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RESULTS OF TESTS ON A SPECIMEN OF THE SRB AFT SKIRT HEAT SHIELD CURTAIN IN THE MSFC LRLF

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Contract NAS8-32982

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

by
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FOREWORD

This report documents work performed by Lockheed-Huntsville Research & Engineering Center for NASA-Marshall Space Flight Center under Contract NAS8-32982, "Solid Rocket Booster Thermal Protection System Material Development." The MSFC Contracting Officer's Representative for this work is Mr. Bill Baker, EP44.

SUMMARY

A full-scale segment of the actual Solid Rocket Booster aft skirt heat shield curtain was tested in the Large Radiant Lamp Facility (LRLF) at Marshall Space Flight Center. The curtain was mounted in the horizontal position in the same manner as it is to be mounted on the SRB. A shaker rig was designed and used to provide a motion of the curtain, simulating that to be caused in flight by vehicle acoustics. Thermocouples were used to monitor curtain materials temperatures. Both ascent and reentry heat loads were applied to the test specimen.

All aspects of the test setup performed as expected, and the test was declared successful.

1. TEST OBJECTIVE

The redesigned curtain now has a layer of nylon on its outer (hot) side which was added for strength purposes. When heated at the flight heating rates, this nylon burns and adds heat to the rest of the curtain materials. Hopefully, the nylon will just burn away and fall off without adversely affecting the high-temperature curtain layers. However, the nylon may not all drop away but rather burn under the protective flaps and damage the attachment areas. Previous tests of this curtain at Wyle Labs were all conducted with the curtain in a "vertical" position, i.e., hung up by just one end. This did not give the proper orientation of the curtain with respect to its end attachments and the flaps which were designed to protect these attachments from heating and burning nylon. The objective of this test was to determine the response of the curtain when hung in the horizontal position as it will be during flight.

2. SUCCESS CRITERION

The criteria for this test to be declared successful were:

- The measured temperature must not exceed the allowable value for each respective material. These allowable temperatures are:
  - Fiberfrax: 2400 F
  - Astroquartz: 2400 F
  - Fiberglass: 700 F
  - Nylon: Undefined (Material is expected to and allowed to burn and drop away early in the ascent phase of the test.)
- Post-test inspection of the curtain must not reveal any problem areas.

3. FACILITY DESCRIPTION

The MSFC Large Radiant Lamp Facility (LRLF) consists of three Modular Heating Units (MHU), their associated controllers, a 15 ft vacuum tank, and a low subsonic air flow duct and blower. The MHUs are radiant heating units using quartz/tungsten lamps and water-cooled aluminum reflectors.

For this test the MHUs were mounted at a 45 deg angle in order to provide space inside the air flow duct for the curtain to be mounted in the horizontal/draped position.

Also for this test a shaker rig was designed and installed. This consisted of a "crankshaft" with two offsets which pulled two rods alternately up and down, 180 deg out of phase. The amplitude of the offset was ± 1 in. The crankshaft speed was approximately 431 rpm, yielding a frequency of 7.2 Hz.

The airflow through the duct for this test was approximately 3 to 6 ft/sec.

Figure 1 is a sketch of this set up.

4. CURTAIN SPECIMEN DESCRIPTION

The SRB aft skirt heat shield curtain is composed of two units — an inner curtain and an outer curtain. The outer curtain consists of: (1) two high-temperature, quilted Fiberfrax and Astroquartz blankets; (2) an outer layer of Nylon on the side exposed to the heating; and (3) one layer of G1582 Fiberglas on the inside of these two blankets. The Nylon and Fiberglas are for strength while the two quilted blankets are for thermal protection. The inner blanket consists of: (1) one high temperature quilted Fiberfrax and Astroquartz blanket; (2) one layer of G1582 Fiberglas; and (3) one layer of G1584 Fiberglas.

A sketch of this design is shown on Fig. 2. The curtain test specimen also has a lap joint along its full length essentially identical to the flight curtain. The two sides of the curtains are called the "right curtain" and "left curtain" — looking into the air flow direction as seen on Fig. 2. The Nylon outer layer is designed to burn away early during the flight.

Curtain Mounting in the LRLF Facility

The curtain was mounted in the facility using mounting parts that closely simulated the flight hardware. On the aft ring, or outboard SRB area, a member was machined to simulate the ring and covered with cork. The aluminum strips that are used to bolt the curtain to the ring were made up according to the flight design and riveted to the curtain. The curtain flaps that cover the aluminum strip was also put in place and sewn down like the flight design.

On the nozzle/compliance ring end of the curtain, an aluminum plate covered with cork was used to simulate the nozzle wall and mounted at the nozzle angle. An actual piece of the EPDM blast shield was also mounted in its place on the nozzle where it meets the compliance ring. A flight size "Mickey Mouse" ring was machined and attached to the curtain and nozzle/compliance ring.

The distance between the aft ring and nozzle compliance ring were the same as on the vehicle in order to give the same curtain "drape" as on the vehicle.

These design details were incorporated into the test in order to simulate the actual flight curtain dimensions and directions, so that the effects of the burning Nylon could be observed in the attachment/flap areas and through the lap joint.

After being installed in the LRLF, "end plates" of high temperature curtain material were sewn in place to prevent hot gases from flowing up and into the draped area of the curtain.

Figure 3 shows the curtain installed in the LRLF facility and ready to be tested.

5. INSTRUMENTATION

The curtain itself was instrumented with 47 chromel alumel thermocouples as shown on Fig. 4. Also two air temperature thermocouples were provided in the space inside the "draped" part of the curtain. Three movie cameras and three TV cameras were used to observe the motion and burning of the curtair during the test.

Figures 5 through 10 and Table 1 show details of locations of all 47 thermocouples.

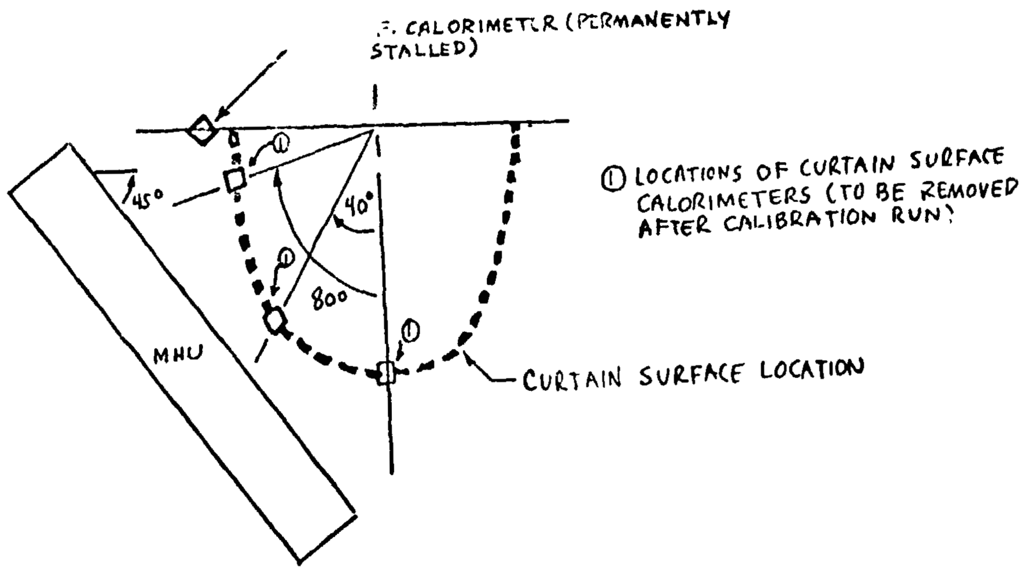
Table 1

THERMOCOUPLE LOCATIONS ON CURTAIN

TC No.	Lateral Location	Circumferential Location	Figure and Location Nos.
1	L-O/L Joint	4	6 - 4
2	L-O/L Joint	5	6 - 5
3	L-O/L Joint	3	6 - 4
4	L-O/L Joint	2	6 - 4
5	L-O/L Joint	5	6 - 3
6	L-O/L Joint	4	6 - 3
7	L-O/L Joint	3	6 - 3
8	L-O/L Joint	2	6 - 3
9	L-O/L Joint	5	6 - 2
10	L-O/L Joint	4	6 - 2
11	L-O/L Joint	3	6 - 2
12	L-O/L Joint	2	6 - 2
13	L-O/L Joint	5	6 - 1
14	L-O/L Joint	4	6 - 1
15	L-O/L Joint	3	6 - 1
16	L-O/L Joint	2	6 - 1
17	RT-O/L Joint	5	7 - 5
18	RT-O/L Joint	5	6 - 4
19	RT-O/L Joint	4	7 - 5
20	RT-O/L Joint	4	7 - 4
21	RT Curtain Center	4	8 - 3
22	RT Curtain Center	4	8 - 2
23	RT Curtain Center	4	8 - 1
24	RT-O/L Joint	4	7 - 3
25	RT-O/L Joint	5	7 - 3
26	RT-O/L Joint	4	7 - 2
27	RT-O/L Joint	5	7 - 2
28	℄ of Joint	5	7 - 1
29	℄ of Joint	4	7 - 1
30	RT-O/L Joint	2	6 - 6
31	RT-O/L Joint	3	6 - 6
32	RT-O/L Joint	2	6 - 7
33	RT-O/L Joint	3	6 - 7
34	℄ of Joint	Aft Ring Area	10 - 4
35	℄ of Joint	Aft Ring Area	10 - 3
36	℄ of Joint	Aft Ring Area	10 - 2
37	℄ of Joint	Nozzle/Compliance Ring Area	9 - 1
38	℄ of Joint	Nozzle/Compliance Ring Area	9 - 2
39	℄ of Joint	Nozzle/Compliance Ring Area	9 - 4
40	℄ of Joint	Nozzle/Compliance Ring Area	9 - 3
41	L-O/L Joint	5	6 - 4
42	L-O/L Joint	4	6 - 5
43	L-O/L Joint	3	6 - 5
44	L-O/L Joint	2	6 - 5
45	℄ of Joint	Aft Ring Area	10 - 5
46	℄ of Joint	Aft Ring Area	10 - 1
47	℄ of Joint	Nozzle/Compliance Ring Area	9 - 5
48	—	(Inside Draped Area of Curtain)	—
49	—	(Inside Draped Area of Curtain)	—

6. CALIBRATION RIG

The pretest and post-test calibration rig is shown in Fig. 11. This rig consisted of four water-cooled calorimeters mounted at 0, 40 and 80 deg along the curtain surface as shown in the sketch below.



These were mounted in such a way that the sensing surface of each calorimeter was in a plane tangent to the draped curtain surface at that point. Also one "reference" calorimeter was used to monitor the $\dot{q}$ during the curtain test, while the remaining three calorimeters were removed during curtain testing. One additional calorimeter was mounted in the nozzle simulator plate during the curtain test to monitor $\dot{q}$ of the nozzle wall. This was located about 28 in. down the nozzle wall.

7. TEST REQUIREMENTS

From Ref. 1, the maximum flight heating rate value to the curtain during ascent occurs during liftoff and is approximately 22 Btu/ft^2-sec. When the vehicle clears the stand, the $\dot{q}$ drops off to about 18 Btu/ft^2-sec and then tapers off slightly during the rest of the flight. The heat load for ascent is 1825 Btu/ft^2. These values are for Body Point 2314.

From Ref. 2, the maximum reentry flight heating rate value is 15.6 Btu/ft^2-sec, and the total heat load is 229 Btu/ft^2 at the center of the curtain. (This is for Body Point 2, Zone 8, as shown in Ref. 2.)

More detailed test requirements are also discussed in Refs. 3 and 4.

It was estimated from previous tests that the maximum heating rate available from this facility was about 13 Btu/ft^2-sec. This is less than the peak value to be expected in flight. However, it was decided to go ahead and run the facility at its maximum $\dot{q}$ level and determine the run time required to achieve the heat loads from the calibration test results.

8. TEST SEQUENCE AND RESULTS

8.1 PRETEST CALIBRATION RUN

The first test was a pretest calibration run to determine the $\dot{q}$ levels. This resulted in the $\dot{q}$ values seen in Fig. 12. A conservative value of 12.6 Btu/ft^2-sec at 40 deg was selected to arrive at the following time line for the curtain test.

Time (sec)	Event	
-30	Air flow on	
-10	Cameras on, shaker on, instrumentation on, TV on	
0	Heat on	Ascent
183	Heat off	
303	Heat on	Reentry
331	Heat off	
335	Cameras, shaker off	
400	Air flow off, instrumentation off, TV off	

This planned test time would yield a 25% margin on heat load for ascent and approximately a 50% margin on heat load for reentry.

8.2 SHAKER TEST

The second test was a pretest checkout run of the shaker rig. This was observed to determine the magnitude and frequency of the curtain motion. Movies were made, developed and analyzed and the results were determined to be satisfactory.

8.3 CURTAIN THERMAL TEST

The next test was the heating test of the curtain itself. Temperature plots for the curtain thermocouples are shown in Figs. 13 through 24. A few thermocouples (Nos. 1, 2, 8, 9 and 44) were bad and were not plotted. An analysis of the data showed that only one thermocouple exceeded its allowable limit. This was thermocouple 25 which went over 700 F, the allowable value for Fiberglas. This value was exceeded at 306 sec, near the time of the end of reentry heating. It was decided that this value would be acceptable because of the conservatism of this test due to: (1) margin on the heat load; (2) extra heat generated by the burning Nylon that fell down on the MHU; (3) it was conducted at a one atmosphere pressure (whereas the flight heating occurs at reduced pressure) and therefore the test blanket would experience more heat conduction; and (4) the shaker rig was kept on for the full duration of the test, whereas in flight the acoustics are for a limited time only.

Post-test analysis of the heating rate data (Fig. 25) showed that the lamps were inadvertently cut off at 172 sec rather than the planned 183 sec. This yielded a reduced heat load margin of 19% rather than the planned 25%. This was declared to be an acceptable margin.

The air temperature thermocouples only rose a few degrees and are not plotted.

Post-test inspection showed the exterior and interior of the curtain to be in remarkably good condition. Figures 26 through 37 show the post-test photos of the curtain after disassembly of the test setup and curtain itself. Some embrittlement of the inner layer of G 1582 Fiberglas on the outer curtain was observed in the right overlap joint area near TC 30. Since TC 30 was only 140 F at the end of ascent, this embrittlement was attributed to post-test burning of the EPDM blast shield. However, it is planned that post-test material samples will be cut out of the curtain at various critical areas of the curtain where the temperature reached a value near the allowable value.

These will be used in strength tests to determine if degradation occurred. These results will be published in a separate document when the results are available.

Figures 38 and 39 show the nozzle simulator plate and aft ring attachment area with cork burned away.

Review of the TV and movie data showed the Nylon dropping away at about 30 sec as expected. The thermal curtain then dropped down as expected to its full draped position. The shaker rig performed well and gave the motion desired.

Figure 40 shows a qualitative prediction which was made of the air currents to be expected around the curtain and nozzle, taking into account the effects of the convective currents up the heated nozzle wall and burning curtain. A very similar smoke flow pattern was observed by the TV coverage, with a distinct vortex or swirl pattern between the curtain and nozzle.

8.4 POST-TEST CALORIMETER RUN

Post-test calorimeter run data are shown on Fig. 41. The centerline calorimeter was bad and is not plotted. These heating rates are somewhat lower than the pretest values, as would be expected due to lamp contamination, but are still within an acceptable range.

9. CONCLUSION

From the review and analysis of the results and data from this test all systems performed satisfactorily. Post-test inspection of the curtain did not reveal any failures.

Only one of the thermocouples on the curtain materials exceeded its allowable limit. This was near the end of reentry and was declared to be an acceptable result. The test was therefore declared successful and the curtain design was declared adequate.

REFERENCES

1. Rockwell Heating Data Book, SD-73-SH-0181-3A, Rockwell International Corporation, Downey, Calif., September 1978.
2. Engel, C. D., R. C. Lewis, J. V. McAnally and E. B. Brewer, The SRB Thermal Environment Data Book, Report RTR-028-1, REMTECH, Inc., Huntsville, Ala., July 1977.
3. "SRB Heat Shield Curtain Test (LRLF)," NASA Memo No. EP44 (80-44) from EP44/Mr. Vaniman to ET18/Mr. Stone, dated 6 May 1980.
4. "Test Requirements for Planned Base Curtain Heat Shield Test at LRLF," NASA Memo No. EP44 (80-28) from EP44/Mr. Vaniman to EE11/Mr. Mann, dated 7 April 1980.

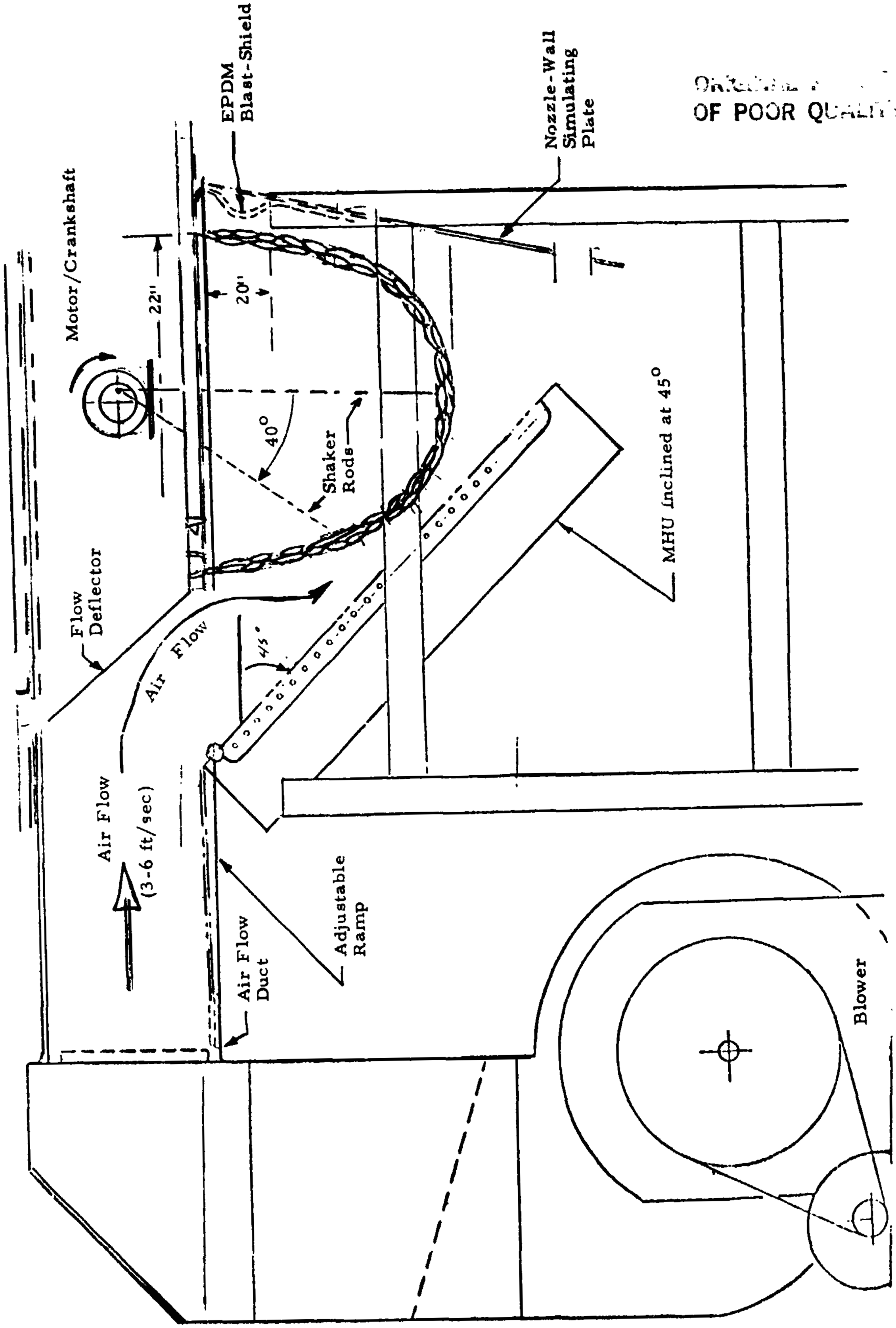


Fig. 1 - Sketch of Curtain Installed in LRLF

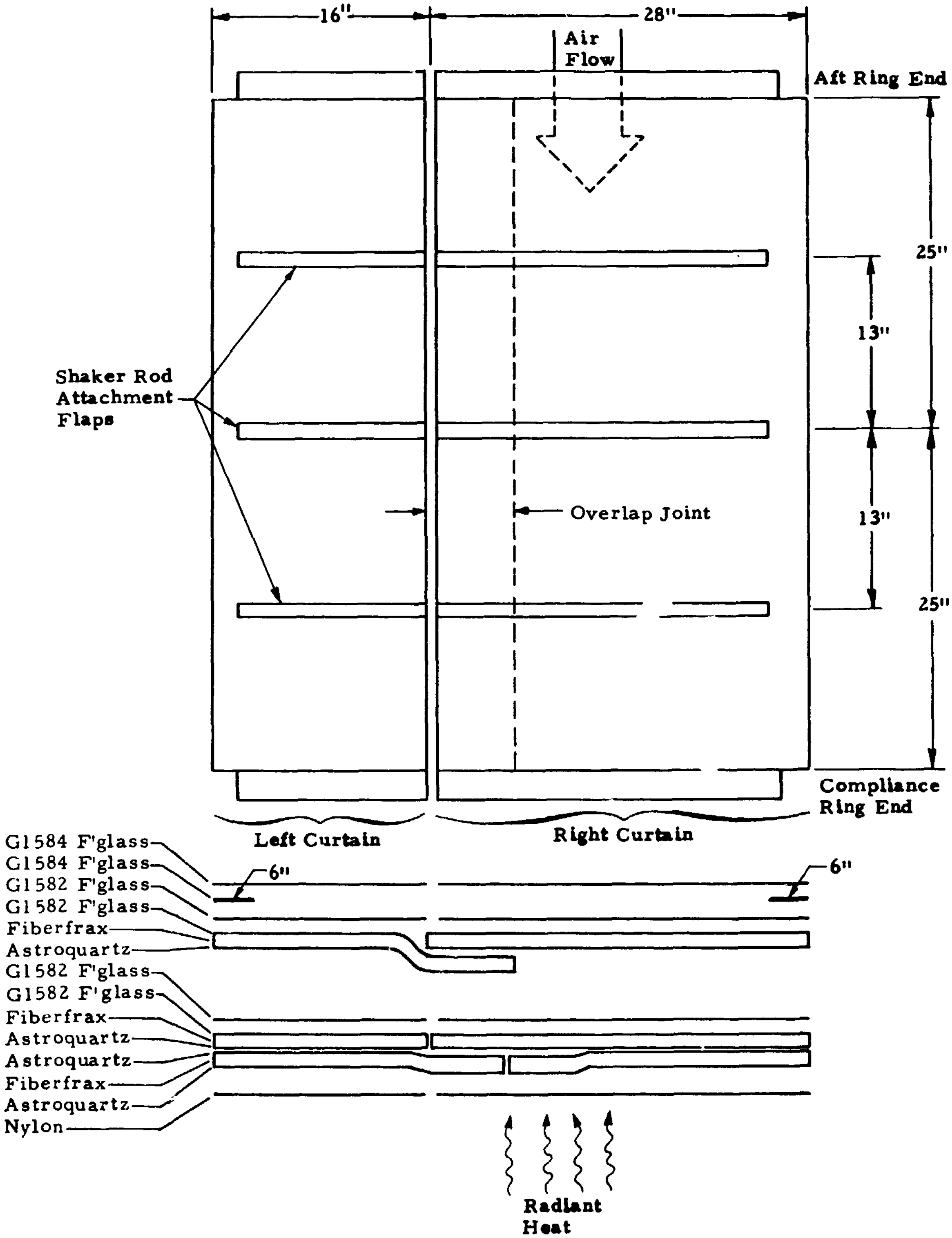


Fig. 2 - Curtain Specimen Basic Parts

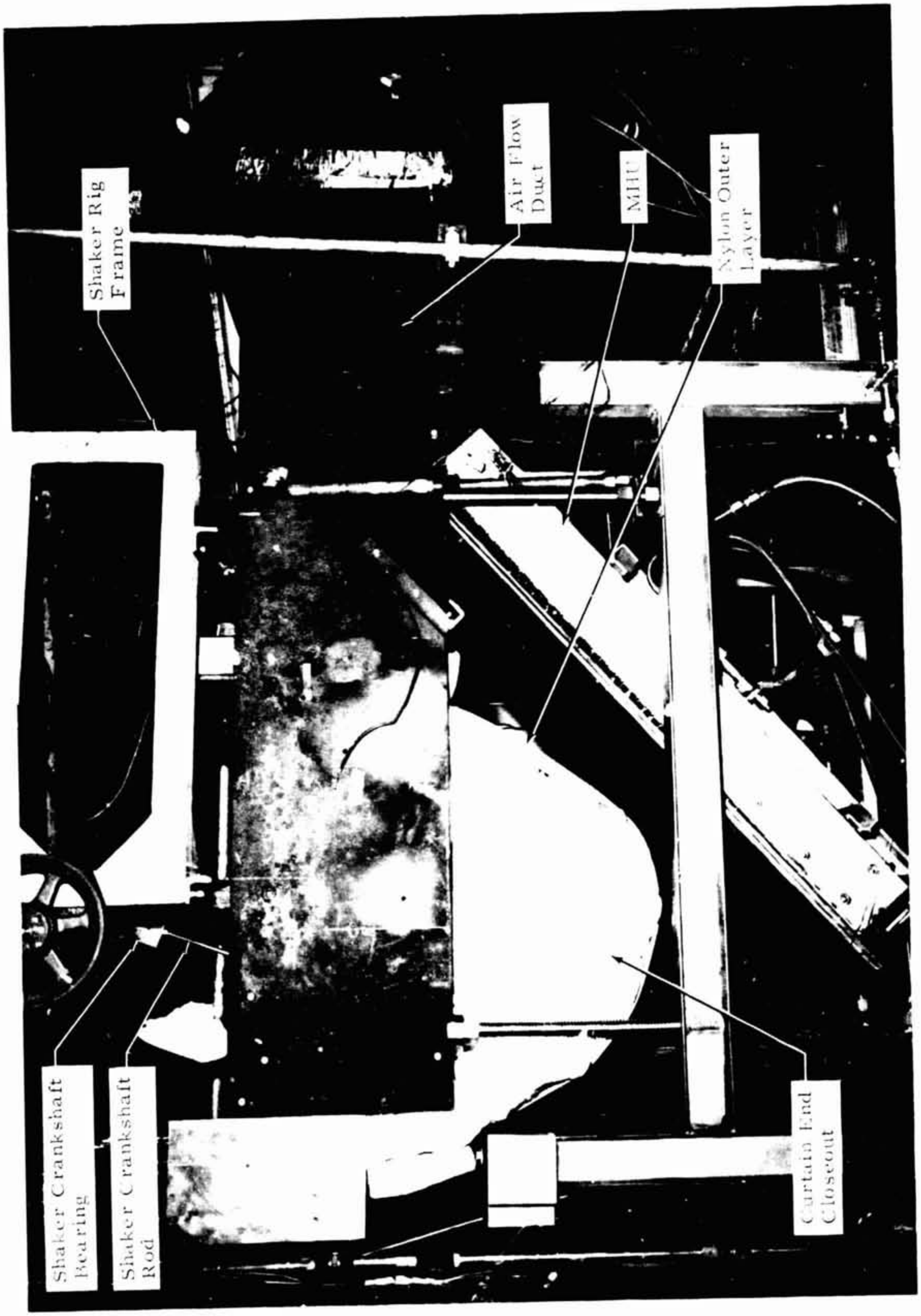


Fig. 3 - Photo of Curtain Mounted in Duct

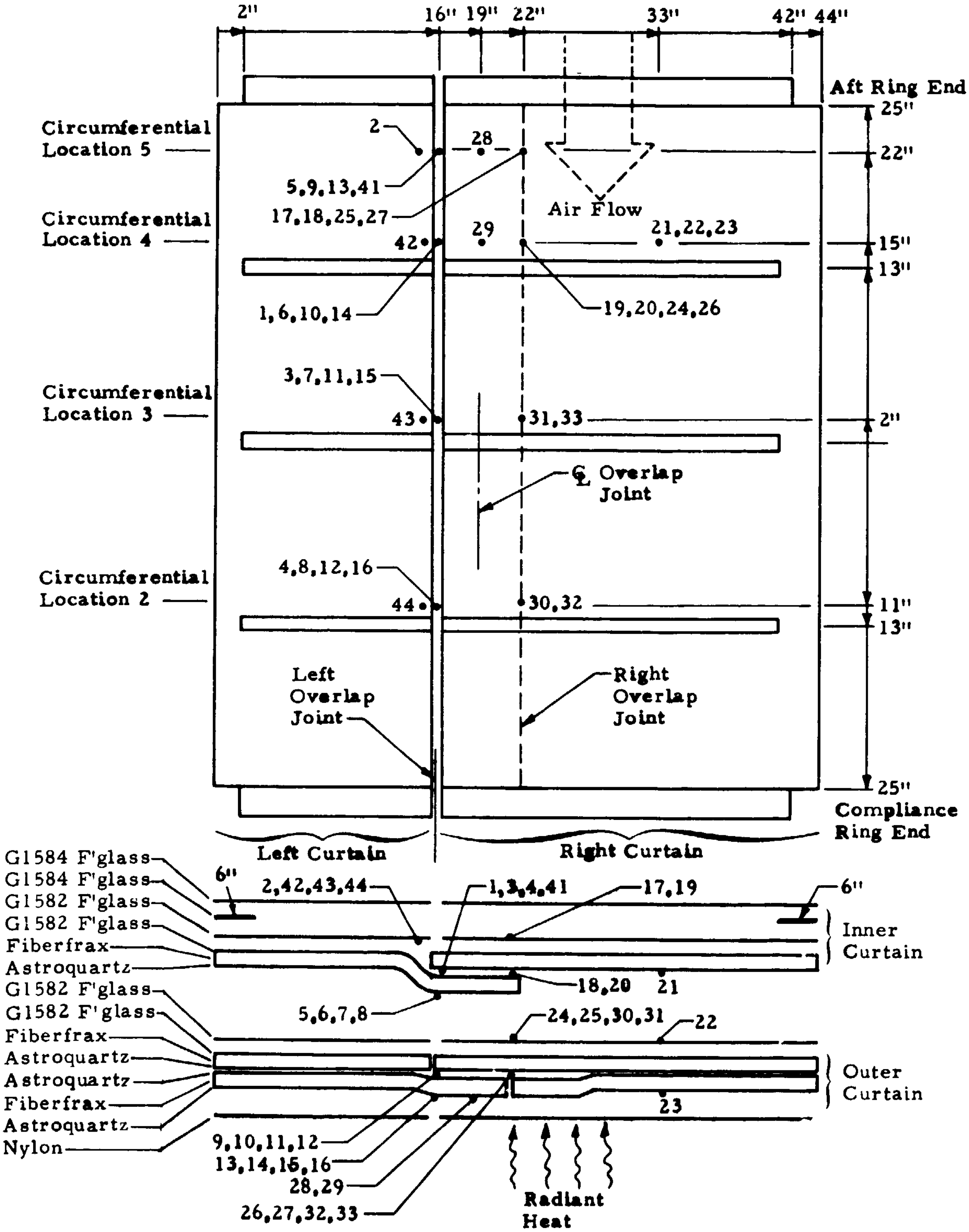


Fig. 4 - Thermocouple Locations on Curtain

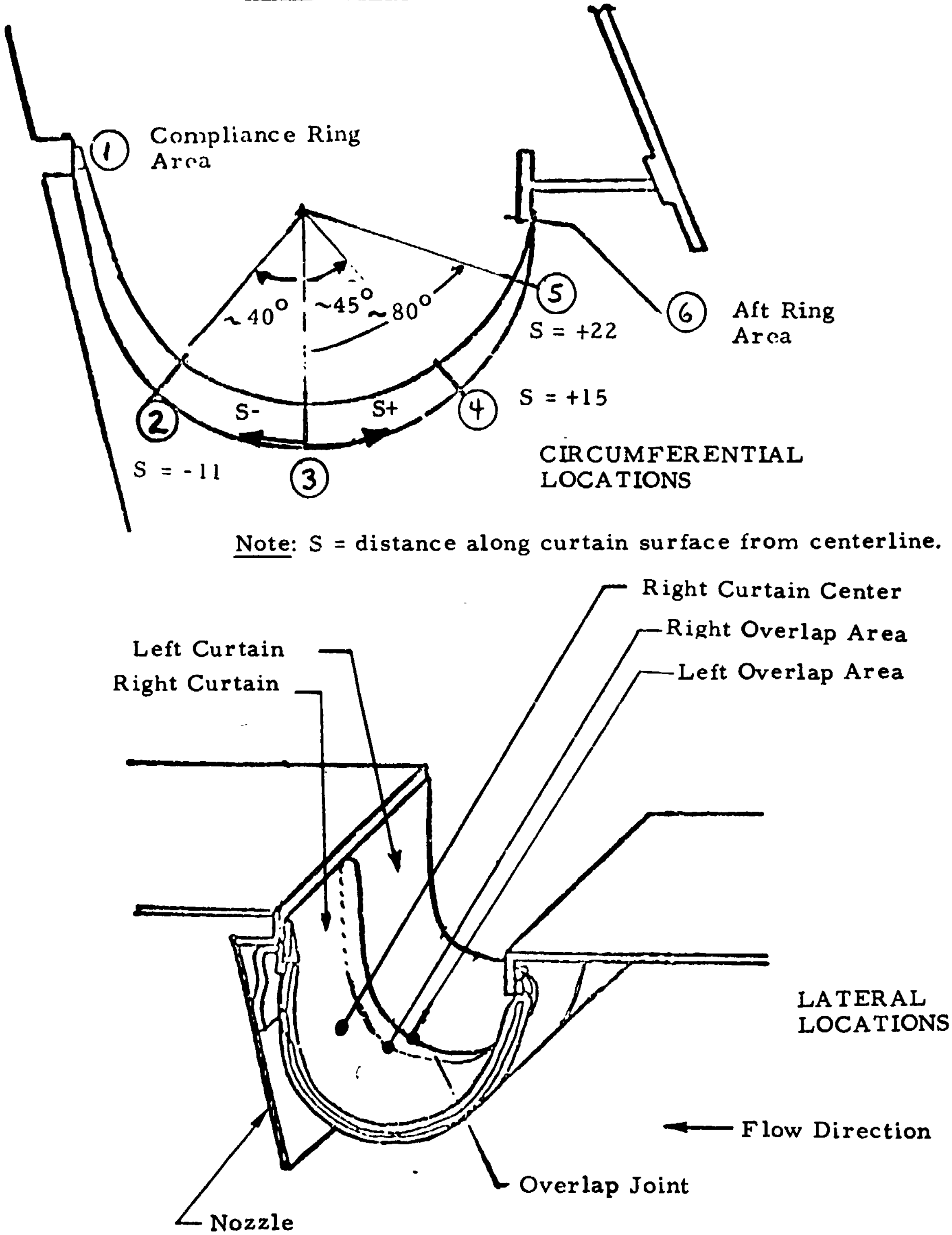


Fig. 5 - Thermocouple Locations

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(Typical Circumferential Locations 2, 3, 4, 5)

Notes:

1. ⊗ = Thermocouple Locations
2. Total No. T.C. This Page = 24
3. T.C. Nos. 6 and 7 Apply Only to Locations 2 and 3

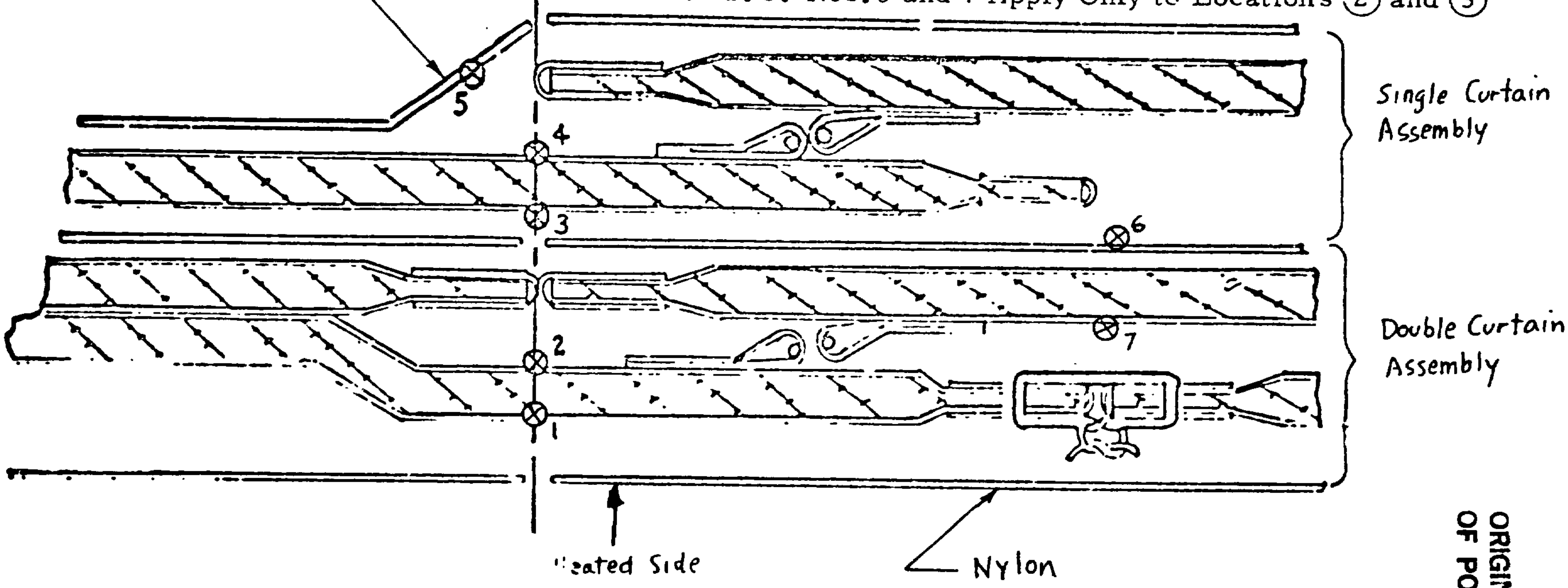


Fig. 6 - Thermal Curtain Thermocouple Locations (Left Overlap Joint Area plus Two Locations on Right Overlap Joint Area)

(Typical Circumferential Locations (4), (5))

Notes:
⊗ = Thermocouple
Total No. T.C.'s This Page = 10

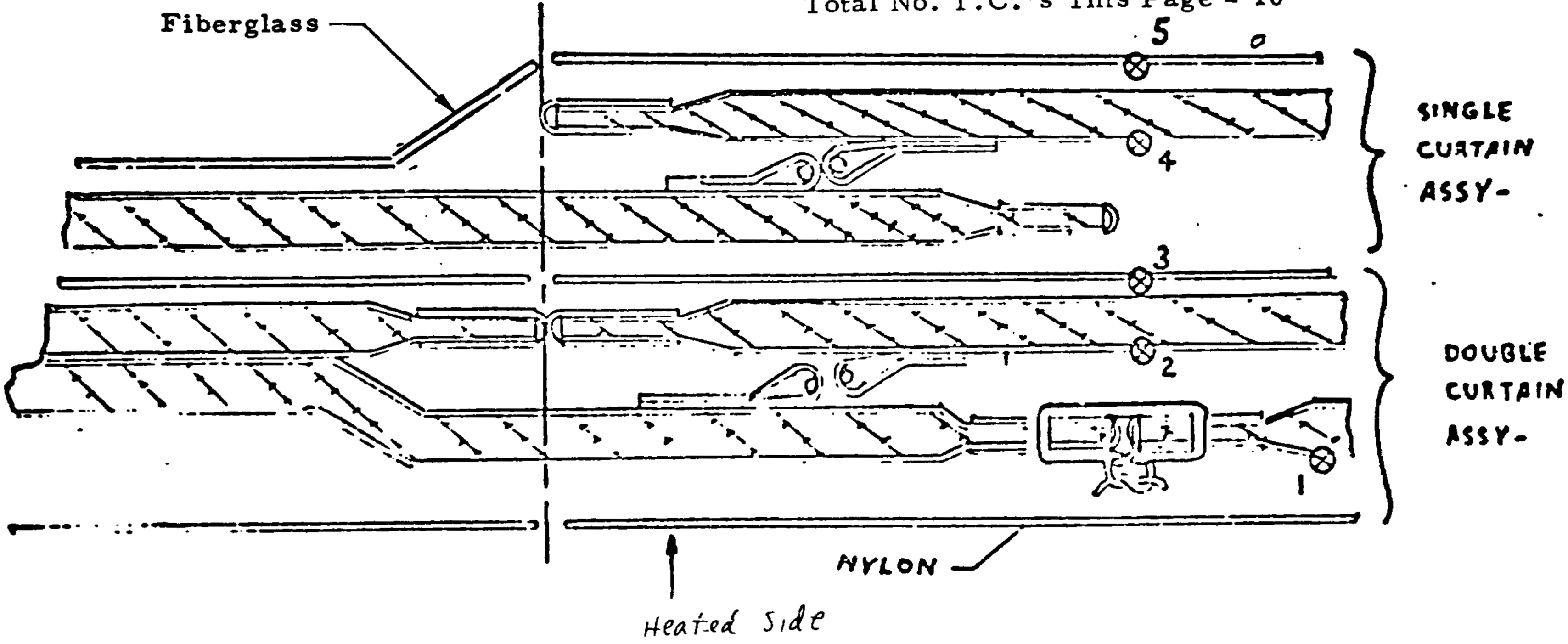


Fig. 7 - Thermal Curtain Thermocouple Locations (Right Overlap Joint Area)

Notes:

1. ⊗ Thermocouple Locations
2. Total No. T.C. This Page = 3
3. Applies to Circumferential Location (4) Only

(Circumferential Location (4) Only)

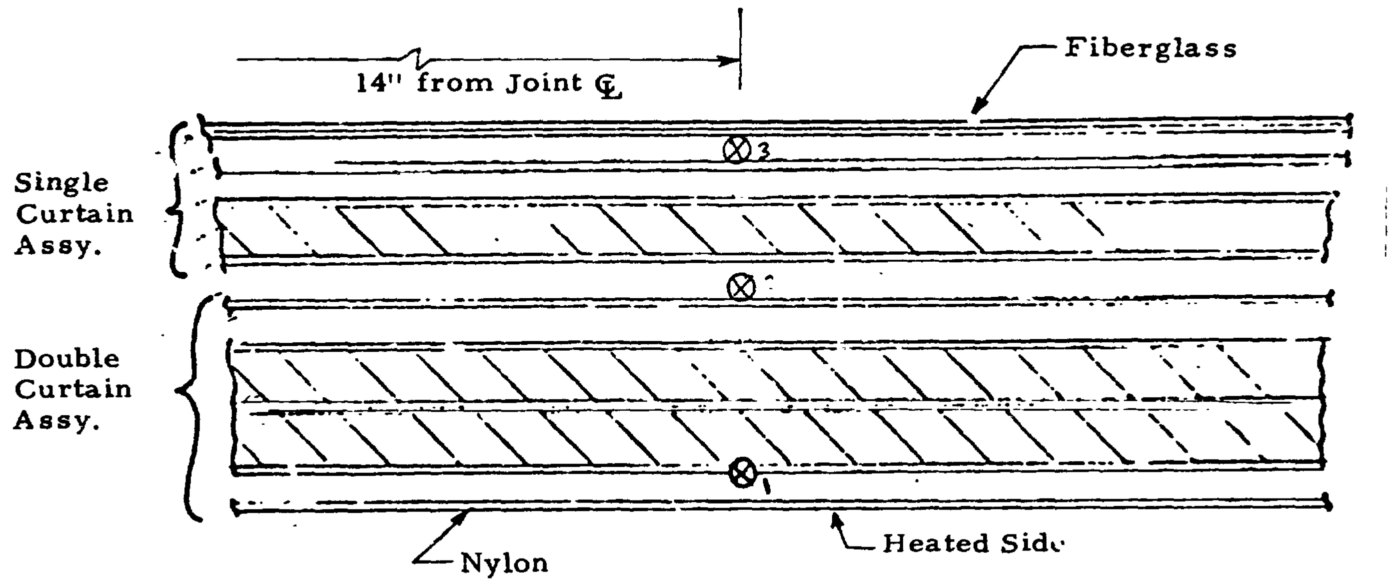
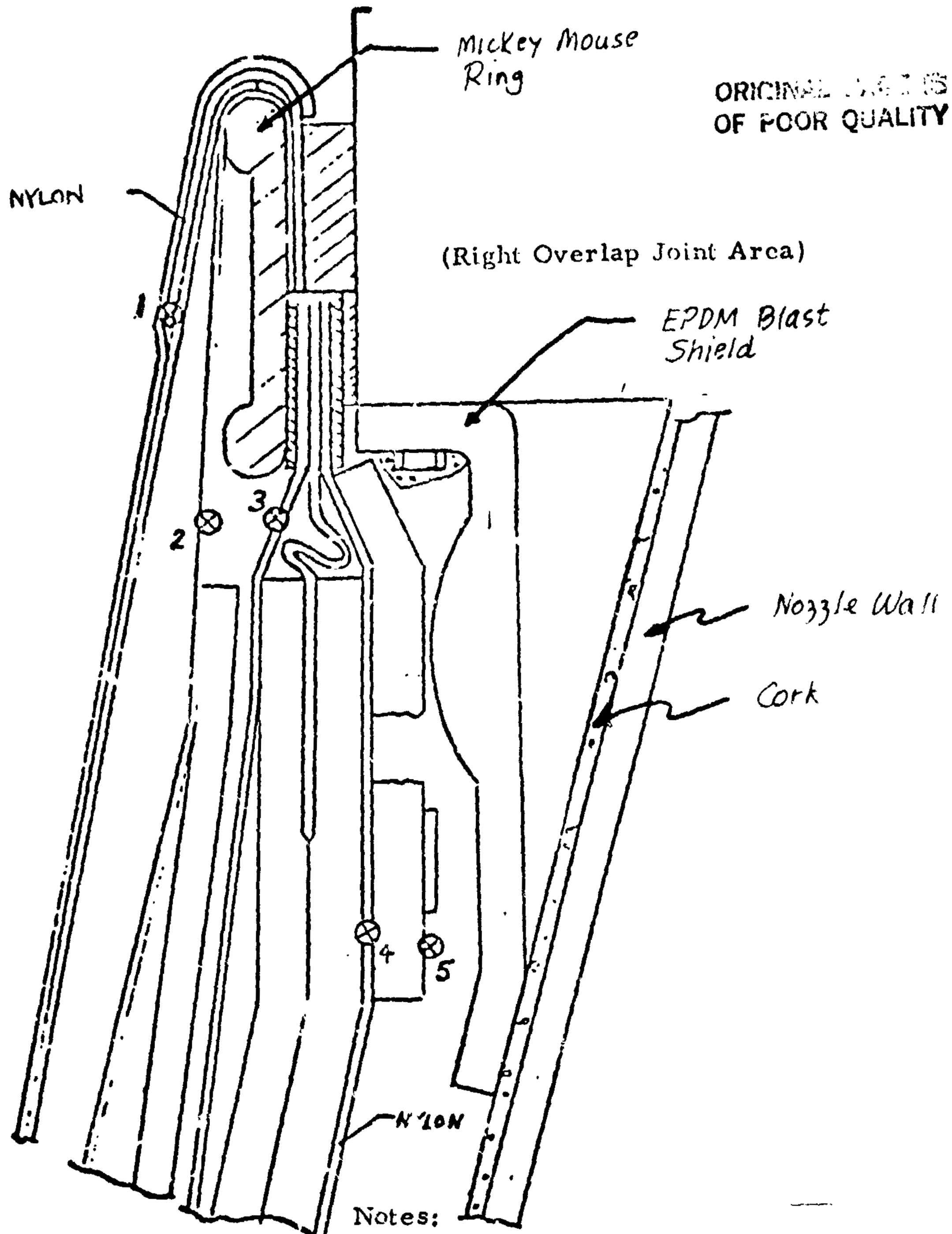
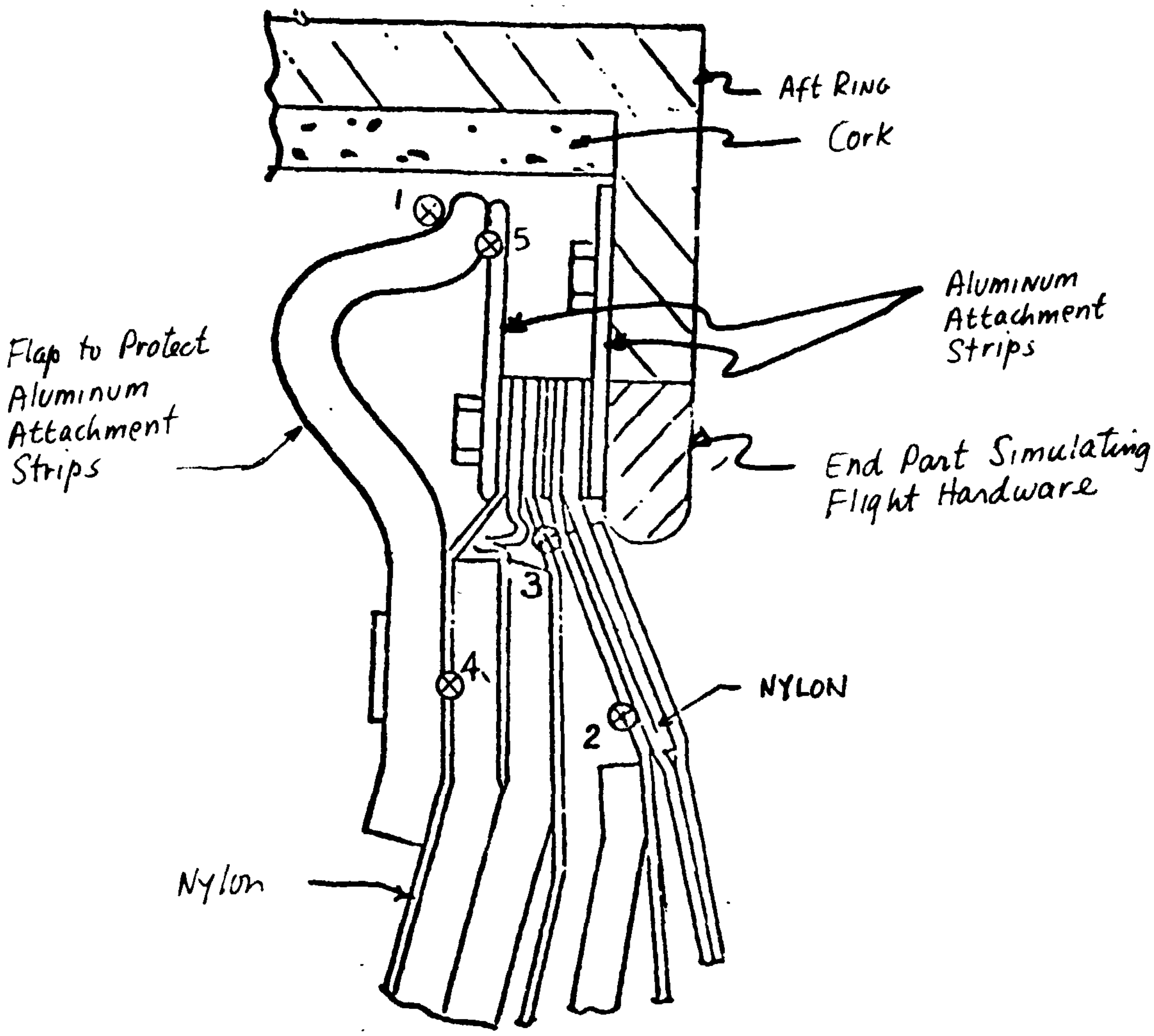


Fig. 8 - Thermal Curtain Thermocouple Locations (Right Curtain Center)



Notes:
1. ⊗ = Thermocouple Location
2. Total Number TCs This Page = 5.

Fig. 9 - Thermal Curtain Thermocouple Locations (Nozzle/Compliance Ring Area)



1. ⊗ = Thermocouple Location
2. Total No. Thermocouples This Page = 5
3. Right Overlay Joint Area

Fig. 10 - Thermal Curtain Thermocouple Locations (Aft Ring Area)

Fig. 11 - Calibration Rig Installed in LRLF

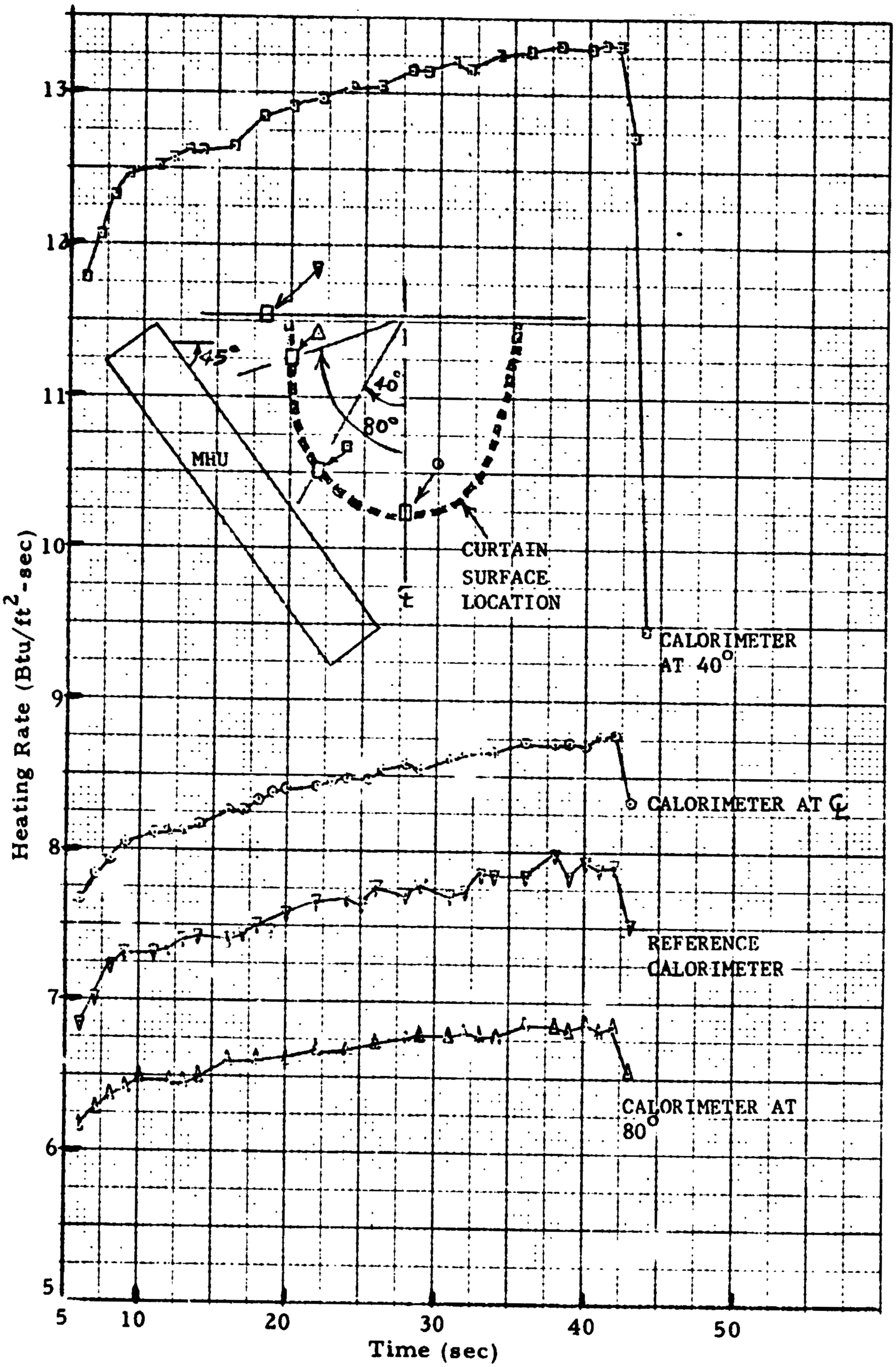


Fig. 12 - Pretest Calibration Run (Heating Rates vs Time)

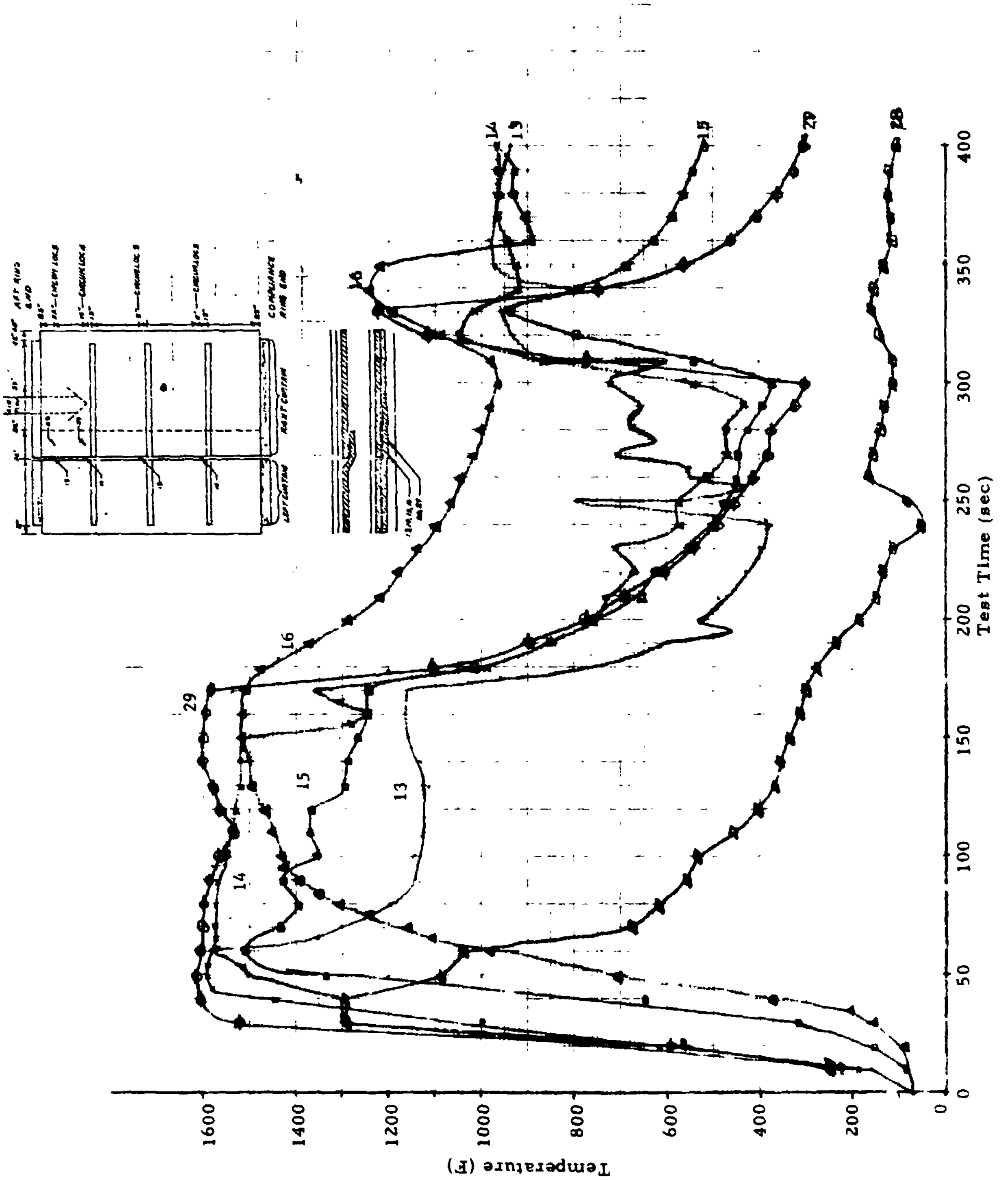


Fig. 13 - Temperature vs Time for All Outer Surface Thermocouples

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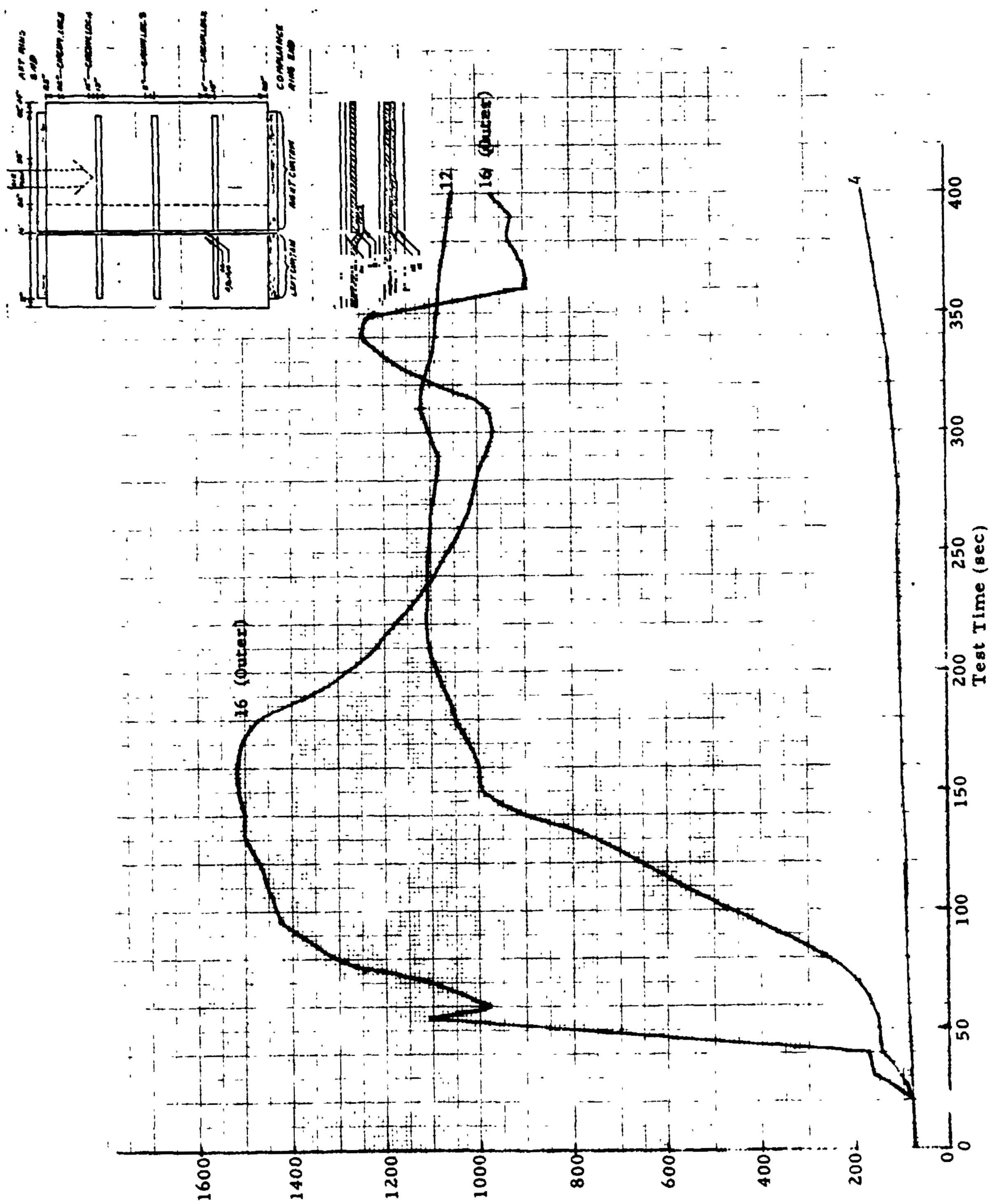

Fig. 14 - Temperature vs Time for Thermocouples 12 and 16

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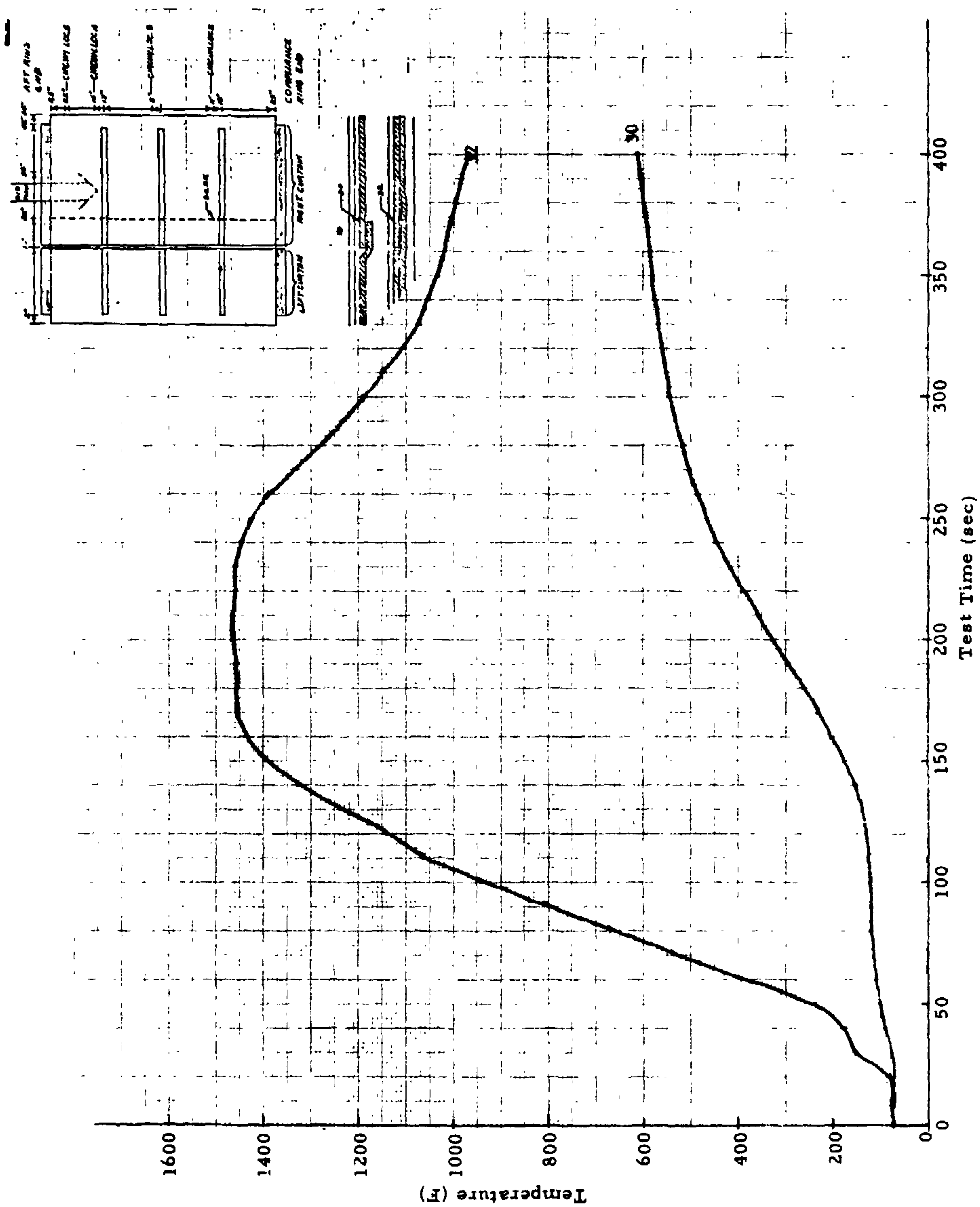

Fig. 15 - Temperature vs Time for Thermocouples 30 and 32

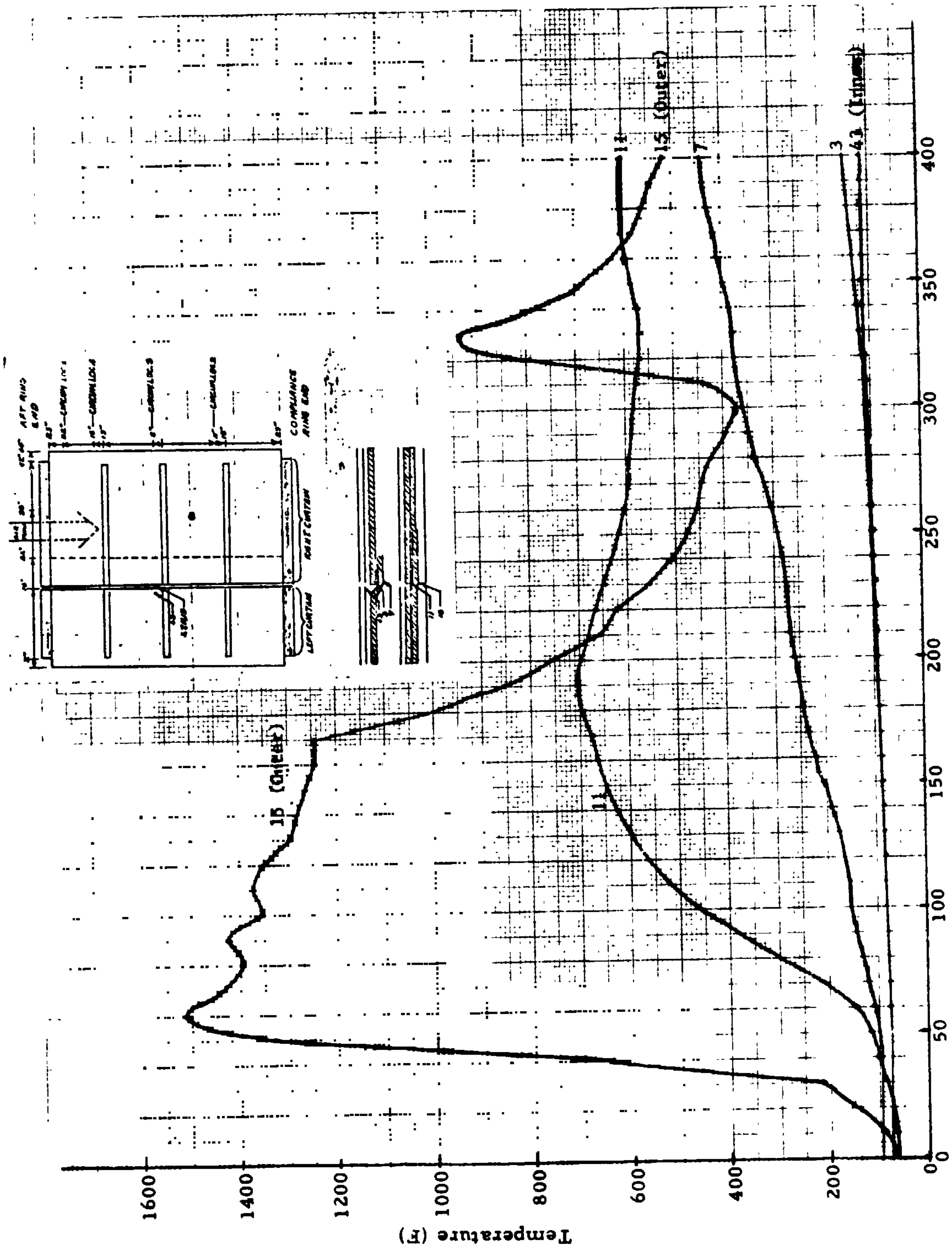

Fig. 16 - Temperature vs Time for Thermocouples 3, 7, 11, 15 and 43

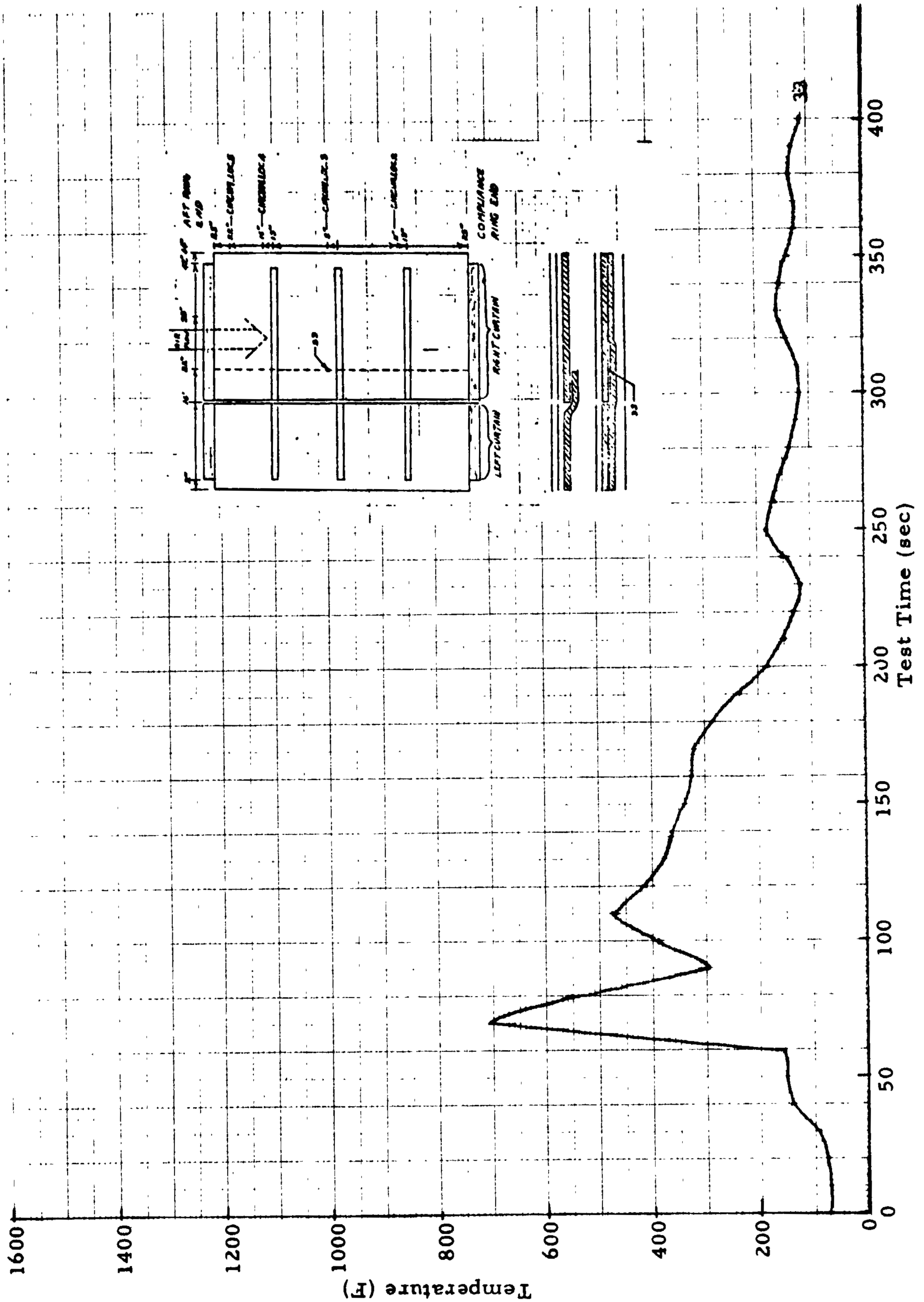

Fig. 17 - Temperature vs Time for Thermocouple 33

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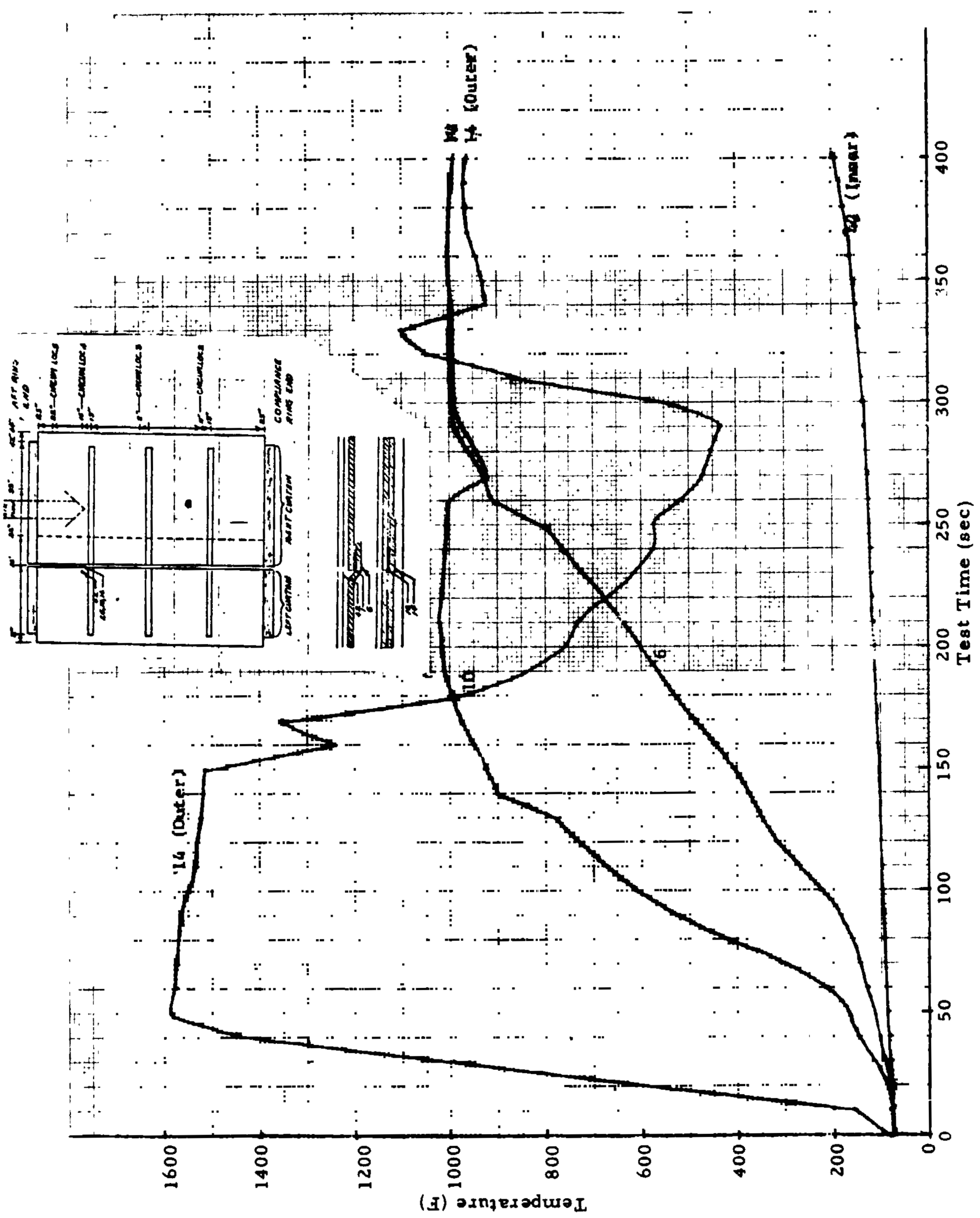

Fig. 18 - Temperature vs Time for Thermocouples 10, 14 and 42

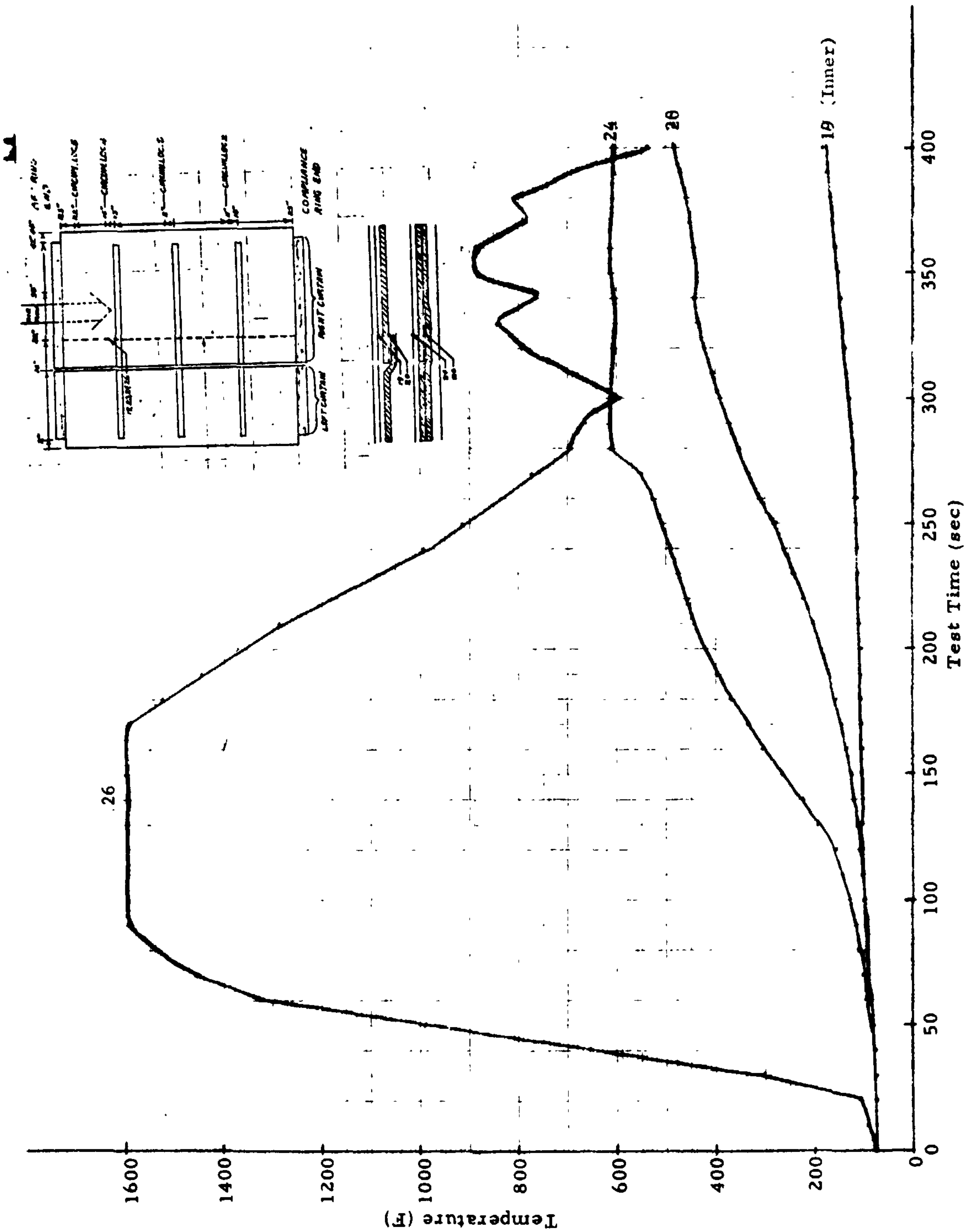

Fig. 19 - Temperature vs Time for Thermocouples 19, 20 and 24

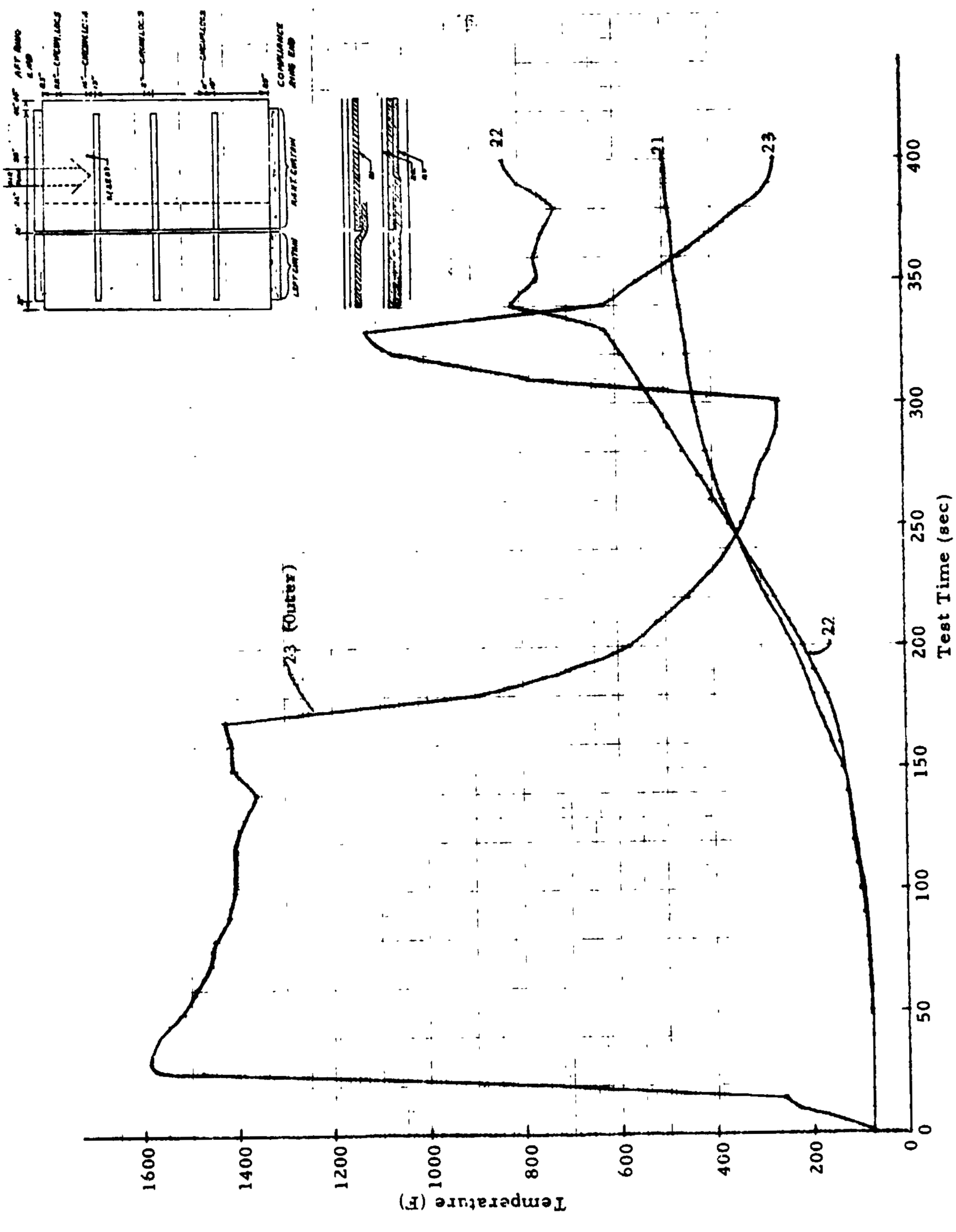

Fig. 20 - Temperature vs Time for Thermocouples 21, 22 and 23

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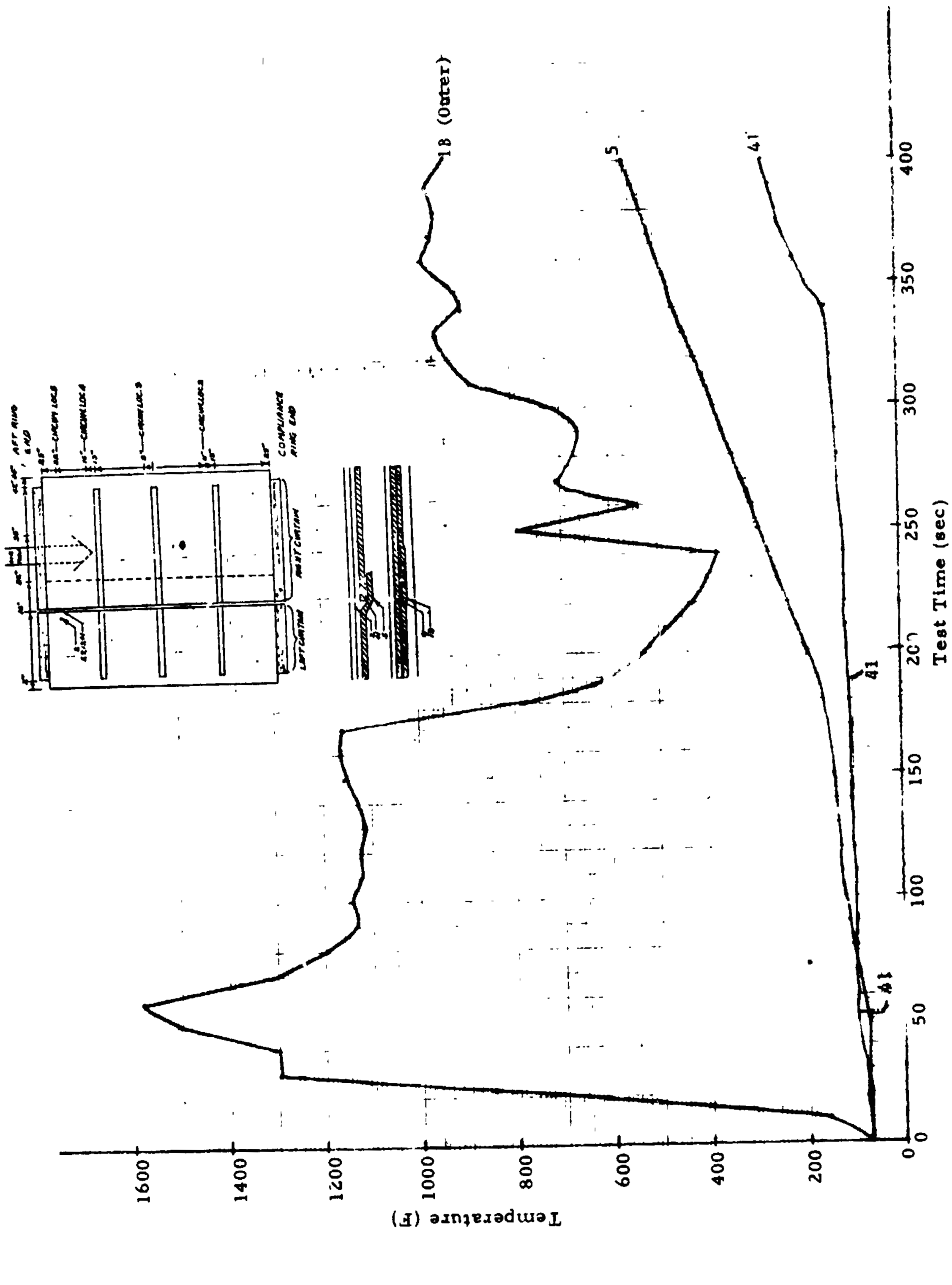

Fig. 21 - Temperature vs Time for Thermocouples 5, 13 and 41

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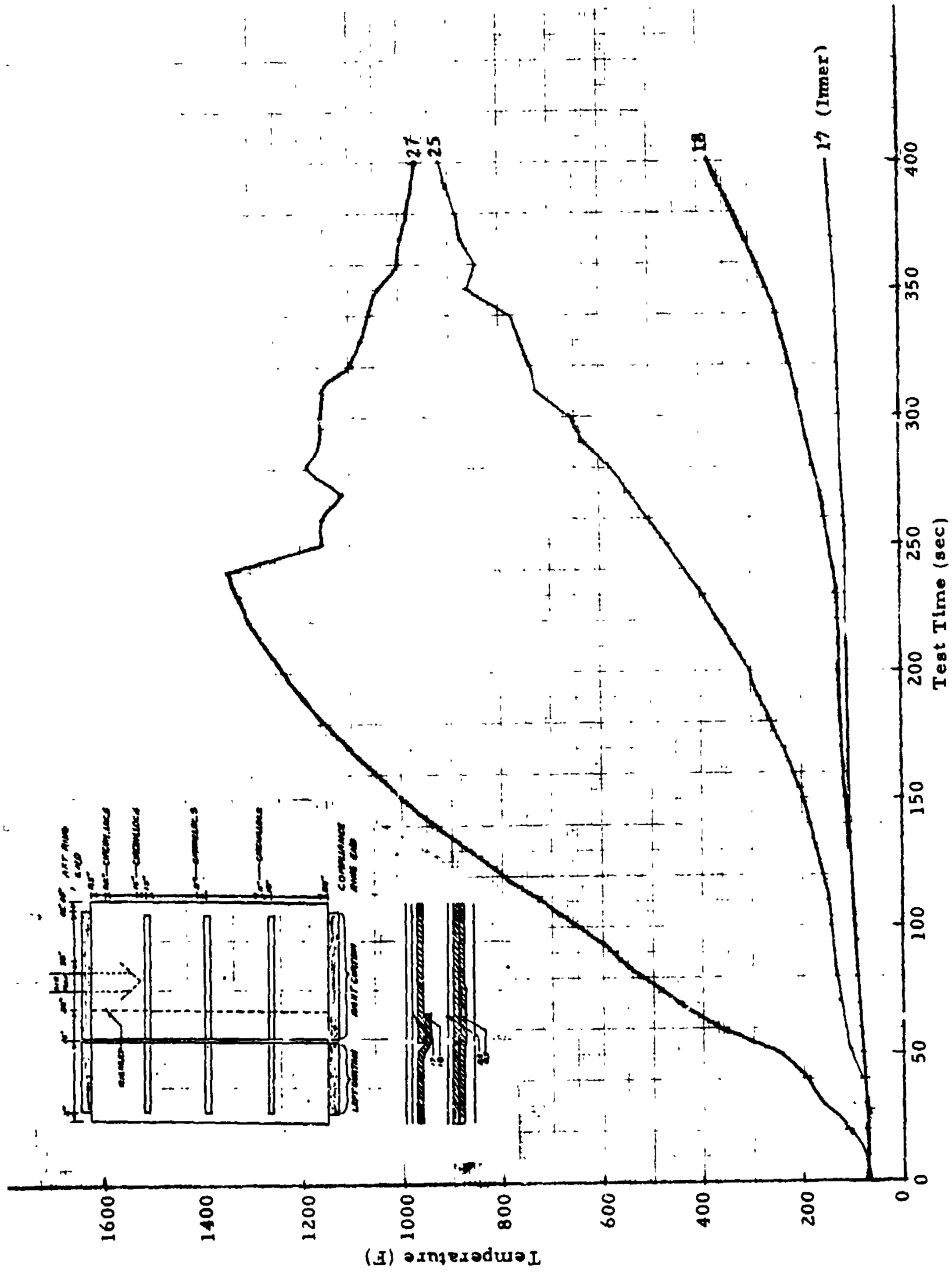

Fig. 22 - Temperature vs Time for Thermocouples 17, 18, 25 and 27

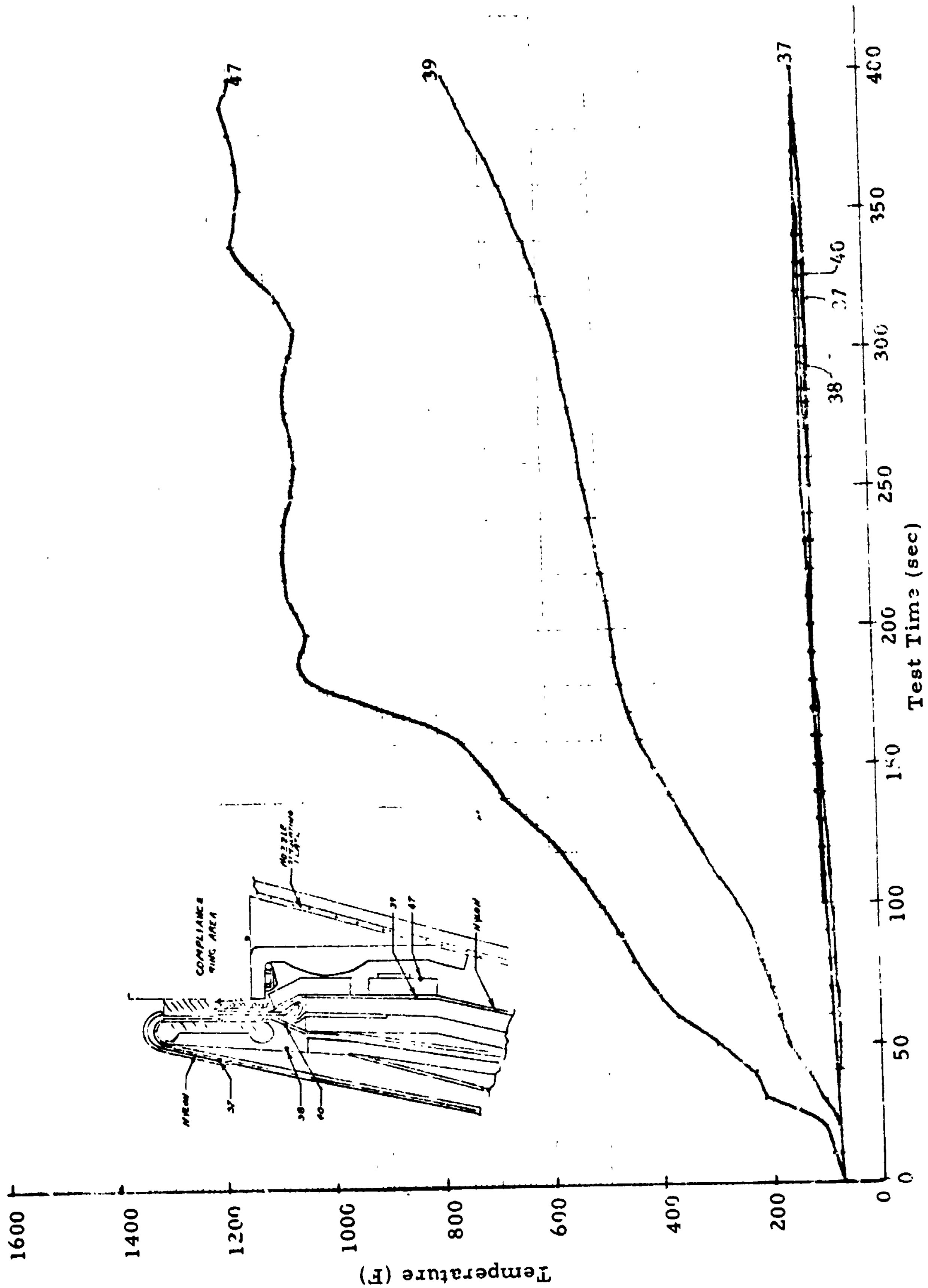

Fig. 23 - Temperature vs Time for Thermocouples 37, 39, 47

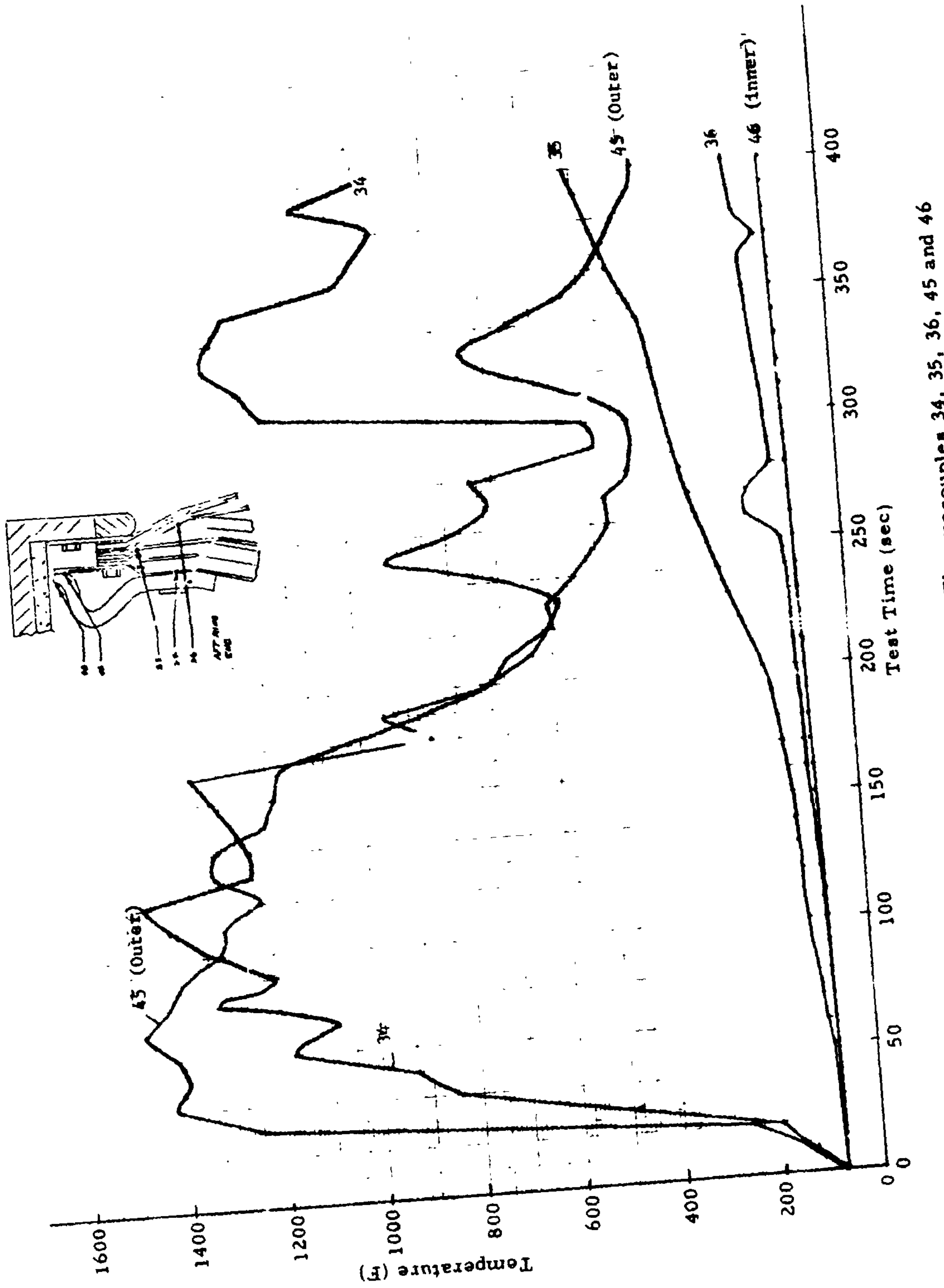

Fig. 24 - Temperature vs Time for Thermocouples 34, 35, 36, 45 and 46

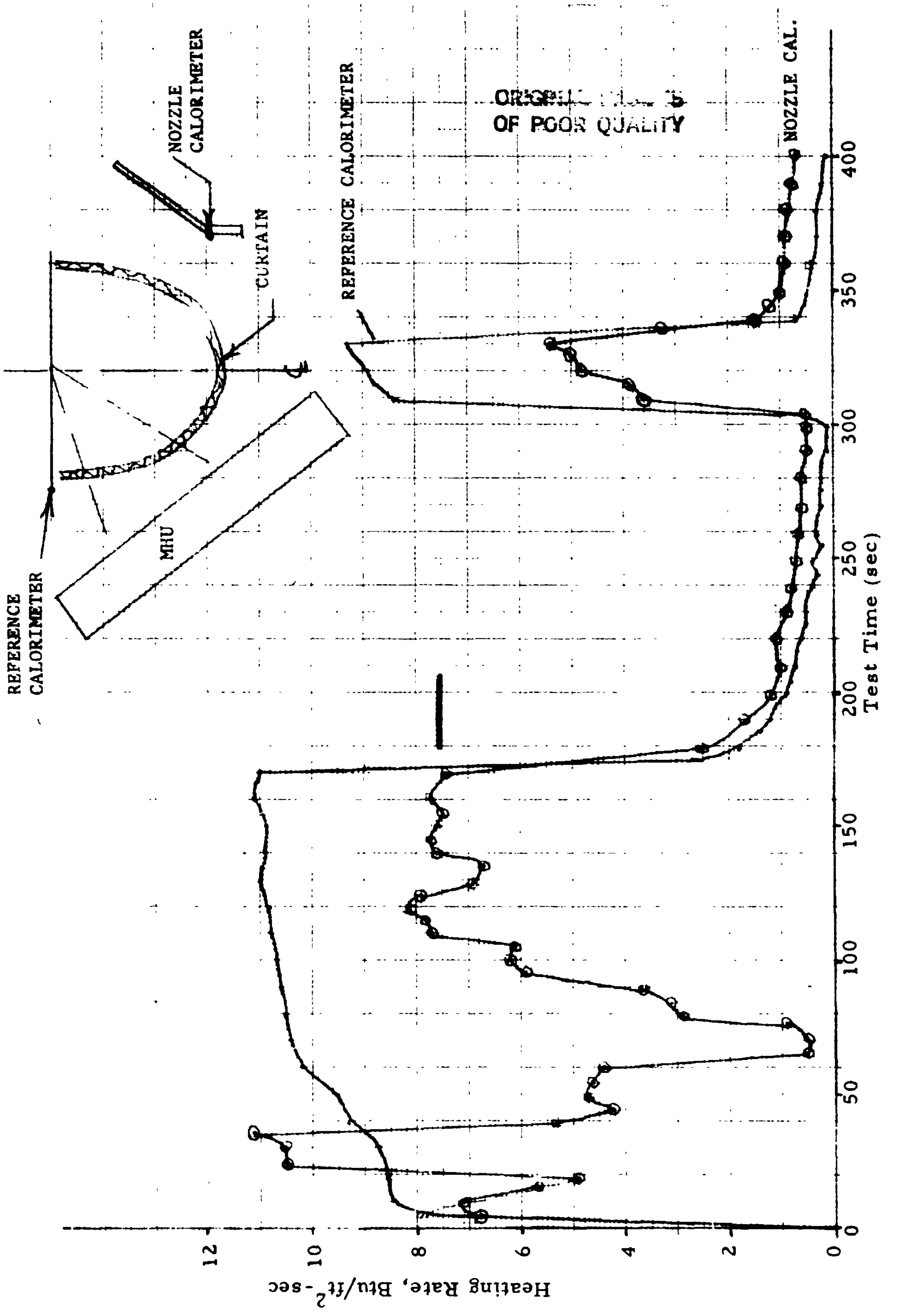

Fig. 25 - Heating Rate vs Time During Curtain Thermal Test for Reference and Nozzle Calorimeters

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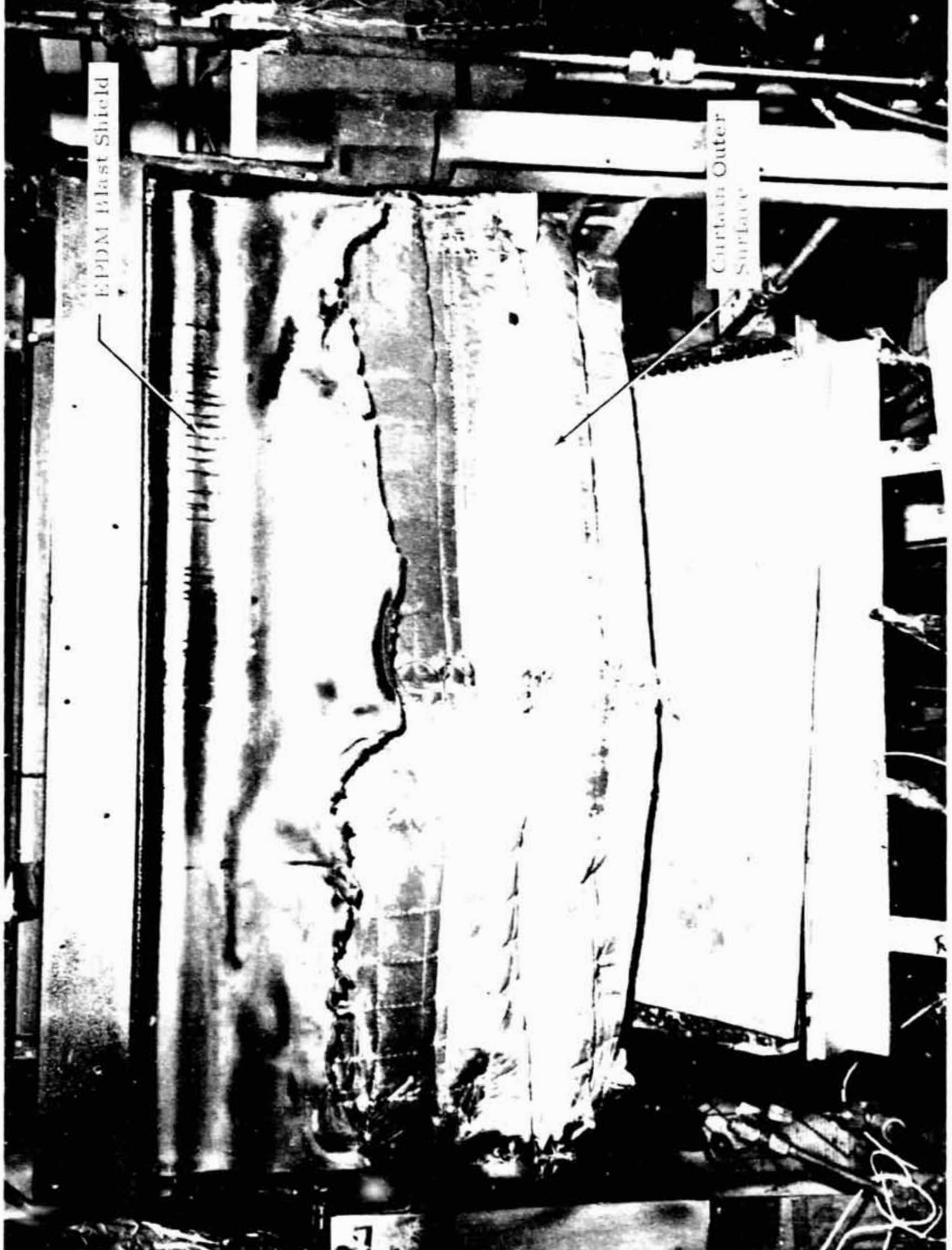

Fig. 26 - Post-Test Photo of Curtain Looking Upstream from the Nozzle End (EPDM Continued to Burn for a Considerable Period After Test Termination)

Fig. 27 - Post-Test Photo of Curtain Still Insalled in LRLF

Fig. 28 - Post-Test Photo of Curtain Still Installed in LRLF

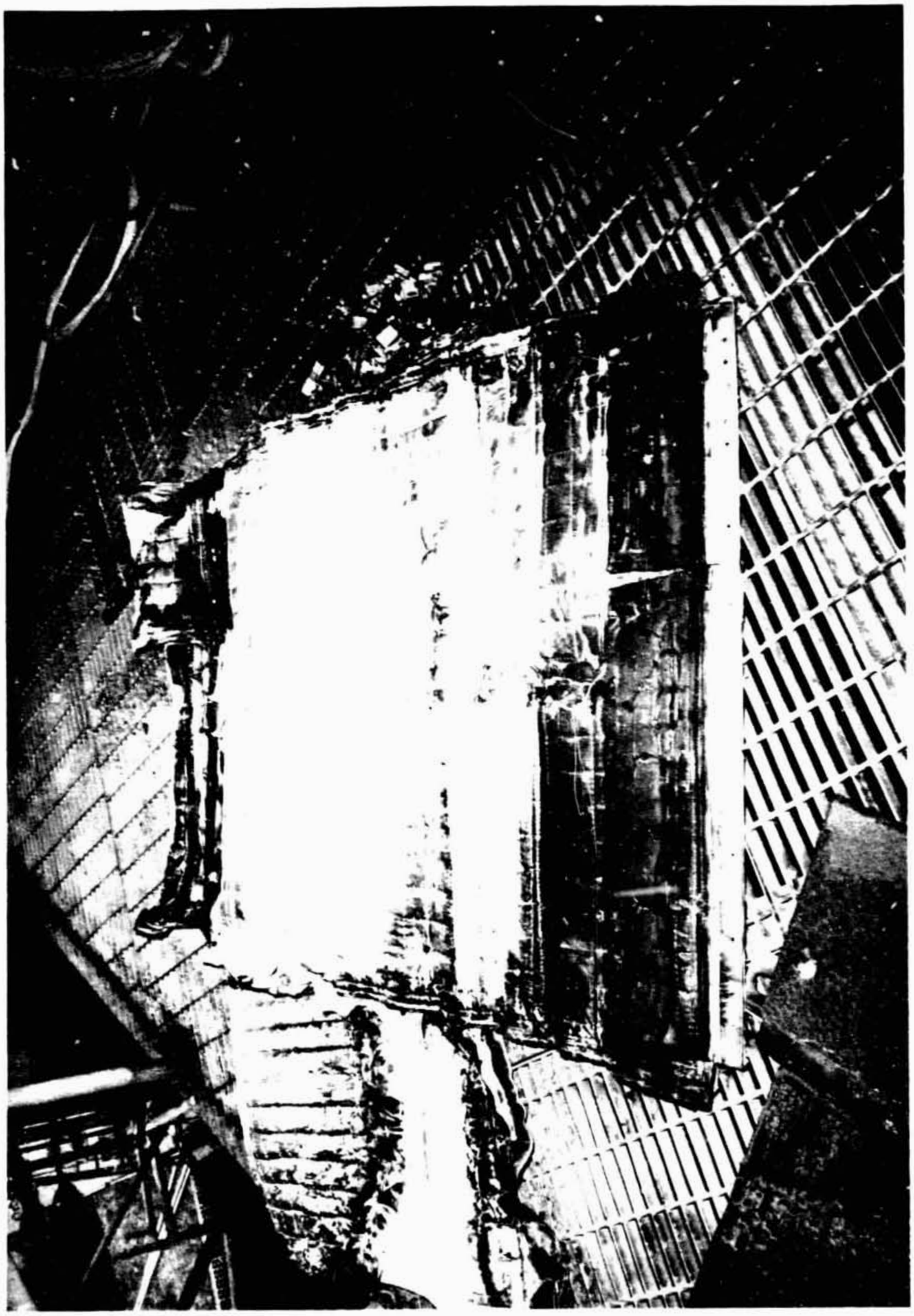

Fig. 29 - Post-Test Photo of Curtain Just After Being Taken Out of LRLF
(Outer Curtain, Outer Surface)

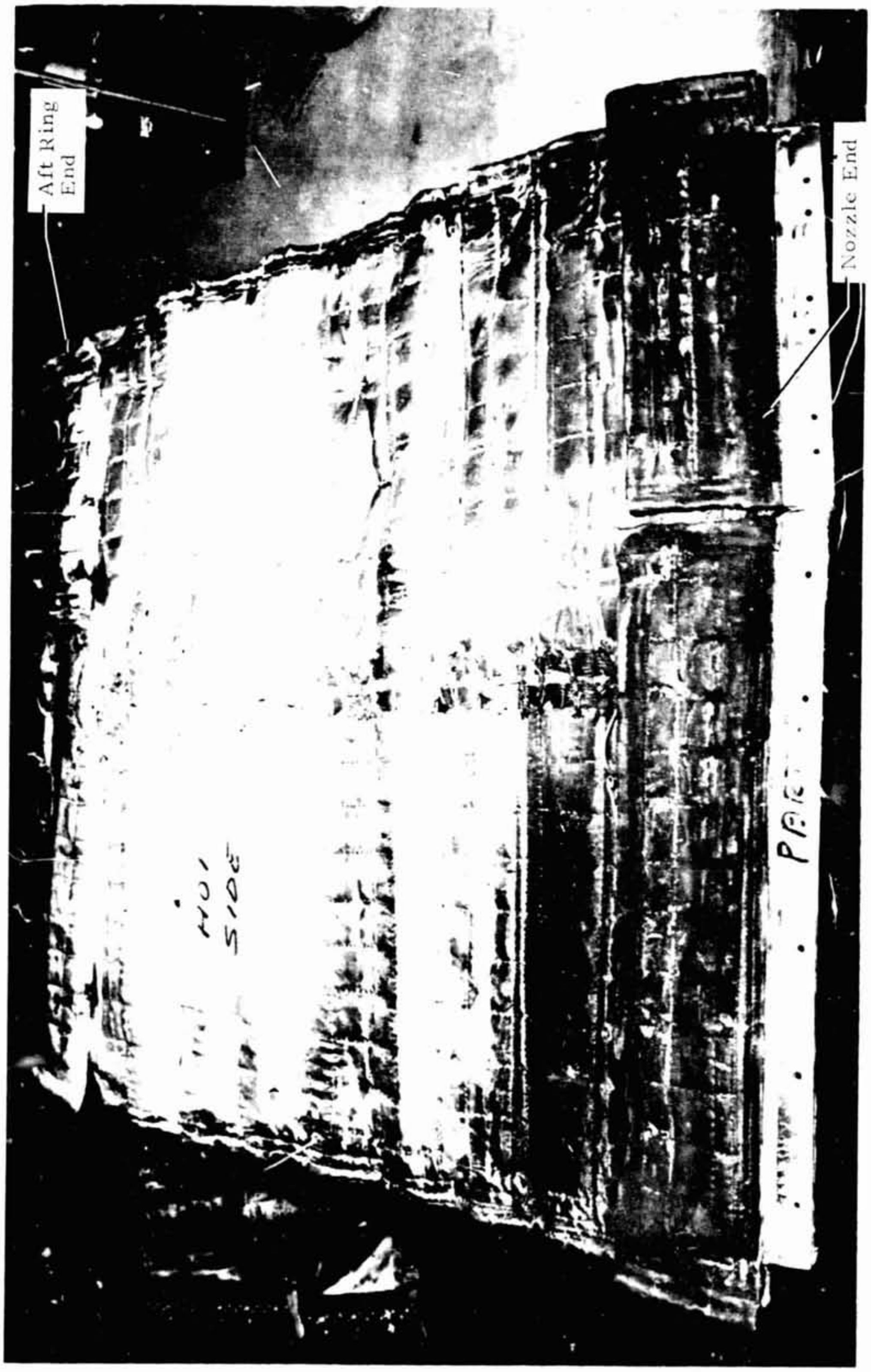

Fig. 30 - Closeup Post-Test Photo of Outer Curtain, Outer Surface

Fig. 31 - Post-Test Photo of Outer Curtain, Outer Surface Showing Flaps Turned Back, Aft Ring End

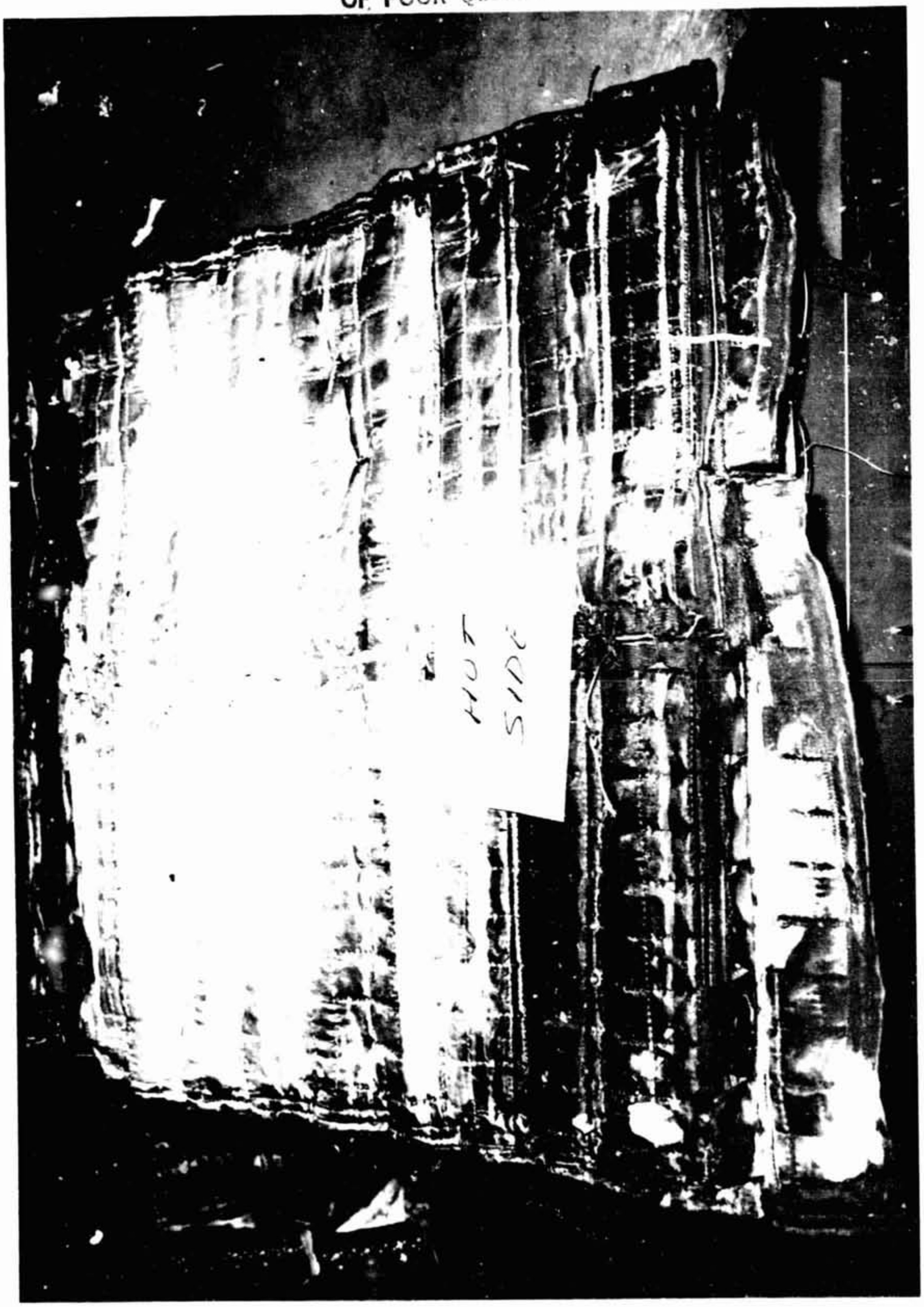

Fig. 32 - Post-Test Photo of Outer Side of Outer Curtain Showing Flaps Turned Back on Nozzle End

Fig. 33 - Post-Test Photo of Outer Curtain, Outer Surface with Flaps Turned Back Looking in the Downstream Direction

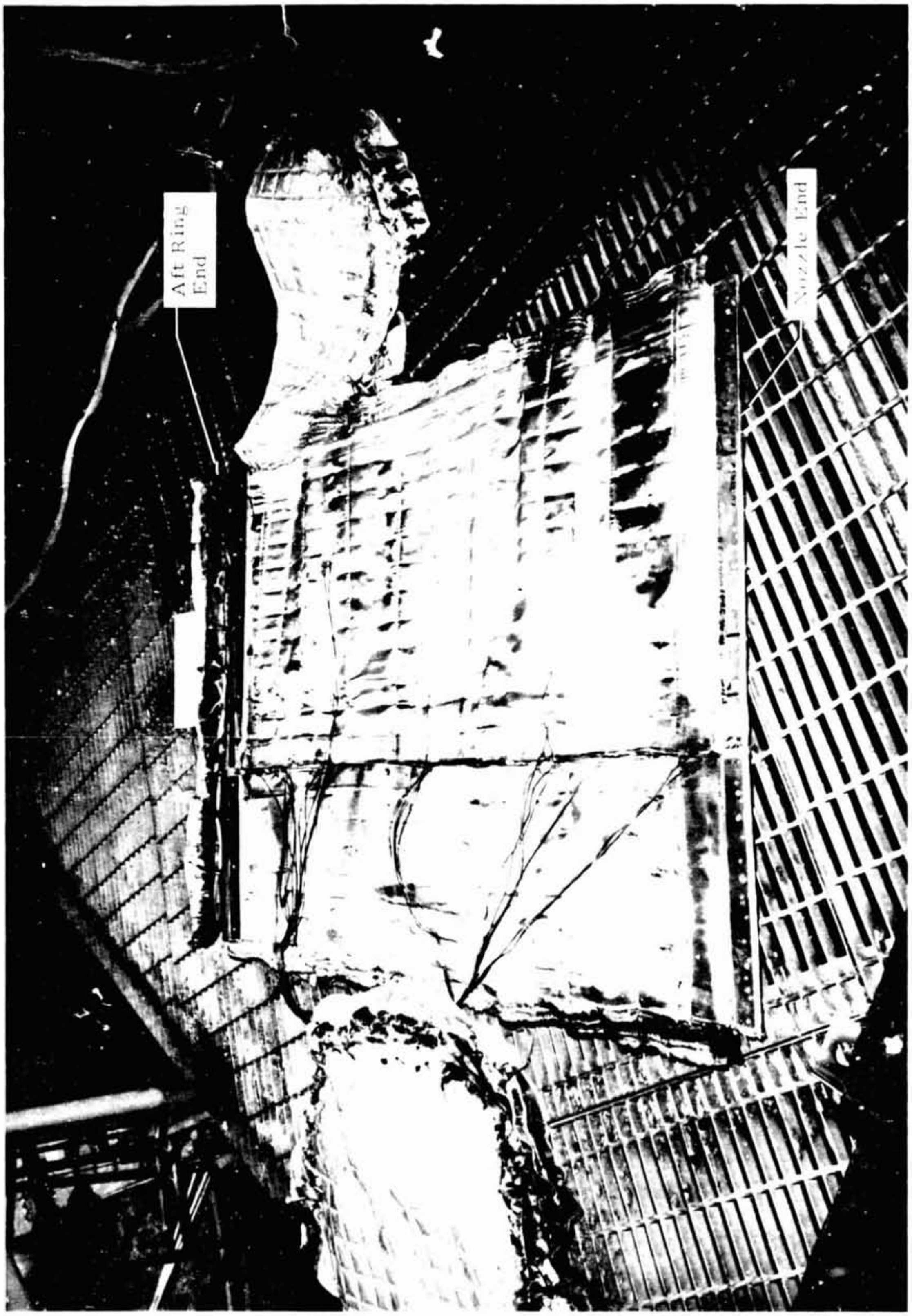

Fig. 34 - Post-Test Photo of Inside Surface of Outer Curtain

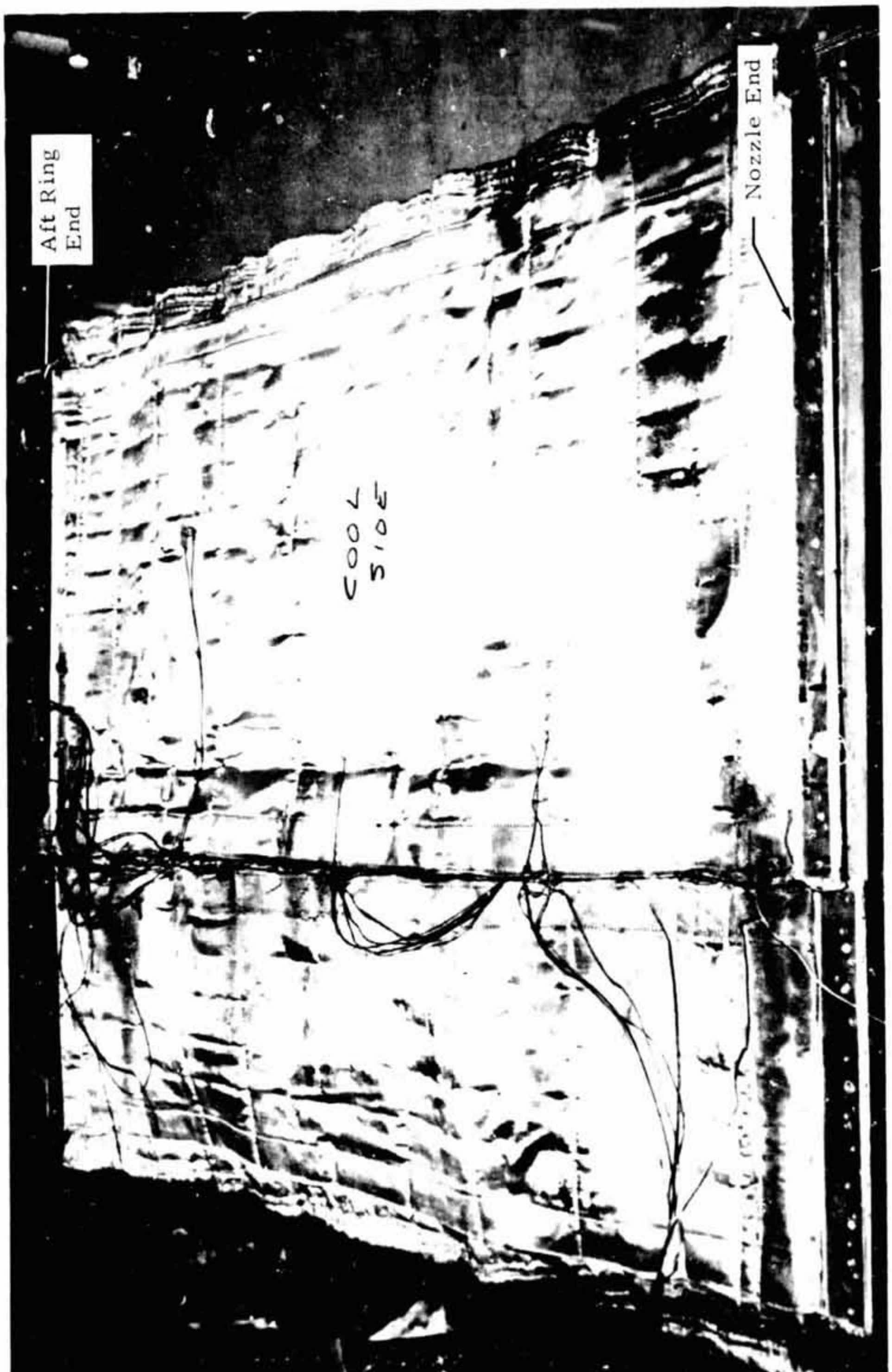

Fig. 35 - Post-Test Photo of Closeup View of Inside Surface of Outer Curtain

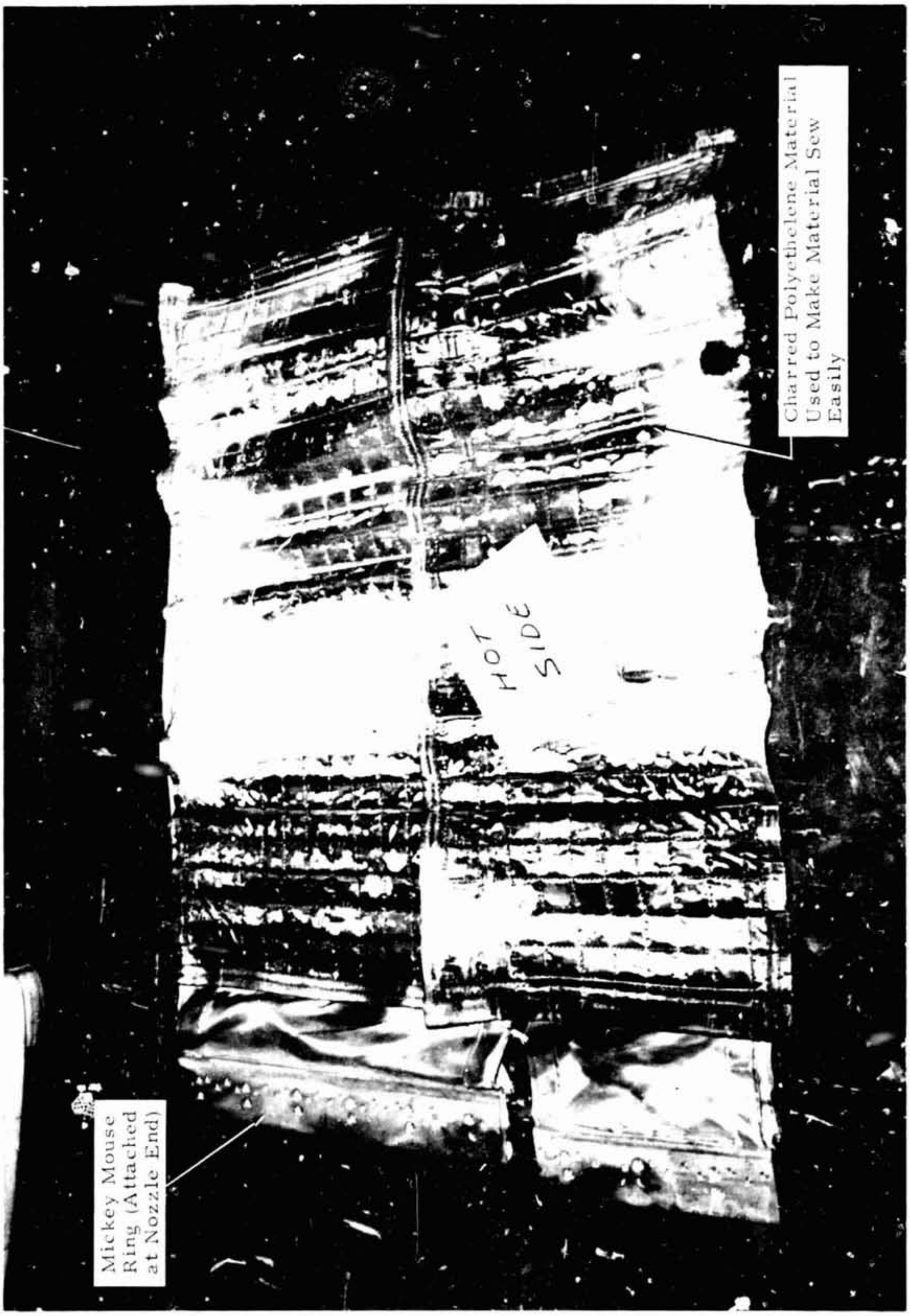

Fig. 36 - Post-Test Photo of Outer Hot Side Surface of Inner Blanket

Fig. 37 - Post-Test Photo of Cool Side Surface of Inner Curtain

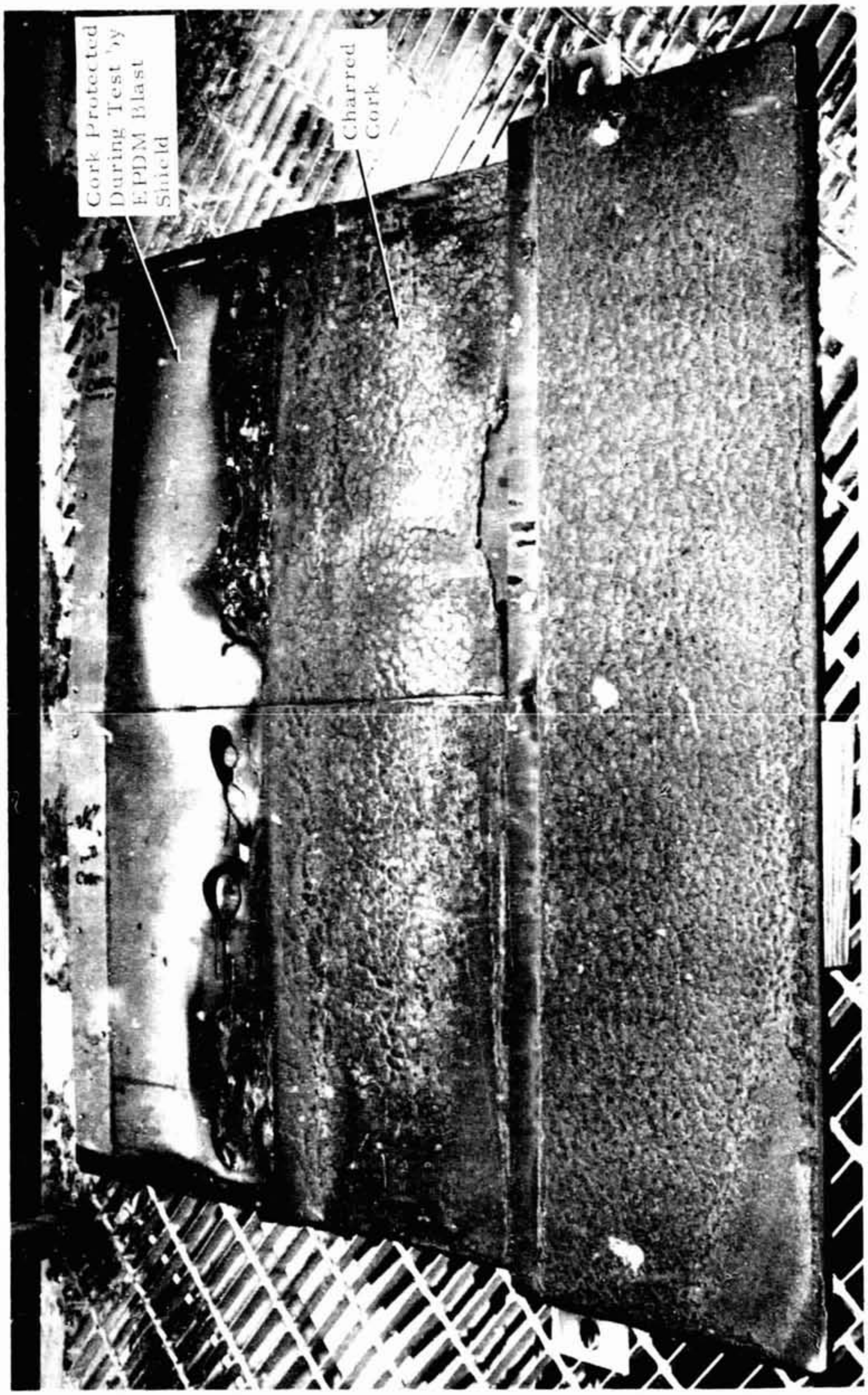

Fig. 38 - Post-Test Photo of Nozzle Simulator Plate

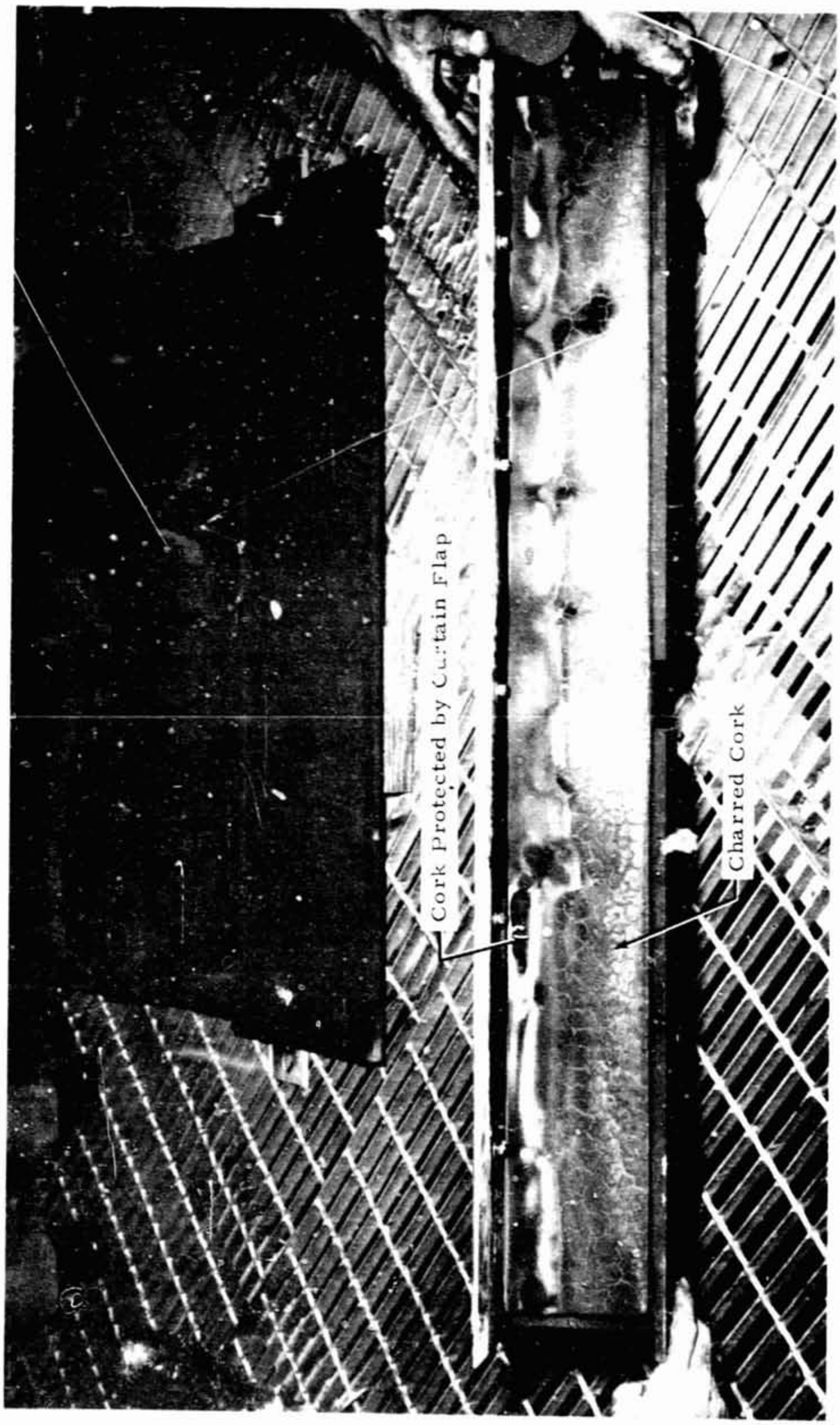

Fig. 39 - Post-Test Photo of Aft Ring Attachment

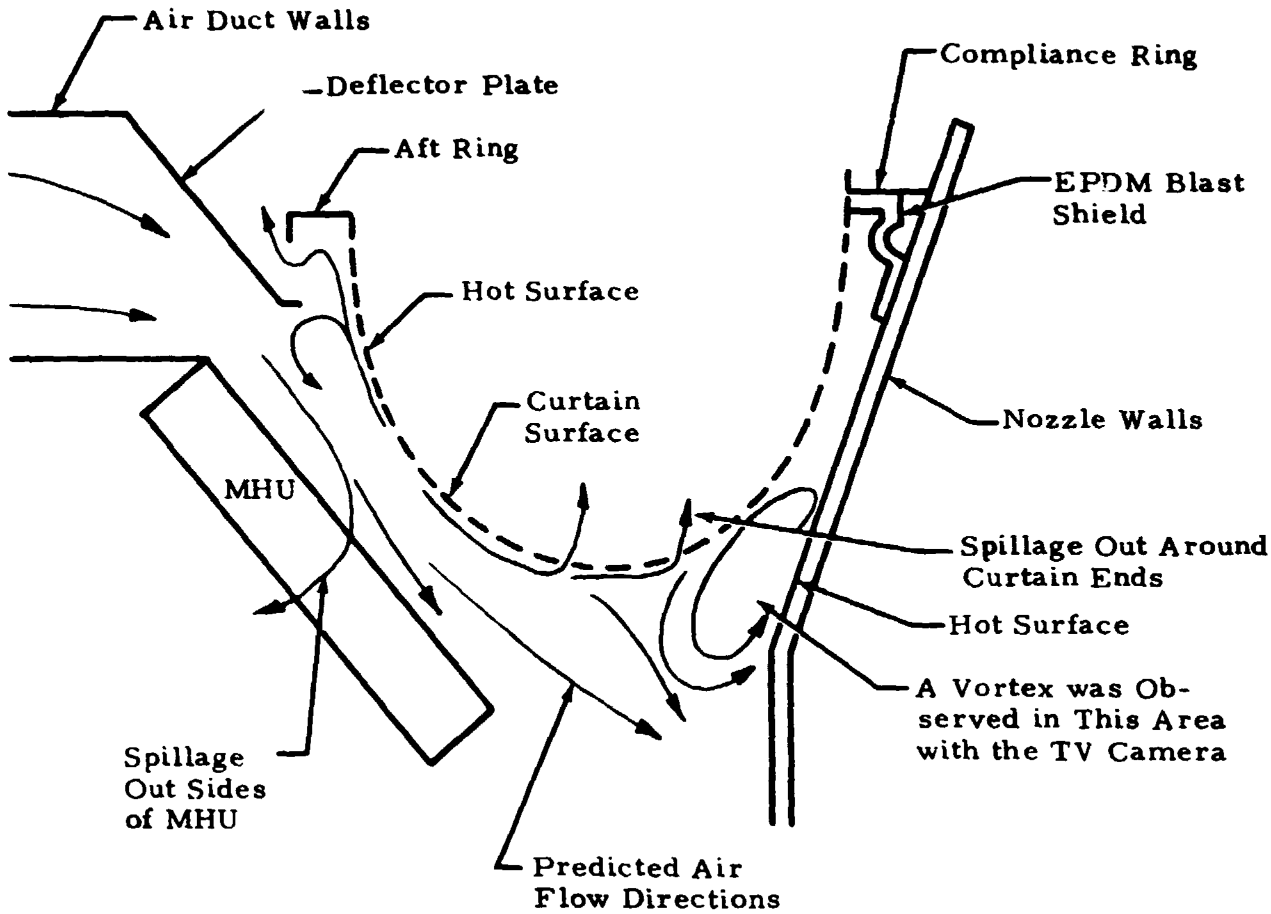

Fig. 40 - Qualitative Prediction of Air Flow Pattern Around Curtain, Nozzle, and MHUs.

Notes:

1. ○ θ = 40 deg
2. □ θ = 80 deg
3. ◇ Reference Calorimeter
4. Calorimeter at θ = 0 deg was bad

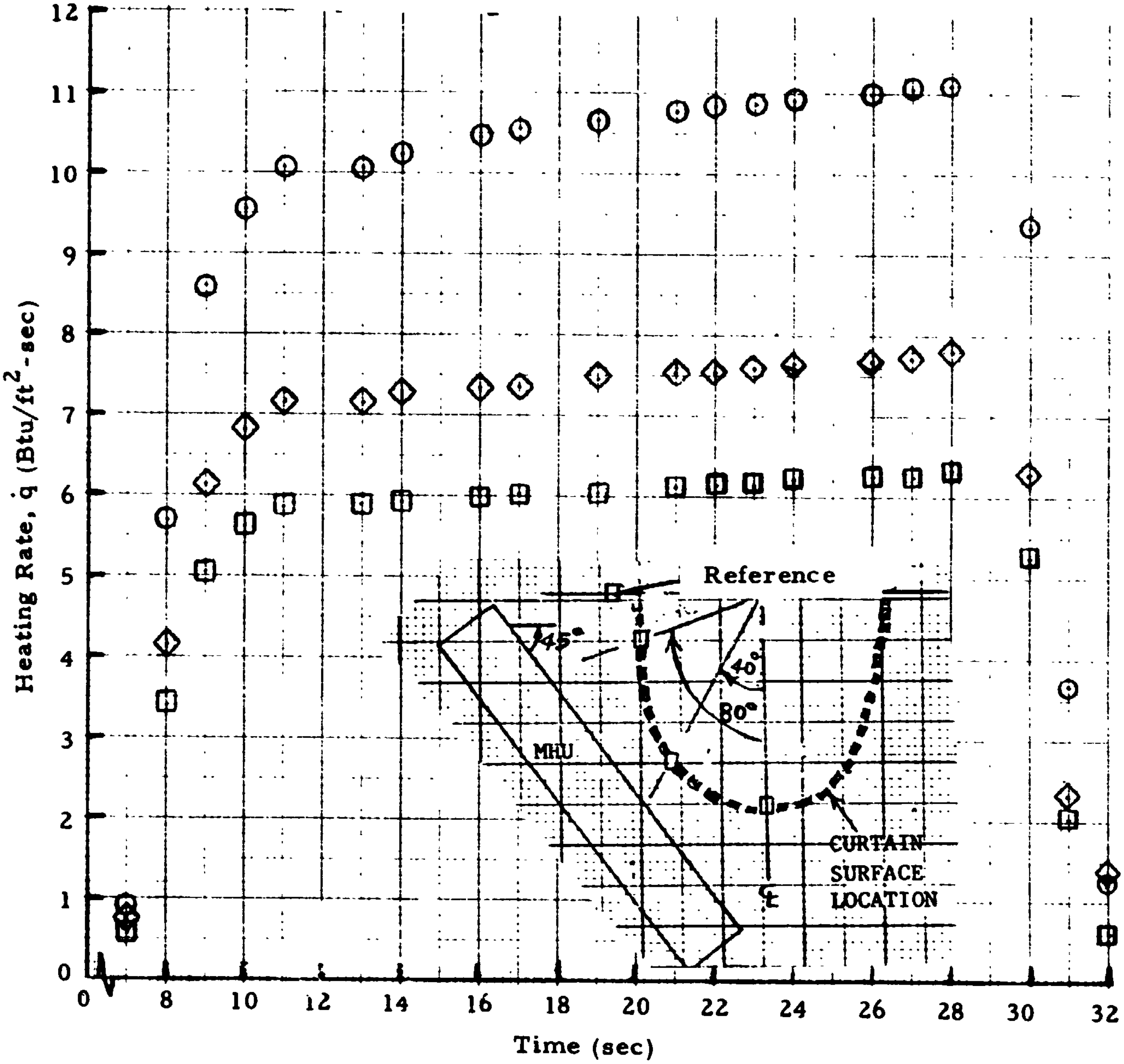

Fig. 41 - Heating Rate vs Time for Post-Test Calibration Run