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VERIFICATION OF THE SRB MOTOR CASE PIN RETAINER BAND TPS

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Prepared for National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812

by

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FOREWORD

This report documents the series of tests conducted in the NASA Hot Gas Facility to verify the performance of the cork Thermal Protection System (TPS) applied over the SRB motor case pin retainer bands. The work was performed under Contract NAS8-32982, "Solid Rocket Booster Thermal Protection System Material Development." The NASA-MSFC Contracting Officer's Representative for this work is Mr. Bill Baker, EP44.

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INTRODUCTION AND SUMMARY

The pin retainer band is a 1-1/4 in. wide by about 1/32 in. thick steel band that is stretched over the pins circumferentially at the joints of the SRB motor case segments. Its purpose is to hold the retaining pins in place during flight. Since the band is thin and is mounted stretched, or under tension, over the pins which are greased in place, it is necessary to protect it thermally. Three typical areas of the band location on the SRB motor case joints were chosen for verifying the cork TPS performance on the band: the joint in front of the attach ring, at the aft skirt joint in front of the kick ring and in an unperturbed area at the forward segments of the SRB motor cases.

Calibration models were built for the ring area bands. For the attach ring area band model, the ring height, the cork TPS and the steel band were scaled down to obtain more realistic protuberance height ratios with respect to the boundary layer thicknesses in flight and in test. For the kick ring area band model, the ring was simulated with only the forward "zee" section phenolic part to obtain heating rates on the band which would be acceptable. No calibration model was built for the unperturbed area band model; here clean body known heating rates were used.

The kick ring area pin retainer band cork TPS passed the test requirements in the region where there are no phenolic splice caps. In the splice cap areas where the band TPS is closed out around the splice with K5NA, additional amounts of K5NA material is required to adequately protect the steel band. TPS requirements were easily met in the one location where the ends of the steel band are joined together after installation and tensioning. The attach ring area pin retainer band TPS did not quite pass the heat load requirements with the .375 in. thick cork TPS as used for the kick ring area band. It is recommended that the cork thickness here be increased to .50 in. The unperturbed area band TPS presented no problems.

TECHNICAL DISCUSSION

The kick ring area pin retainer band test model is shown sketched in Fig. 1. The model was yawed at an angle of 50 deg to ensure that the heating rate on the band was not too excessive. The maximum flight environments encountered on the pin retainer band occurs at $\theta = 30$ degrees on the left-hand SRB (B.P. 1957 for ascent, B.P. 6211 for reentry). These are listed as follows:

	$\dot{q}_{cw}$ (Btu/ft^2-sec)	Q_{load} (Btu/ft^2)
• SSME Plume Radiation	1.65	121
• SSME Plume Convective Recirculation	1.48	8
• ET-TPS Burn, Radiation and Convection	12.83	198
• Aero Heating During Ascent	4.07	222
• SRM Separation	165.0	524
• Reentry Aero Heating	11.5	330
Total Heat Load		1403

A calibration model similar to the one shown in Fig. 1 was made up with a single water-cooled calorimeter in the center of the band. The heating rate measured was 29.8 Btu/ft^2-sec in the Hot Gas Facility. For a complete description of the facility, see Ref. 1.

The kick ring area band TPS model shown in Fig. 2 was required to be run for a duration of 47.1 sec to obtain the flight equivalent heat load. However, the run had to be terminated at 37 sec as the steel band temperature suddenly shot up to 1000 F from a 200 F reading indicating TPS failure. Inspection of the model (see post-test picture in Fig. 3) and review of the movies showed that failure first occurred at the bond line on the downstream edge parallel to the "zee" section part of the kick ring. This was due to the strong recirculating flow vortices in the separation region allowing the flow to escape under the TPS and affect the steel band.

A remedy for the above situation was to protect the downstr am cork band edge by closing it out with a trowelable material such as K5NA. The test was repeated with the area between the cork band and the "Zee" section uniformly covered with K5NA of thickness equal to that of cork (see pre-test picture in Fig. 4). The model was run longer than required, a full 60 seconds, and as expected it performed well. The maximum steel band temperature was 406 F. A post-test picture of the model is shown in Fig. 5.

The unperturbed area pin retainer band test model was constructed from a full-scale section of the motor case clevis joint A sketch of the model is shown in Fig. 6. No calibration model of this configuration was made but a heating rate of 9 Btu/ft^2-sec was estimated on top of the band with respect to the known clean body heating rate in the test section of the Hot Gas Facility.

The maximum flight environments on the pin retainer band in this configuration are (B. P. 1581 for ascent, B. P. 4063 for reentry):

	$\dot{q}_{cw}$ (Btu/ft^2-sec)	Q_{load} (Btu/ft^2)
• Ascent Aero Heating	3.42	167
• SRM Separation	20.4	29
• Re-entry Aero Heating	26.2	342
Total Heat Load		538 Btu/ft^2

The model was run for the duration of 60 seconds as required to obtain the full heat load. The pre- and post-test pictures of this test are shown in Figs. 7 and 8. The leading edge of the cork is seen to have receded back but there was no appreciable surface rec ssion. There was little or no rise in band temperature.

The unperturbed area pin retainer band test was repeated at a later date with one change. The change was that a certain number of "voids" were intentionally incorporated in the bonding of the cork TPS. This was done by first laying the cork TPS over the bond material in the normal way and then lifting the cork up and laying it down again for the bond to set. Figure 8a depicts the voids found under the cork which was machined off after the unperturbed area model was run successfully in the Hot Gas Facility. The results of this test were similar to the one run earlier indicating no ill effects due to the "voids" in the TPS bonding.

The attach ring area pin retainer band model was designed by NASA/MSFC's Mr. Lee Foster, ED33, as a scaled down configuration. This was done to obtain as near a simulation as possible of the height of the protuberance with respect to the boundary layer thickness in flight and in the HGF test section. The details of the model are shown in Fig. 9.

A calibration model of the area of interest was first constructed with three water-cooled calorimeters, one in the center of the band, one at the end and a third one behind the second one on the area between the cork simulator bar and the ring protuberance. The latter two were installed to study the magnitude of the end effects of the model in the flow. The location of the calorimeters can be seen in the picture of the model in Fig. 10. The heat fluxes measured by the three sensors were 23, 50 and 67 Btu/ft^2-sec, respectively.

The maximum flight environments on the attach ring area pin retainer band occurs at B.P. 10515 (Ascent) and B.P. 5022 (Re-entry) at $\theta = 60^\circ$ on the left-hand SRB:

	$\dot{q}_{cw}$ (Btu/ft^2-sec)	Q_{load} (Btu/ft^2)
• Ascent Aero Heating	20.67	860
• SRM Separation	71.3	159
• Re-entry Aero Heating	27.9	465
Total Heat Load		1484 Btu/ft^2

The TPS model of the attach ring pin retainer band shown in Fig. 11 was required to be run for a duration of 65 sec to obtain this heat load in the center portion of the band. The model was run successfully though the band temperature rose to 315 F at the end of the test. The post-test picture is shown in Fig. 12. It is seen that the ends of the cork band did not recede more than in the middle even though the ends recorded a higher $\dot{q}$. This was believed to be attributed to either the shear being higher in the center portion of the band or the heat flux changing as the cork TPS receded. In order to confirm this, the calibration was re-checked without the cork simulator steel bar in place. But the heat fluxes obtained were fairly close to those obtained before with the cork simulator bar leaving the problem of disproportionate cork recession with respect to the prevalent heating rates quite unexplained at that time.

The evaluation of the pin retainer band TPS was also to be performed in the area in front of the kick ring splice cap which extends all the way down over the trailing edge of the pin retainer band. It was deemed necessary to calibrate this configuration for heating rates. The kick ring area band calibration model was used for this with a 6 in. wide by 0.25 in. thick steel plate bolted on front to simulate the splice. The model was mounted at 90 deg to the flow as opposed to the yawed configuration run earlier for the "non-spliced" model. While this set up shown in Fig. 13 was available, it was decided to run it without the splice again for obtaining a set of heating rates for the kick ring area band at 90 degrees to the flow. This was done because it was felt all along that the kick ring area band model run at the 50 deg angle of attack had more severe than anticipated flow vortices in the region between the protuberance and the band TPS.

The two calibration runs just described above yielded heating rates higher than desirable and so in an effort to reduce the heating rates, the height of the kick ring protuberance was reduced from 3-in. to 2.5 in. The two calibrations, with and without the splice plate, were repeated and this resulted in lowering the $\dot{q}$ value on the band by about 5 Btu/ft^2-sec. A summary of the calibration performed so far is shown in Fig. 14 in a pictorial sketch of all the different configurations run.

A TPS model for the kick ring pin retainer band was made up by the materials lab of NASA-MSFC. The pretest picture is shown in Fig. 15. The model was run in the Hot Gas Facility for 51 sec with a heating rate of 35 Btu/ ft^2-sec in the center of band as measured during calibration runs. To obtain the required heat load of 1403 Btu/ft^2, the run time required was only 40 sec and as seen in the band temperature transient of Fig. 16 the temperature of the band was well below 150 deg at the end of 40 sec. The post-test picture of this model is shown in Fig. 17.

Figure 18 shows the pretest model of the kick ring splice cap area pin retainer band. The cork TPS is notched out with a 0.125 in. clearance around the splice plate and the gap is "flush filled" with K5NA. Also as per the configuration on finished parts at KSC the cork band, which is put on in pieces on the SRB motor case, is butt-jointed in front of the splice plate. This model was run in the Hot Gas Facility for a duration of 40 sec which was the required duration for the "non-spliced" configuration even though the heating rate was higher on the band in front of the splice (see Fig. 14). This was done because the actual heat load during flight (value not specified in SRB environments) was not expected to exceed the heat load of 1800 (45 Btu/ft^2-sec x 40 sec) Btu/ft^2 obtained during test. The post-test photograph of the model is shown in Fig. 19. The cork band is seen receded to the pin retainer band which started to suddenly rise in temperature near the end of the run as seen in the temperature plot of Fig. 20.

Another area of interest on the pin retainer bands is the point where the two ends of the band are crimped together after tensioning the band. The cork TPS is stopped short on either side of the crimp and the region over the band is closed out by a smooth hump (maximum height in center approximately 0.62 in.) of K5NA closeout material. A test model simulating this configuration was made up for the kick ring area pin retainer band model and tested in the

Hot Gas Facility. A picture of the model is shown in Fig. 21. The test environment for this region are:

	$\dot{q}_{cw}$ (Btu/ft^2-sec)	Q_{load} (Btu/ft^2)
• Aero Heating During Ascent	8.7	267
• SRM Separation	1.0	3
• Reentry Aerodynamic Heating	14.8	338
Total Heat Load		608 Btu/ft^2

The model was run for a duration of 17.4 sec to obtain the total heat load of 608 Btu/ft^2. The model performed very well in protecting the metal band. There was little or no rise in the band temperature during the test.

RECALIBRATION AND ADJUSTMENT OF MEASURED HEATING RATES

A review of the test movies and test samples after each TPS test indicated a not so drastic heat flux distribution as obtained in calibration runs depicted in Fig. 14. The heat flux distribution was debated and it was actually thought that the heating rate was higher in the middle of the band and lower if not the same near the ends of the band. After long deliberations it was decided to reconfirm the calibration using new calorimeters and also to obtain thin skin thermocouple temperature response on several locations on the band in front of the attach ring area pin retainer band test model. The temperature responses would be used to determine the heat flux (reduced to cold wall values) distribution over the whole band and the calorimeters would be helpful in determining the accuracy of the "thin-skin" heat fluxes. So the attach ring area pin retainer band calibration model used previously (Fig. 10) was taken and was fitted with a "thin-skin" calibration plate in place of the solid cork simulator bar shown in Fig. 10. Also the three old calorimeters were replaced by brand new water-cooled types bought especially for this test.

The results of this re-calibration test confirmed the suspicions of the heat flux distribution on the pin retainer band. The heat flux was indeed slightly (1.1 Btu/ft^2-sec) higher in the center than near the ends. The absolute value of the heat flux measured by the center calorimeter after having been reduced to cold wall value was 19.3 Btu/ft^2-sec as opposed to 23 Btu/ft^2-sec (Fig. 14) in earlier calibrations, a difference of 16%.

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CONCLUSIONS

To make the right conclusions in light of the new calibration results, each test is summarized and evaluated individually in Appendix A. The kick ring area pin retainer band test heat fluxes are reduced by 16% to correct for errors in the original calorimeter data. Conclusions are then drawn for each individual test based on percent over-test, TPS material remaining and band temperature response. The conclusions as drawn in the App ıdix are final and supercede any that might be inferred before the recalibration of the Attach Ring area pin retainer band.

All pin retainer band area TPS designs as now updated and specified in Appendix A are acceptable per these test results.

REFERENCE

1. Karu, Z.S., and W.G. Dean, "SRB Materials Test and Evaluation in NASA-MSFC Hot Gas Facility, NASA-Ames 3.5-Foot HWT and AEDC Tunnel C," Lockheed Missiles & Space Company, Huntsville, Ala., LMSC-HREC TM 497497, November 1977.

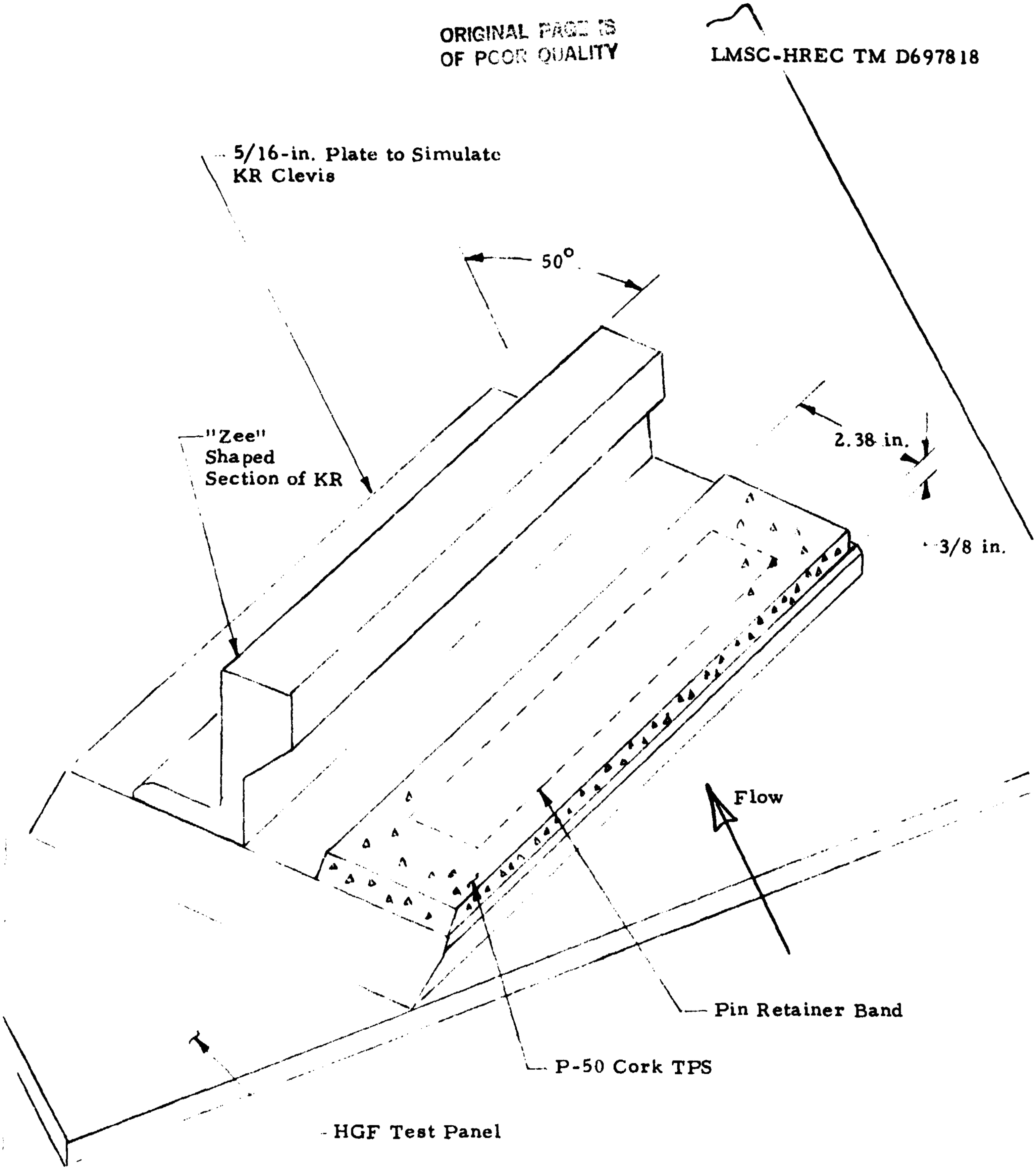

Fig. 1 - Sketch of the Kick Ring/Motor Case Pin Retainer Band TPS Model in HGF

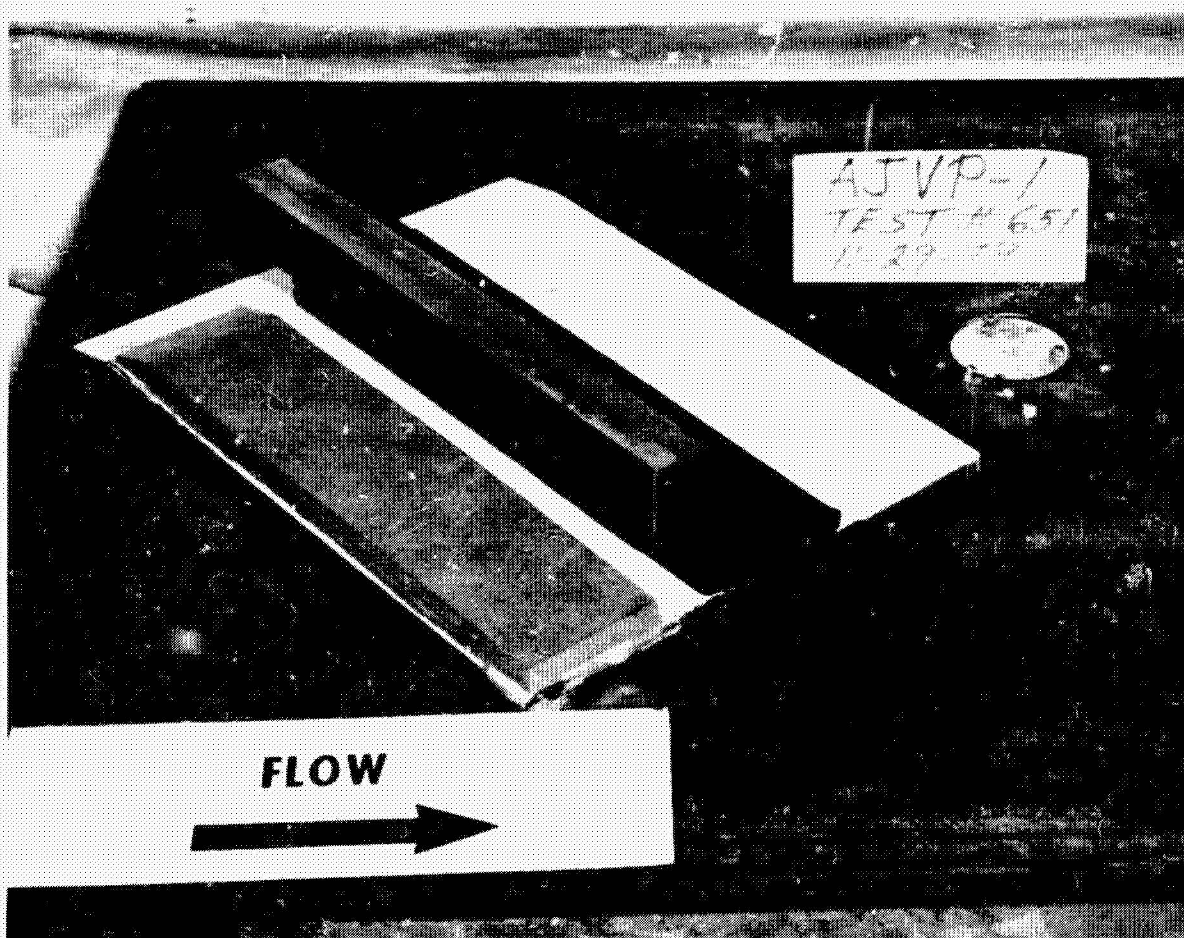

Fig. 2 - Pretest Picture of the Kick Ring Area Pin Retainer Band TPS Test Model at 50 deg to the Flow in the Hot Gas Facility

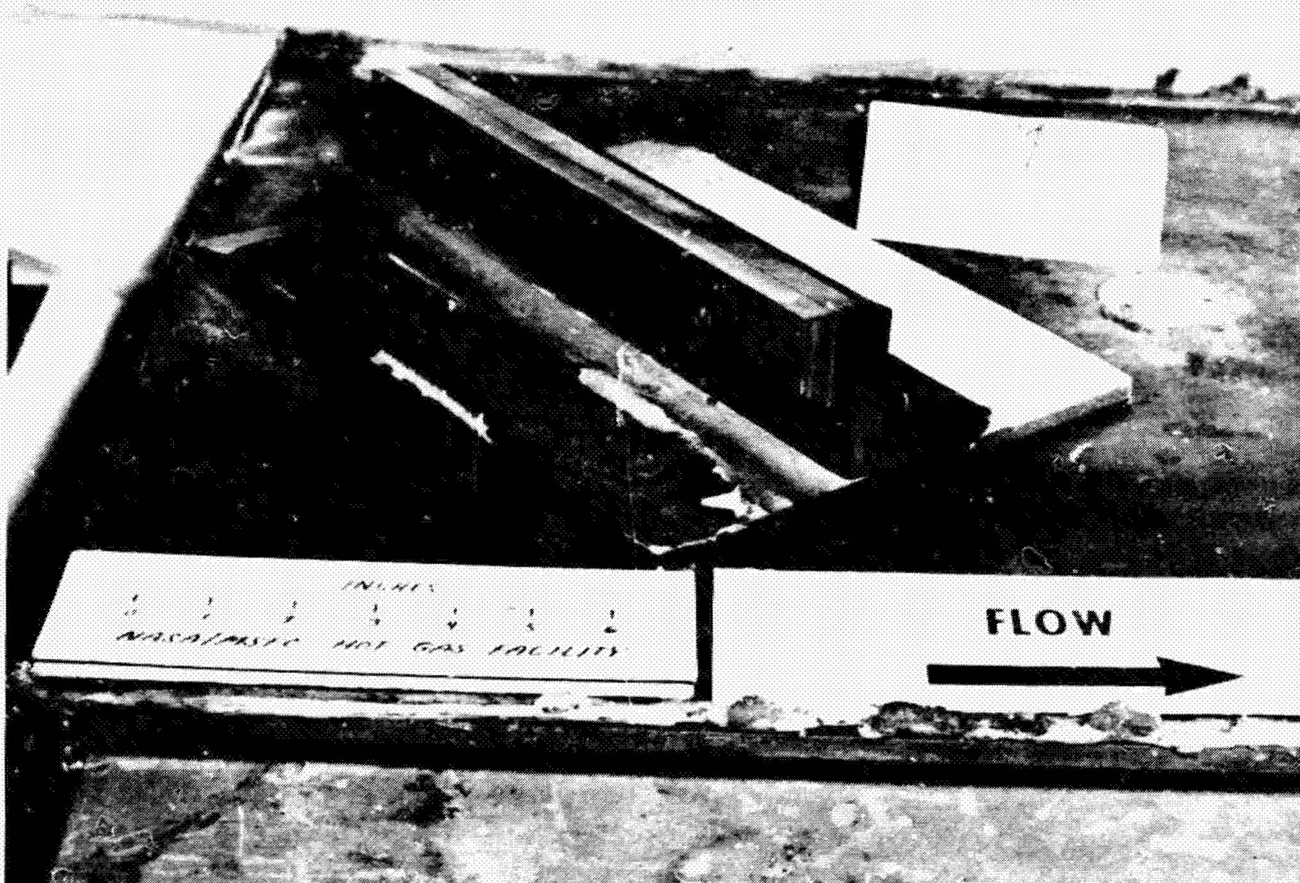

Fig. 3 - Post-Test Picture of the Kick Ring Area Pin Retainer Band TPS Model Showing the Degradation of the Cork TPS

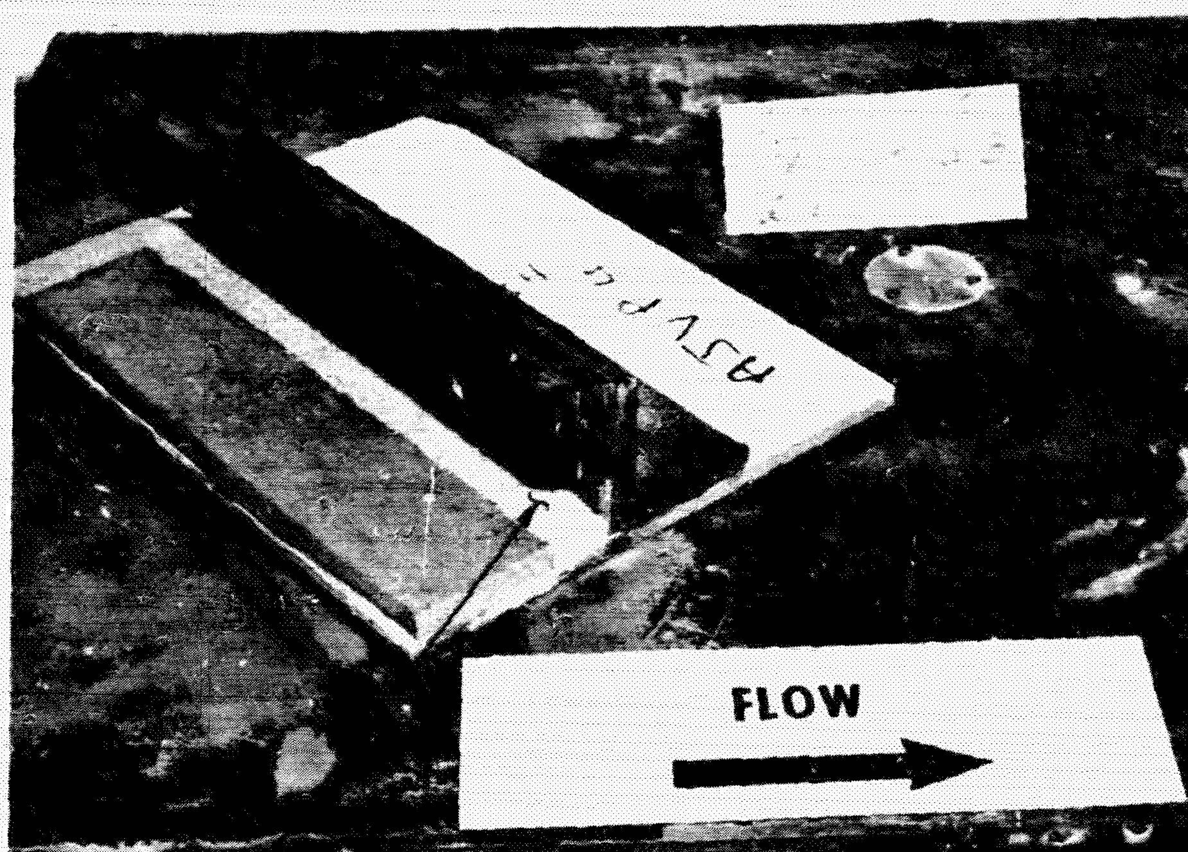

Fig. 4 - Pretest Picture of the Model of Fig. 2 with K5NA Closeout Material Added Between the Cork TPS and the Protuberance

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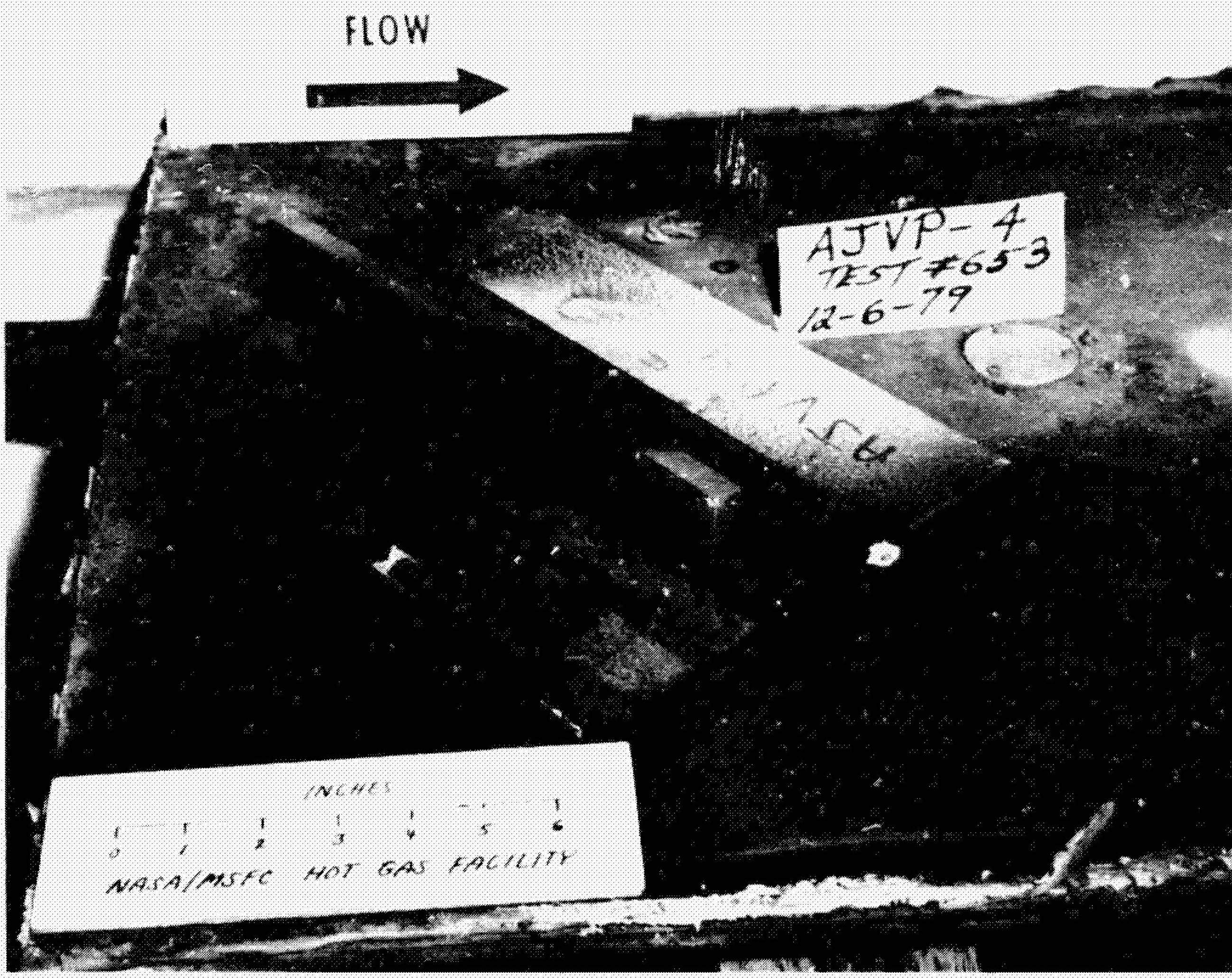


Fig. 5 - Post-Test Picture of the Kick Ring Area Pin Retainer Band Cork TPS Which Was Closed Out with K5NA

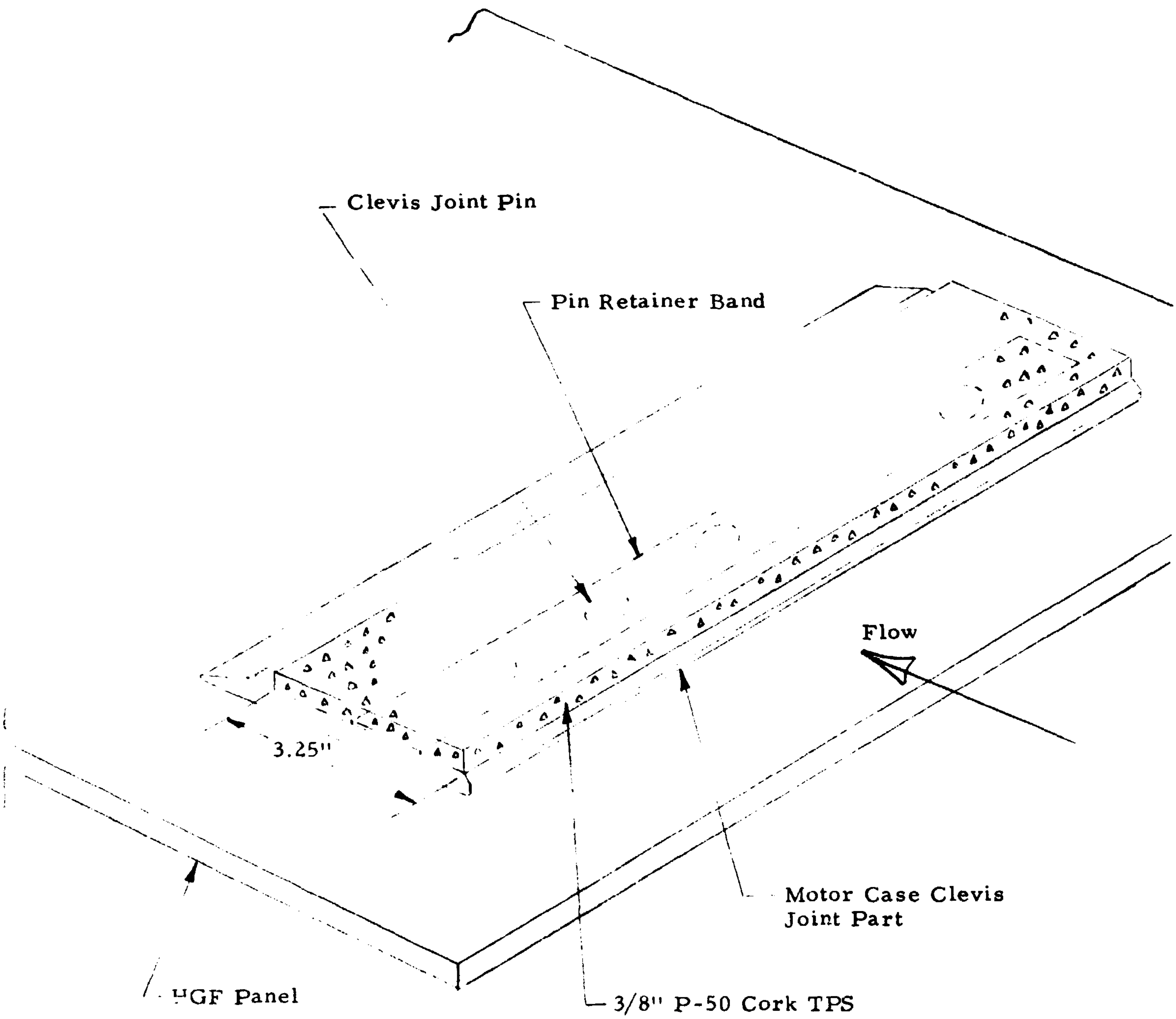


Fig. 6 - Sketch of the SRB Motor Case Segments Clevis Joint Pin Retainer Band TPS Test Model

Fig. 7 - Pretest Photograph of the Unperturbed Area Pin Retainer Band TPS Model in Hot Gas Facility

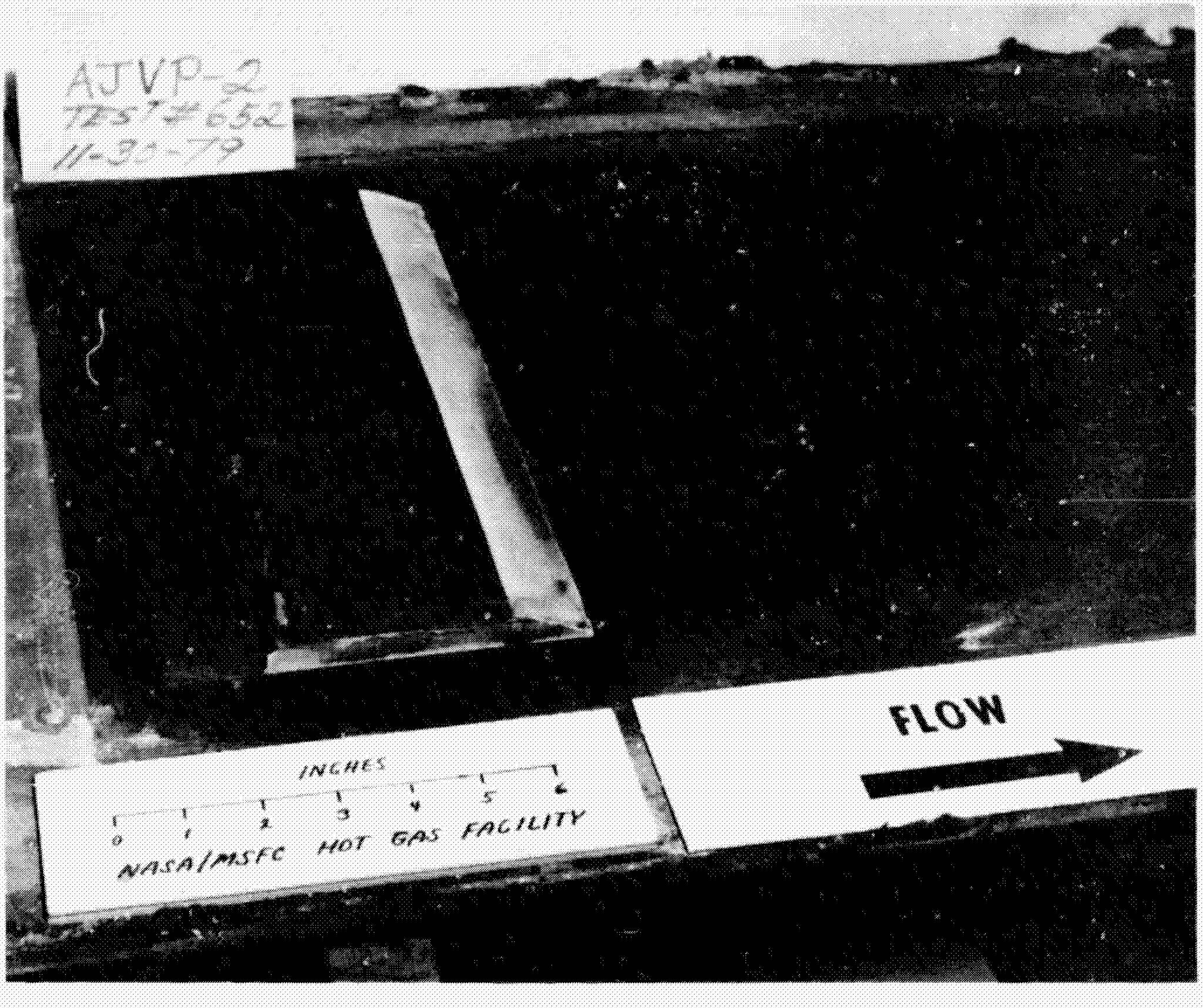


Fig. 8 - Post-Test Photograph of the Model in Fig. 7

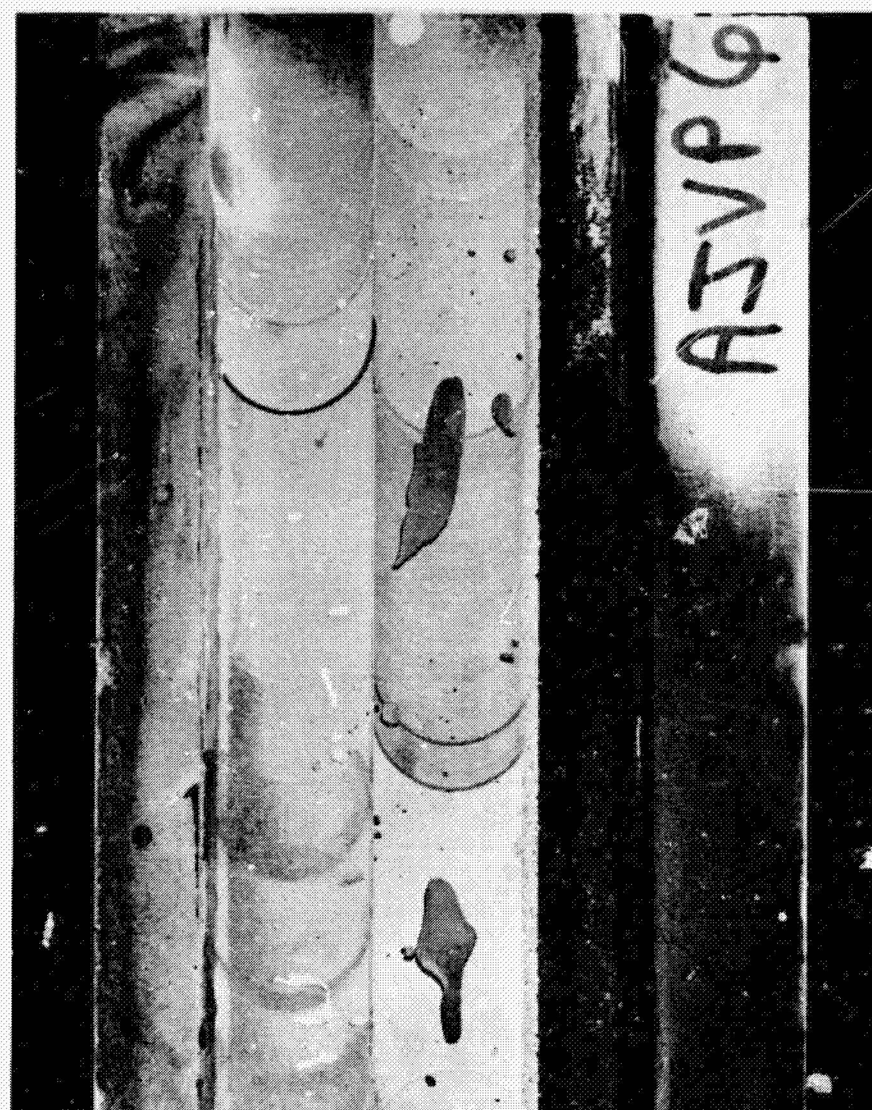
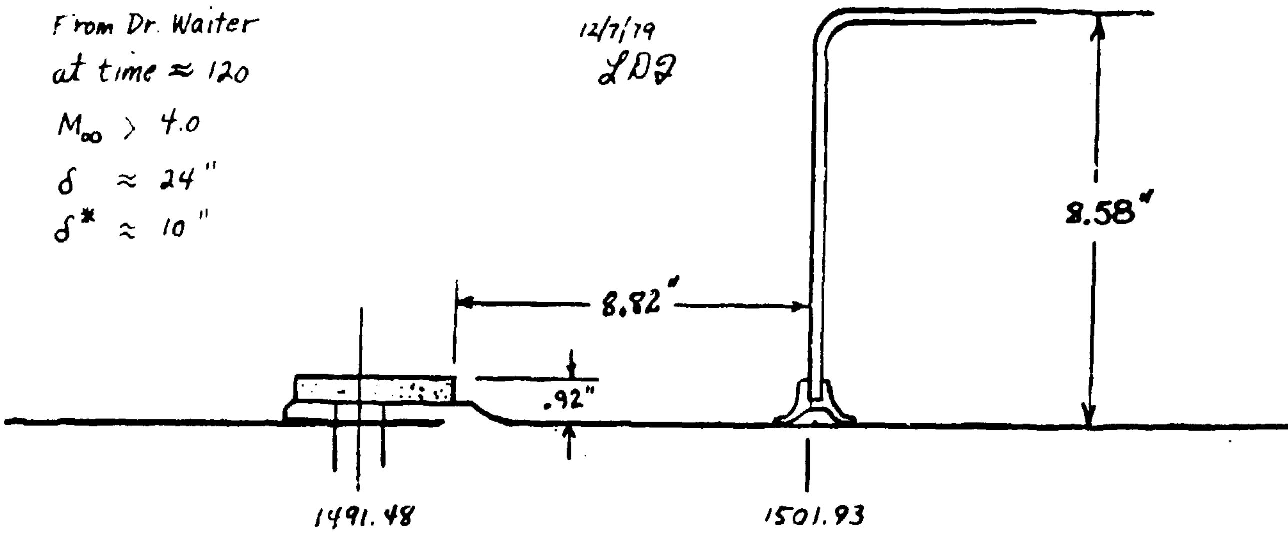


Fig. 8a - Top View of the Unperturbed Area Pin Retainer Band Model After Test with the Cork TPS Machined Off to Reveal the "Voids" Which Were Intentionally Created in the Cork Bonding System

From Dr. Waiter
at time ≈ 120
$M_\infty > 4.0$
$\delta \approx 24''$
$\delta^* \approx 10''$

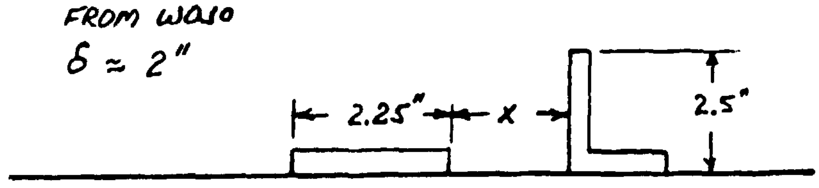
12/7/79
LDJ



∴ TRAILING EDGE OF CORK IS 1.03 PROTUBERANCE HEIGHTS UPSTREAM
CORK IS .11 PROTUBERANCE HEIGHTS OFF OF SKIN
BOUNDARY LAYER IS 3 TIMES PROTUBERANCE HEIGHT
LEADING EDGE OF CORK IS 1.4 PROTUBERANCE HEIGHTS UPSTREAM

FROM WA10
$\delta \approx 2''$

& USE 2.25" WIDE CORK



.375" CORK MOUNTED ON FLAT PLATE IS .15 PROTUBERANCE HEIGHTS

MAKE X = 1.75"

∴ LEADING EDGE IS 1.6 PH UPSTREAM
TRAILING EDGE IS .7 PH UPSTREAM

INSTALL CALORIMETERS AS SHOWN
& INSTALL IN A METAL
STRIP SIMULATING THE CORK

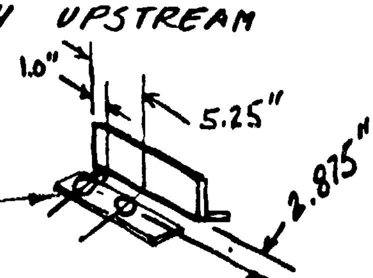


Fig. 9 - Determination of the Scaled Down Attach Ring Pin Retainer Band Model

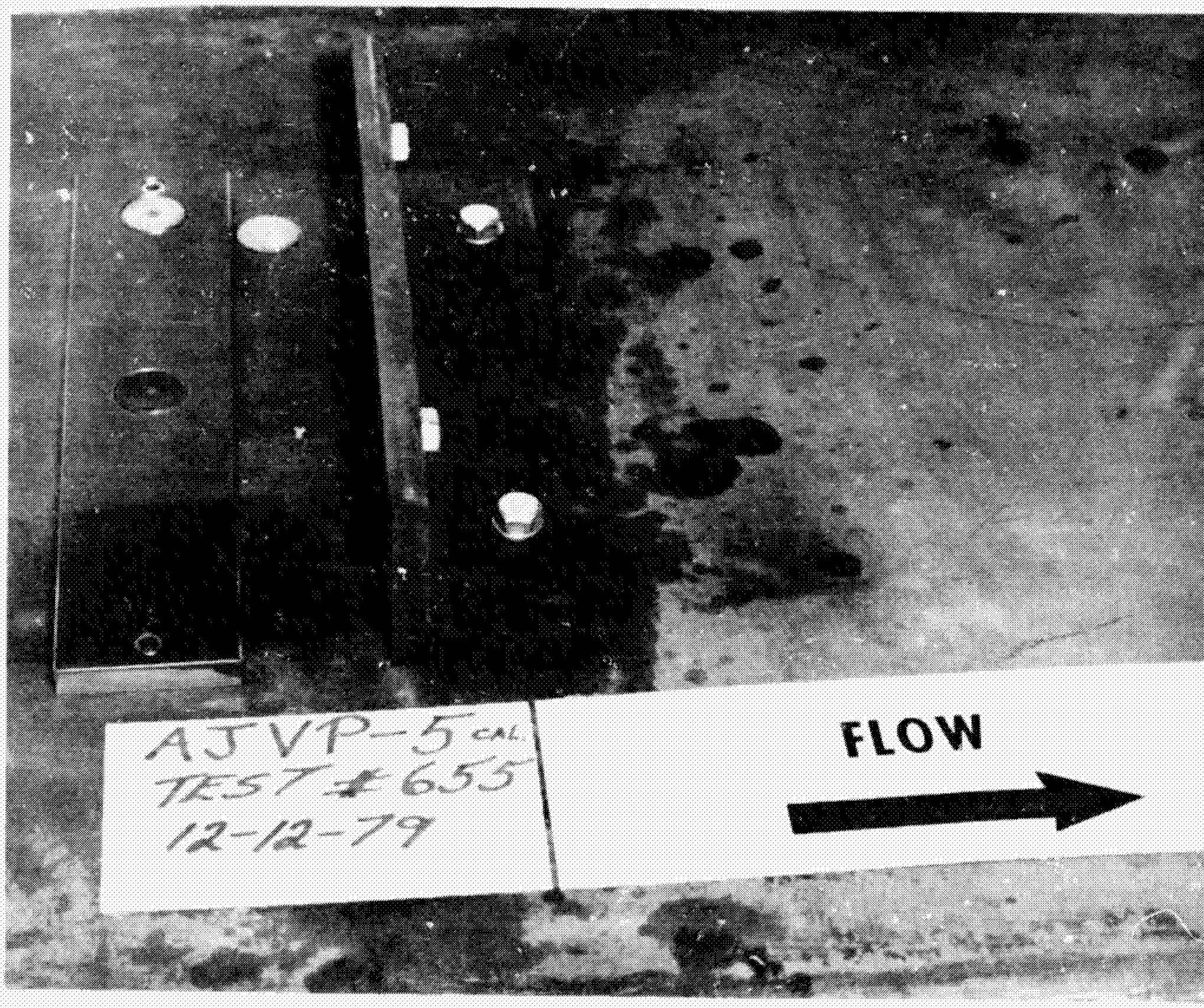


Fig. 10 - Calibration Model of the "Scaled-Down" Configuration of the Attach Ring Area Pin Retainer Band Showing Calorimeter Locations

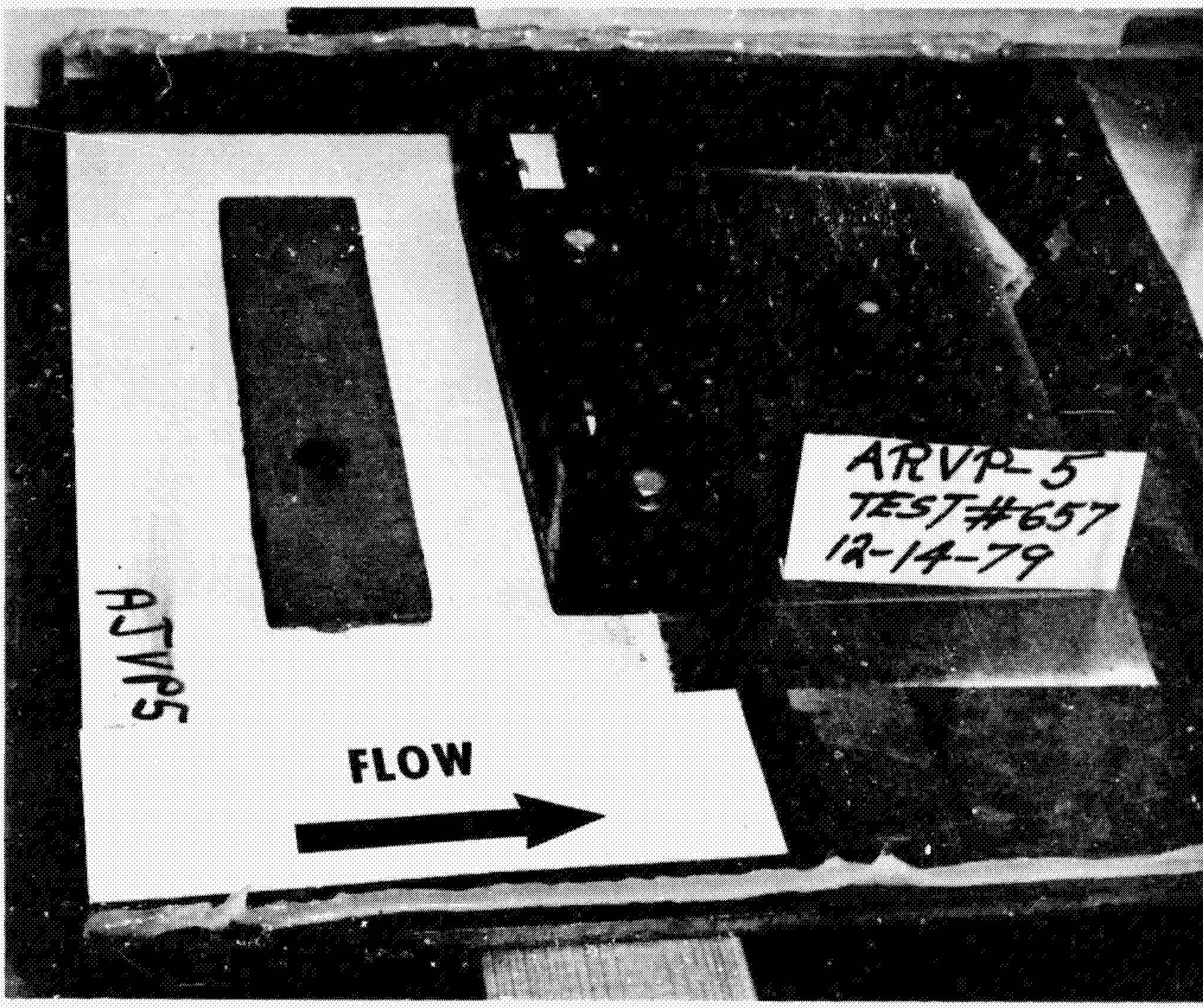
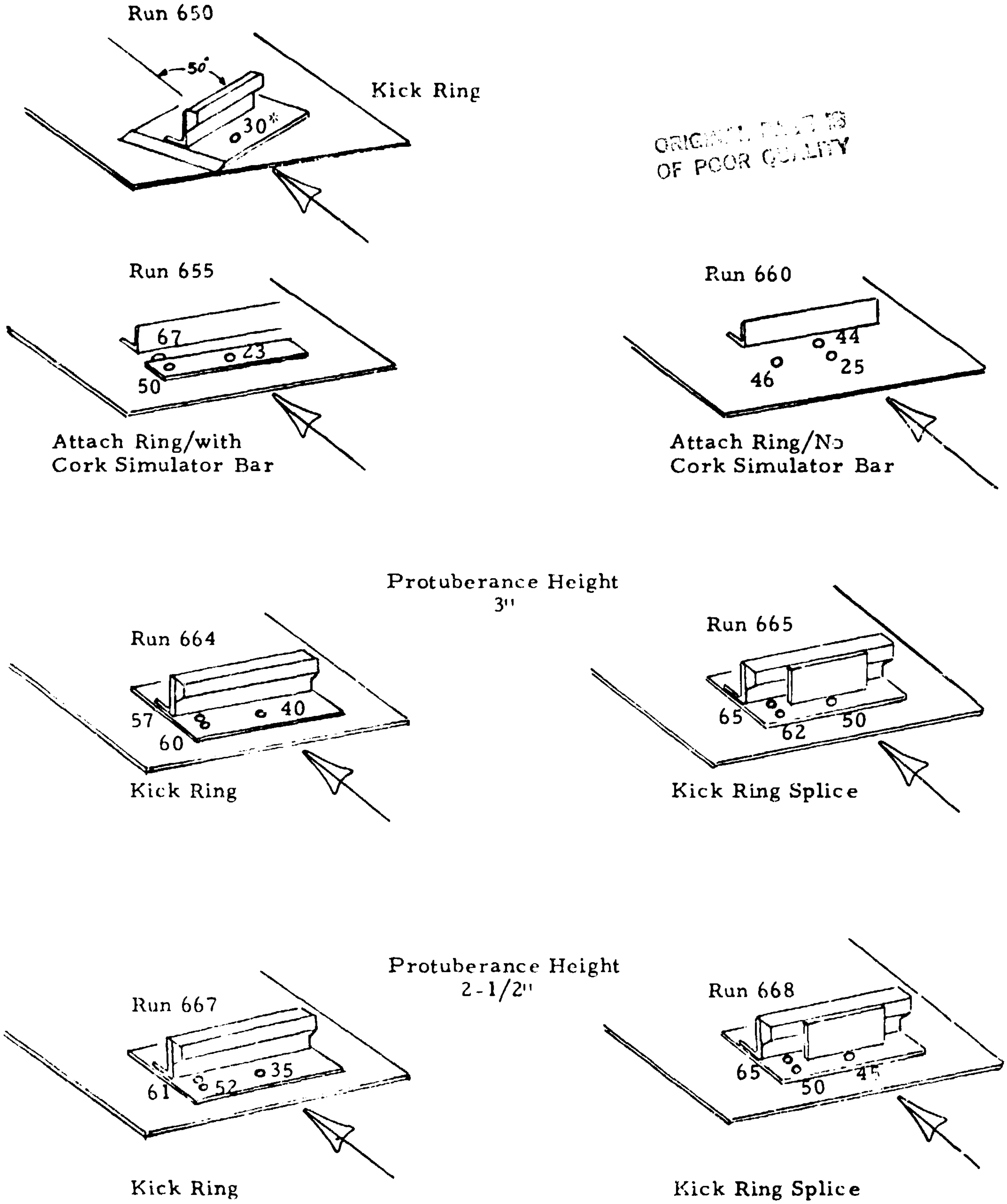


Fig. 11 - Pretest Photograph of the Attach Ring Area Pin Retainer Band TPS Model

Fig. 12 - Post-Test Photograph of the Model in Fig. 11 (Picture not clear; model showed greater cork recession in the center than near the ends of the cork TPS.)

Splice Plate

Fig. 13 - Kick Ring Splice Area Pin Retainer Band Calibrat on Model (Third calorimeter or far side behind the splice plate is not seen – compare with Fig. 10; the model was run 90 deg to flow.)



*Heating Rate, Btu/ft^2-sec

Fig. 14 - Summary Sketch of Several Different Calibration Runs Made for the SRB Pin Retainer Band Evaluation in the Hot Gas Facility

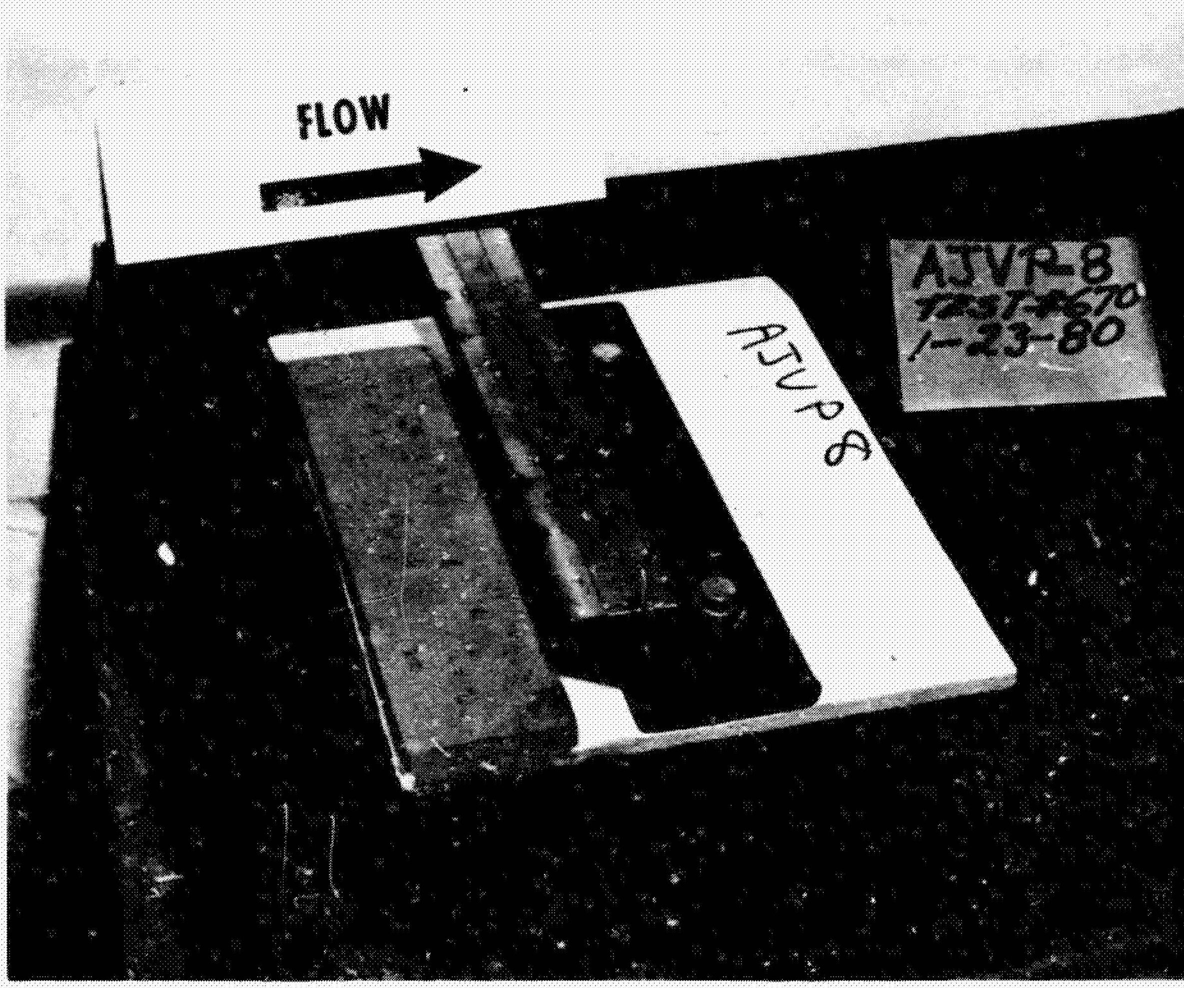


Fig. 15 - The Kick Ring Area Pin Retainer Band TPS Model Run at 90 deg to Flow (Compare with Fig. 2)

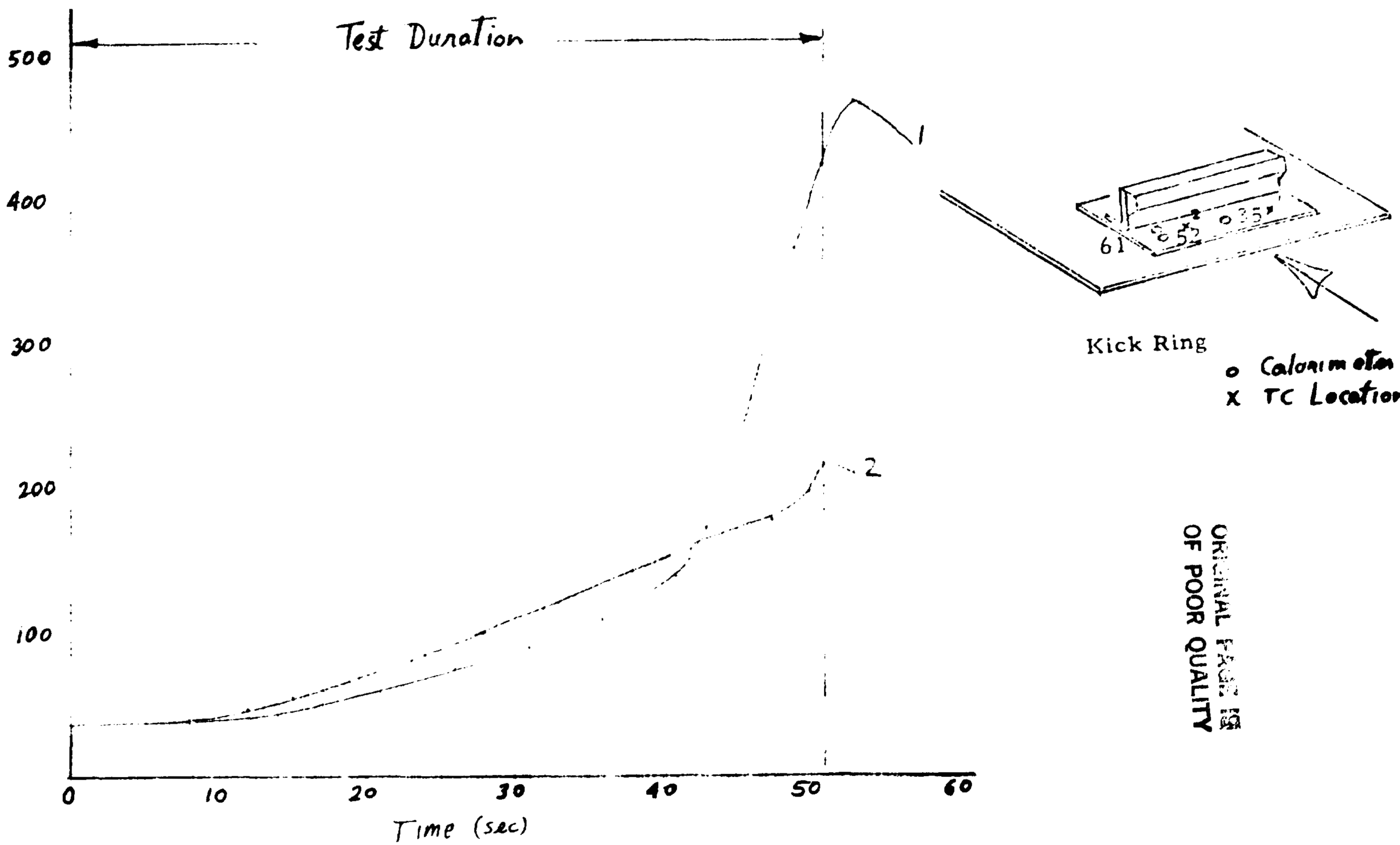


Fig. 16 - Temperature Response for the Kick Ring Area Pin Retainer Band in the Hot Gas Facility

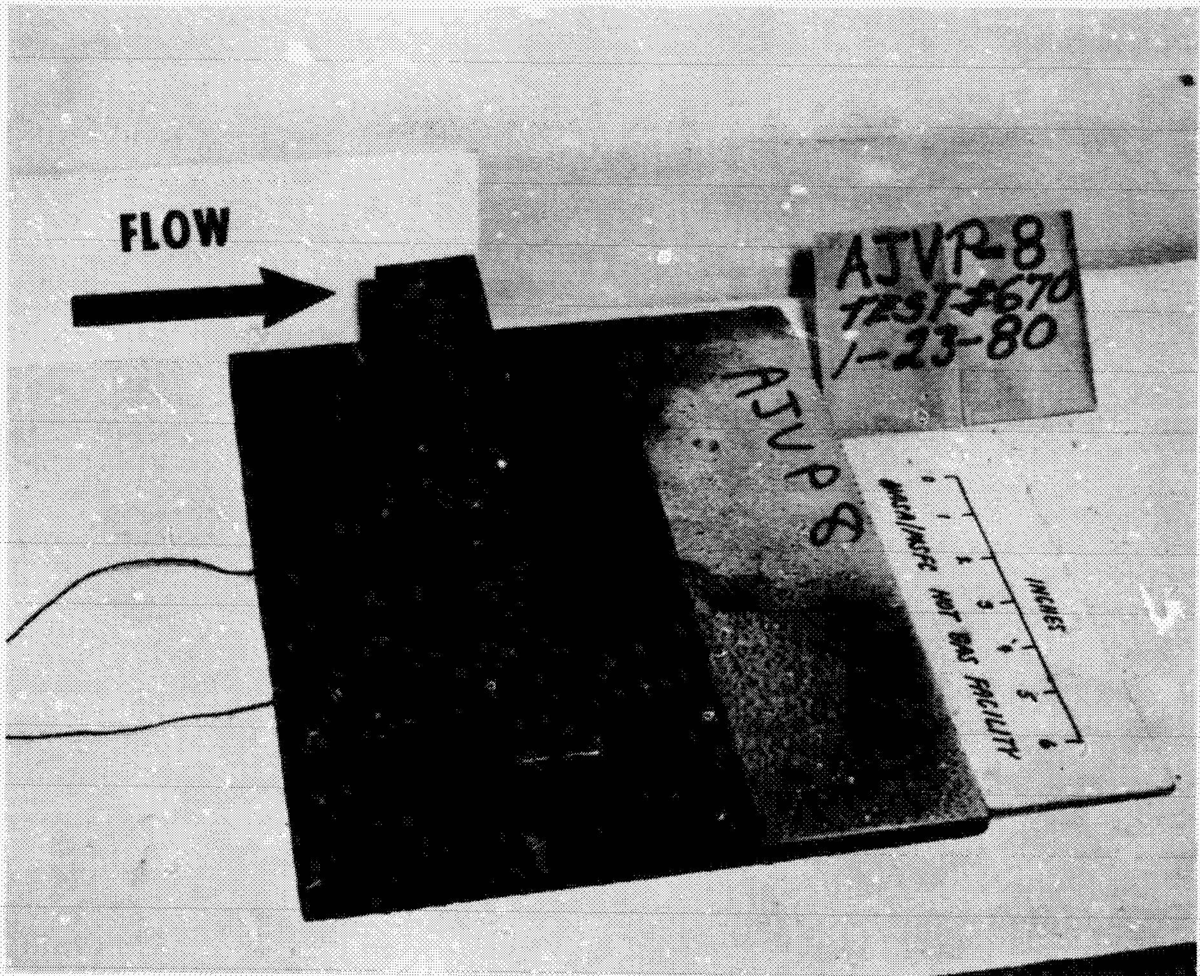


Fig. 17 - Post-Test Photograph of the Model of Fig. 15 (Picture not clear; cork TPS has receded down to the metal band in the center. A little cork was still left near the ends of the cork band.)

Note: Butt Joint
in Cork TPS

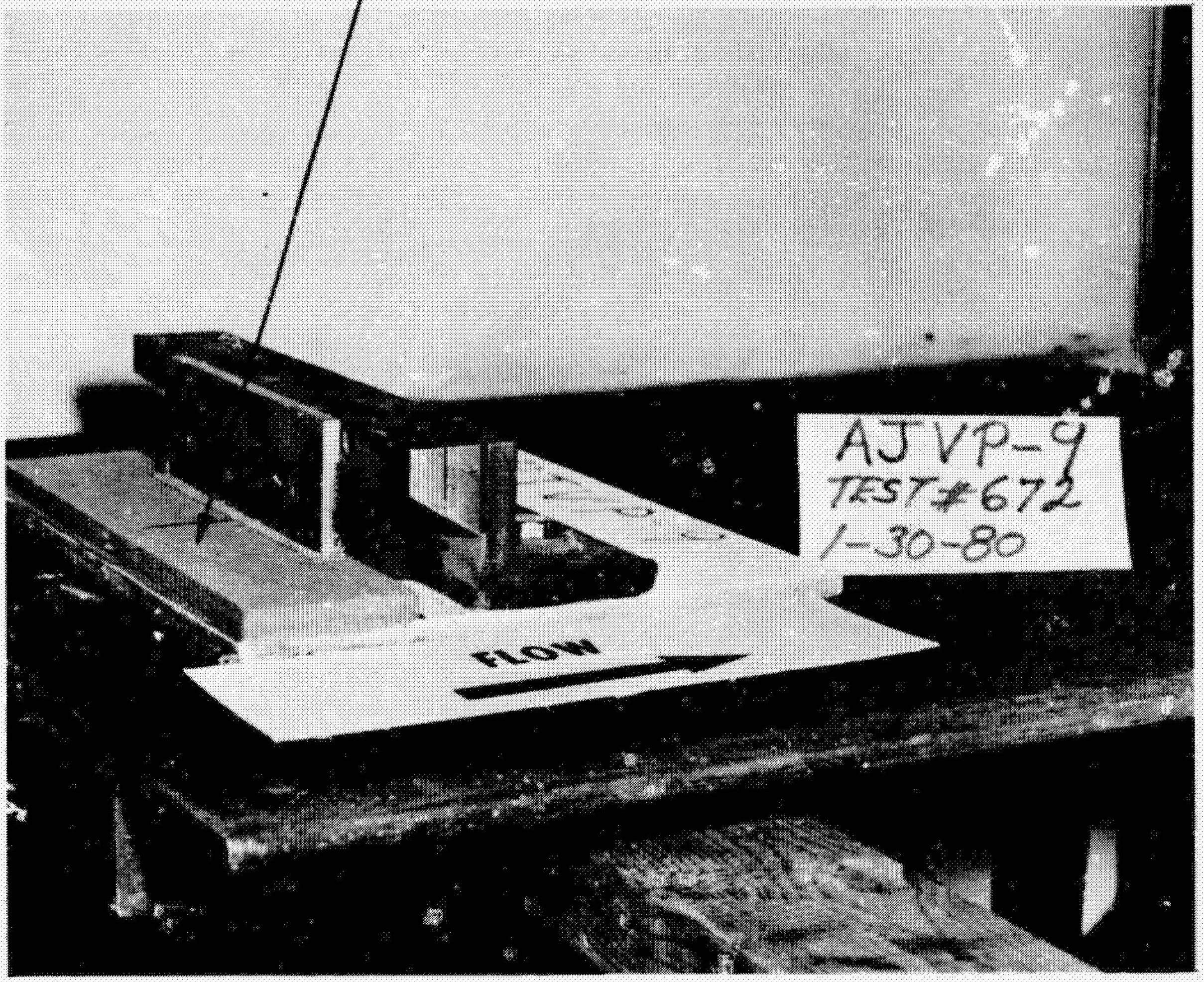


Fig. 18 - Pretest Picture of the Kick Ring Splice Area Pin Retainer Band TPS Model

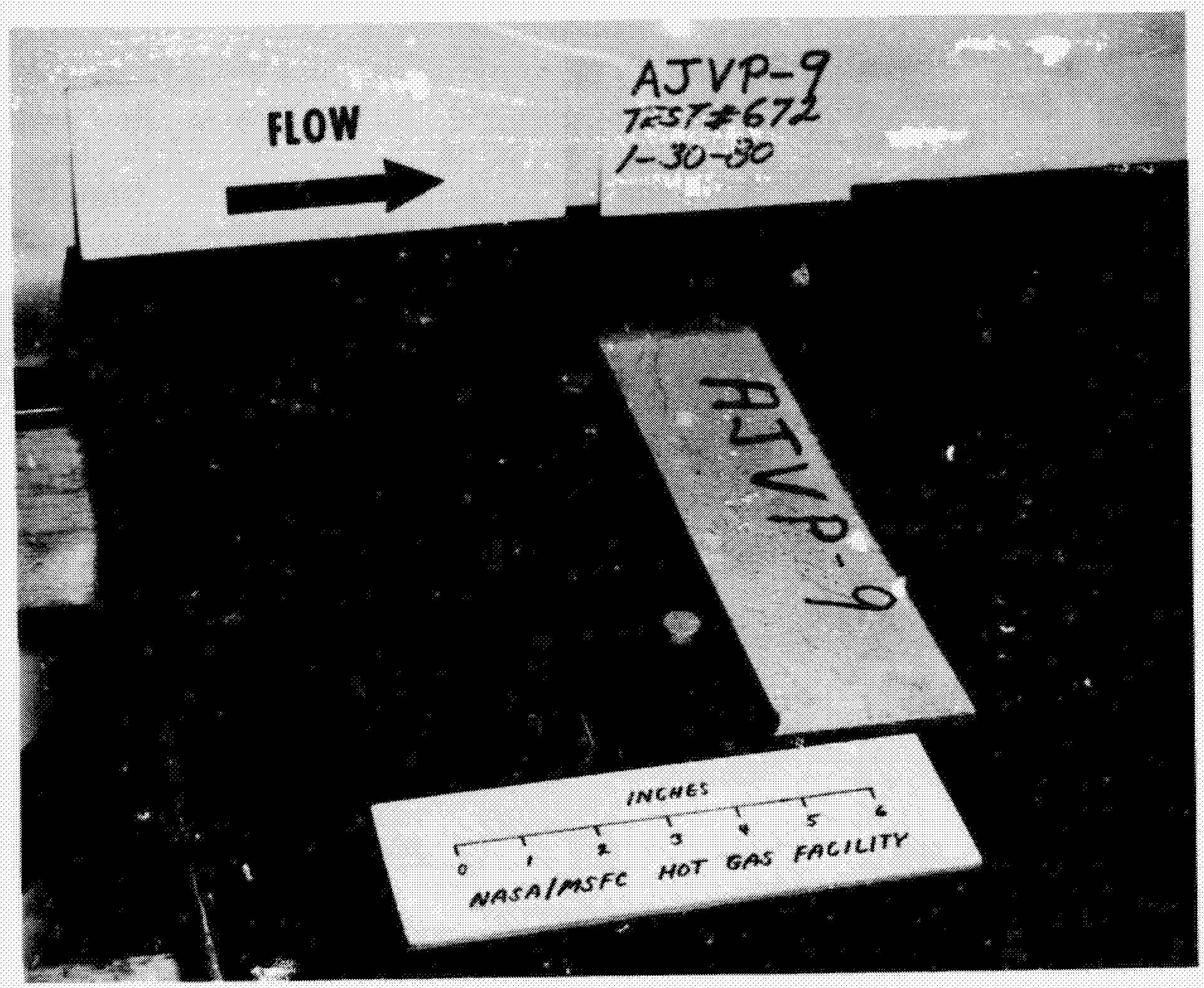


Fig. 19 - Post-Test Picture of the Model in Fig. 18

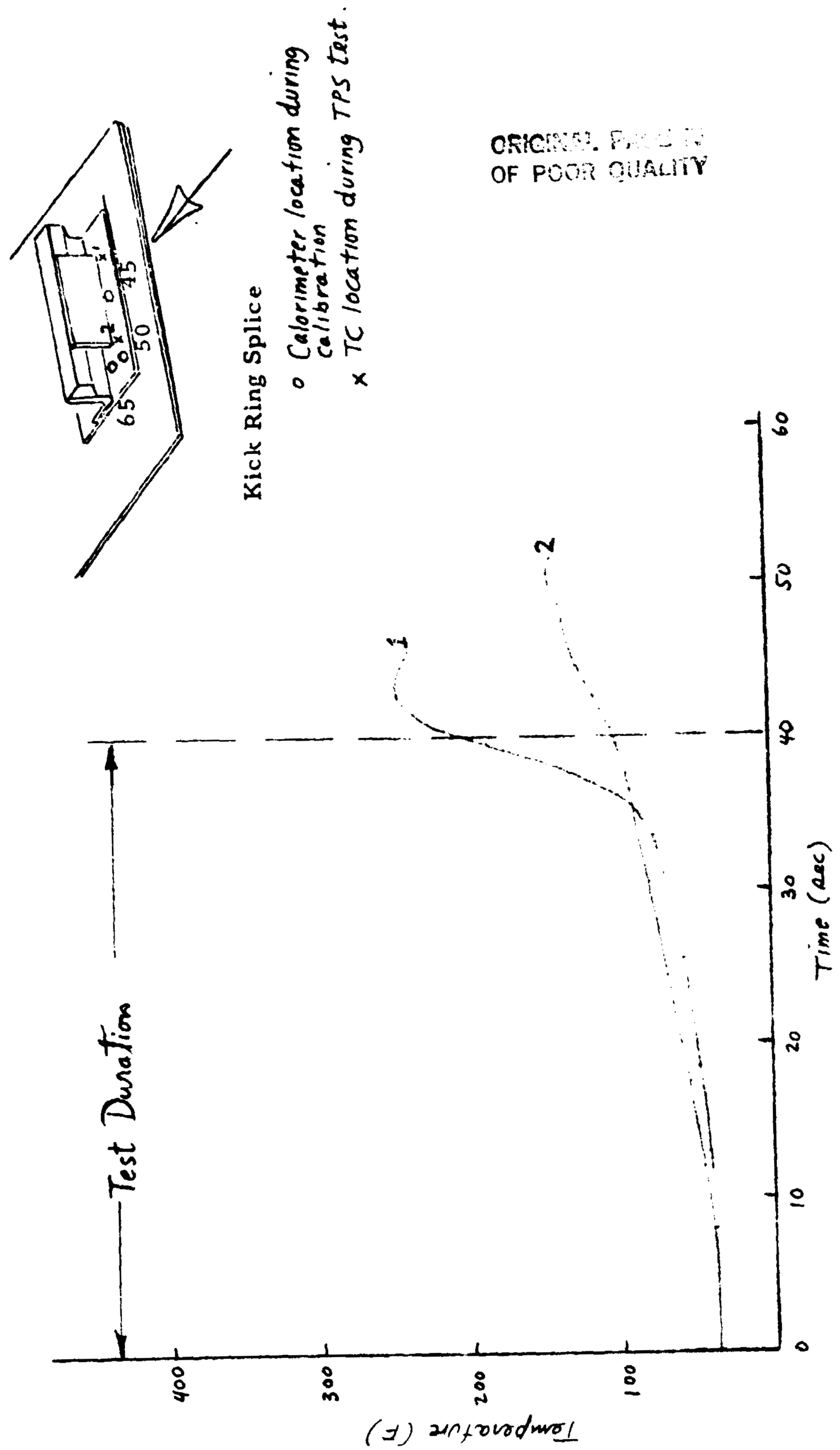


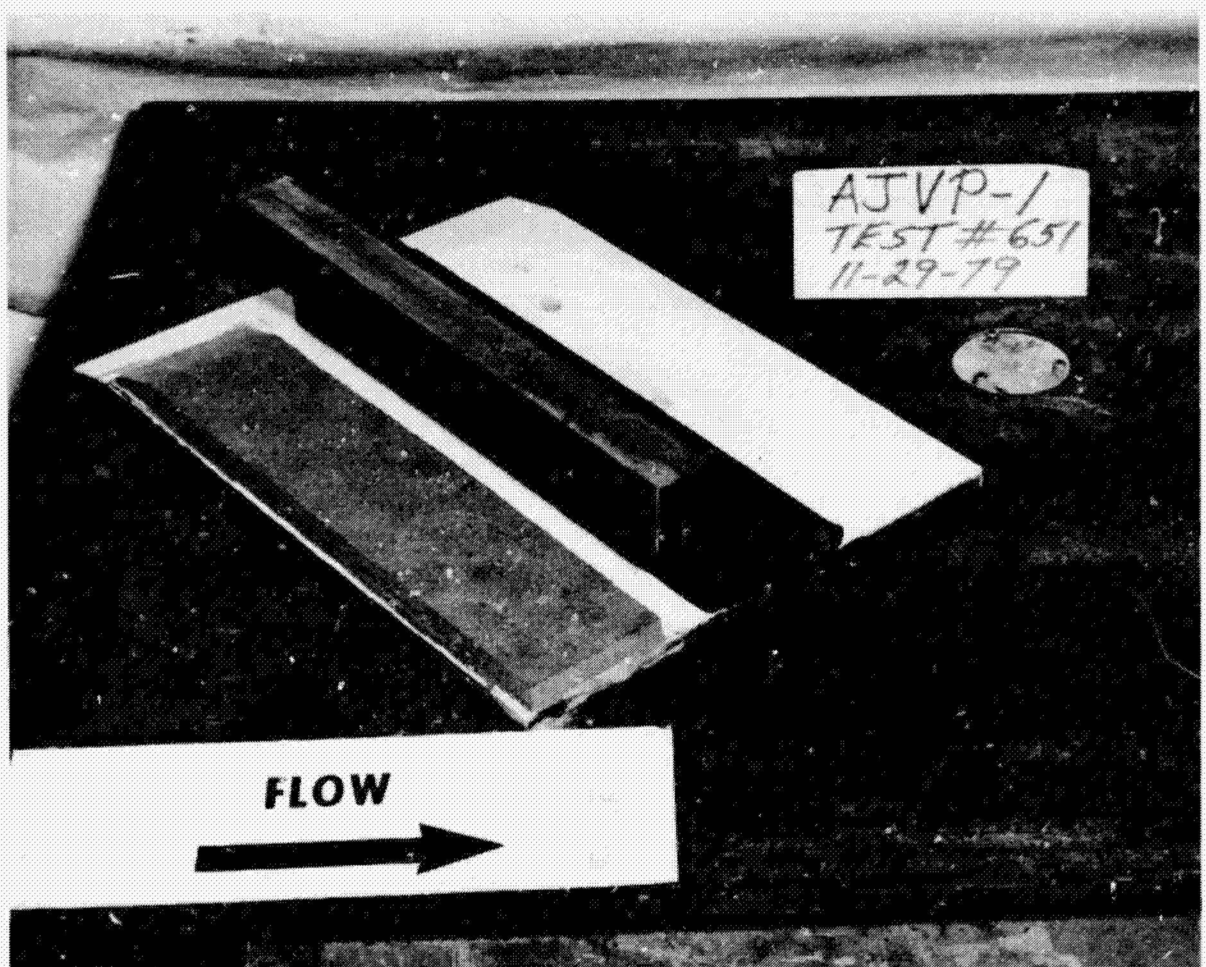
Fig. 20 - Temperature Response on Kick Ring Splice Area Pin Retainer Steel Band

Fig. 21 - Pin Retainer Band TPS Model in the Area Where the Band is "Crimped" and Closed Out with K5NA

Appendix A
TEST SUMMARY AND CONCLUSIONS

Model Description: 3-in. high KR protuberance with .375 in. cork over steel band; model at 50 deg angle of attack

$\dot{q}_{center}$ (measured) = 30 Btu/ft^2-sec $\dot{q}_{center}$ (based on re-cal) = 25.2 Btu/ft^2-sec
Q_{load} Required = 1403 Btu/ft^2 Test duration = 37.0 sec (cut-off)
Q_{load} Obtained = 932 Btu/ft^2



Percent Over-Test = -34%

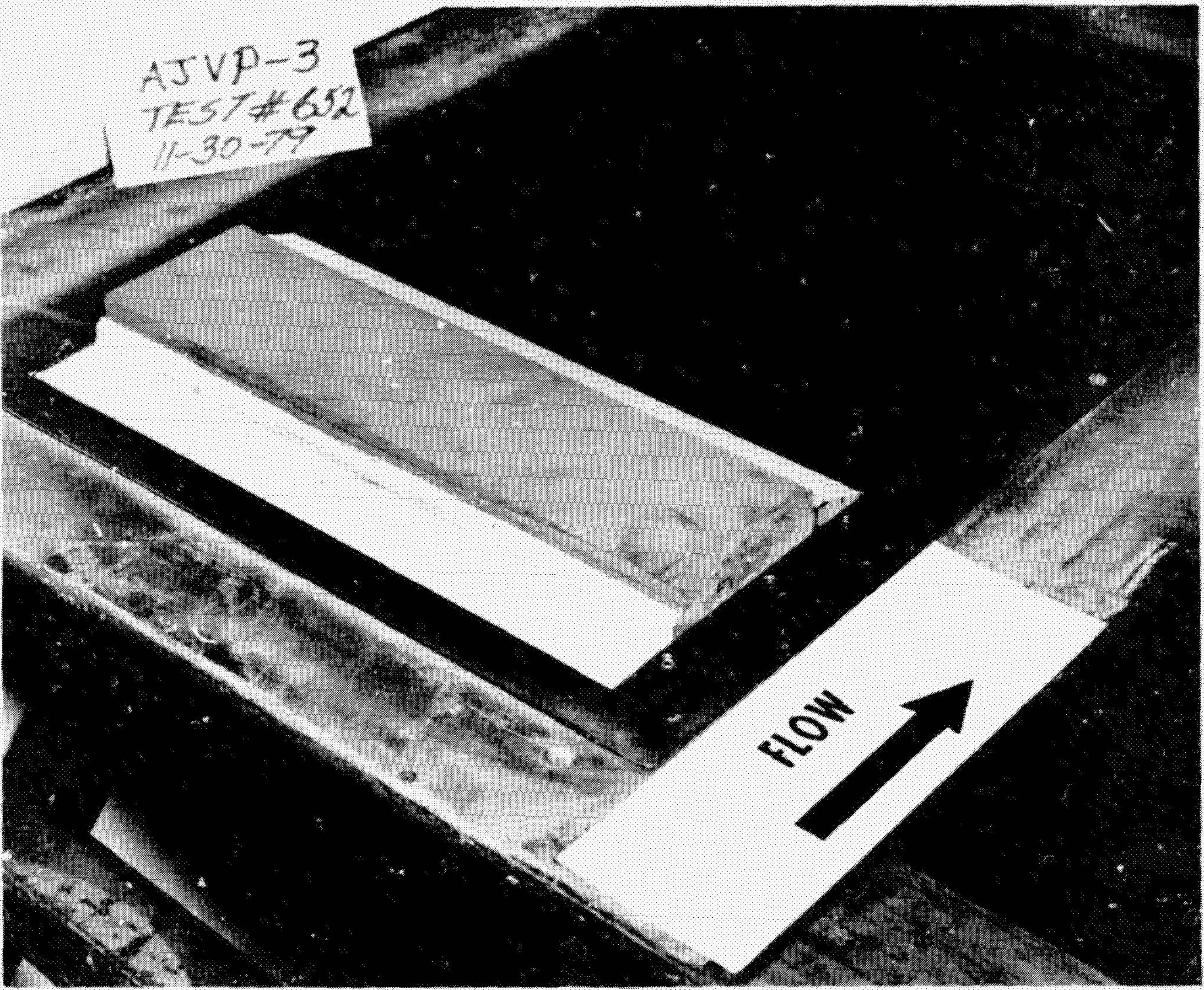
Results:
- Band Temperature — T_{start} = 31 F, T_{end} = 1140 F
- TPS Thickness Over Band — Pretest = .375 in. Post-Test = .000 in.
- Flow got under the cork and the steel band temperature rose rapidly.

Conclusions: Test configuratio of 50 deg swept angle allowed stronger than anticipated flow vortices in the region between cork and protuberance causing flow to penetrate under the cork.

Model Description: Unperturbed area clevis joint pin retainer band model with .375 in. cork over steel band

$\dot{q}_{center\ (estimated)}$ = 9 Btu/ft^2-sec Q_{load} Required = 538 Btu/ft^2

Test Duration = 60 sec Q_{load} Obtained = 540 Btu/ft^2



Percent Over-Test 0%

Results:
- Band Temperature — T_{start} = 27 F, T_{end} = 130 F
- TPS Thickness Over Band — Pretest = .375 in, Post-Test = .350 in.
- The LE of cork TPS receded back about .125 in; no appreciable surface recession

Conclusions: A good design margin available in this configuration since plenty of cork left after test.

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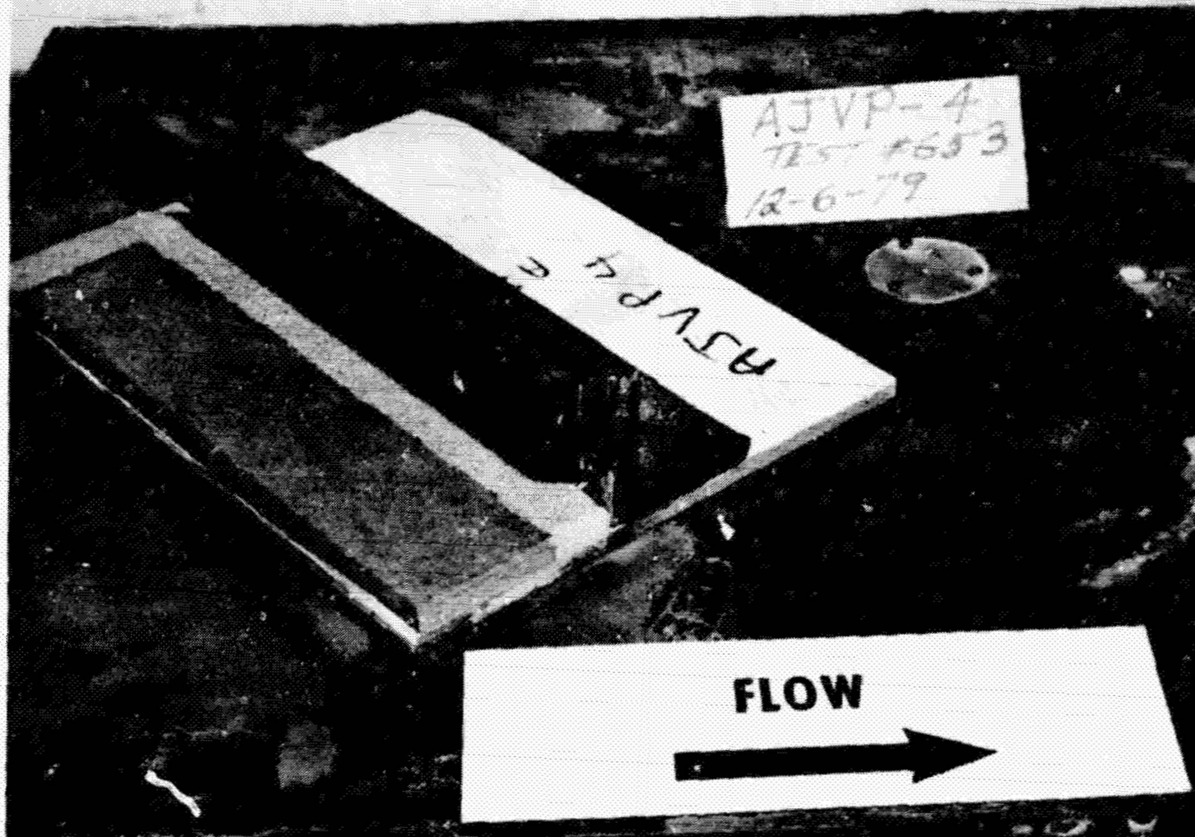
Model Description: 3 in. high KR protuberance with .375 in. cork o· ·r band and area between band and protuberance closed out with K5NA — model at 50 deg angle of attack

$\dot{q}_{center}$ (measured) = 30 Btu/ft^2-sec $\dot{q}_{center}$ (based on re-cal) = 25.2 Btu/ft^2-sec

Q_{load} Required = 1403 Btu/ft^2 Test Duration = 59.0 sec

Q_{load} Obtained = 1487 Btu/ft^2



Percent Over-Test = 6%

Results:
- Band Temperature — T_{start} = 52 F, T_{end} = 400 F
- TPS Thickness Over Band — Pretest = .375 in.; Post-Test = .010 in.

Conclusions: Passes the requirements but flow not quite desirable due to high angle of attack.

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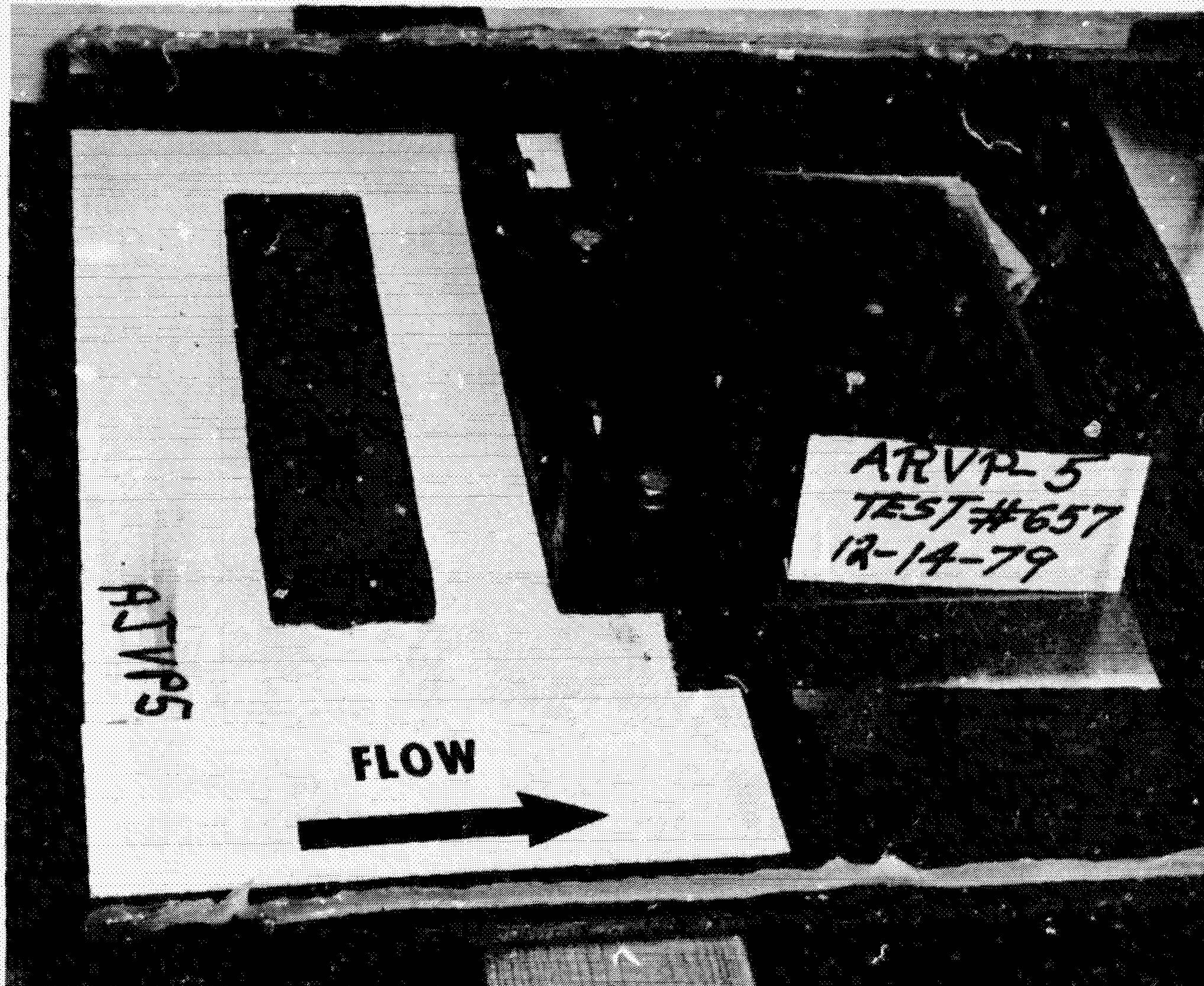
Model Description: Scaled-down version of Attach Ring area pin retainer band model with .375 in. cork over steel band – 90 deg to flow

$\dot{q}_{center\ (measured)}$ = 23 Btu/ft^2-sec $\dot{q}_{center\ (re\text{-}cal)}$ = 19.3 Btu/ft^2-sec

Q_{load} Required = 1484 Btu/ft^2 Test Duration = 65 sec

Q_{load} Obtained = 1255 Btu/ft^2



Percent Over-Test = -16%

Results:
- Band Temperature – T_{start} = 40 F, T_{end} = 315 F
- TPS Thickness Over Band – Pretest = .375 in.; Post-Test = .010 in.

Conclusions: Since no cork left over band, need to increase the cork thickness to .50 in. (33% increase) so full heat load could be obtained.

Model Description: 2.5 in. high KR protuberance with .375 in. cork over steel band – at 90 deg to flow

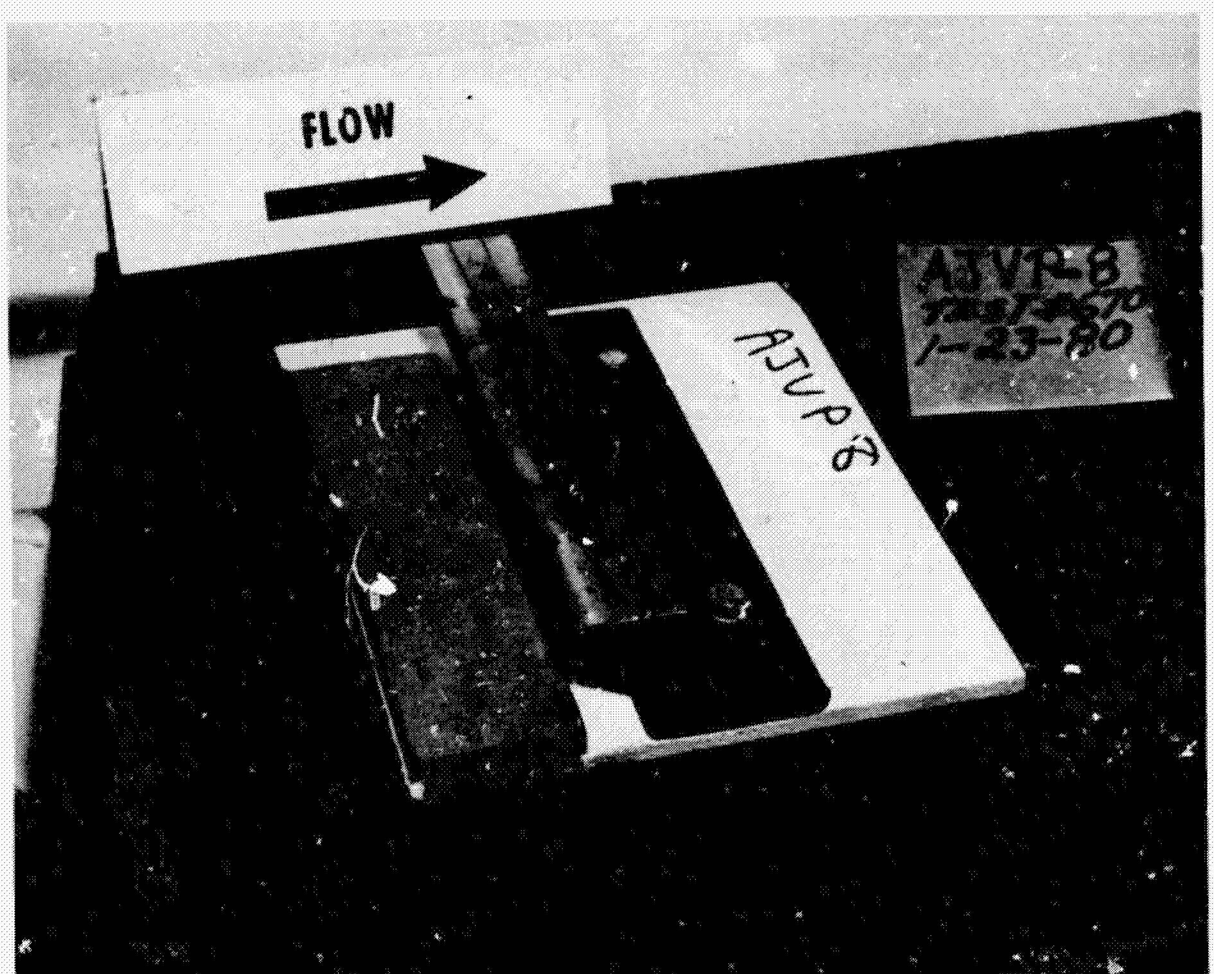
$\dot{q}_{center}$ (measured) = 35 Btu/ft^2-sec

$\dot{q}_{center}$ (based on re-cal) = 29.4 Btu/ft^2-sec

Q_{load} Required = 1403 Btu/ft^2

Test Duration = 51.0 sec (cut-off)

Q_{load} Obtained = 1500 Btu/ft^2



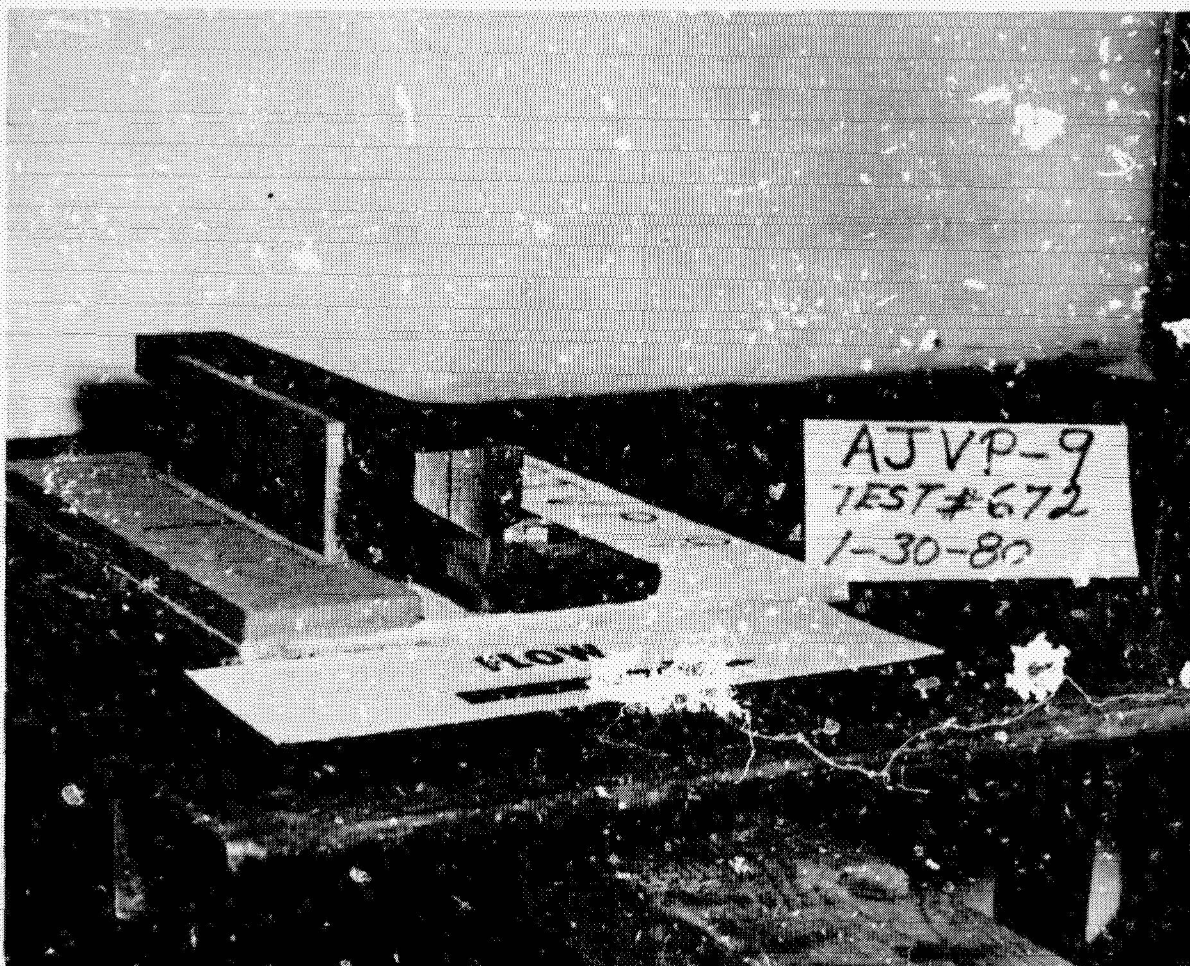
Percent Over-Test = 7%

Results:
- Band Temperature – T_{start} = 37 F, T_{end} = 420 F
- TPS Thickness Over Band – Pretest = .375 in. Post-Test = .010 in.
- Band temperature rose quickly near the end of the run (see Fig. 16). Temperature at 47 sec (run time sufficient for full heat load) was 300 F

Conclusions: This configuration passes the requirements with a 7% margin without any K5NA closeout requirements as in Test 653.

Model Description: 2.5 in. high KR protuberance with splice plate in .375 in. cork over steel band

$\dot{q}_{center}$ (measured)	= 45 Btu/ft^2-sec	$\dot{q}_{center}$ (based on re-cal)	= 37.8 Btu/ft^2-sec
Q_{load} Required	= 1800 Btu/ft^2 (estimated)	Test Duration	= 40 sec
Q_{load} Obtained	= 1512 Btu/ft^2		



Percent Over Test = -16% (based on estimated Required Q_{load})

Results:
- Band Temperature — T_{start} = 38 F, T_{end} = 200 F
- TPS Thickness Over Bands — Pretest = .375 in., Post-Test = .010 in.
- Band temperatures rose gradually, then rose rapidly to 200 F at end of test. Lost K5NA closeout and cork in front of the splice

Conclusions: Extra K5NA closeout material (at least .375 in.) is required due to 16% under-test and due to the loss of most all cork TPS in front of the splice.

Model Description: 2.5 in. KR protuberance in front of .375 in. cork TPS over the steel pin retainer band that is crimped within a 6 in. wide gap in the cork band. The gap is closed out with K5NA

$\dot{q}_{center\ (measured)}$ = 35 Btu/ft^2-sec
Q_{load} Required = 608 Btu/ft^2
Q_{load} Obtained = 512 Btu/ft^2
$\dot{q}_{center\ (based\ on\ re-cal)}$ = 29.4 Btu/ft^2-sec
Test Duration = 17.4 sec

Percent Over Test = -16%

Results:
- Band Temperature — T_{start} = 57 F, T_{end} = 59 F
- K5NA Thickness Over Band — Pretest = .62 in.; Post Test = .60 in.

Conclusions: The run time of 17.4 sec was determined based on the initial measured heat flux of 35 Btu/ft^2-sec. The new $\dot{q}$ of 29.4 rendered a shortage of 16%. Since hardly any degradation of K5NA obtained, the configuration as tested is completely acceptable.