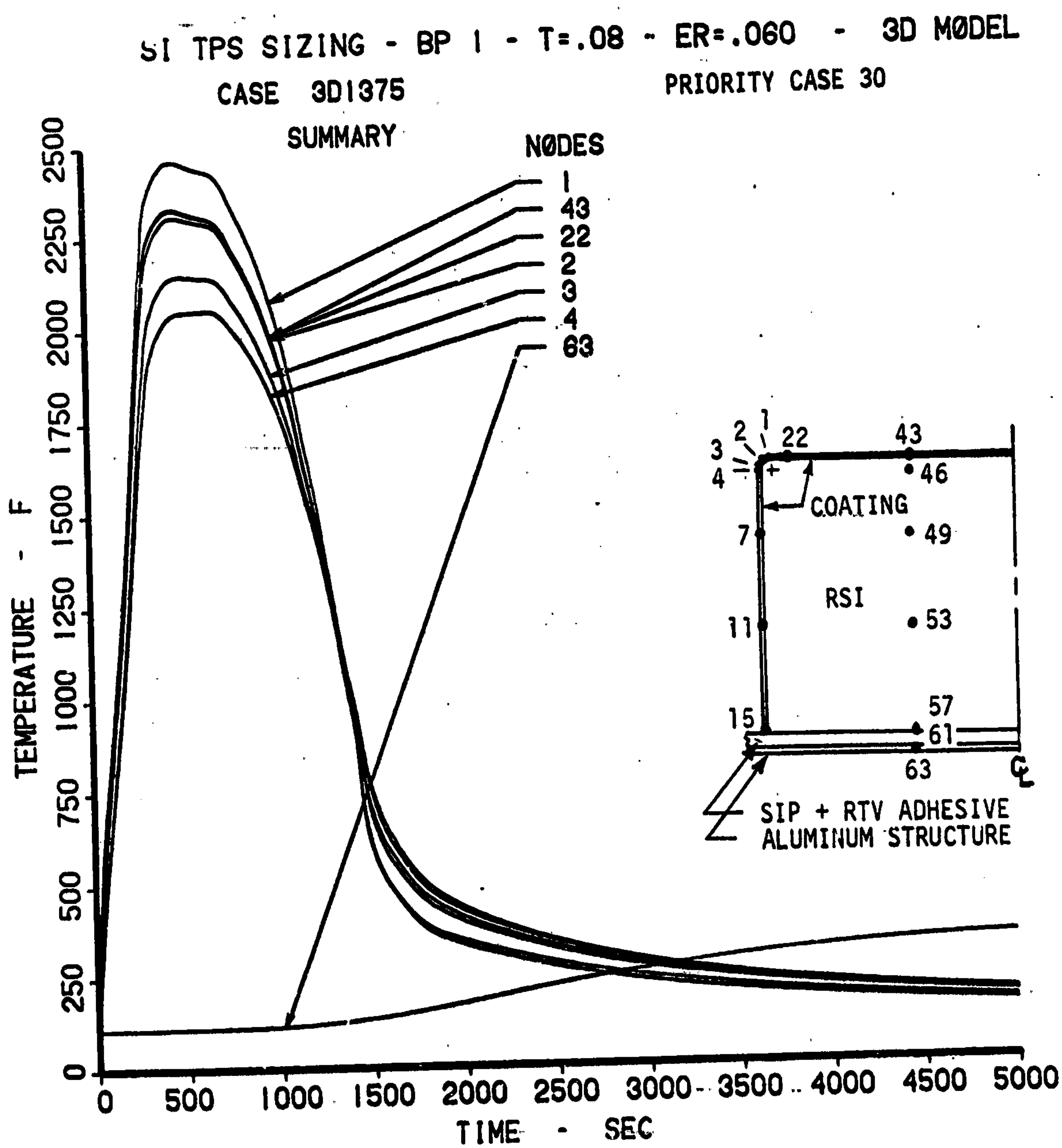

SI TPS SIZING - BP 1 - T=.08 - ER=.001
CASE 29350
PRIORITY CASE 14
COATING
NODES
2
3
4
22
7
11
15
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1
2
3
4
22
43
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

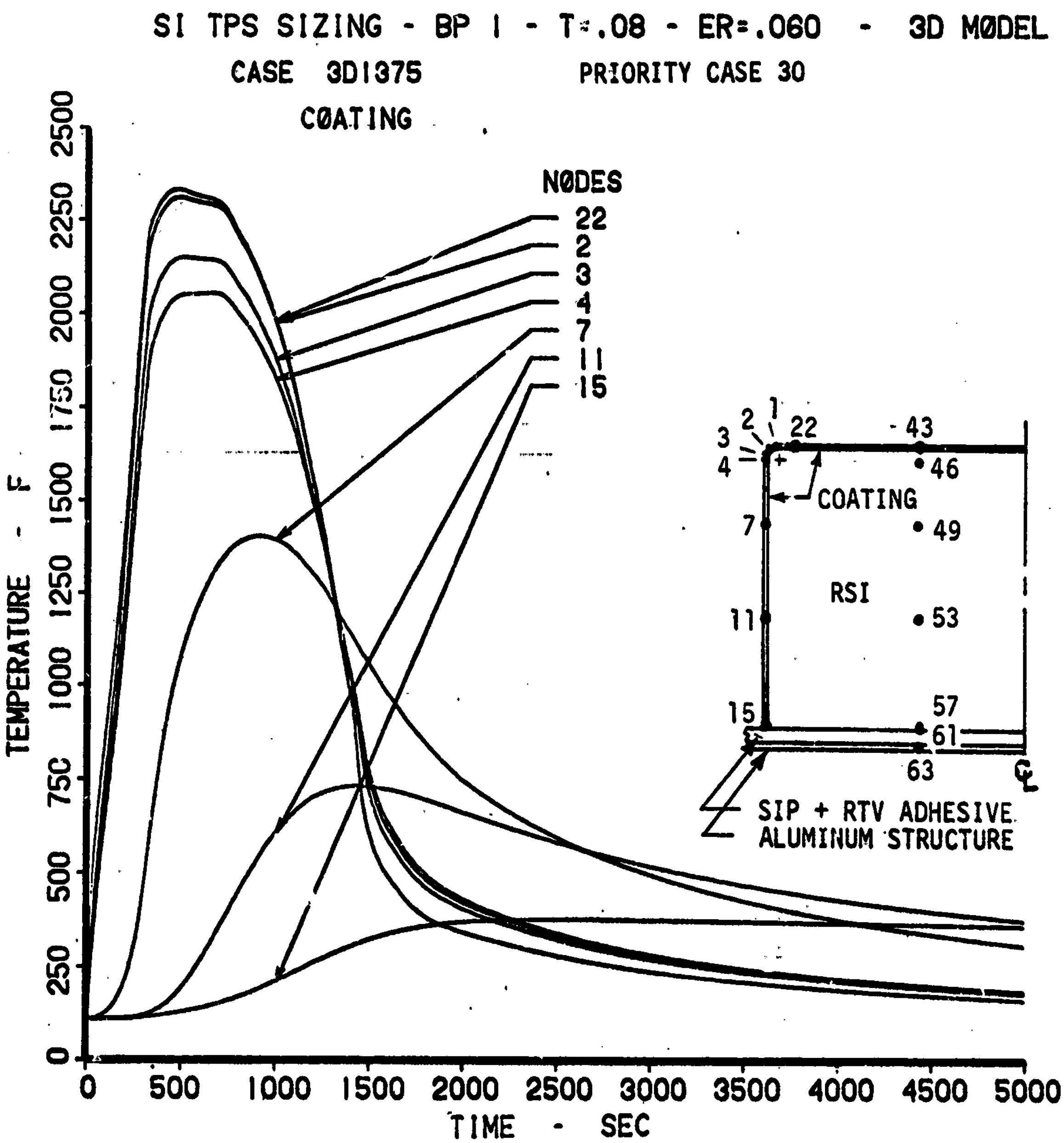

SI TPS SIZING - BP 1 - T=.08 - ER=.001
CASE 29350
PRIORITY CASE 14
CENTER ØF TILE
NØDES
43
46
49
53
57
61
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

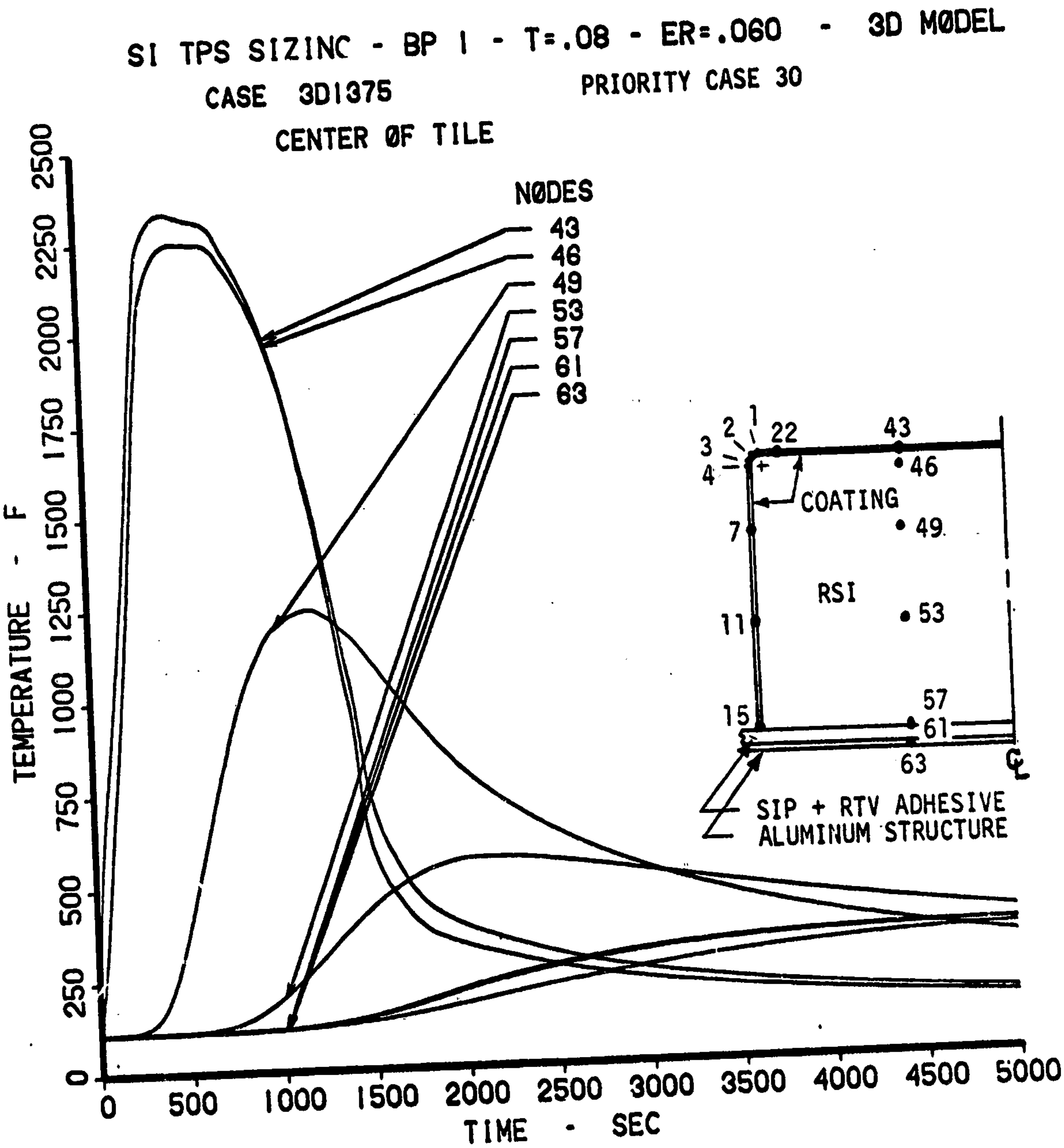

SI TPS SIZING - BP I - T=.08 - ER=.120
CASE 33320
PRIORITY CASE 17
SUMMARY
NØDES
1
43
22
2
3
4
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME - SEC
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP I - T=.08 - ER=.120
CASE 33320 PRIORITY CASE 17
CØATING
NØDES
22
2
3
4
7
11
15
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME - SEC
2
1
22
43
3
4
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP I - T=.08 - ER=.120
CASE 33320
PRIORITY CASE 17
CENTER ØF TILE
NØDES
43
46
49
53
57
61
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP 1 - T=.08 - ER=.060 - 3D MØDEL
CASE 3D1375
PRIORITY CASE 30
SUMMARY
NØDES
1
43
22
2
3
4
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
COATING
RSI
46
49
53
57
61
7
11
15
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

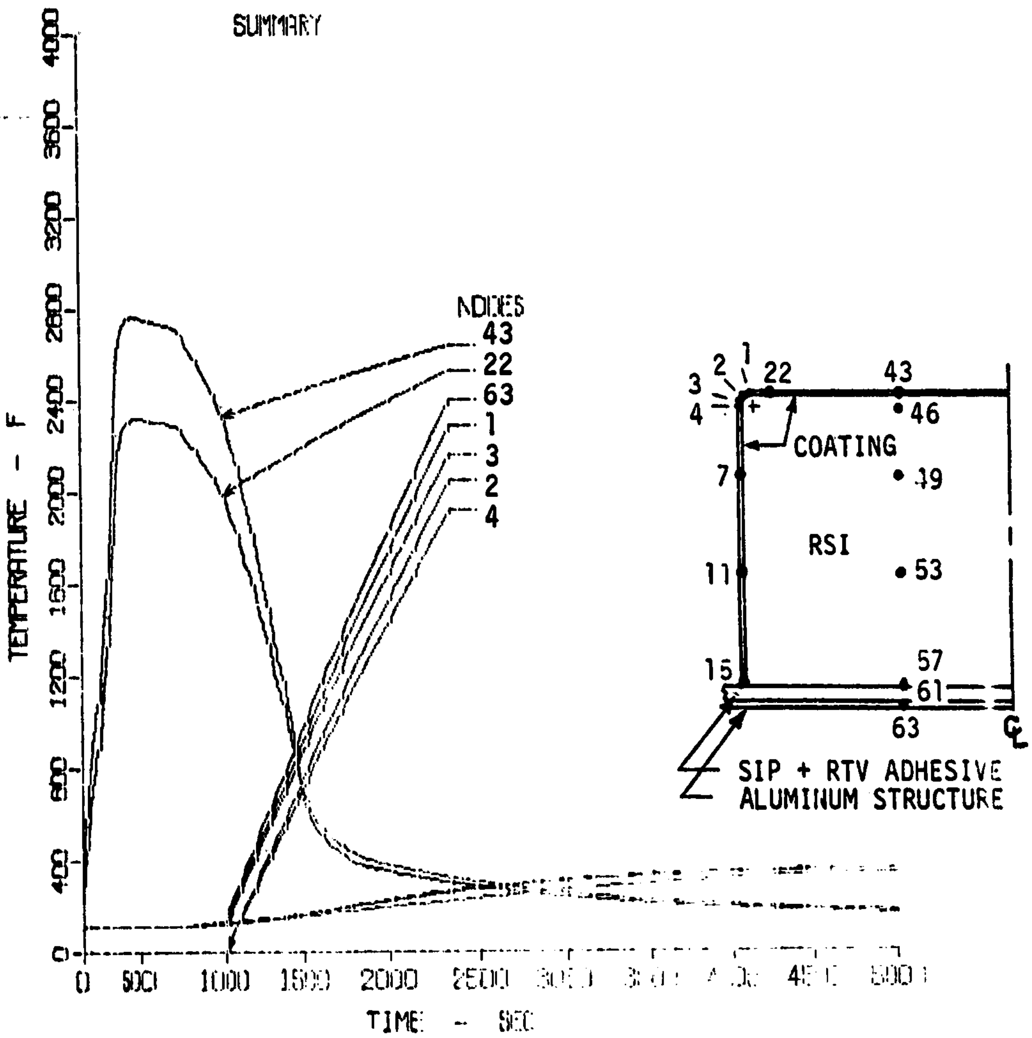

SI TPS SIZING - BP I - T=.08 - ER=.060 - 3D MØDEL
CASE 3D1375 PRIORITY CASE 30
CØATING
NØDES
22
2
3
4
7
11
15
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
TIME - SEC
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZINC - BP I - T=.08 - ER=.060 - 3D MØDEL
CASE 3D1375
PRIORITY CASE 30
CENTER ØF TILE
NØDES
43
46
49
53
57
61
63
TEMPERATURE - F
TIME - SEC
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .20 GAP

CASE 50388 PRIORITY CASE 38

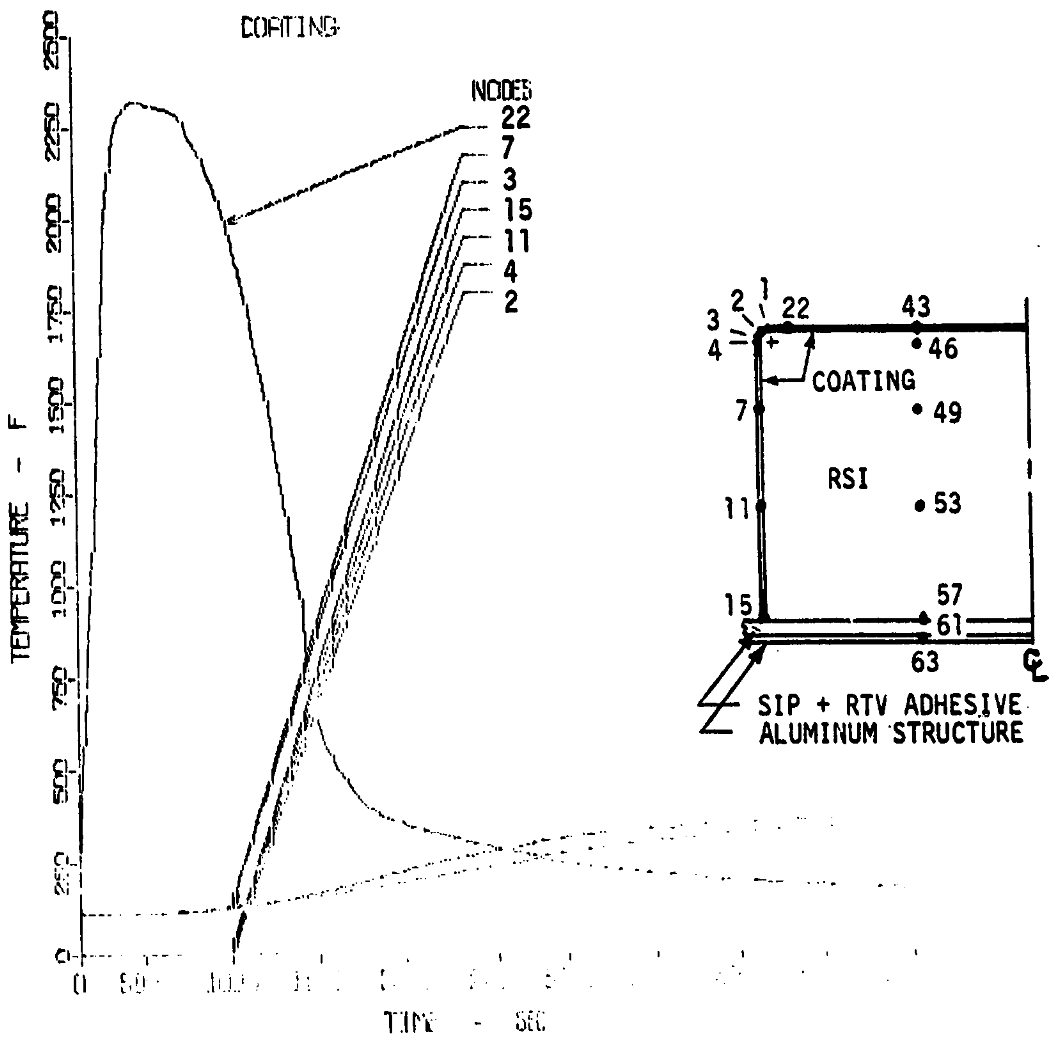
SUMMARY

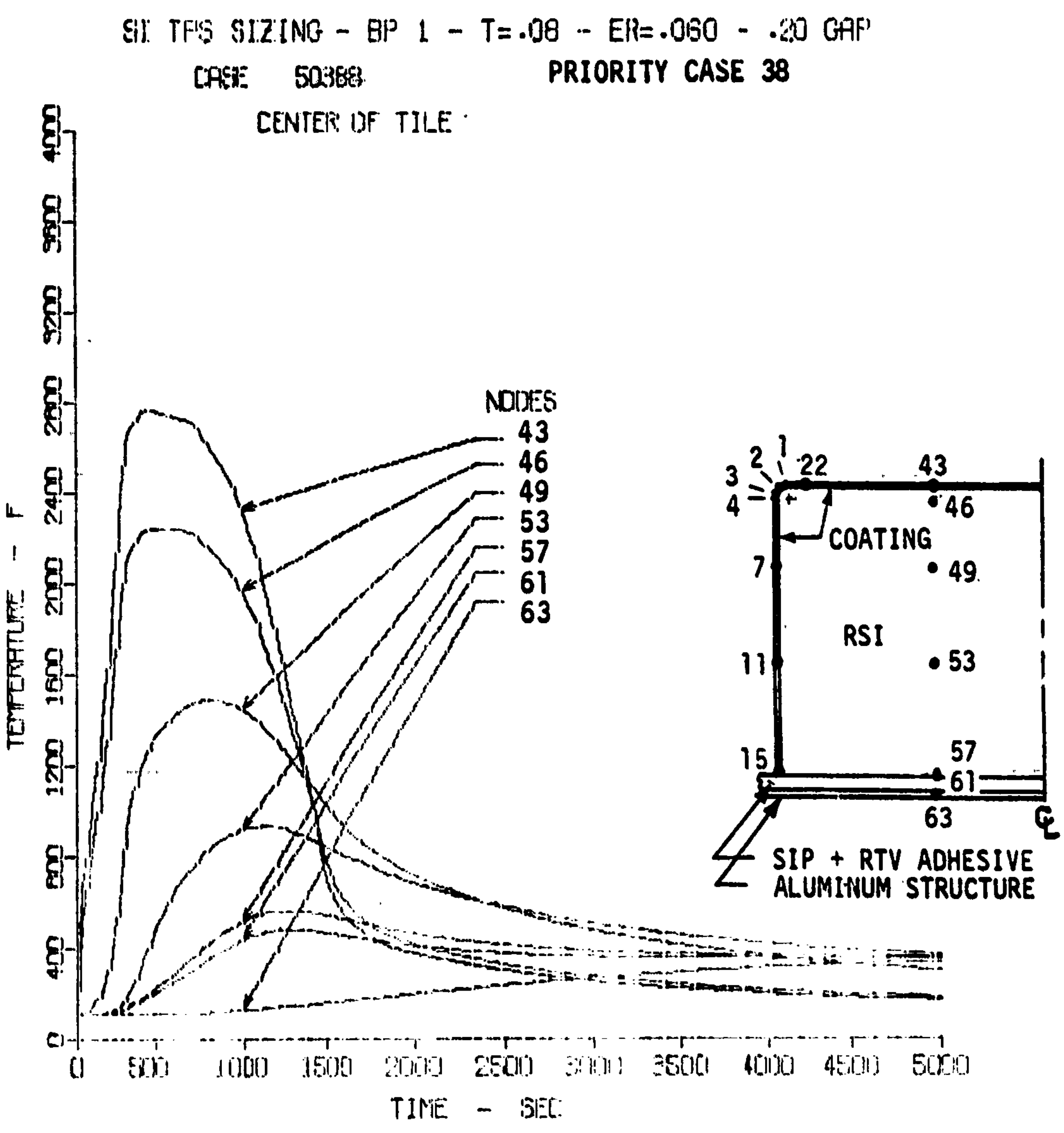


SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .20 GAP

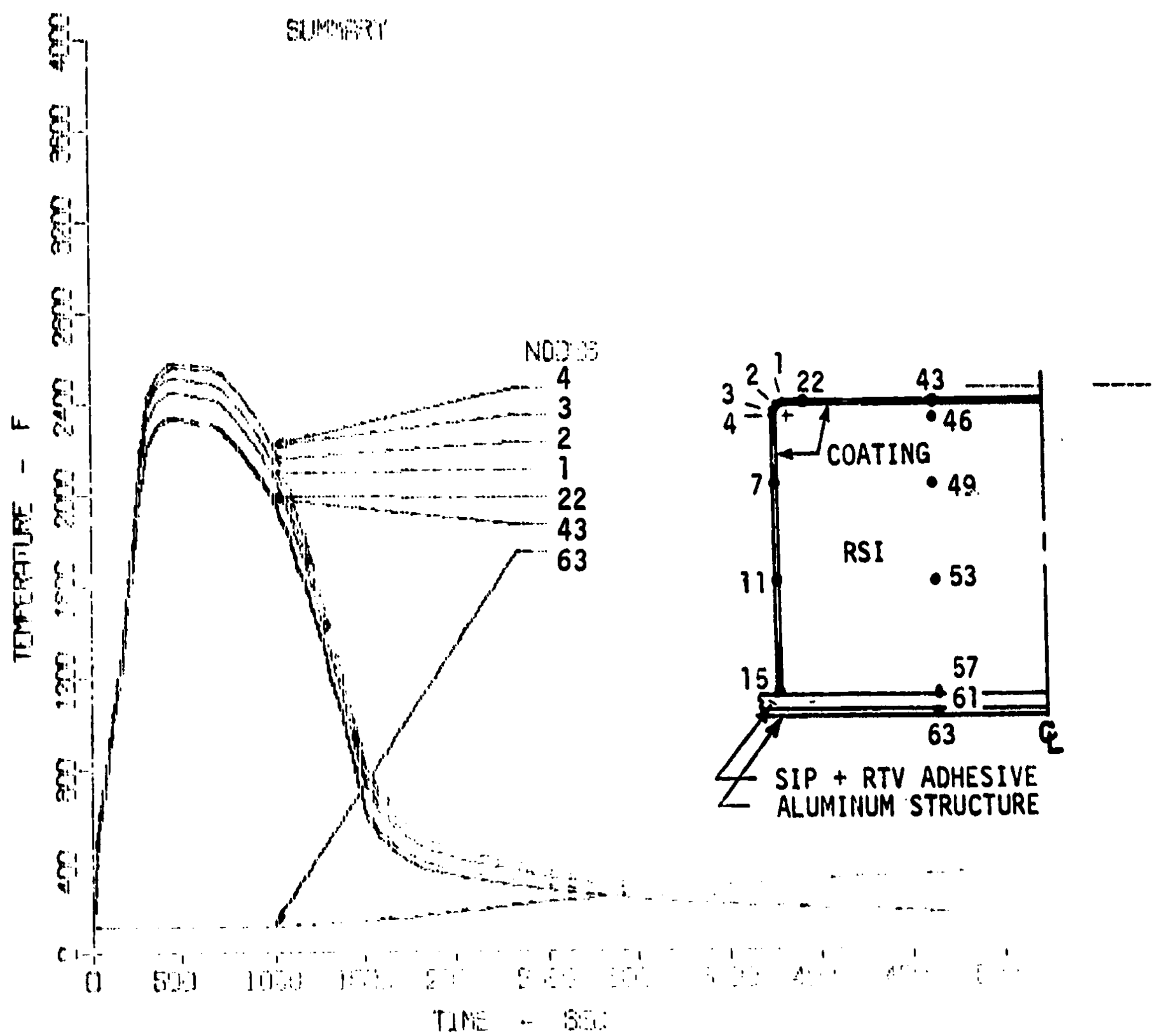
CASE 50388 PRIORITY CASE 38

COATING

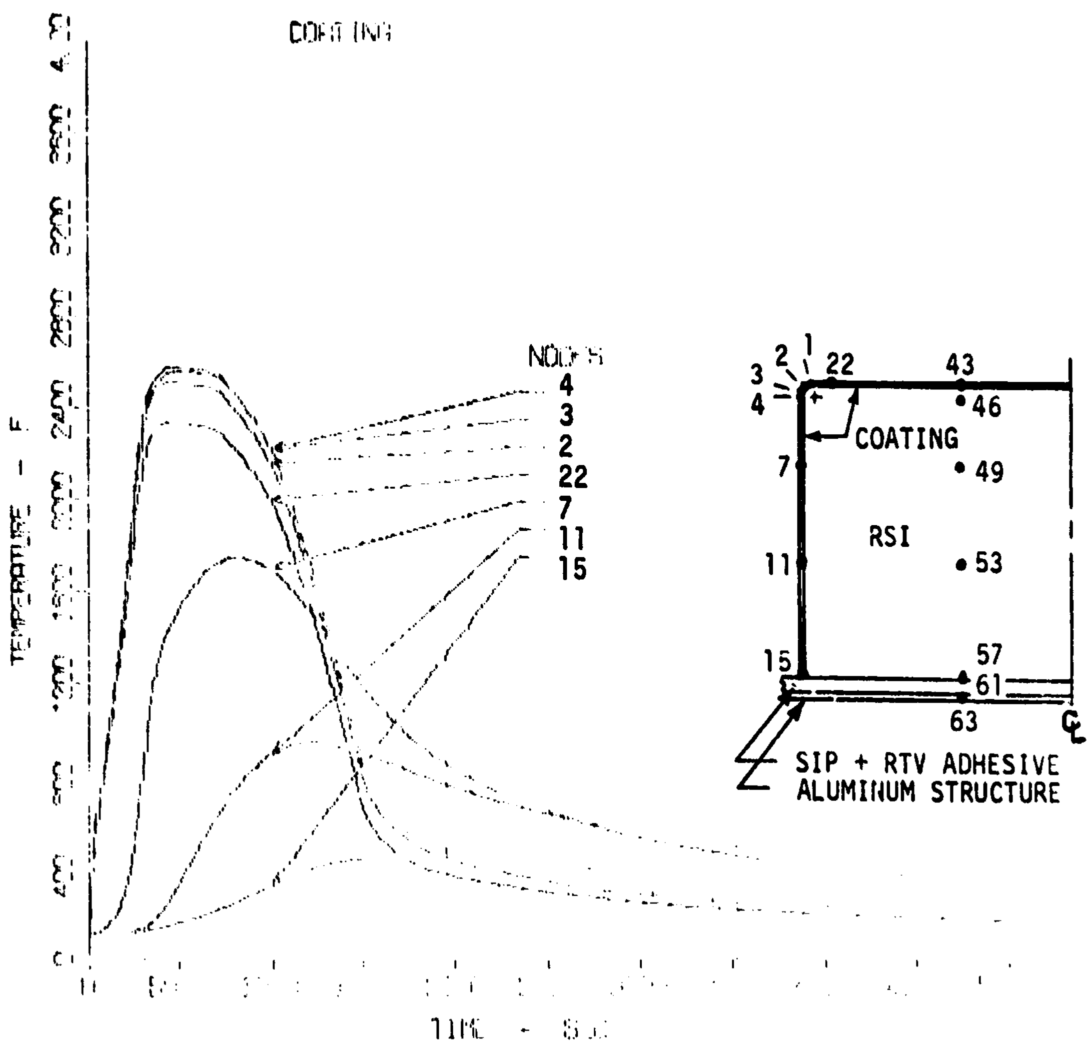



SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .20 GAP
CASE 50388
PRIORITY CASE 38
CENTER OF TILE
TEMPERATURE - F
TIME - SEC
NODES
43
46
49
53
57
61
63
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
1
2
3
4
22
7
11
15
COATING
RSI
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .10 GAP
CASE 54882 PRIORITY CASE 39
SUMMARY

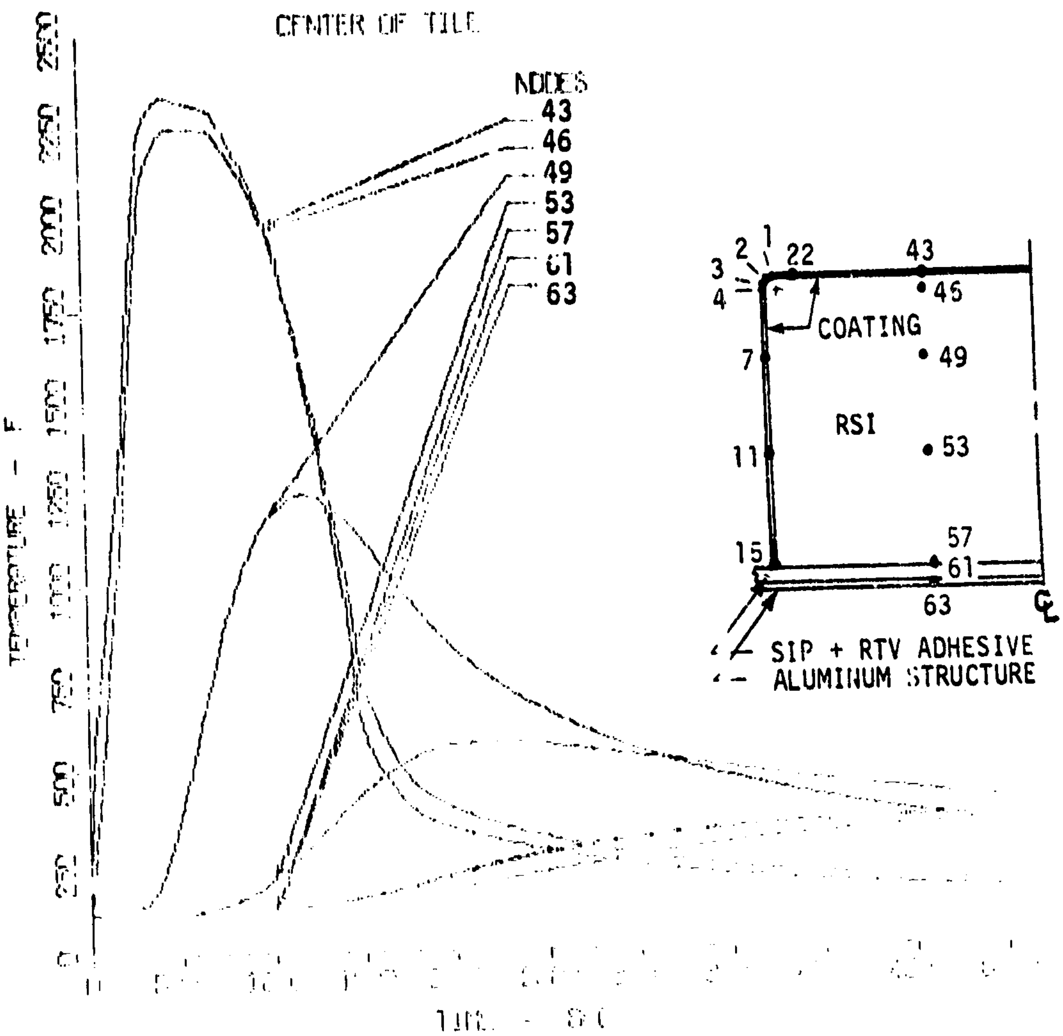


PRIORITY CASE 39



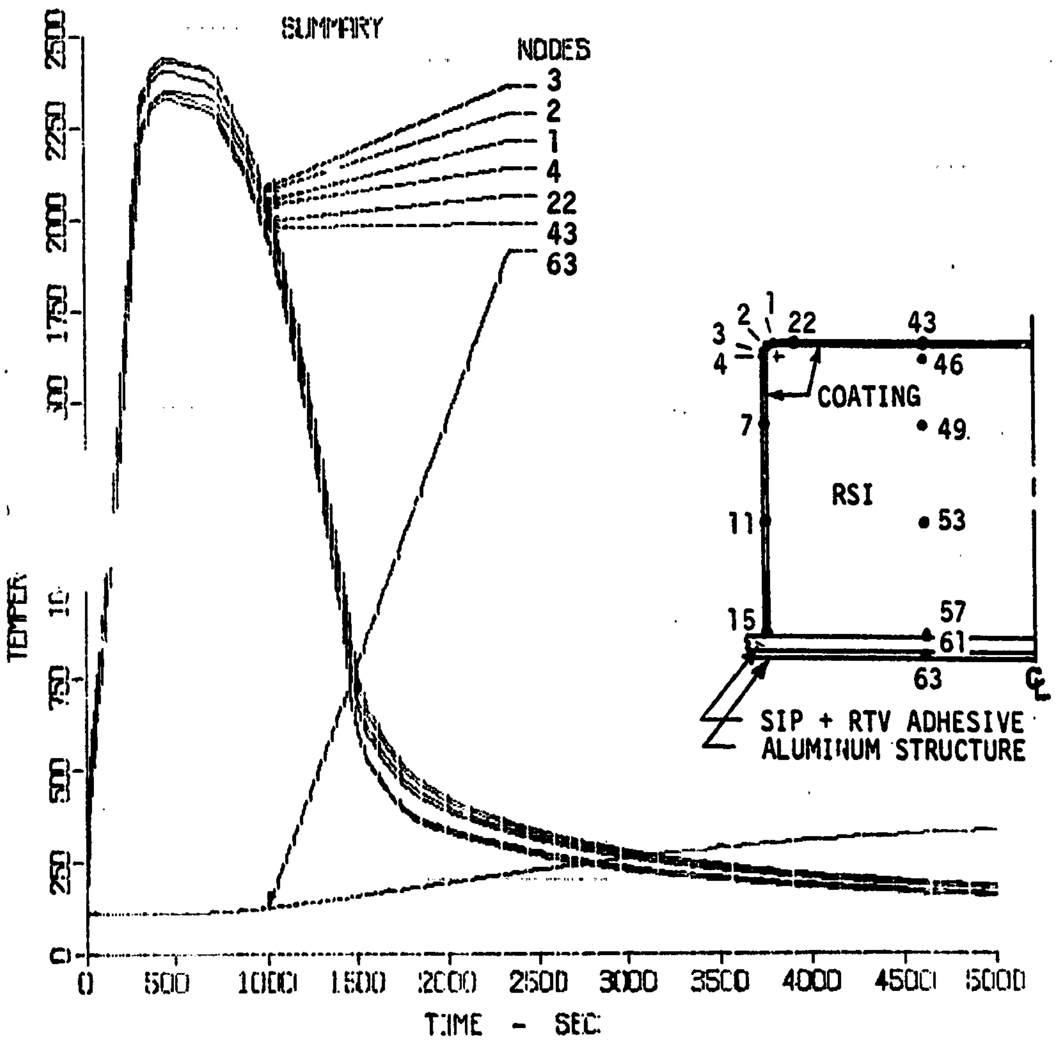
SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .10 GAP

CASE 54382 PRIORITY CASE 39



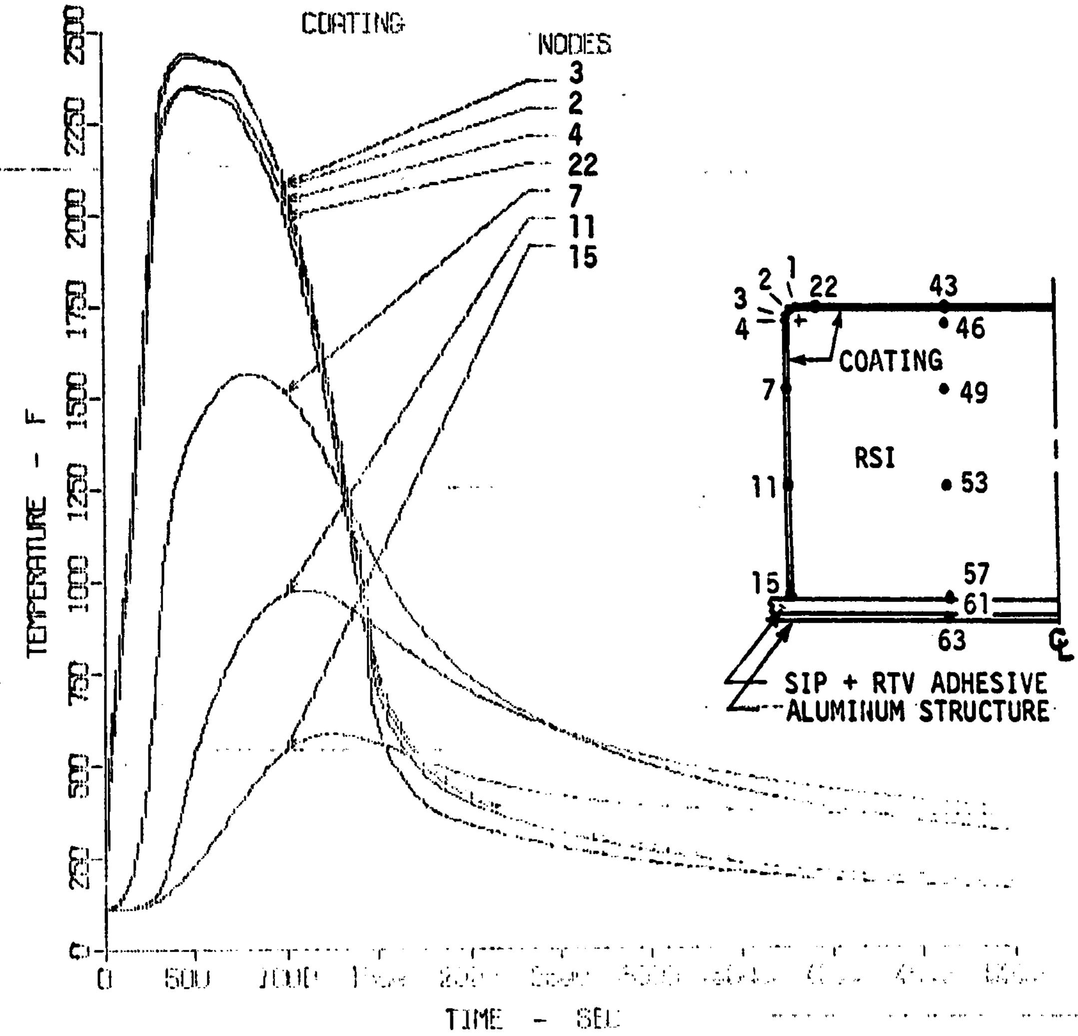
SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .20 GAP

CASE 51410 PRIORITY CASE 40

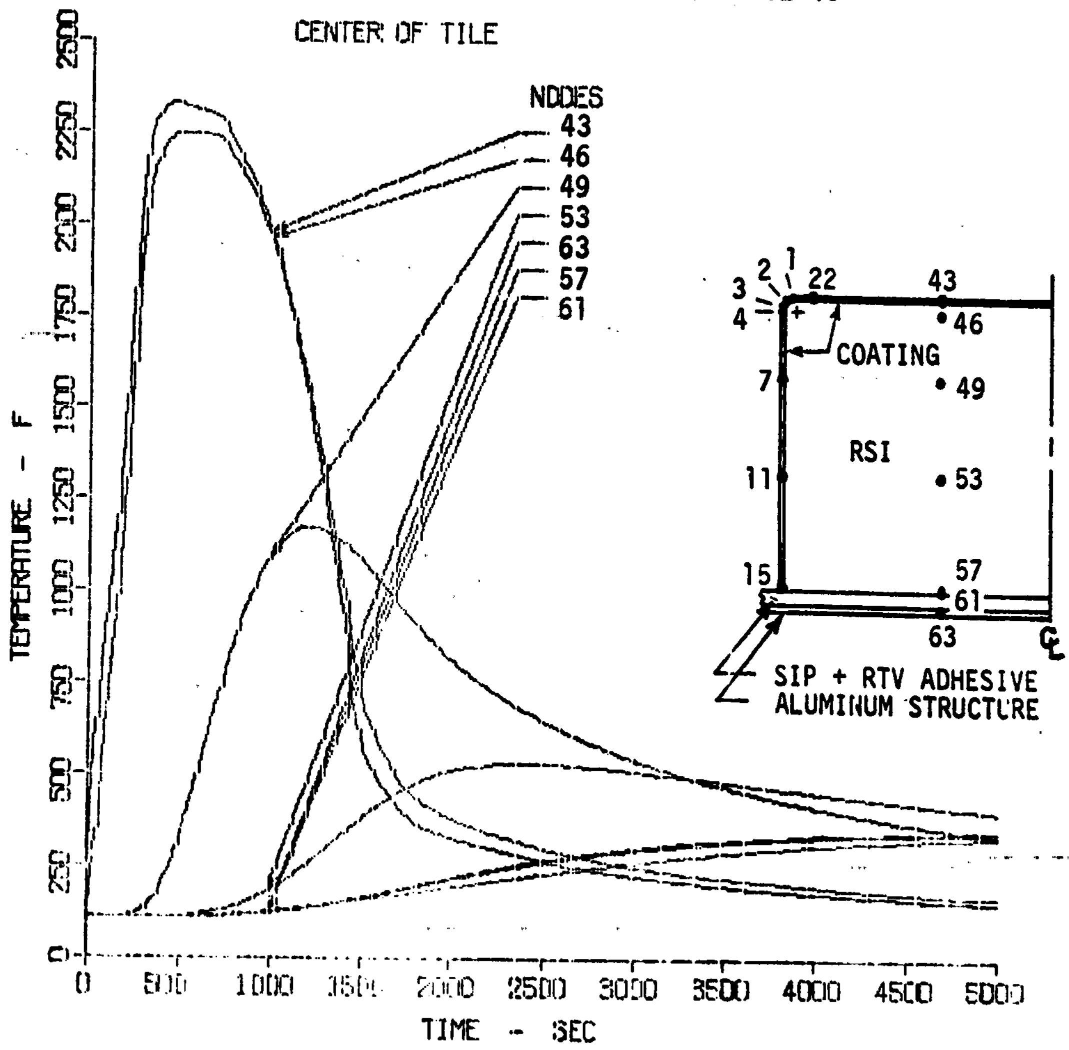


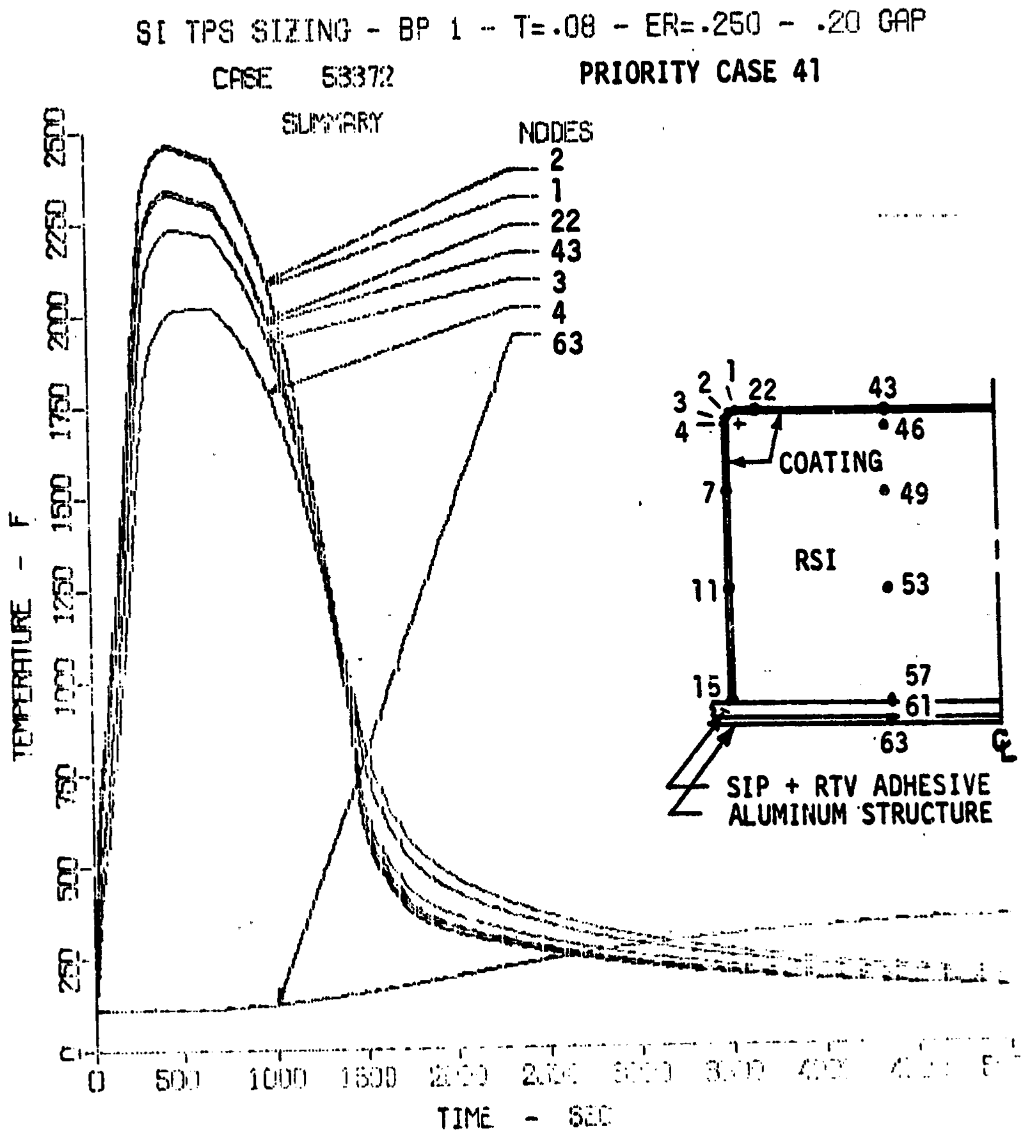
SI TPS SIZING - BP 1 - T=.08 - ER=.060 - .20 GAP

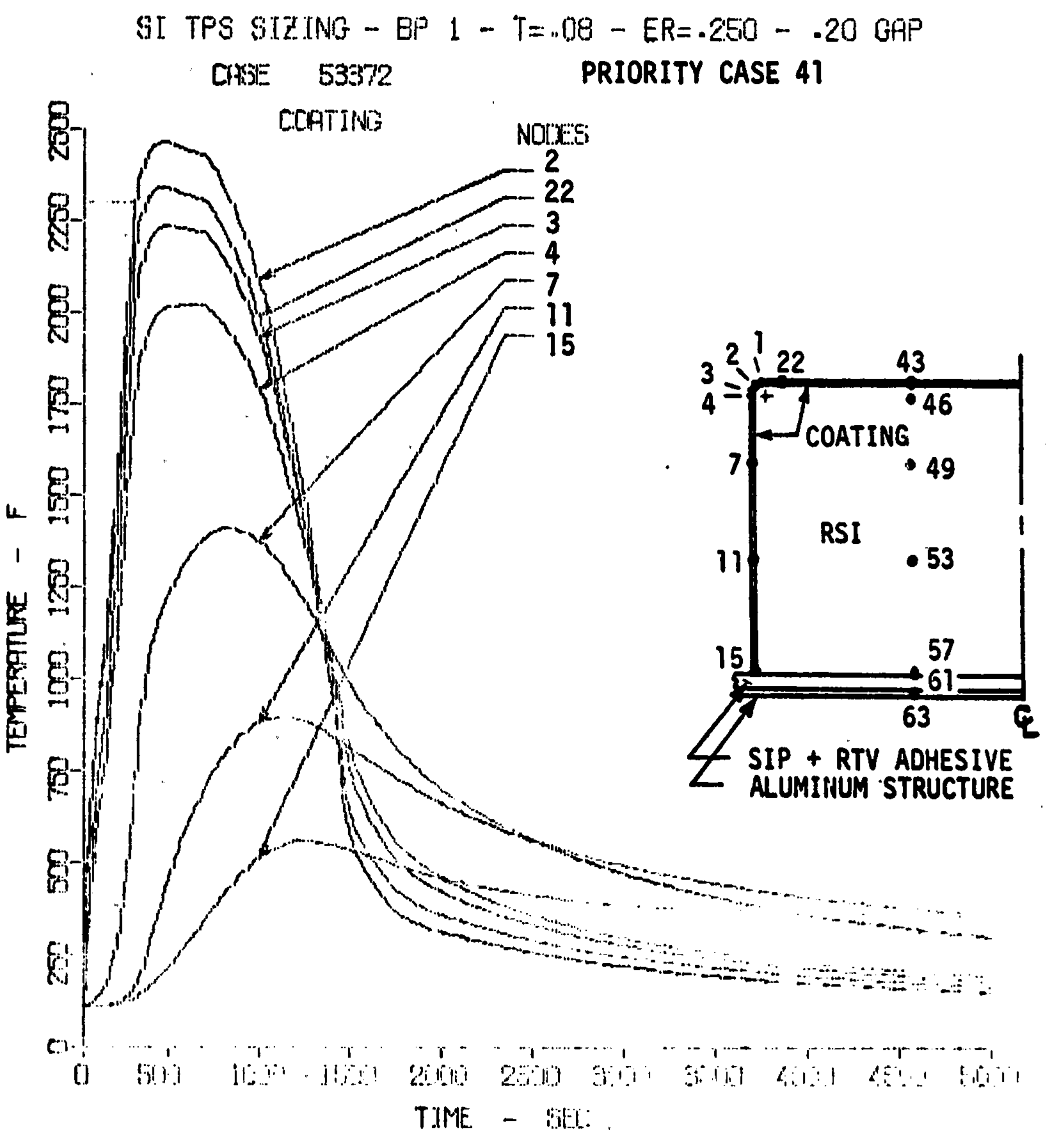
CASE 51410 PRIORITY CASE 40



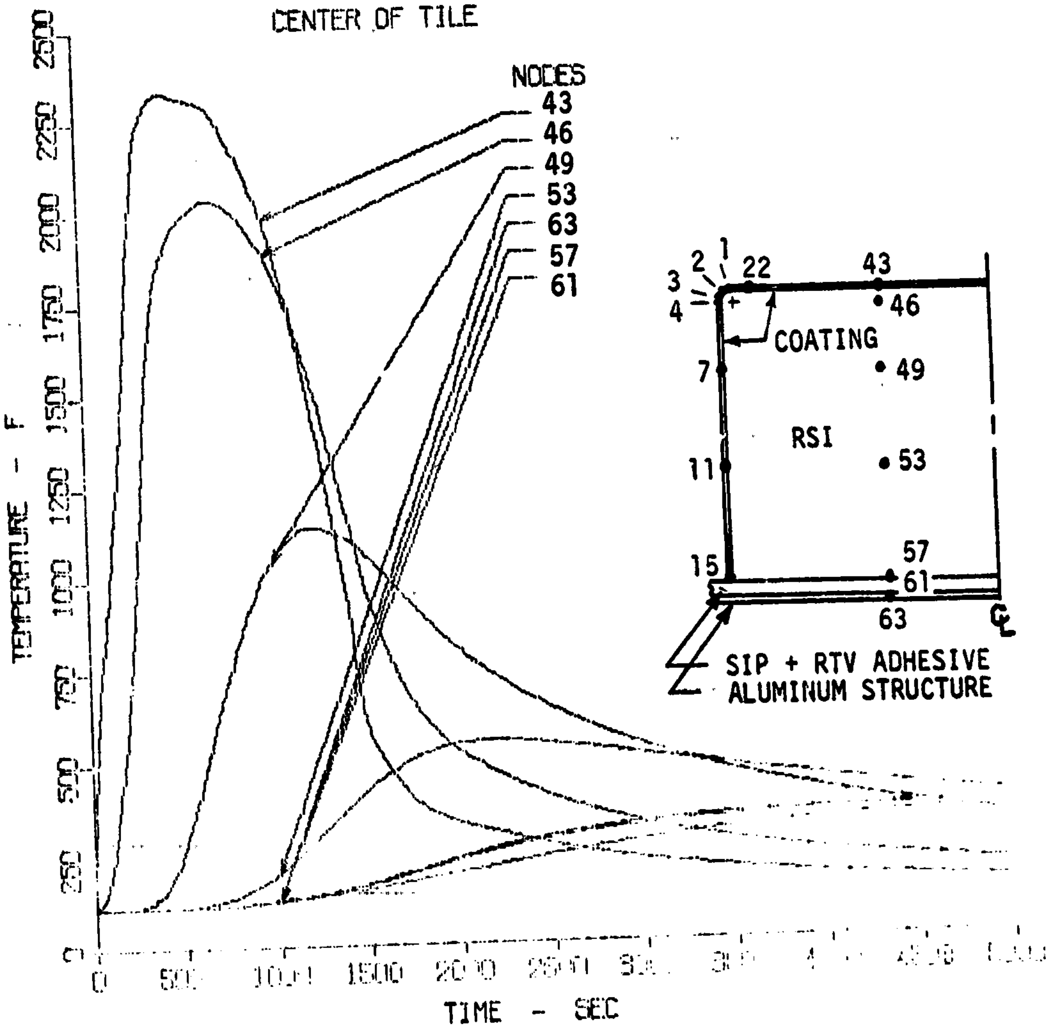
SI TPS SIZING - EIP 1 - T=.08 - ER=.060 - .20 GAP
CASE 51410 PRIORITY CASE 40
CENTER OF TILE

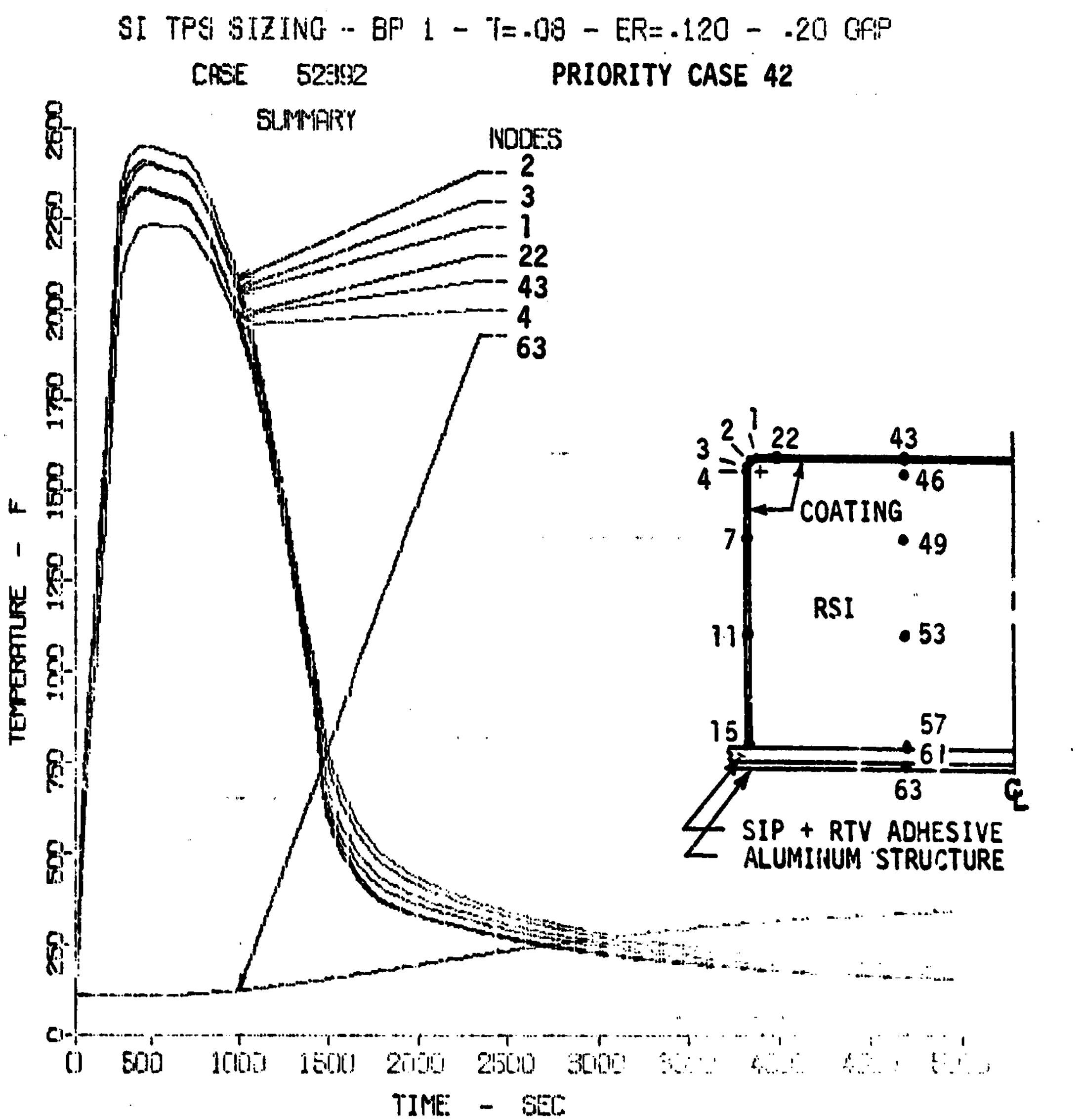


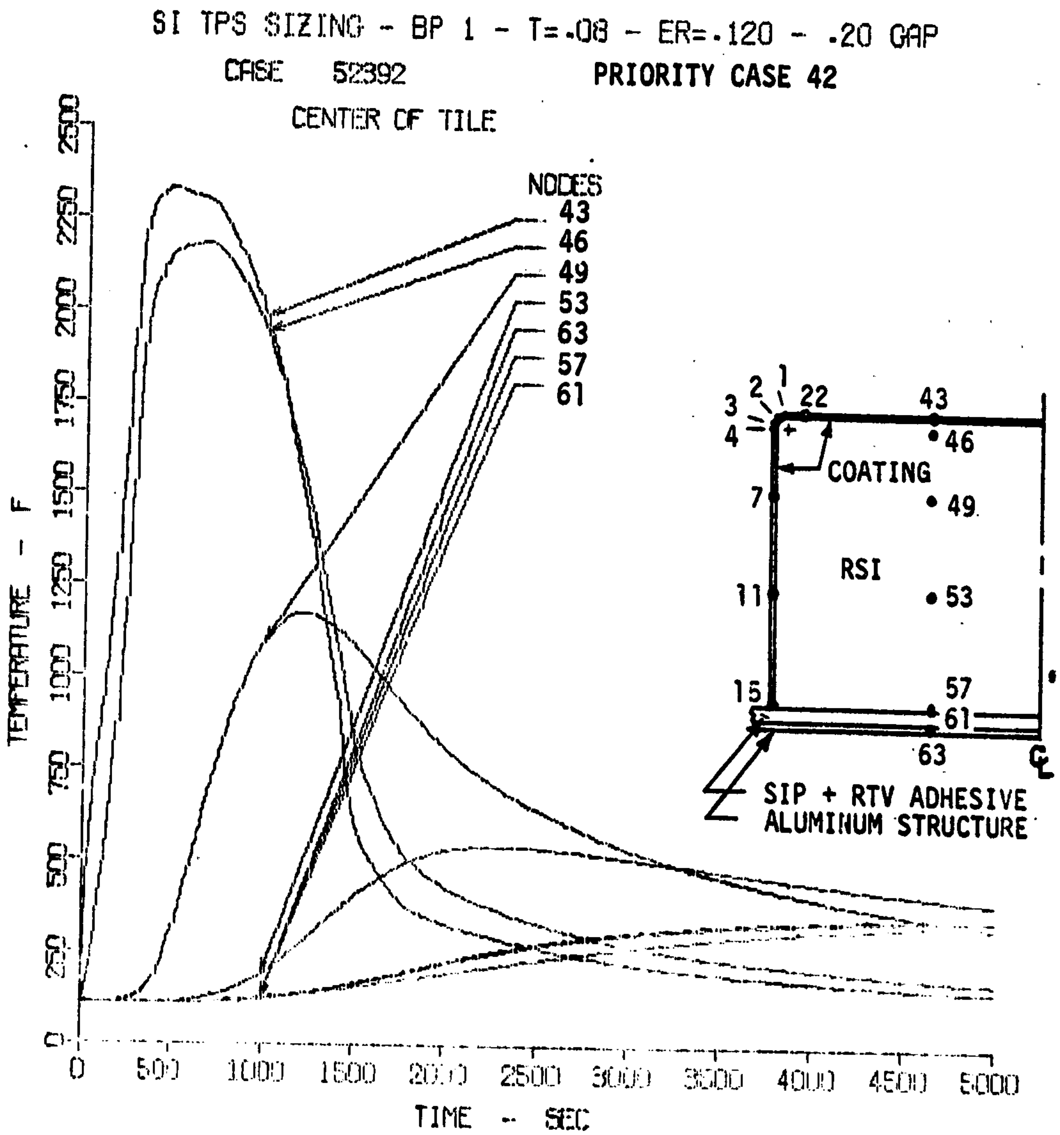

SI TPS SIZING - BP 1 - T=.08 - ER=.250 - .20 GAP
CASE 53372
PRIORITY CASE 41
SUMMARY
NODES
2
1
22
43
3
4
63
TEMPERATURE - F
TIME - SEC
0
500
1000
1500
250
500
750
1250
1500
1750
2000
2250
2500
2 1 22 43
3
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP 1 - T=.08 - ER=.250 - .20 GAP
CASE 53372
PRIORITY CASE 41
COATING
NODES
2
22
3
4
7
11
15
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
2
1
22
43
3
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - BP 1 - T=.08 - ER=.250 - .20 GAP
CASE 53372 PRIORITY CASE 41
CENTER OF TILE

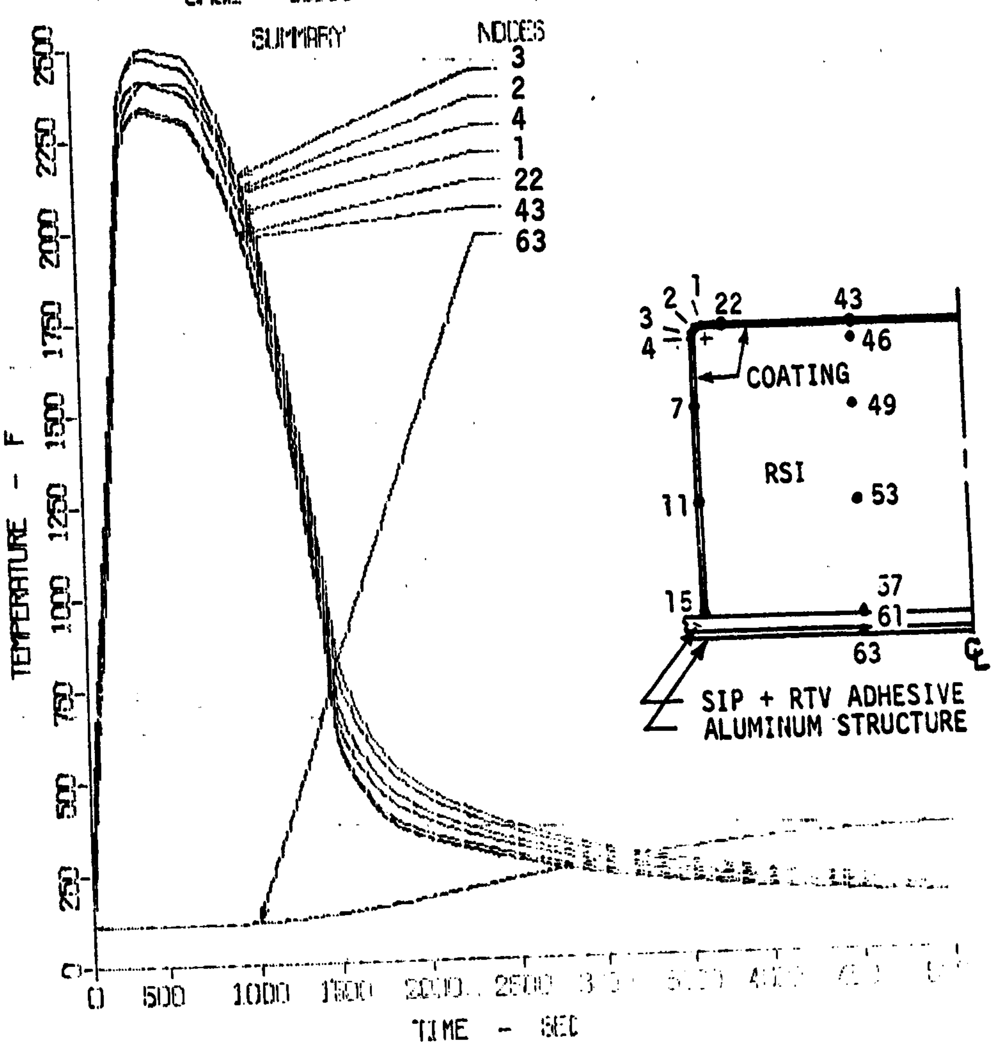


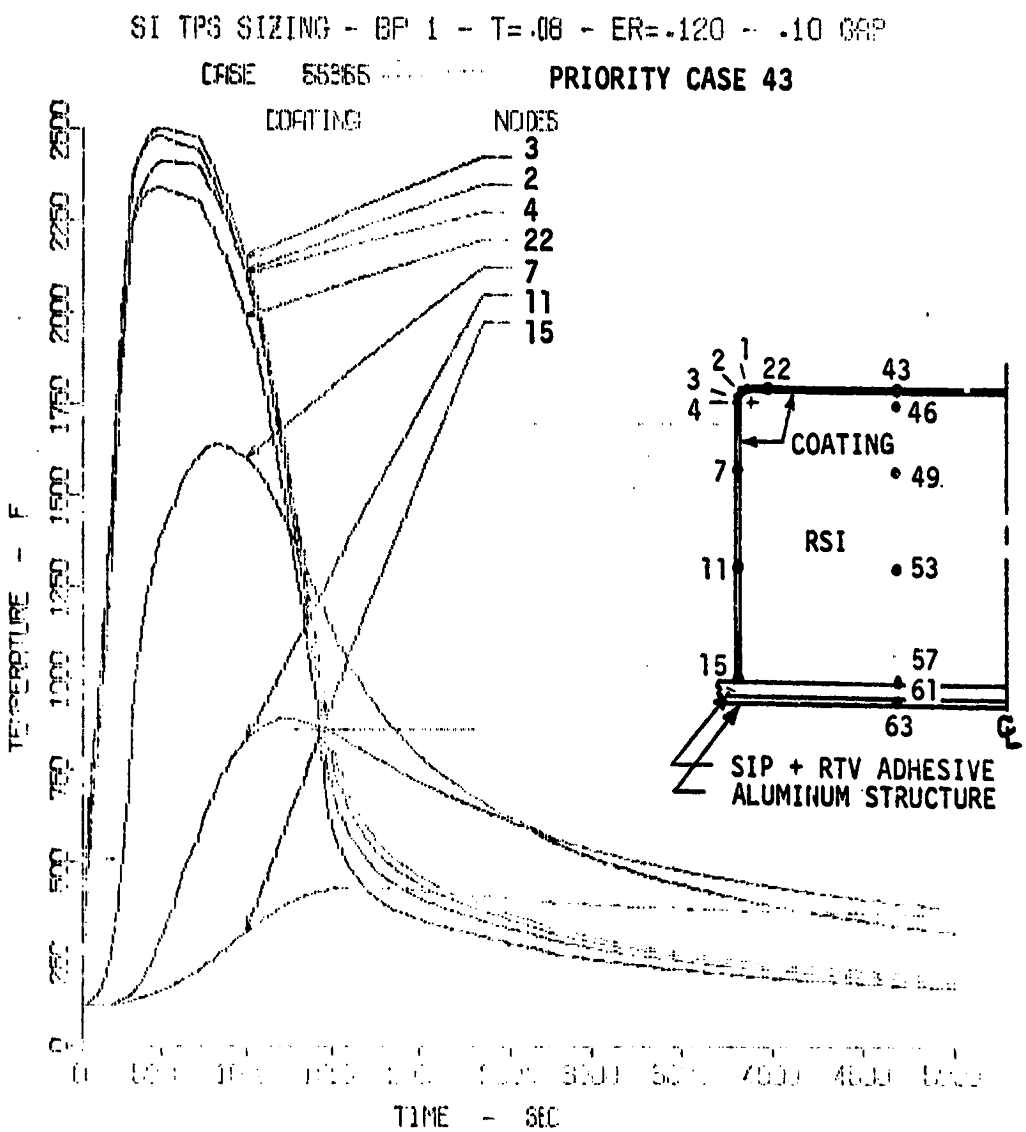

SI TPS SIZING - BP 1 - T=.08 - ER=.120 - .20 GAP
CASE 52392
PRIORITY CASE 42
SUMMARY
NODES
2
3
1
22
43
4
63
TEMPERATURE - F
TIME - SEC
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
500
1000
1500
2000
2500
3000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - BP 1 - T=.08 - ER=.120 - .20 GAP
CASE 52392
PRIORITY CASE 42
CENTER OF TILE
NODES
43
46
49
53
63
57
61
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

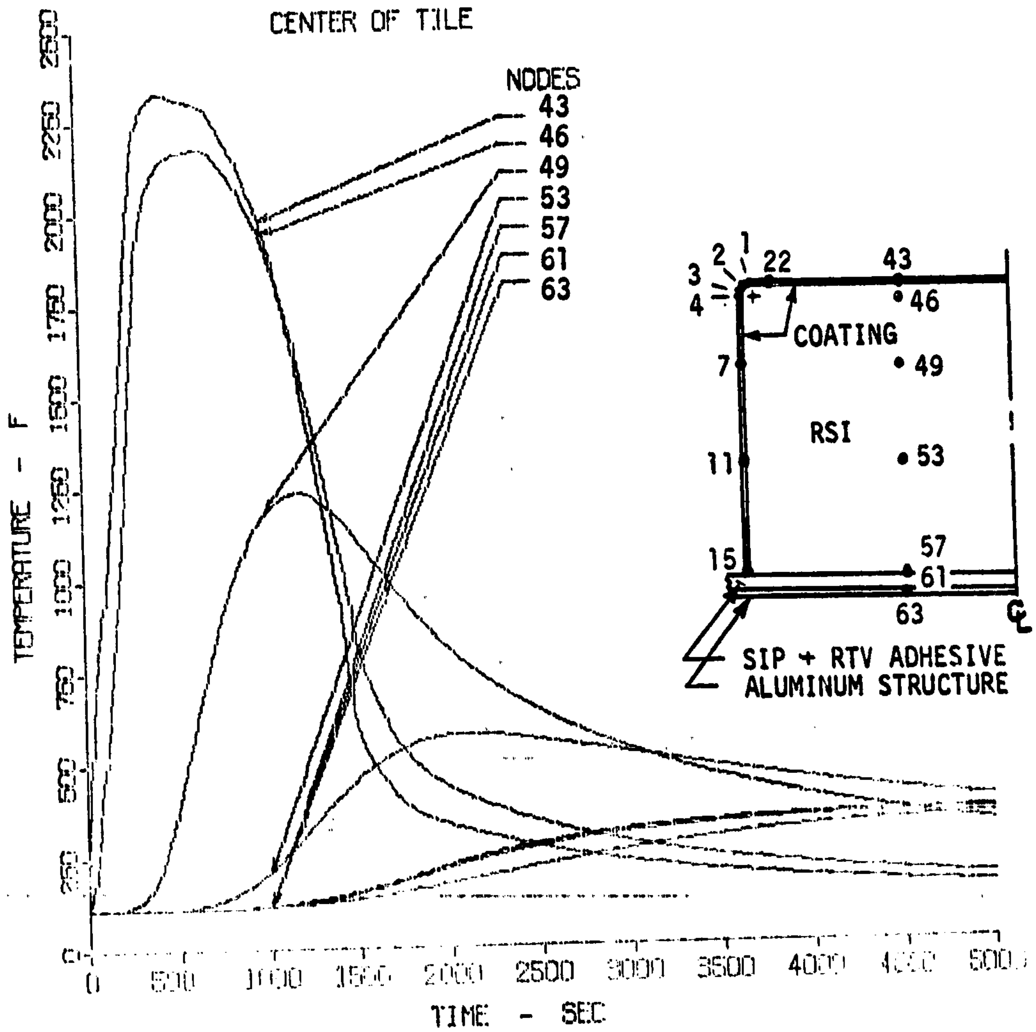
SI TPS SIZING - BP 1 - T=.08 - ER=.120 - .10 GAP

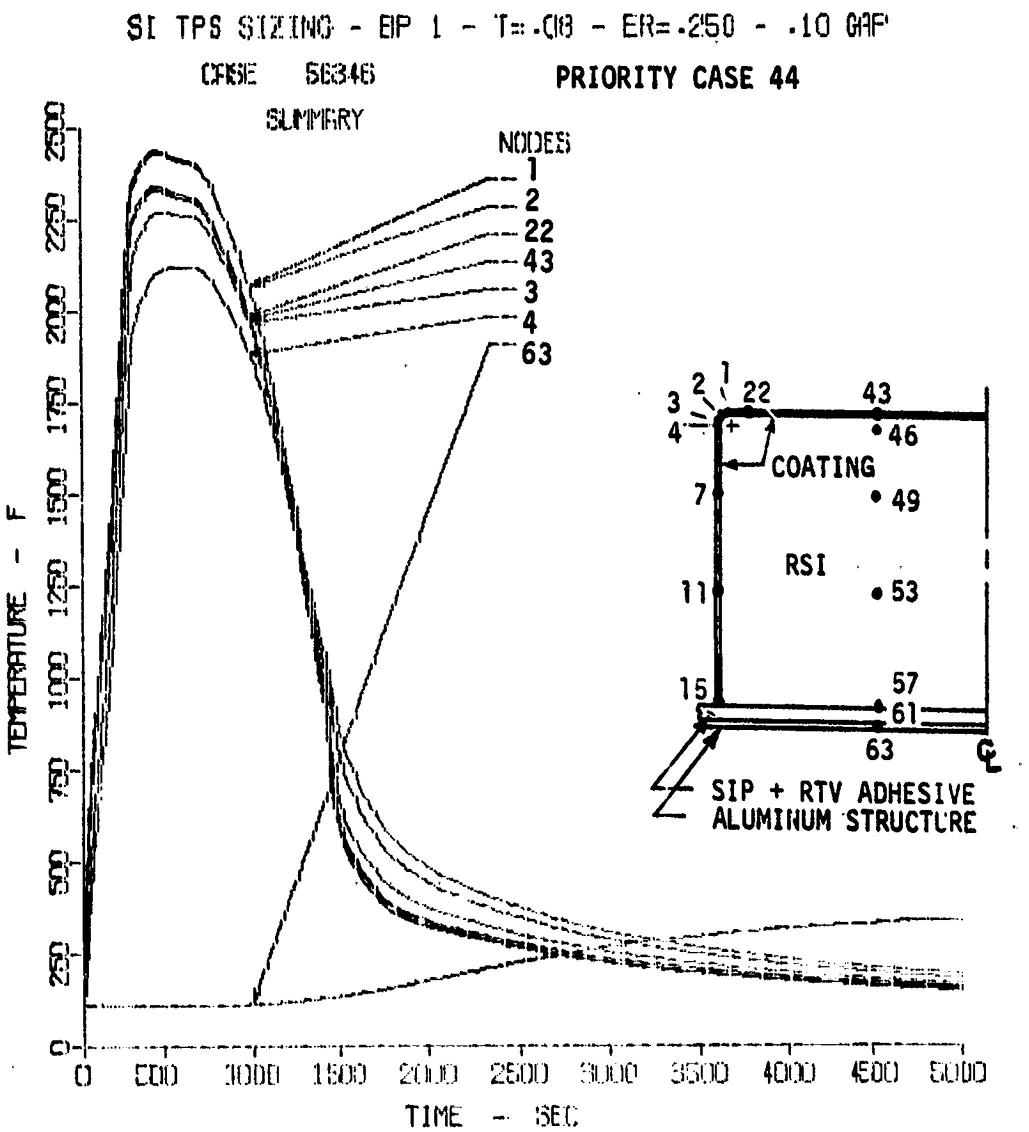
CASE E5365 PRIORITY CASE 43




SI TPS SIZING - BP 1 - T=.08 - ER=.120 - .10 GAP
CASE 55365
PRIORITY CASE 43
COATING
NODES
3
2
4
22
7
11
15
TEMPERATURE - F
TIME - SEC
3
4
2
1
22
43
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

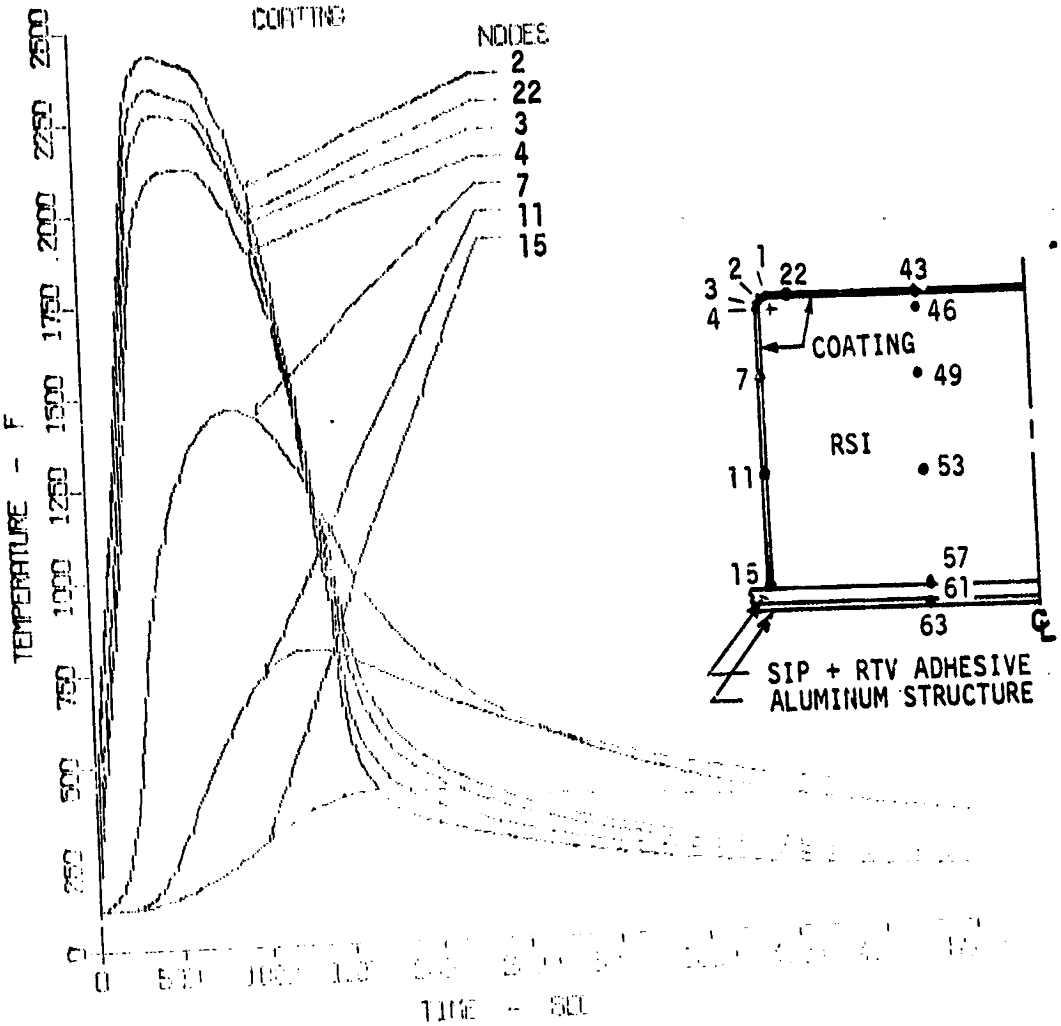
SI TPS SIZING - BP 1 - T=.08 - ER=.120 - .10 GAP
CASE 55365 PRIORITY CASE 43
CENTER OF TILE

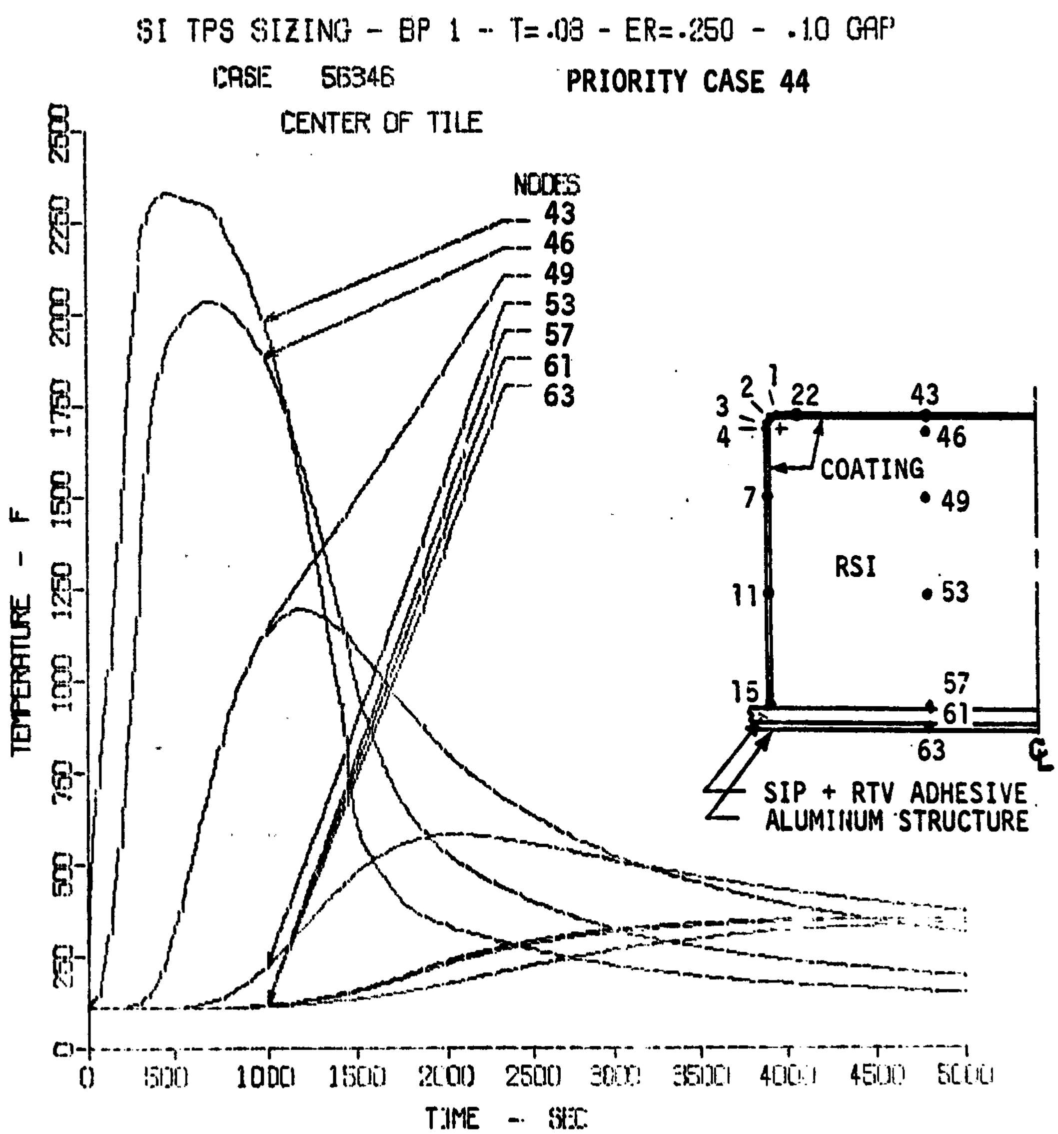


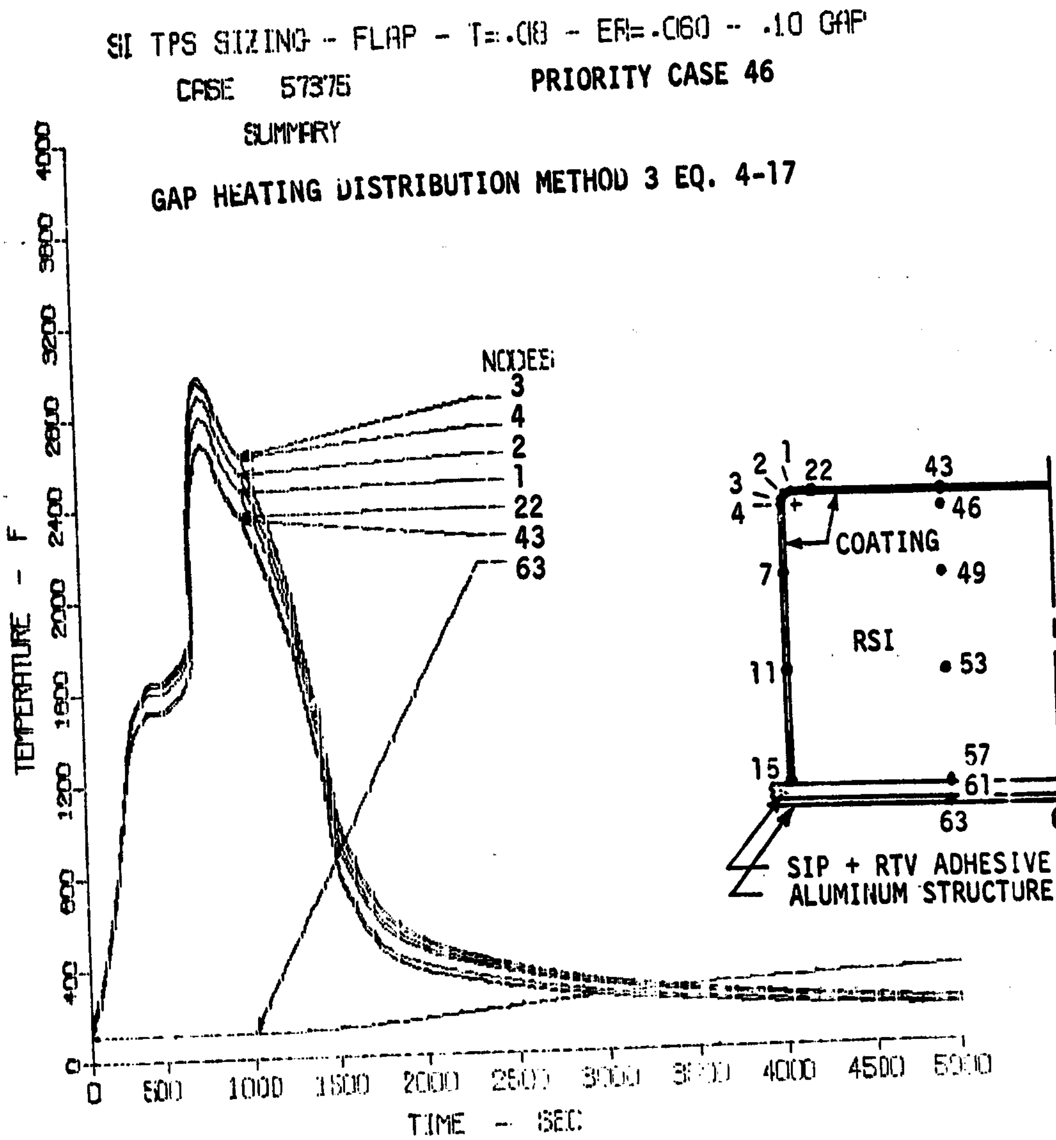

SI TPS SIZING - BP 1 - T=.08 - ER=.250 - .10 GAP
CASE 56346
PRIORITY CASE 44
SUMMARY
NODES
1
2
22
43
3
4
63
TEMPERATURE - F
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
COATING
RSI
46
49
53
7
11
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - BP 1 - T=.08 - ER=.250 - .10 GAP

CASE 58346 PRIORITY CASE 44

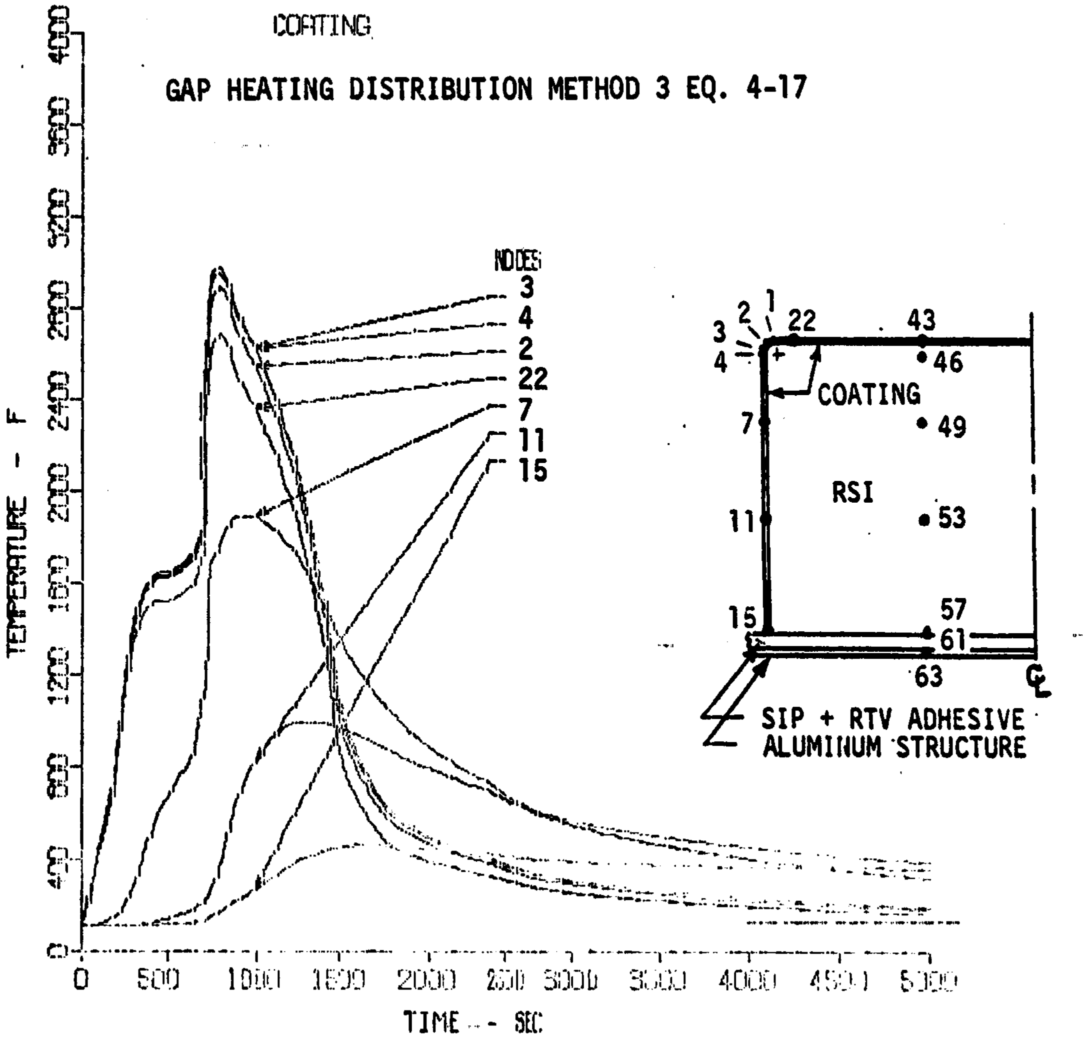



SI TPS SIZING - BP 1 - T=.08 - ER=.250 - .10 GAP
CASE 56346
PRIORITY CASE 44
CENTER OF TILE
NODES
43
46
49
53
57
61
63
TEMPERATURE - F
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
250
750
1000
1250
1500
1750
2000
2250
2500
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP
CASE 57375
PRIORITY CASE 46
SUMMARY
GAP HEATING DISTRIBUTION METHOD 3 EQ. 4-17
TEMPERATURE - F
TIME - SEC
NODES
3
4
2
1
22
43
63
COATING
RSI
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE
46
49
53
57
61
7
11
15

SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP
CASE 57375 PRIORITY CASE 46
COATING

GAP HEATING DISTRIBUTION METHOD 3 EQ. 4-17

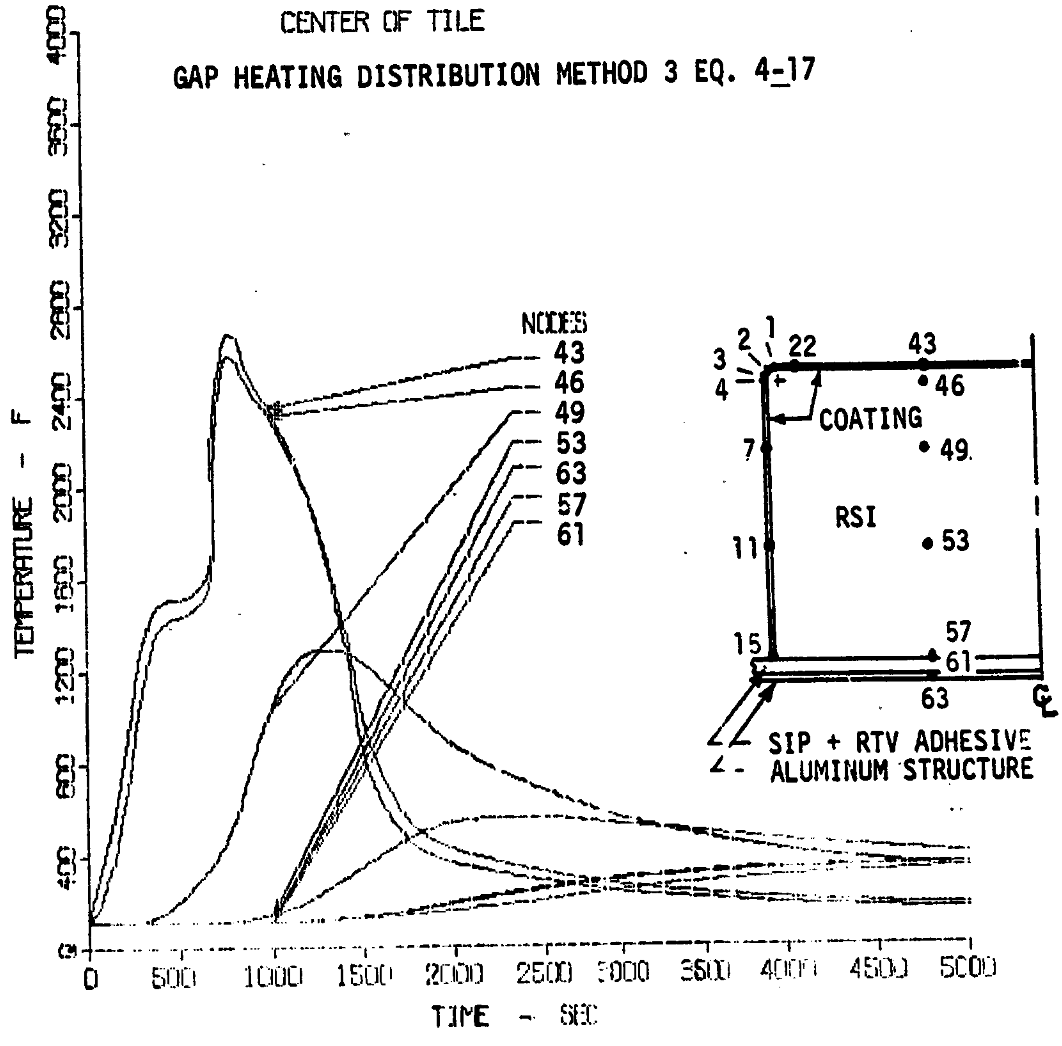


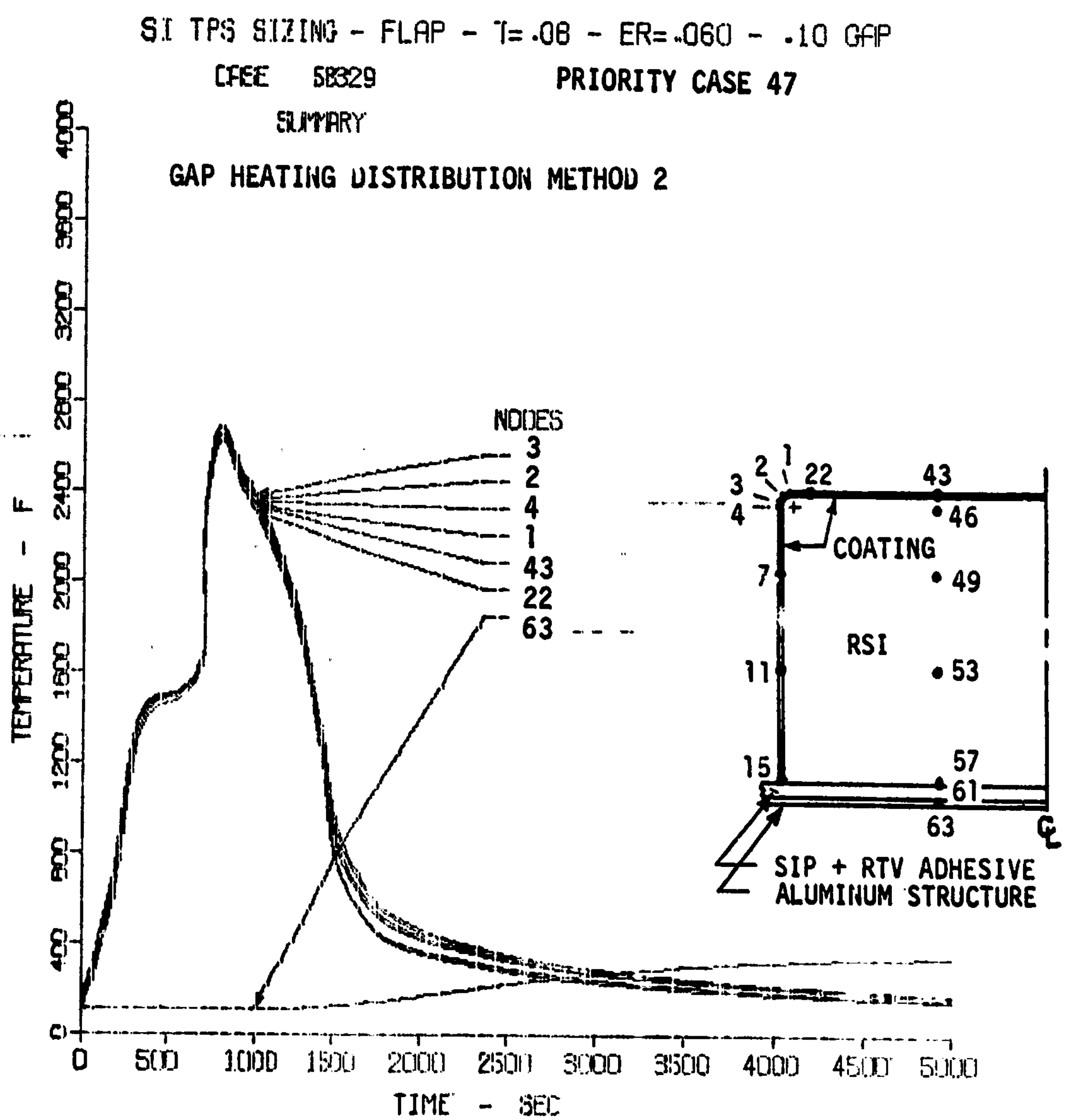
SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP

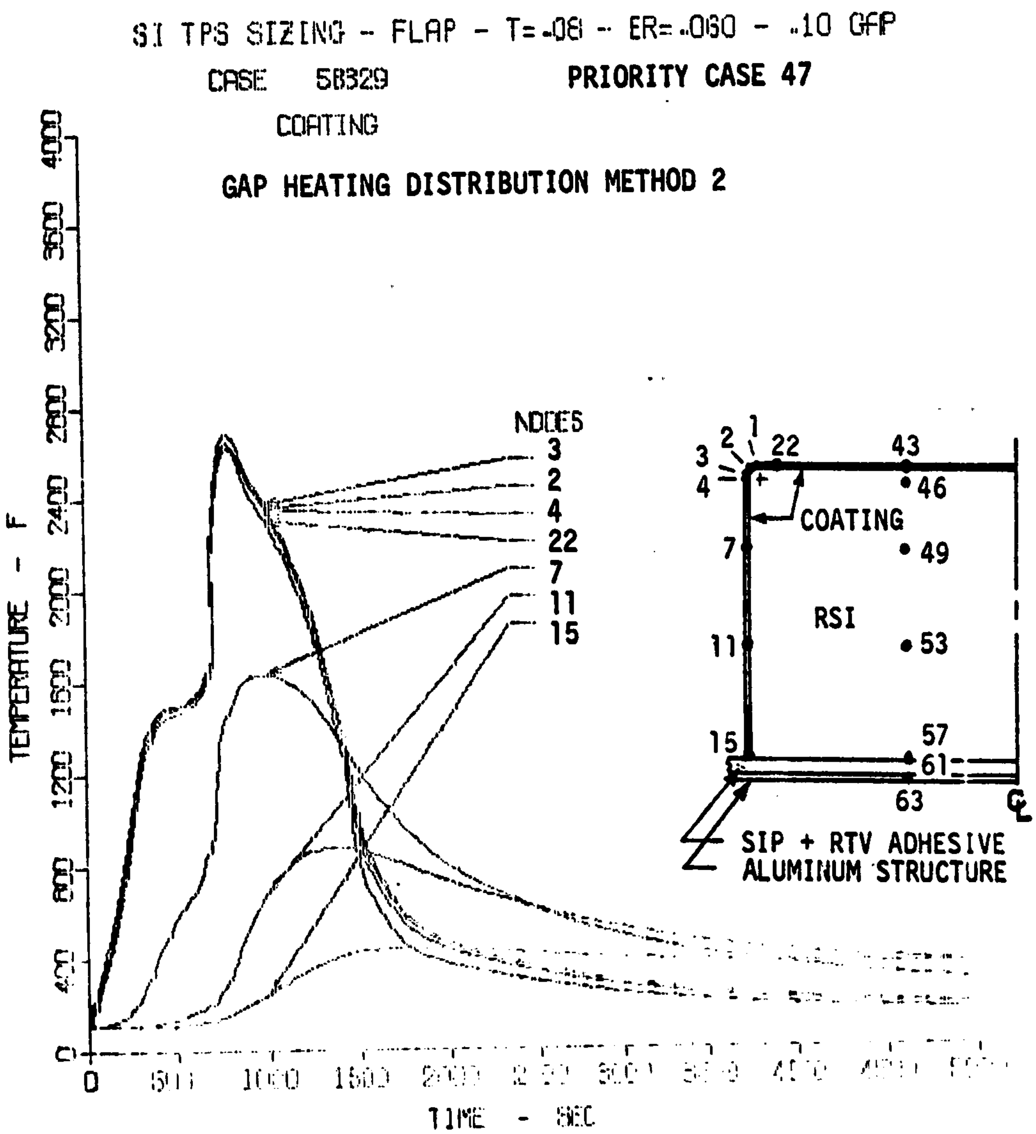
CASE 57375 PRIORITY CASE 46

CENTER OF TILE

GAP HEATING DISTRIBUTION METHOD 3 EQ. 4-17

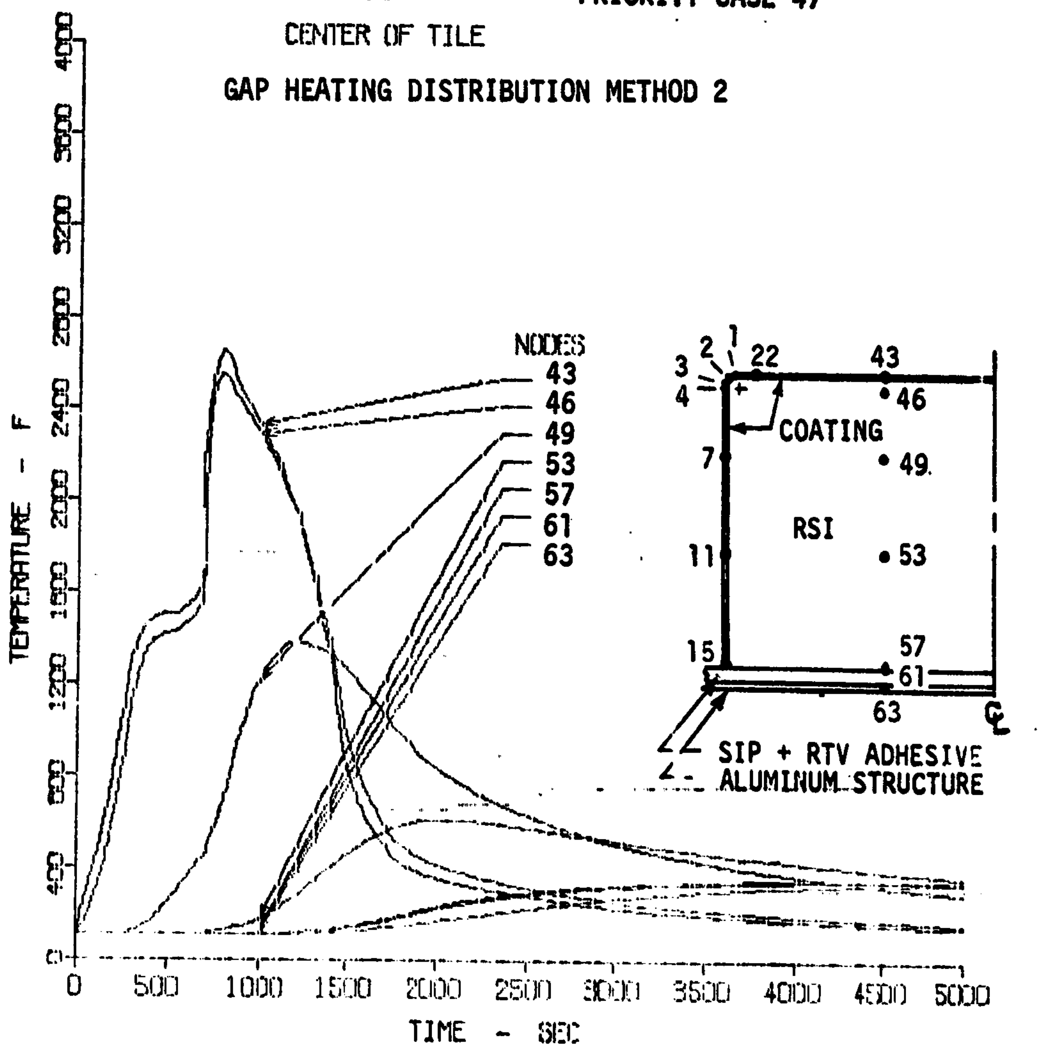



SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP
CASE 58329
PRIORITY CASE 47
SUMMARY
GAP HEATING DISTRIBUTION METHOD 2
TEMPERATURE - F
0
400
800
1200
1600
2000
2400
2800
3200
3600
4000
TIME - SEC
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
NODES
3
2
4
1
43
22
63
3
2
1
22
43
4
46
COATING
7
49
RSI
11
53
15
57
61
63
℄
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE


SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GFP
CASE 58329
PRIORITY CASE 47
COATING
GAP HEATING DISTRIBUTION METHOD 2
TEMPERATURE - F
TIME - SEC
NODES
3
2
4
22
7
11
15
COATING
RSI
43
46
49
53
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP
CASE 58329 PRIORITY CASE 47
CENTER OF TILE

GAP HEATING DISTRIBUTION METHOD 2

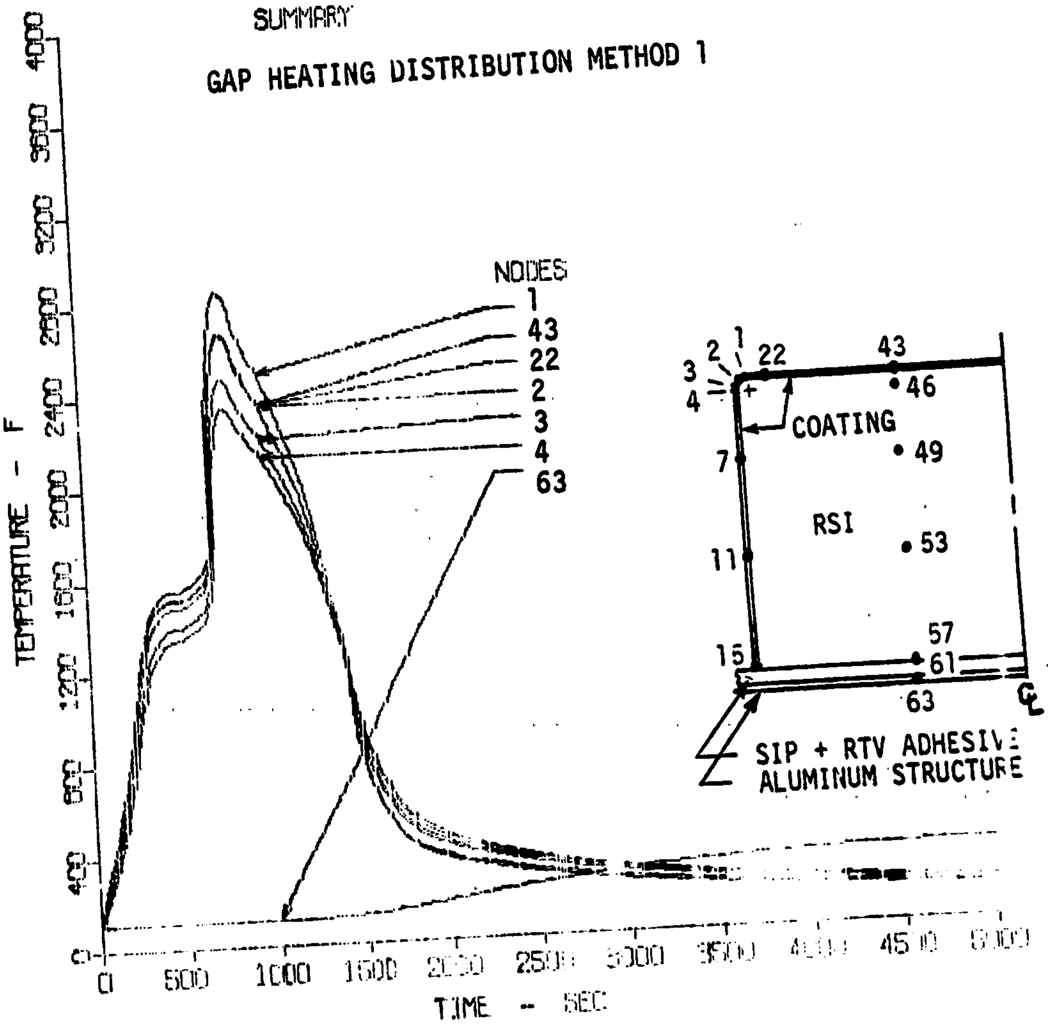


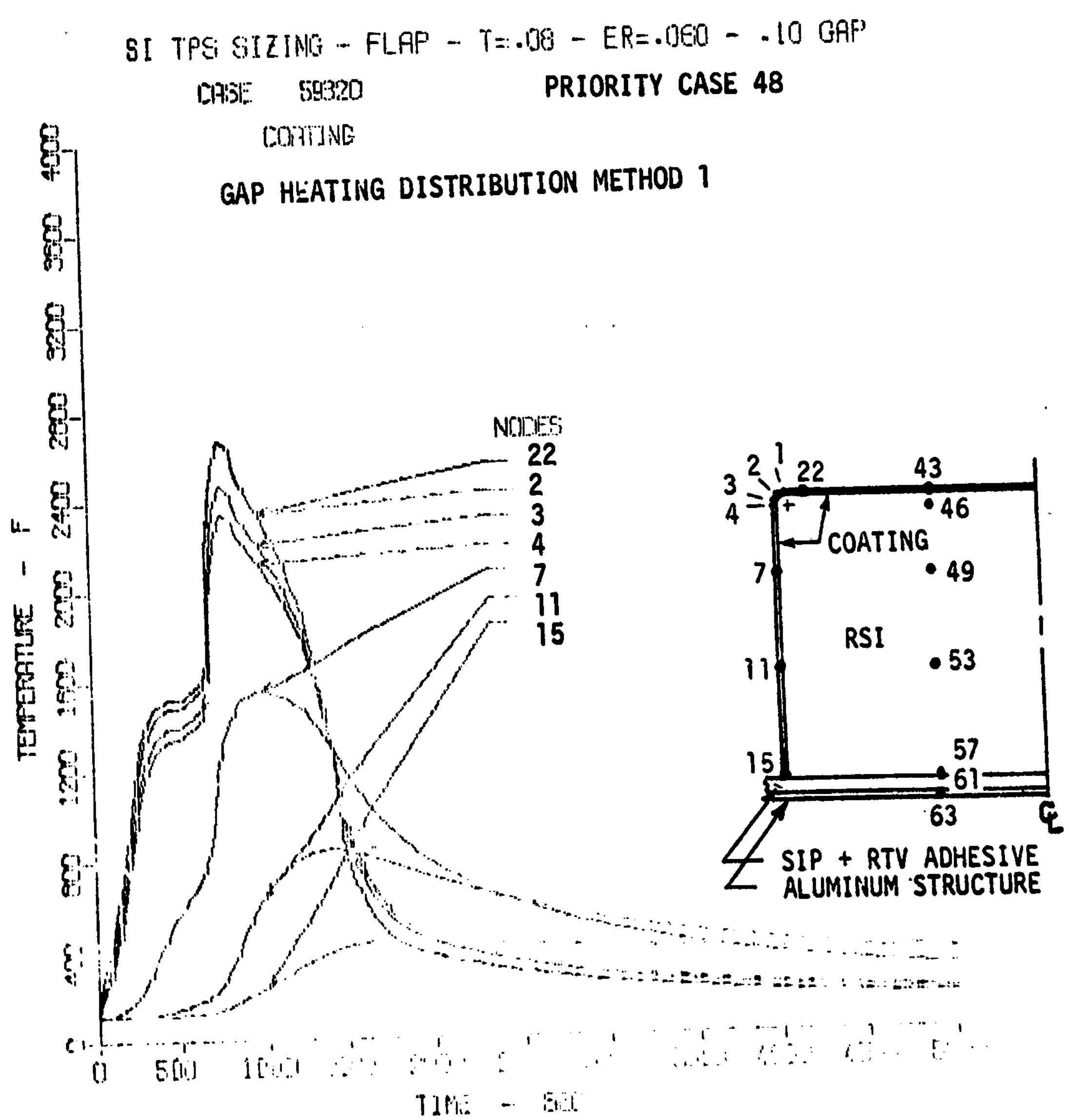
SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP

CASE 59320 PRIORITY CASE 48

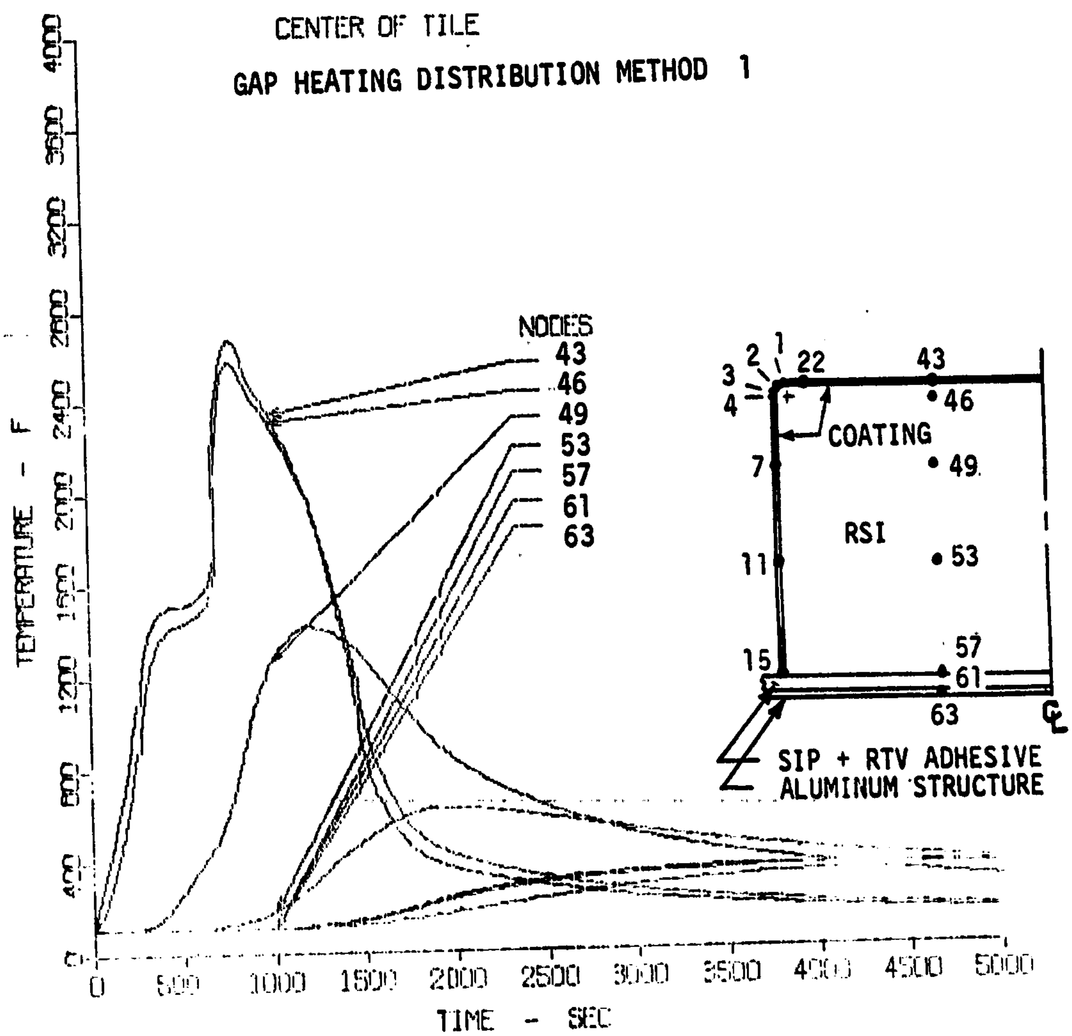
SUMMARY

GAP HEATING DISTRIBUTION METHOD 1




SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP
CASE 59320
PRIORITY CASE 48
COATING
GAP HEATING DISTRIBUTION METHOD 1
TEMPERATURE - F
TIME - SEC
NODES
22
2
3
4
7
11
15
COATING
RSI
43
46
49
53
57
61
63
SIP + RTV ADHESIVE
ALUMINUM STRUCTURE

SI TPS SIZING - FLAP - T=.08 - ER=.060 - .10 GAP
CASE 59320 PRIORITY CASE 48
CENTER OF TILE
GAP HEATING DISTRIBUTION METHOD 1



APPENDIX C THERMAL PROPERTIES

Thermal properties were used in the analysis as provided by NASA-Ames from Rockwell International Corporation except that those for the RTV bond and strain isolation pad. Composite thermal properties were used for the bond/SIP/bond layer. Interpolation with pressure in the property tables was logarithmic.

The properties used in this analysis are listed in the tables below.

HRSI COATING (SILICON CARBIDE)

Density = 104 lb/ft^3 Emittance = 0.80

Temperature °F	Conductivity BTU/ft-hr-°F	Specific Heat BTU/LB-°F
-250	.425	.15
-150	.450	.17
0	.487	.19
250	.550	.215
500	.604	.24
750	.654	.26
1000	.704	.285
1250	.750	.30
1500	.796	.315
1700	.829	.325
1750	.837	.33
1950	.871	.34
2000	.883	.345
2100	.896	.35
2150	.904	.353
2300	.933	.36

HIGH TEMPERATURE REUSABLE SURFACE INSULATION (HRSI)

Density = 9.0 lb/ft^3

Temperature °F \ Pressure (PSF)	Conductivity - Btu/ft-hr-°F				
	0.21	2.12	21.16	211.6	2116.
-250.	0.0050	0.0075	0.0150	0.0216	0.0233
0.	0.0075	0.0100	0.0183	0.0250	0.0275
250.	0.0092	0.0125	0.0225	0.0316	0.0341
500.	0.0125	0.0167	0.0276	0.0400	0.0433
750.	0.0175	0.0216	0.0325	0.0492	0.0534
1000.	0.0233	0.0275	0.0392	0.0600	0.0658
1250.	0.0308	0.0350	0.0492	0.0725	0.0782
1500.	0.0416	0.0459	0.0617	0.0875	0.0942
1750.	0.0567	0.0610	0.0767	0.1060	0.1130
2000.	0.0734	0.0782	0.0942	0.1270	0.1360
2300.	0.0966	0.1020	0.1160	0.1550	0.1670

HRSI PROPERTIES CONTINUED

Temperature °F	Specific Heat Btu/lb-°F
-250.	0.070
-150.	0.105
0.	0.150
250.	0.210
500.	0.252
750.	0.275
1000.	0.288
1250.	0.296
1500.	0.300
1700.	0.302
1750.	0.303
2300.	0.303

RTV BOND AND NOMEX FELT (SIP) COMPOSITE

Density = 12.28 lb/ft^3 Specific Heat = 0.29 Btu/lb-°F

Temperature °F	Conductivity Btu/ft-hr-°F
40	0.0182
400	0.0227
540	0.0301
600	0.0380

2024-T8XX ALUMINUM

Density = 175 lb/ft^3

Temperature °F	Specific Heat Btu/lb-°F	Conductivity Btu/ft-hr-°F
-400	0.088	--
-300	0.117	--
-200	0.147	69.6
0	0.195	84.0
200	0.216	95.0
300	0.224	99.0
400	0.233	102.5
600	0.250	104.5