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SRB ATTACH RING PHENOLIC TPS FISHTAIL SEAL EVALUATION TESTS

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FOREWORD

This report documents tests performed on the Space Shuttle Solid Rocket Booster (SRB) aft attach ring fishtail seal. The work was performed under Contract NAS8-32982, "Solid Rocket Booster Thermal Protection System Material Development." The NASA Contracting Officer's Representative for this work is Mr. Bill Baker, EP44.

CONTENTS

INTRODUCTION

The SRB attach ring is thermally protected with layered phenolic cloth fairings that are fastened to the ring. The gap between the fairings and the motor case is closed off with a rubber seal of a "fishtail" cross-sectional shape bonded to the phenolic. On both the STS-1 and STS-2 flights this gap was discovered to vary anywhere from an intended gap of 0.375 in. to an actual measured gap of 0.60 in. due to tolerances. This raised concern that the rubber seal would not be able to perform its function of keeping the hot flow from inside the ring which houses important components such as electrical cables. Tests were conducted with and without a 0.25 in. thick cork shim placed under the seal with a 0.60 in. gap under the phenolic TPS to determine and compare the performance of the seal in the two different configurations. This was also done with and without the seal bonded to the phenolic fairings at the front of the seal groove in addition to the usual bonding at the back and bottom of the groove.

To alleviate the difficult and costly procedure of installing the cork shim under the seal, especially after phenolic TPS mounting on the attach ring, "large" fishtail seals of identical Edler gray silicone material and two different hardnesses were tested. A similar matrix of tests was conducted with this new large fishtail seal,and seals with both type hardnesses performed well regardless of whether or not the seal was bonded to the phenolic at the front of the seal groove. Similar results had been obtained with the original small fishtail seal which performed adequately with the 0.25 in. cork shim under it.

TECHNICAL DISCUSSION

The evaluation of the fishtail seal was first started on the fixture used for the development testing of the phenolic TPS in the NASA-MSFC Hot Gas Facility. The fixture was mounted on the test panel at a 41-deg angle to the flow (see Figs. 1 through 6). The seal, when tested in this orientation, was seen to be exposed to a very high shear environment causing it to thin out and eventually break away from the TPS as seen in Figs. 4 and 6. Figures 1 and 2 are the pretest and post-test photographs of an E60C Viton fluoronated seal material which was the only other seal material tested. This material performed well, but was not pursued further because of possible contamination of the motor case surface due to the material melting and spreading its residue. To reduce the shear on the seal, the model was turned at 90 · g to the flow, but this led to very high heating on the top of the model causing the model to fail (see Figs. 7 and 8). This led to reducing the height of the model which concept was later used successfully in a series of runs to evaluate the fishtail seal.

A thin-skin calibration model of the reduced height attach ring fairing with both the small seal and the large seal was made up on a new fixture designed to test the seals. The two cal models are shown in Figs. 9 and 10. Since a low heating rate was desired on the models, they were first tested under lower than usual enthalpy conditions in the Hot Gas Facility (HGF run numbers 904 through 907). However, the recovery temperature obtained was much lower (less than 1400 F) than the desired maximum that occurs during peak heating in flight. Therefore the models were recalibrated at the usual higher enthalpy conditions (recovery temperature = 1680 F) for the heating rates (HGF run numbers 948 through 951). The heating rates and heat loads predicted for the forward or aft face of the attach ring were based on measurements to the flat vertical surface and not measurements made at the seal level. It was therefore decided to calibrate a clean flat vertical surface of the model without the seals as seen in the model of Fig. 11 (HGF run numbers 946 and 947). It was this calibration that provided the average heating rate at the seal level that was used to determine the test duration.

The maximum total heat load experienced by the fishtail seal in flight = 2017 Btu/ft^2 (as per Mr. Fisher, EP44). Allowing for a 25% overtest, the maximum heat load on the seal during test would be 2521 Btu/ft^2 (2017 x 1.25 Btu/ft^2). The average heating rate from the calibration runs of the forward face of attach ring cal model was 24 Btu/ft^2-sec giving a test duration required of 105 sec. Since the maximum run time in the HGF is limited to 60 sec, two tests 55 sec each were run to obtain the full heat load on each model.

The objective of the tests was to determine if the small fishtail seal would perform its function when the gap under the phenolic was increased to 0.60 in. and if not, whether the "fix" of placing a 0.25 in. cork shim under the seal would be adequate. Another purpose was to determine the effect of bonding the seal to the phenolic at the front of the seal groove for it was believed that the bond at the front could lead to seal failure when phenolic plies charred and delaminated as they did during phenolic TPS testing. The objectives of these series of tests was also to evaluate an alternate large fishtail seal to accommodate for the increased phenolic gap of 0.60 in.

The TPS test fixture shown in Fig. 12 is constructed so that there is an enclosed cavity provided behind the phenolic fairing. This cavity is vented at the back and becomes evacuated to a pressure of about 3.0 psi during test providing a crush pressure ΔP of about 6.0 psi on the phenolic and the seal. The cavity pressure was monitored during each test to see if it rose, indicating seal failure. However, this check could not be validated for the entire test duration because after approximately 50 sec the phenolic top surface would be lost opening up the cavity to the main flow and raising its pressure. This type event was typical of all tests performed with the exception of three where the top edge of the phenolic was protected with a thin steel shield. All the different configurations of the seal tests were repeated for repeatability checks and conclusions drawn mainly form qualitative results of the tests.

The material of the seal is a silicone RTV (ZZ-R-765) which consisted of two different hardnesses or rubber. The small seal was a harder type Class 3/ grade 50, whereas the large seal was made with this hardness and type Class 2B/ grade 40. The grade number indicates the durometer reading of the hardness of the rubber. The seal is gray in color and is made by Edler Industries, Inc., as a rubber extrusion.

The series of tests to evaluate the performance of the seals was started with the small fishtail seal bonded to the phenolic in the standard usual way, i.e., at the back and bottom of the seal groove. The gap left under the phenolic was 0.60 in. and a 0.25 in. thick shim of cork was placed under the seal to provide the designed compression (see Fig. 12). This configuration proved adequate as seen by the performance of the seal which has eroded fairly uniformly in Fig. 13. Figs. 14 and 15 are for the repeat test of this configuration and here the seal is seen to be affected a little more. A cavity pressure pickup was installed beginning this test and the pressure held in the first 55 sec test indicating that the seal performed well at least for half of the required heat load.

Figures 16 and 17 represent an identical test setup except for the cork shim which is left out to see if the seal would perform or not. Movies indicated that the seal was very weak and could not stay firmly on the bottom surface, allowing flow to get under it till it finally broke in the middle of the second 55 sec test. This configuration without the cork shim is not adequate as indicated by the broken seal of the repeat test also, shown in Figs. 18 and 19.

Figures 20 and 21 are for the seal test of the original design configuration with 0 375 in. gap under phenolic. As per design requirements, the seal performed well. The cavity pressure held until about 45 sec into the first test. This type configuration was not repeated.

The harder (Class3/grade 50) silicone material "large" fishtail seal was tested next. The large fishtail seal was made so that it could fit firmly under the maximum gap of 0.60 in. under the phenolic TPS as shown in Fig. 22. About

50% of the front half of the seal was lost during the second exposure to the flow (Fig. 23). The first exposure had lasted only 29.62 sec due to facility problems. It is not known why the large chunk of seal was lost on this model. The repeat run of Figs. 24 and 25 was to throw more light on this problem. During the repeat test, the seal performed very well with the cavity pressure holding throughout the first run of 55 sec.

The other hardness type (Class 2B/grade 40), which is less hard, of silicone rubber large seal was tested. To prevent the phenolic TPS from burning through at the top of the model, a protective steel strip was installed over the phenolic upper edge as seen in Fig. 26. This protection helped the phenolic TPS stay together (Fig. 27) and hence the cavity pressure held up throughout both the runs indicating a perfect function of the seal. The repeat run of Figs. 28 and 29 performed identically.

The test setup for the next model (Fig. 30) is similar to the previous one except that the seal is bonded to the phenolic at the front of the seal groove also. The seal is of the harder (Class 3/grade 50) of the two types under evaluation. The seal performed very well once again with no gain of cavity pressure (see Fig. 31). For the repeat test, the steel protection strip lining the top edge of the phenolic TPS was omitted (Fig. 32) because it was necessary to observe what would happen to the seal when the phenolic, which is bonded to the seal at front, charred and delaminated. The performance was not any different from before as seen in Fig. 33 except cavity pressure change was indicated as expected due to phenolic upper edge burn-through.

Figures 34 through 37 were two runs similar to those of Figs. 30 and 31 except the seal material was of the softer type (Class 2B/grade 40).

Lastly, a run was made with the small fishtail seal which had not been tested earlier with the seal bonded to phenolic at the front of the seal groove. The gap under the phenolic was 0.60 in. and there was no cork shim under the seal. Because of the lack of the cork shim, the seal did not survive (see Fig. 38) as in the similar tests of Figs. 16 through 19.

RESULTS AND CONCLUSIONS

The small fishtail seal performs adequately with a 0.25 in. cork shim under it when the phenolic gap was 0.60 in. but cannot withstand the aerodynamic forces without the cork shim since it has to have sufficient compression to stay firmly on the bottom surface. Enough compression of the seal is provided when the gap under the phenolic is 0.375 in. and therefore this configuration is adequate without the cork shim. Bonding the seal to the phenolic in front of the seal groove does not change its performance.

Although the large seal of Figure 23 failed during its second exposure, it was decided that this seal was acceptable because it performed well during the repeat test.

Both material hardness of the large fishtail seal, made to accommodate the bigger gaps under the phenolic, performed well irrespective of whether or not the seal was bonded to the phenolic at the front of the seal groove.

Fig. 1 - Attach Ring Phenolic TPS Fishtail Seal Test on Fixture Mounted at 41 deg to Flow (Material of Seal is E60C Viton Fluoronated)

Fig. 2 - E60C Viton Rubber Seal Performed Well But the Material Is Seen to Have Melted and the Residue Spread Onto the Bottom Panel

Fig. 3 - Initial Test Setup for Evaluation Testing of Small Fistail Seal with Design 0.375 in. Gap Under Phenolic

Fig. 4 - Seal Is Lost Due to High Shear Environment In This Test Configuration

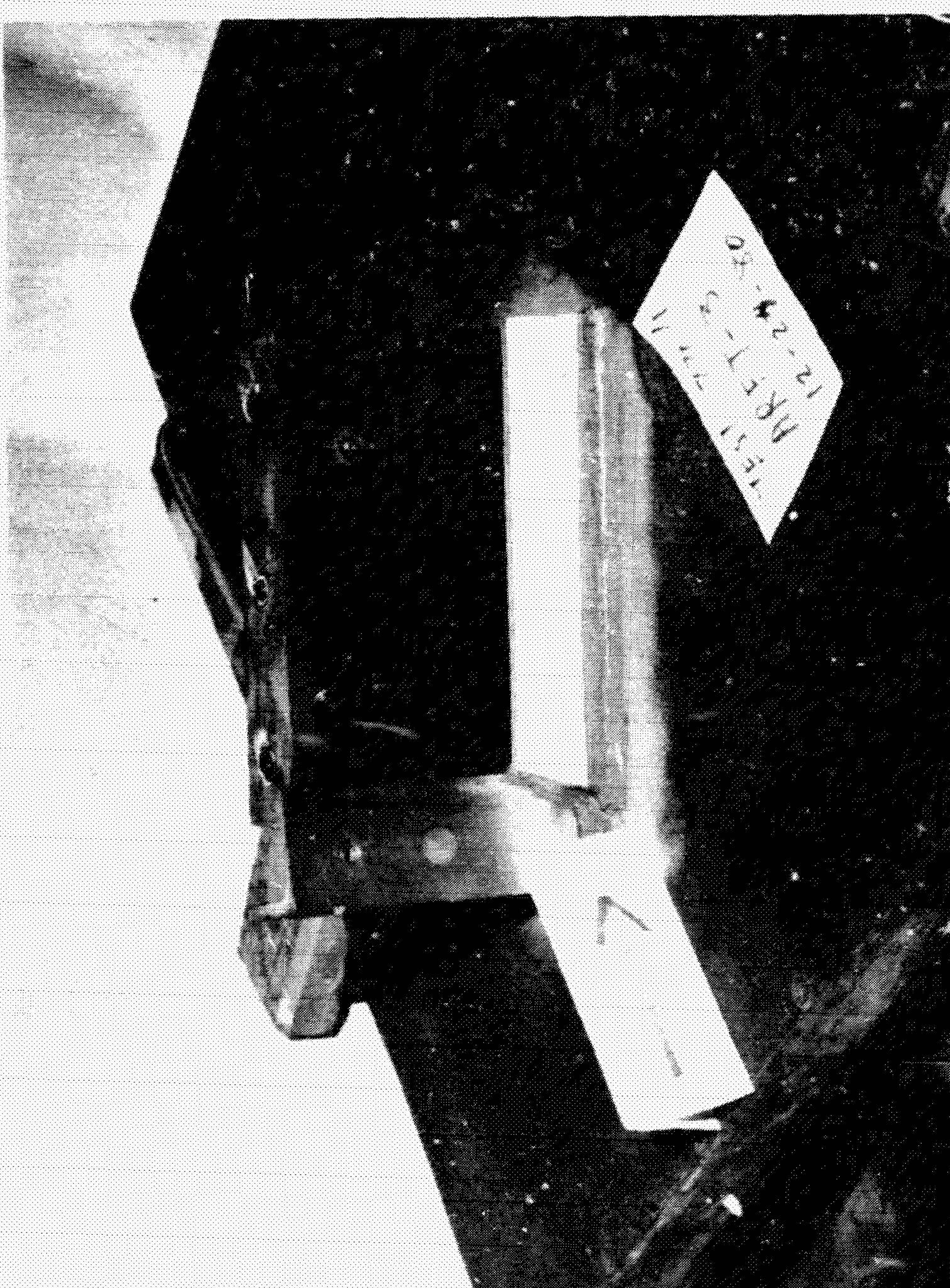

Fig. 5 - Test Setup Similar to That of Fig. 3

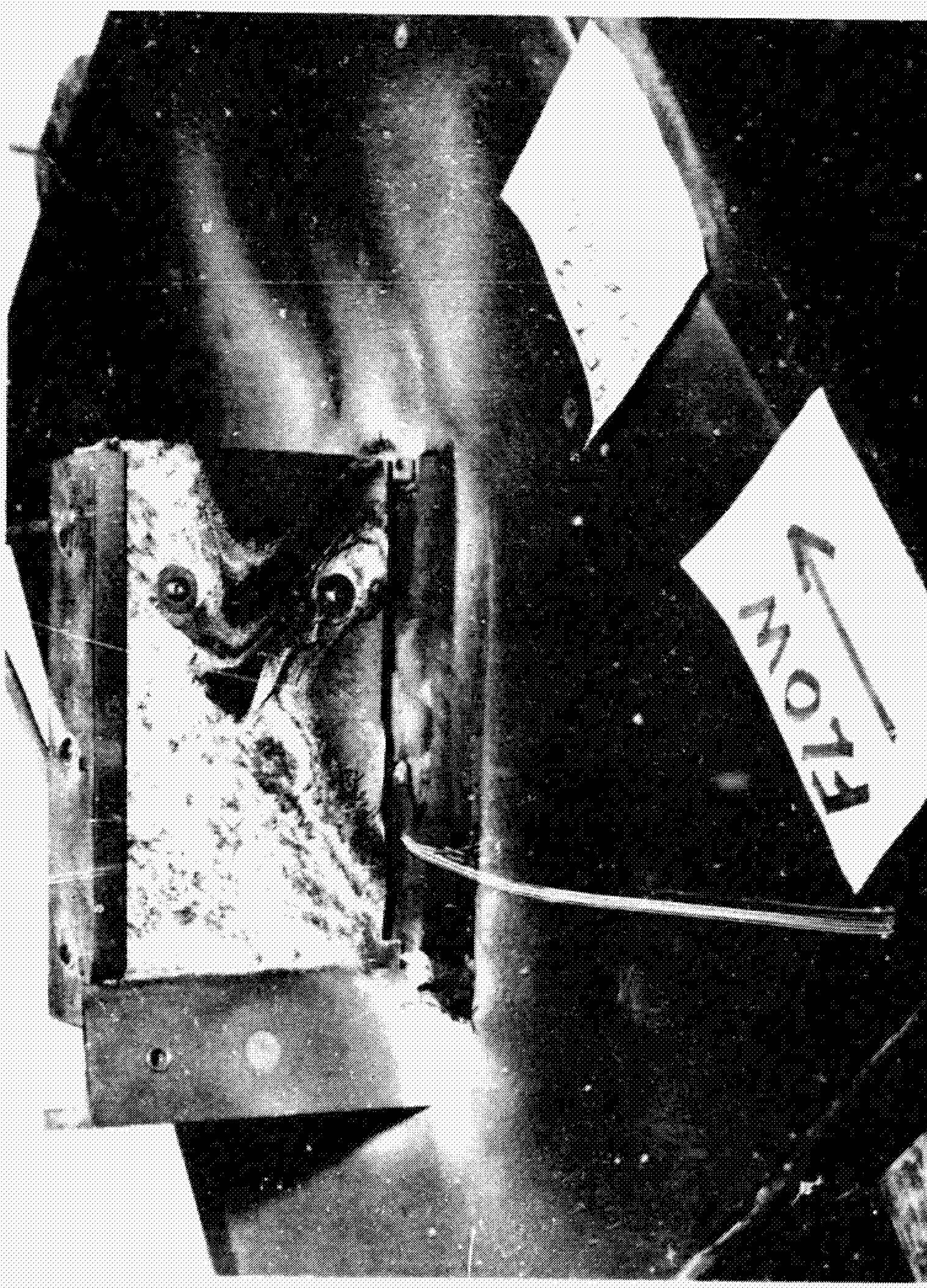

Fig. 6 - Results of This Test Are Similar to Those of Test in Fig. 4

Fig. 7 - Test Fixture Mounted at 90 deg to Flow to Reduce Shear Environment on Rubber Seal

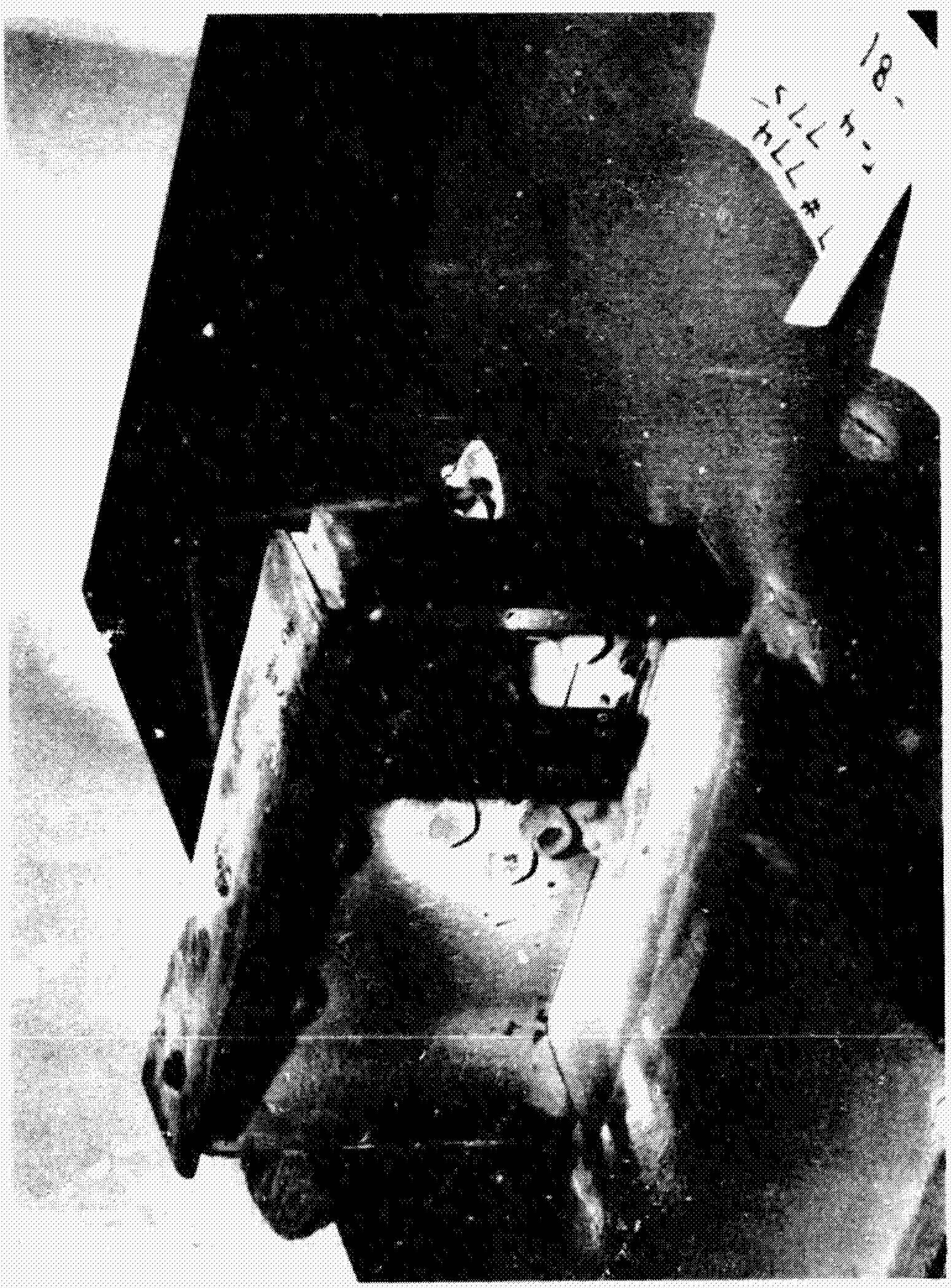

Fig. 8 - This Orientation of the Test Fixture Stagnated the Flow, Produced Severe Heating Along the Top Edge and Failed the Phenolic TPS

Fig. 9 - Height of This Thin Skin Calibration Model with the Large Fishtail Seal Included Was Reduced to 3 in. to Lower the Heat Flux

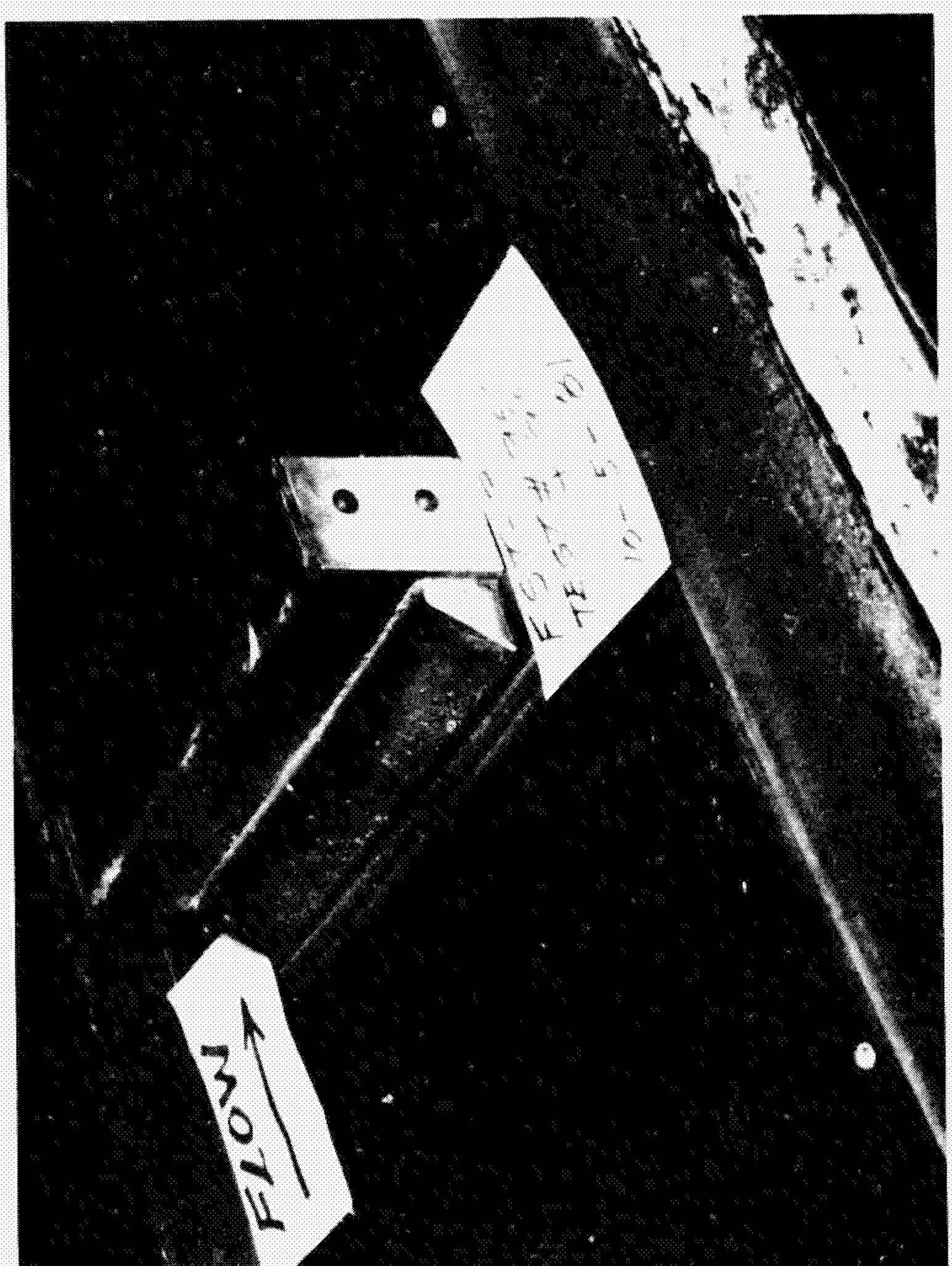

Fig. 10 - Calibration Model of Small Fishtail Seal Similar to That Shown in Fig. 9.

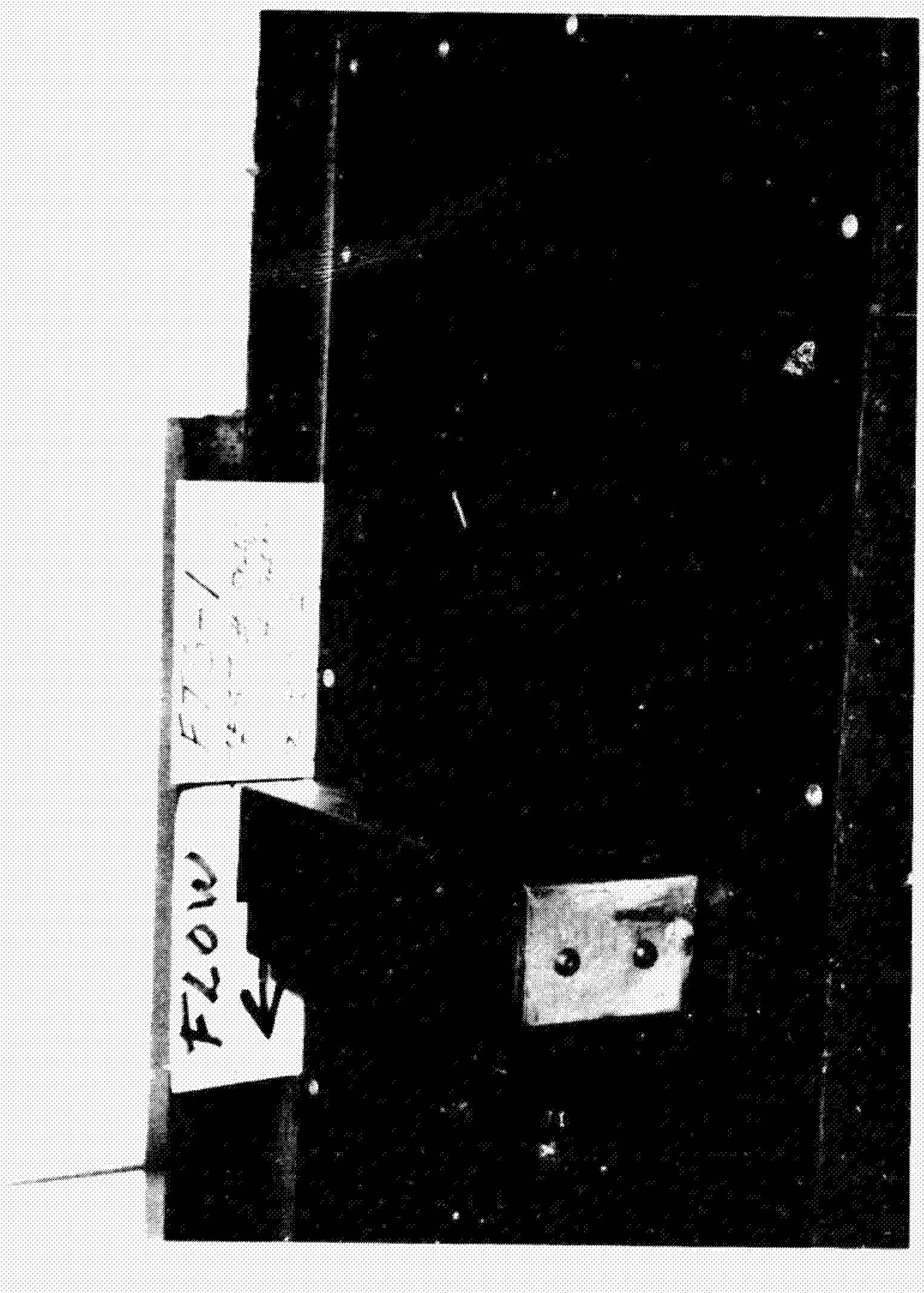

Fig. 11 - Attach Ring Flat Face Calibration Model Without Fishtail Seal

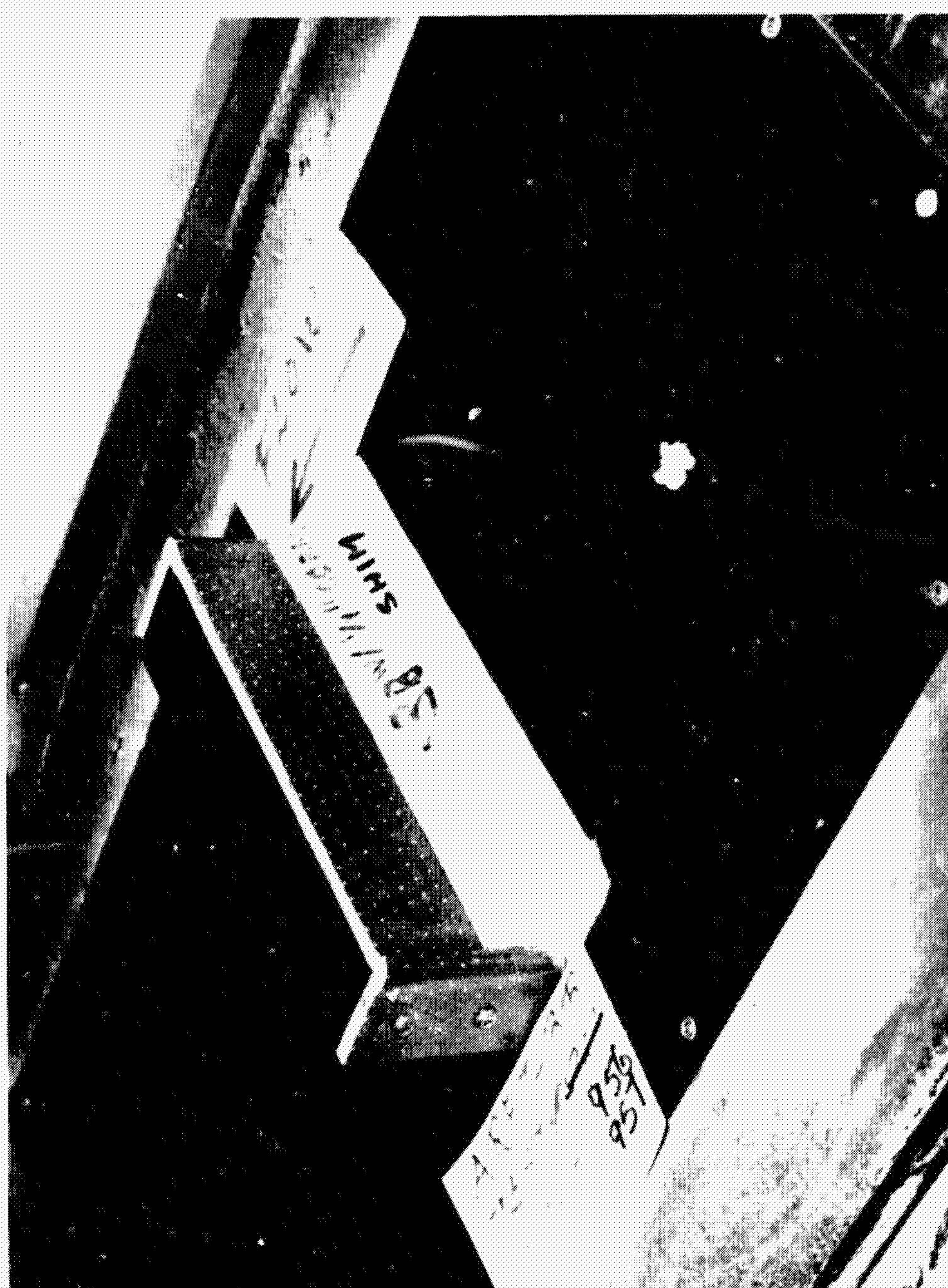

Fig. 12 - Small Fishtail Seal Bonded to Phenolic TPS With 0.60 in. Gap Under it. A 0.25 in. Thick Cork Shim is Seen Placed Under the Seal to Provide Necessary Compression for Sealing

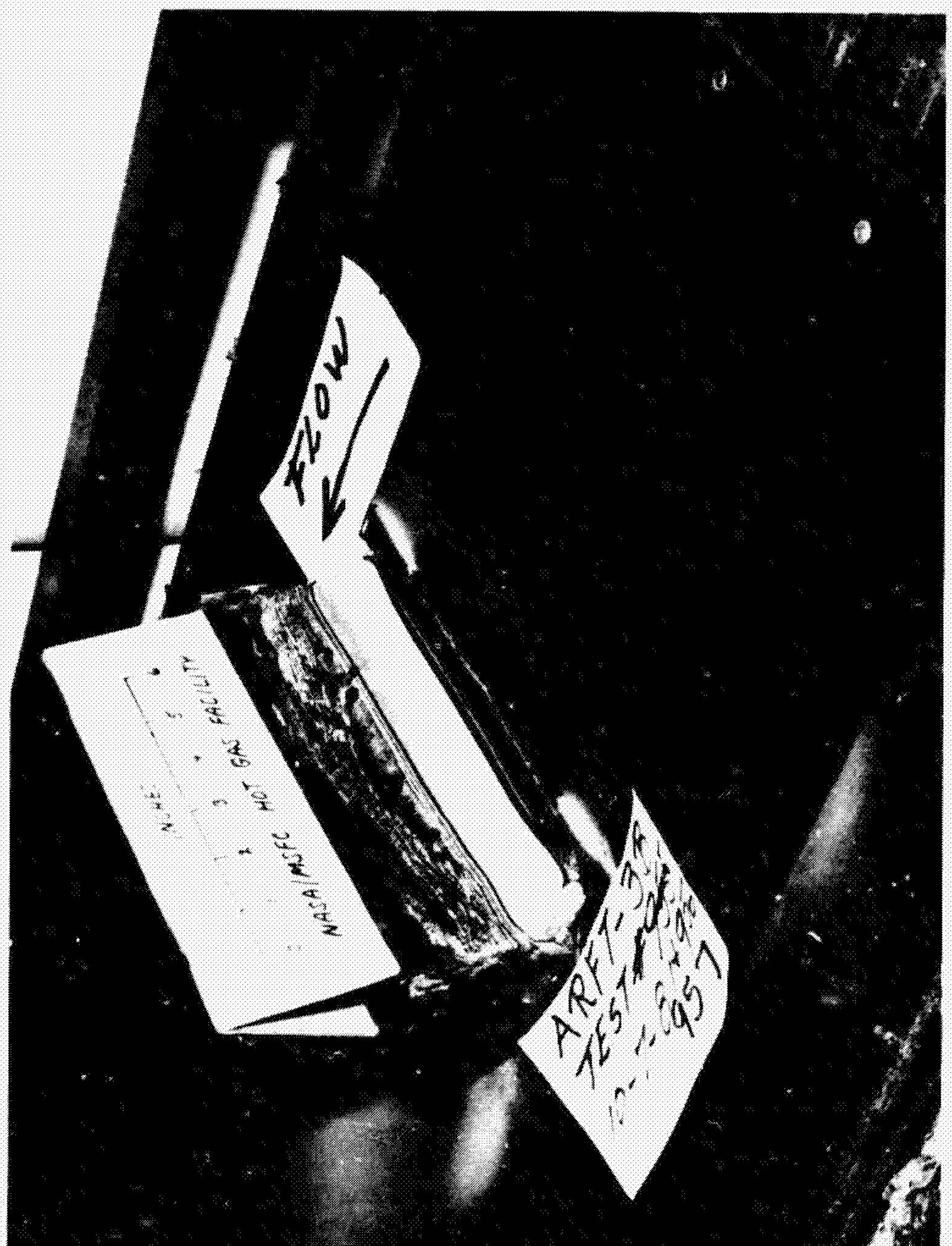

Fig. 13 - Phenolic TPS Burned Through But Seal Looks Good

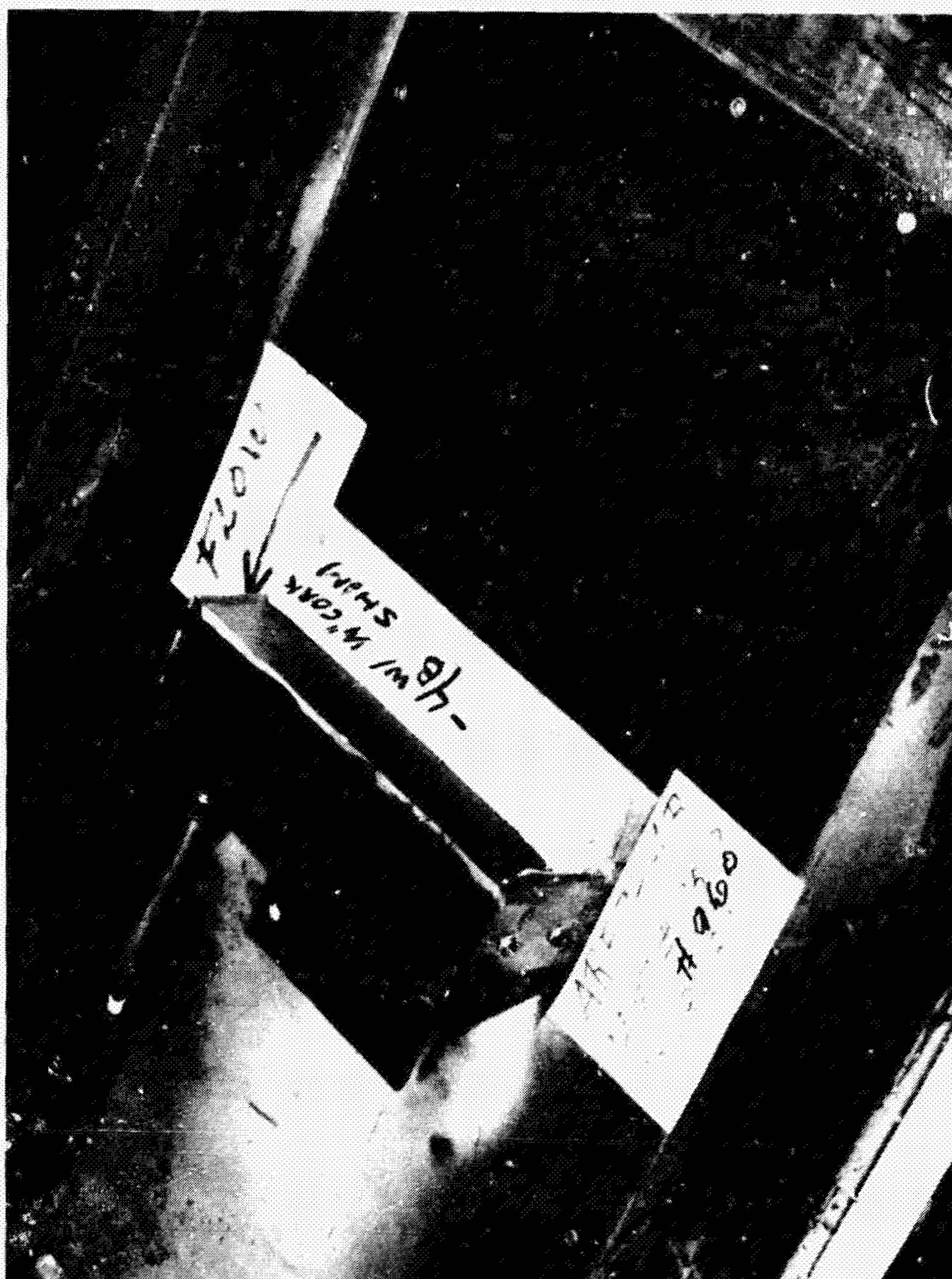

Fig. 14 - Repeat of Test of Fig. 12

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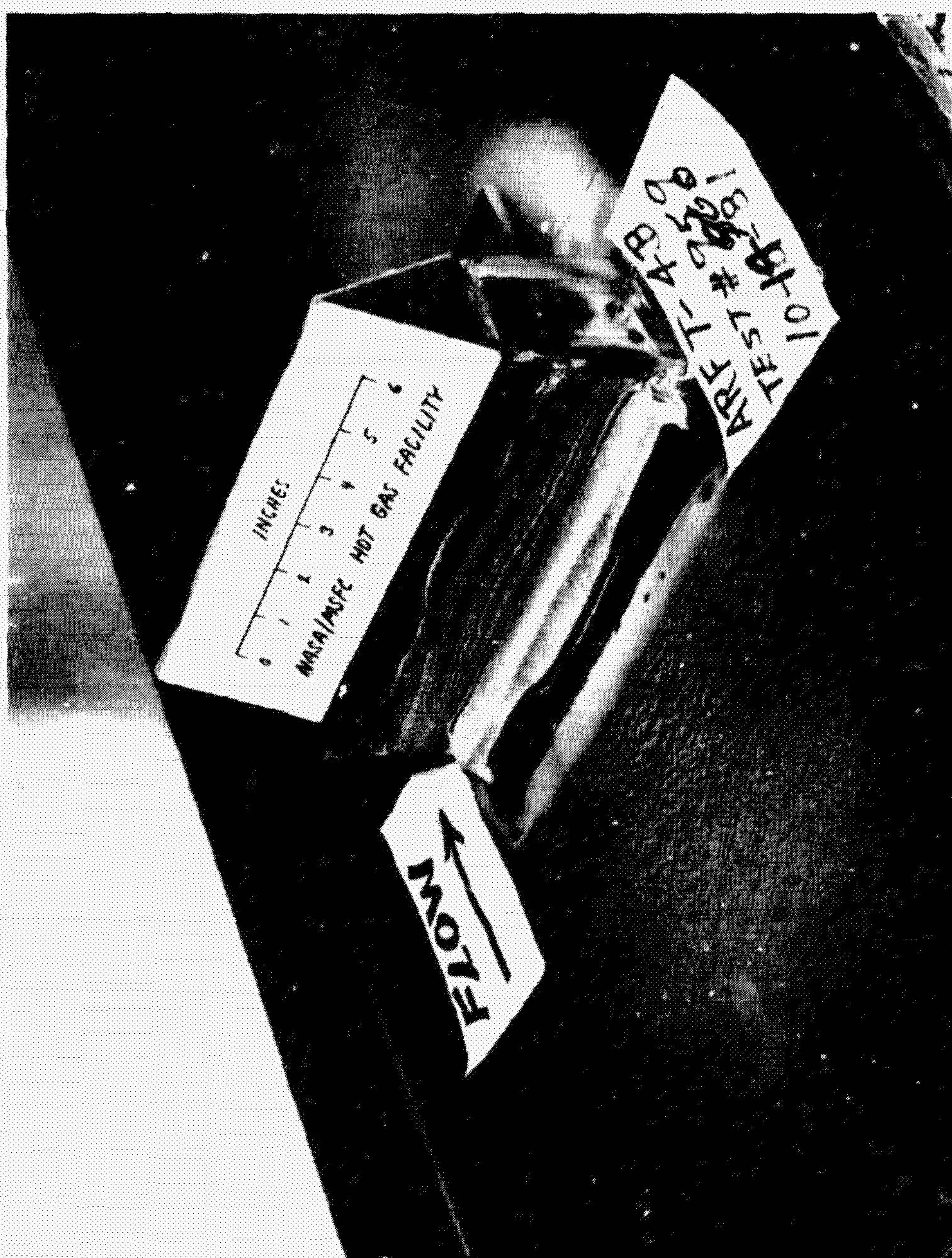

Fig. 15 - Phenolic and Seal Performance in This Test Was Similar to That of Fig. 13

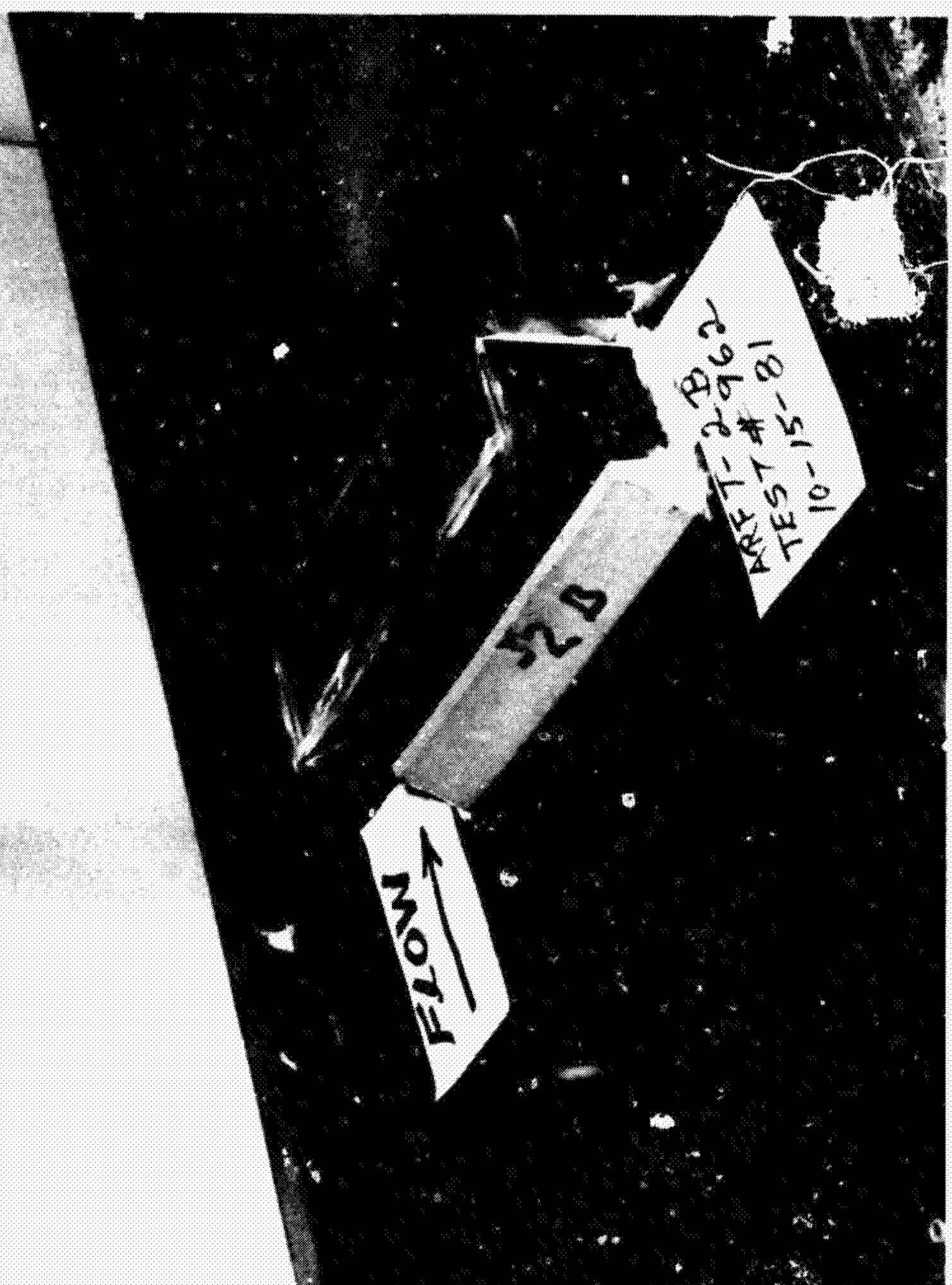

Fig. 16 – Small Fishtail Seal With 0.60 in. Gap Under Phenolic But Without the Cork Shim to Provide Required Compression of Seal

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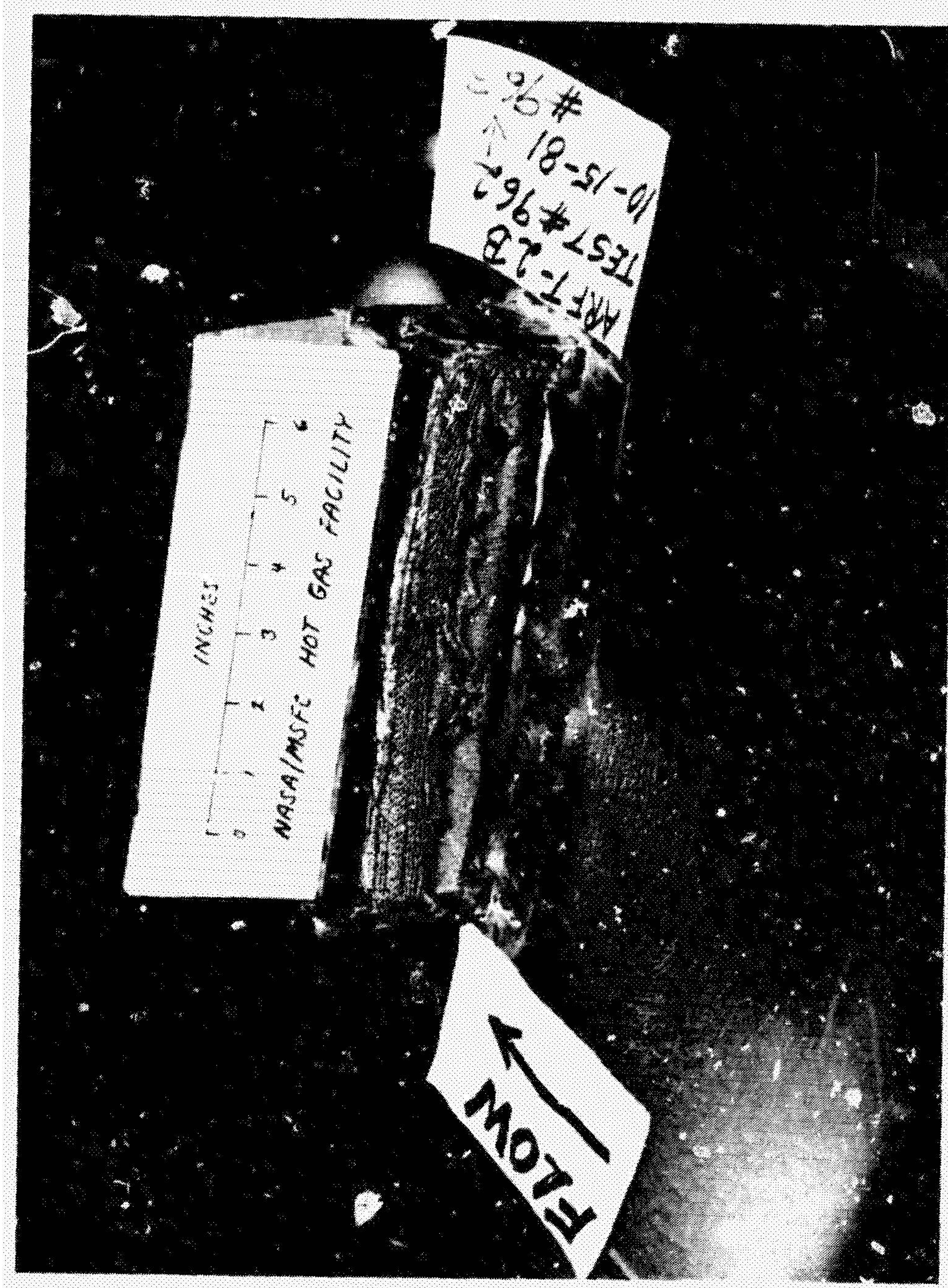

Fig. 17 - Seal Did Not Survive Test Since It Did Not Have Sufficient Compression to Be Held Down Firmly Against Bottom Plate

Fig. 18 - Repeat Test on Model Similar to That Shown in Fig. 16

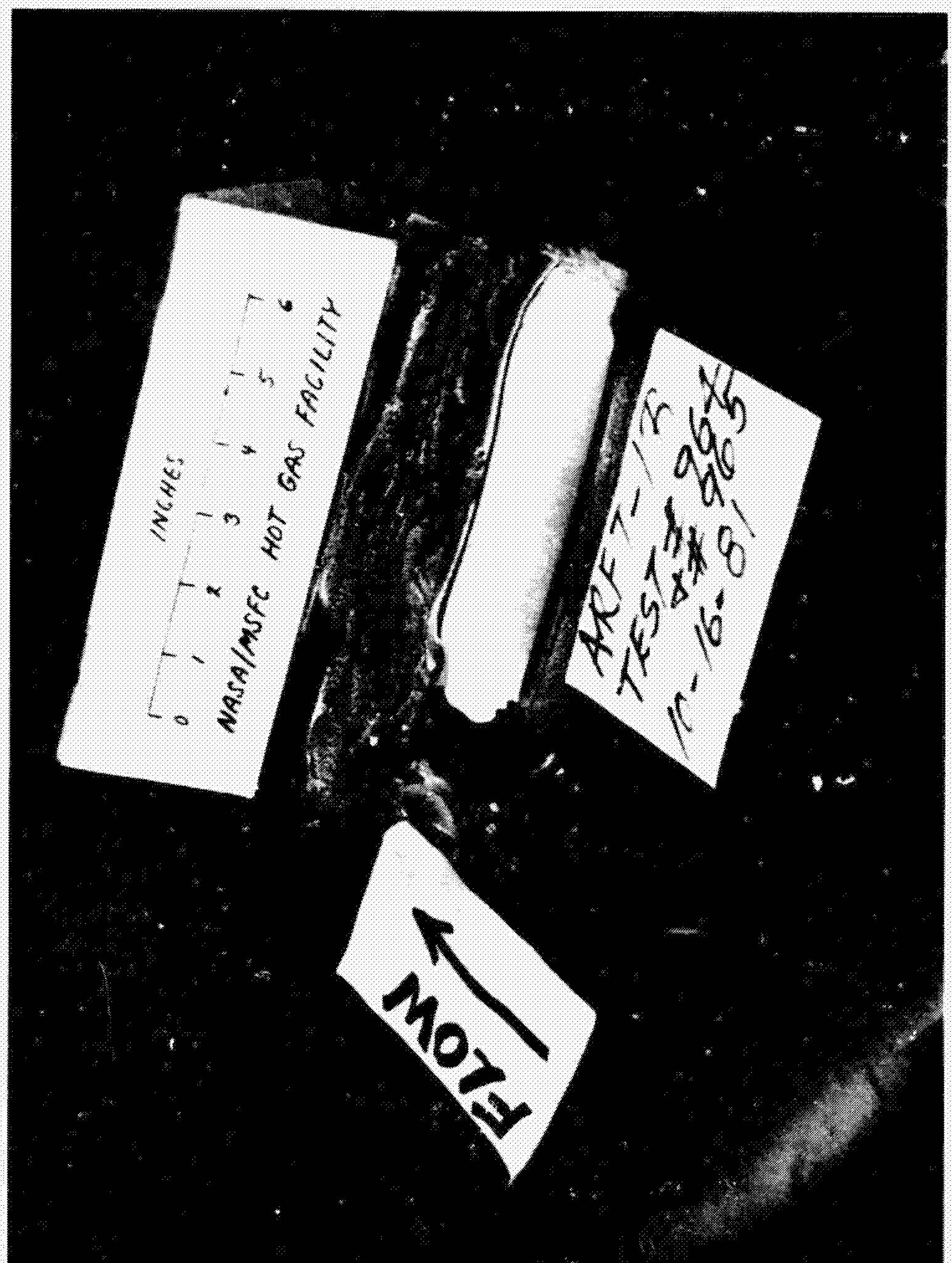

Fig. 19 - Though The Seal Has Not Been Completely Lost, It Has Nevertheless Failed Due to Lack of Sufficient Compression to Give It Strength

Fig. 20 - Small Fishtail Seal with 0.375 in. Gap Under Phenolic. (The Seal is Designed for This Nominal Gap)

Fig. 21 - Though the Phenolic Has Burned Through at the Top, the Seal Has Performed Adequately

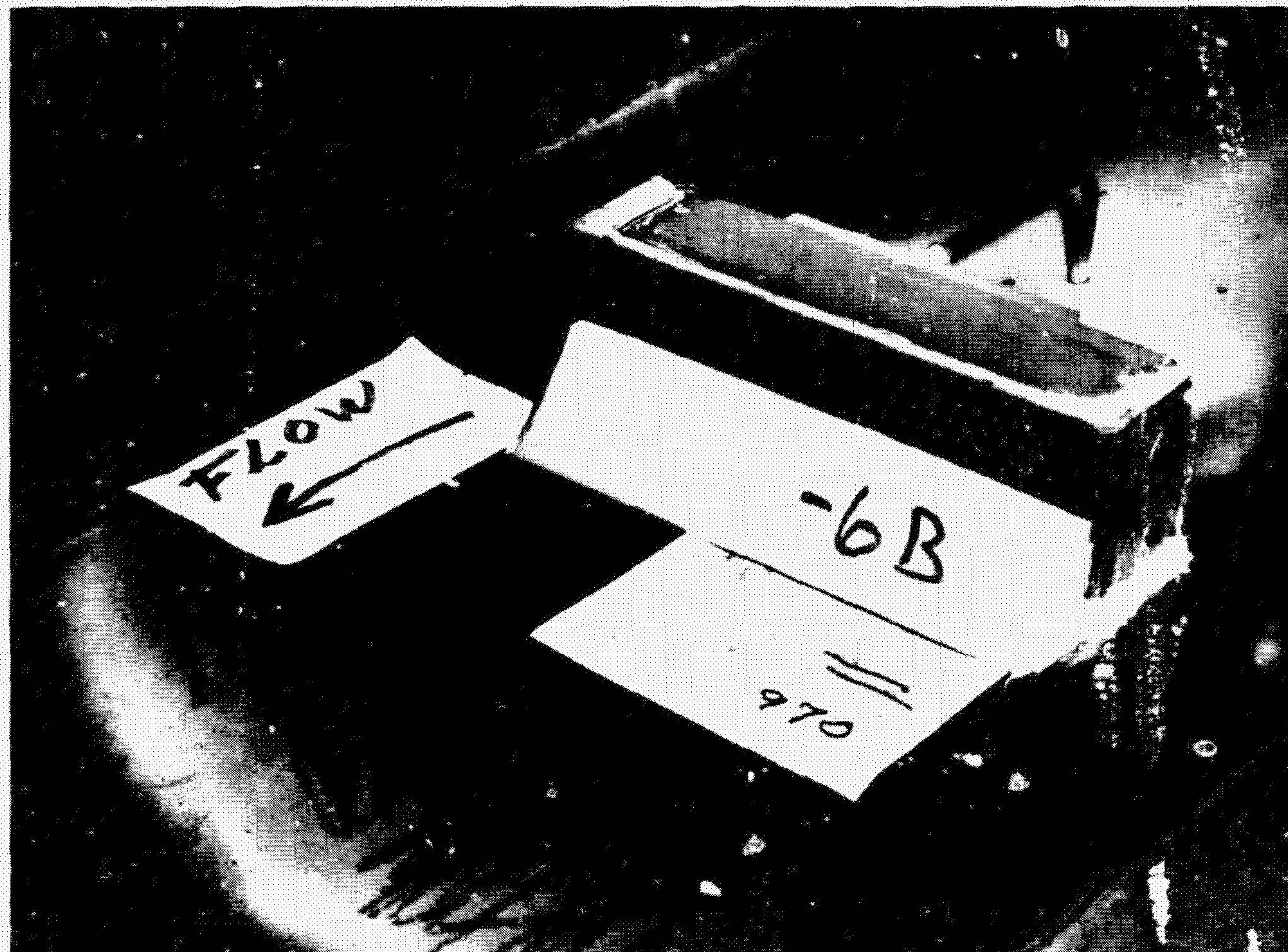

Fig. 22 - Large Fishtail Seal Was Designed to Cover the 0.60 in. Gap Under Phenolic TPS Without Need of Installing a Cork Shim Under It. In This Model the Seal is of The Type Class 3/Grade 50 Which is Harder of the Two Types Evaluated

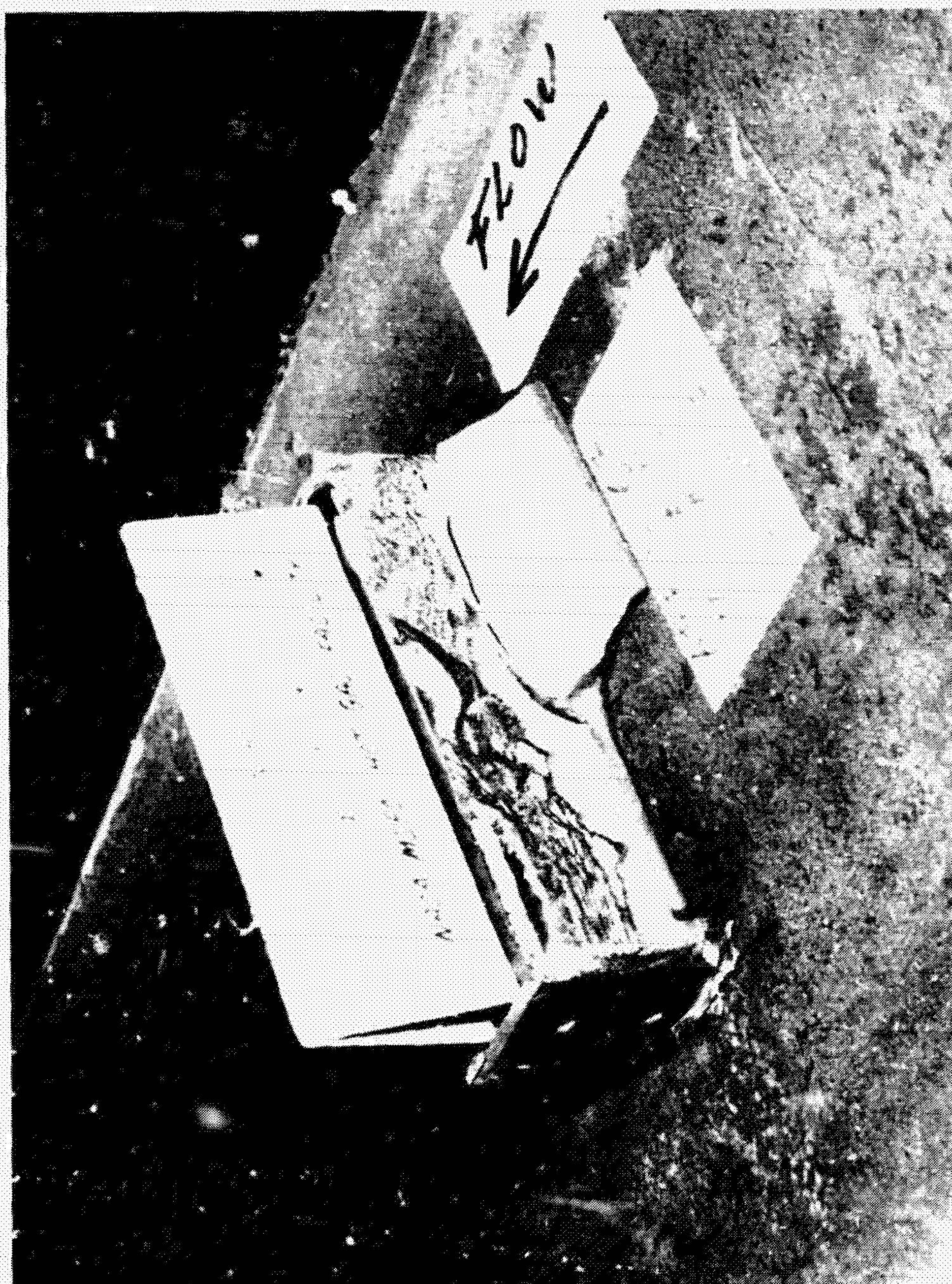

Fig. 23 - Front Half of the Seal Was Lost Near the End of Test

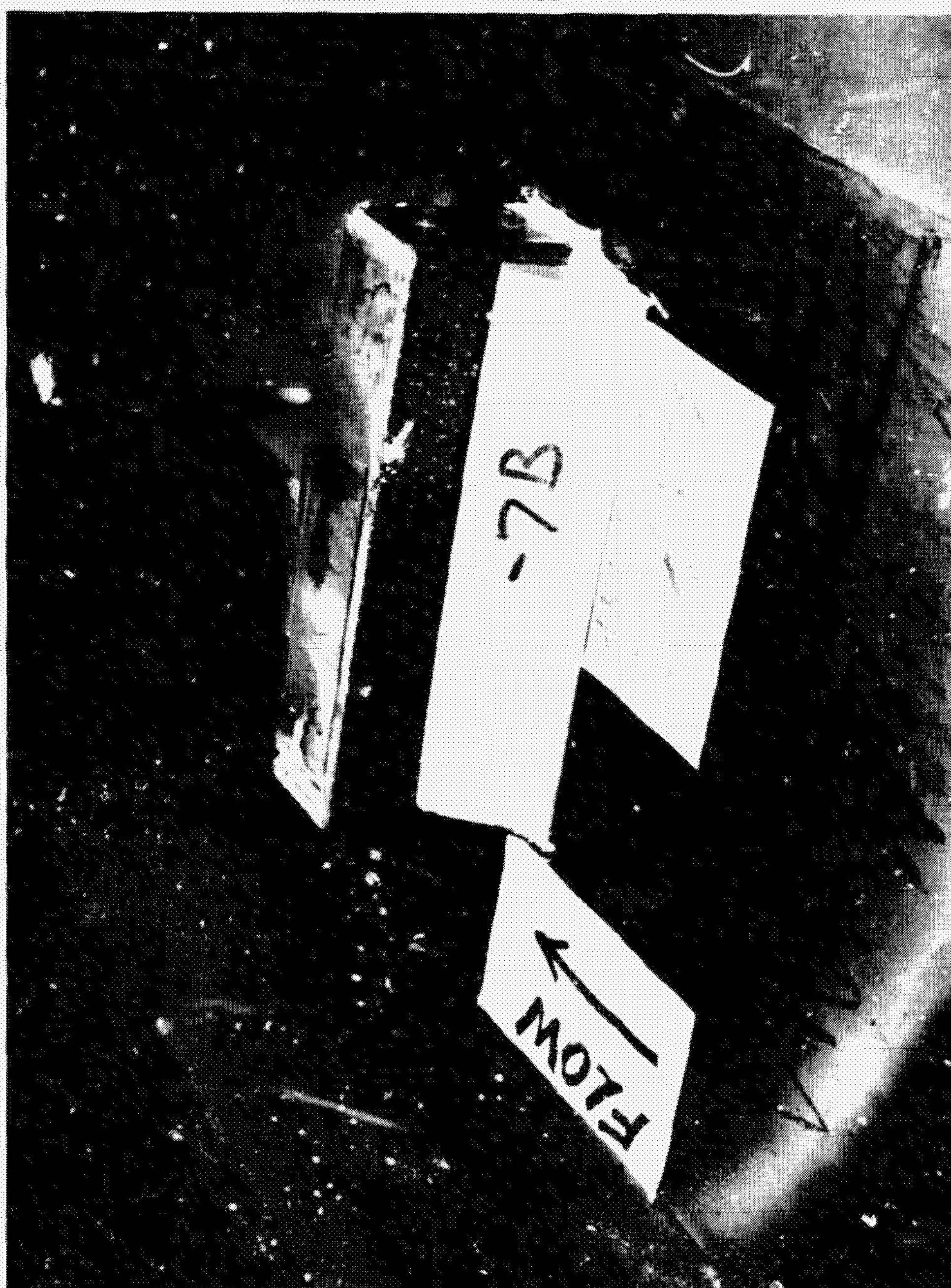

Fig. 24 - Repeat Test of Seal Configuration and Material Hardness of That Shown in Fig. 22

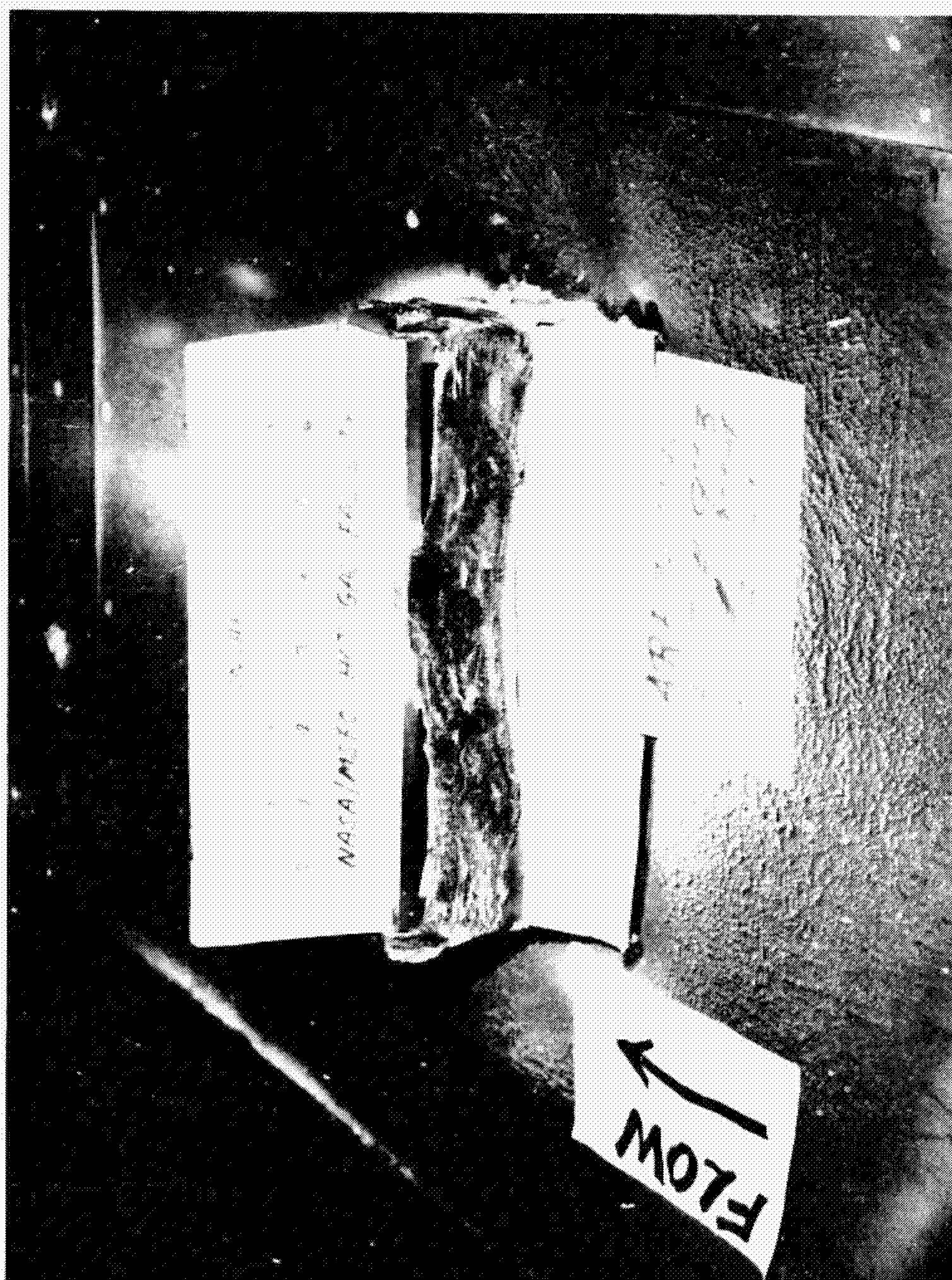

Fig. 25 - Seal Performed Well Unlike the Previous Identical Type Shown in Fig. 23

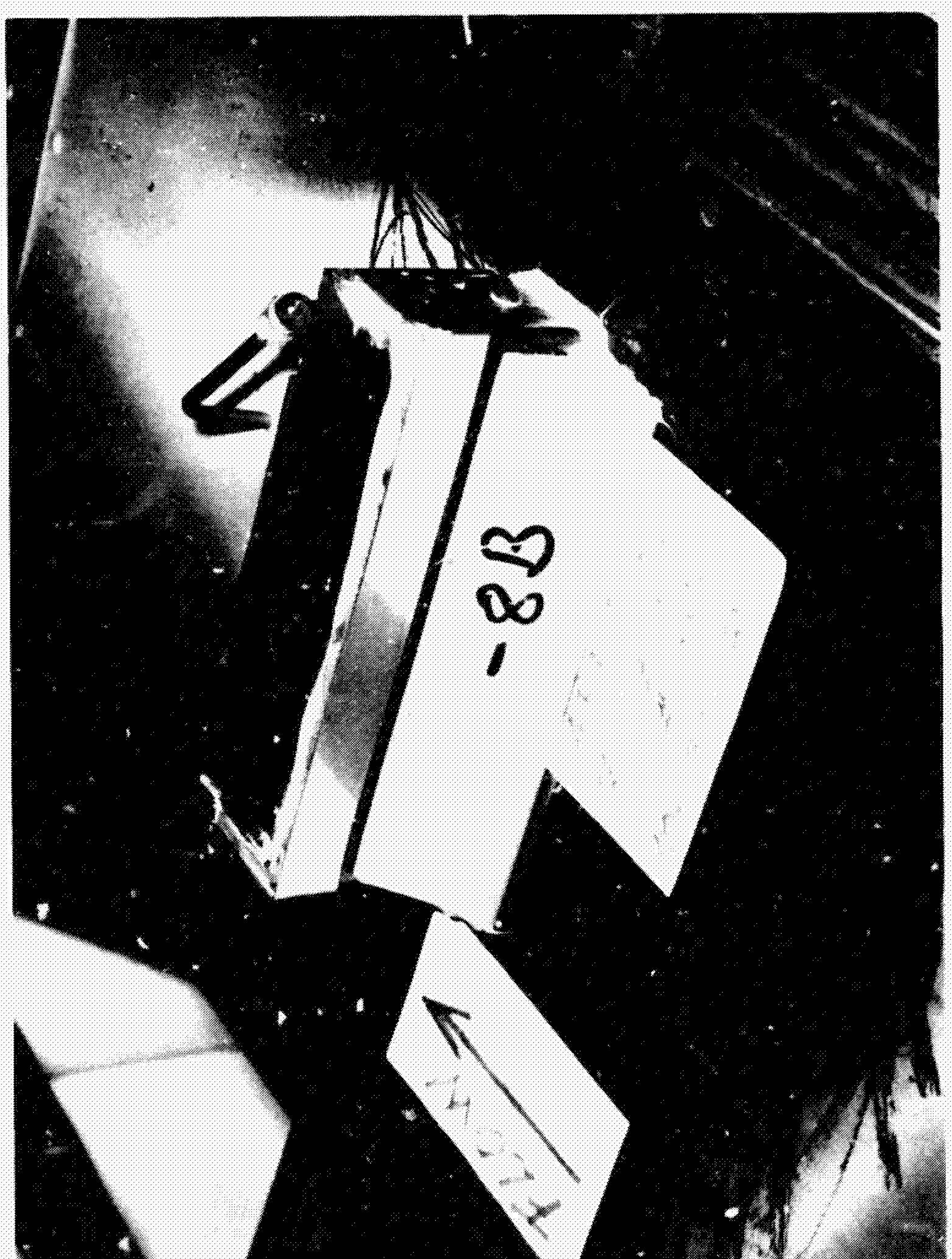

Fig. 26 – Seal Configuration Identical to Previous Large Fishtail Seal Tests Except the Seal Material Was of Class 2B/Grade 40. (Note Protective Steel Strip Along Top Edge of the Phenolic).

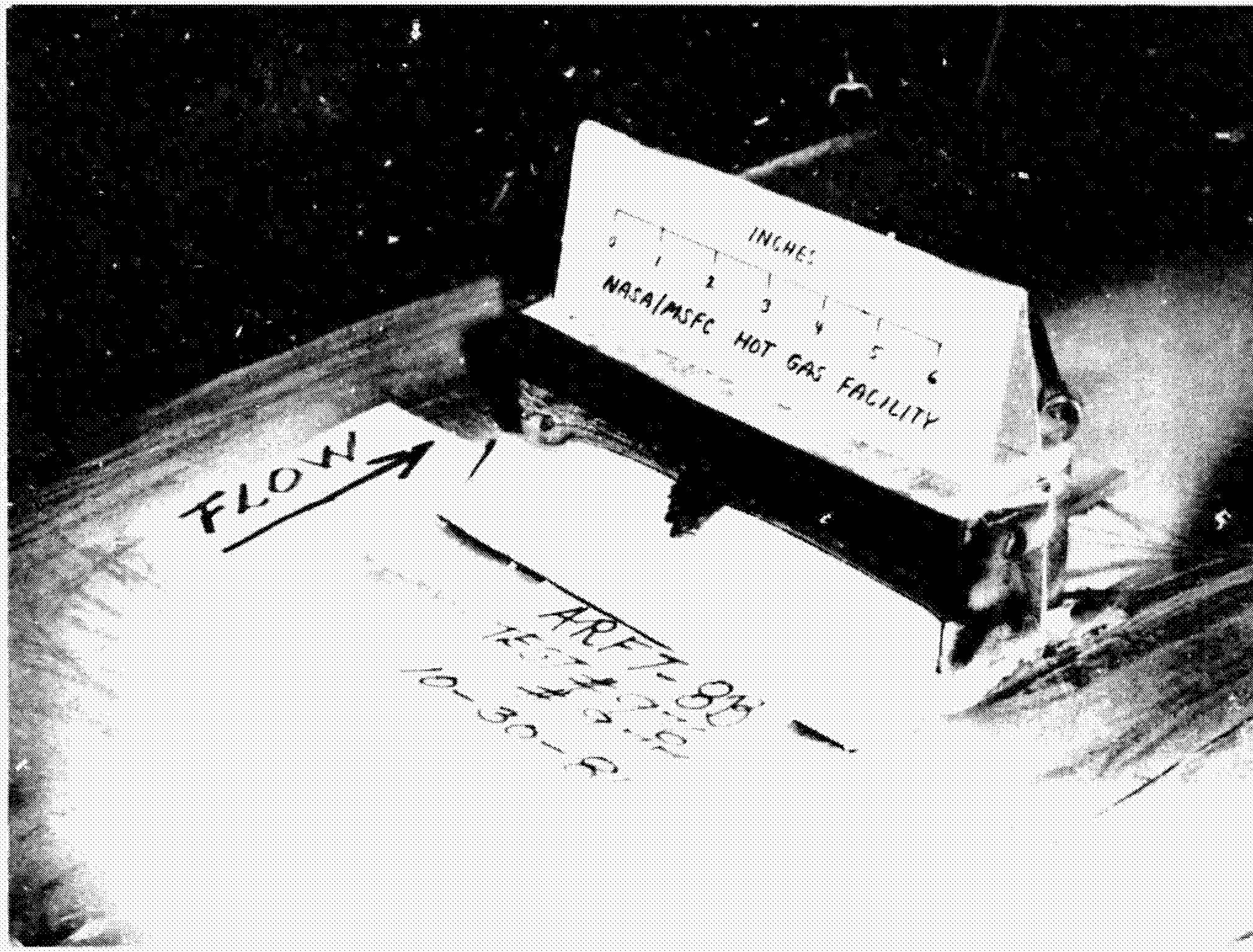

Fig. 27 - Seal Performed Well and Due to the Protective Strip on the Phenolic, Model Cavity Pressure Held Up

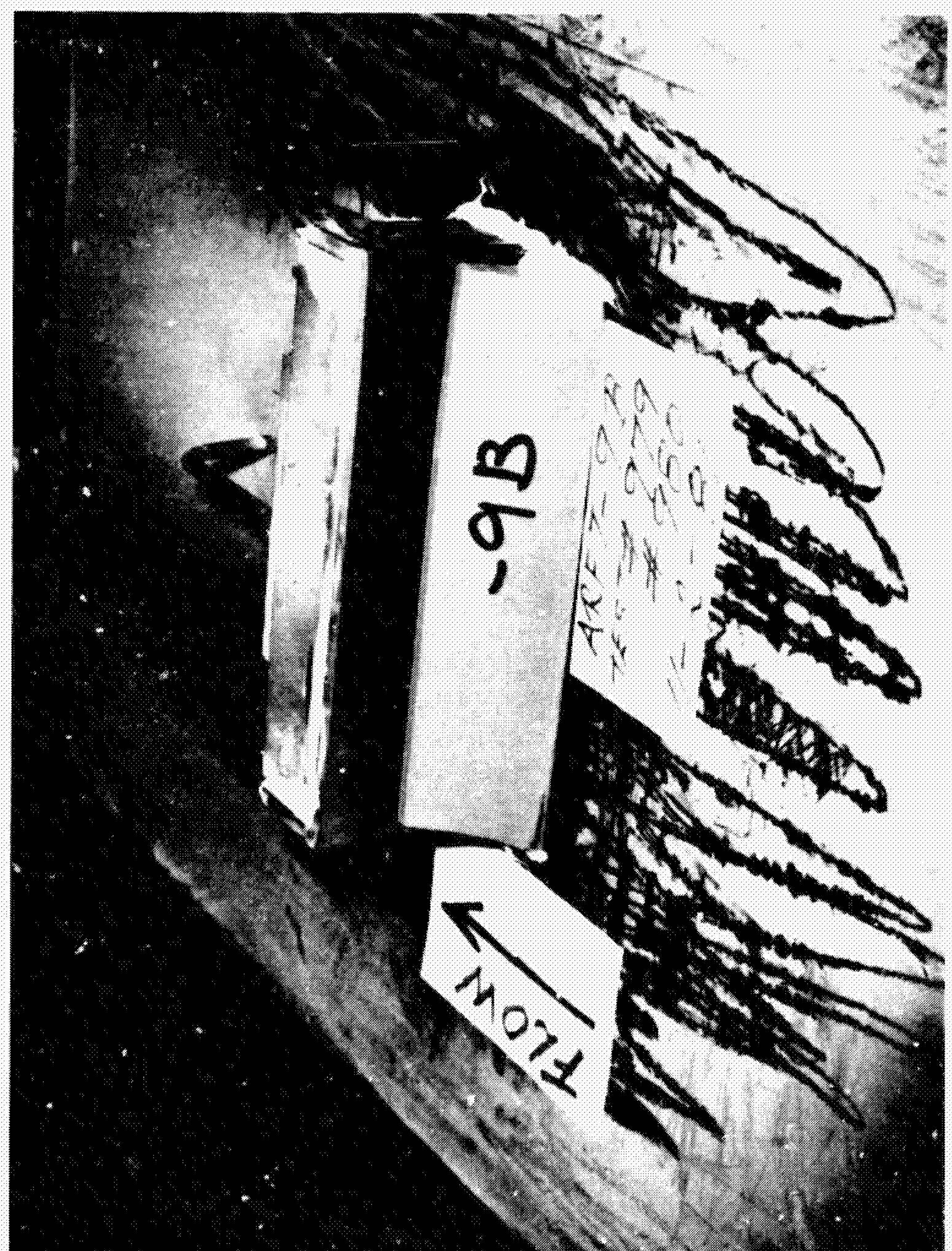

Fig. 28 - Repeat Test of That Shown in Fig. 26

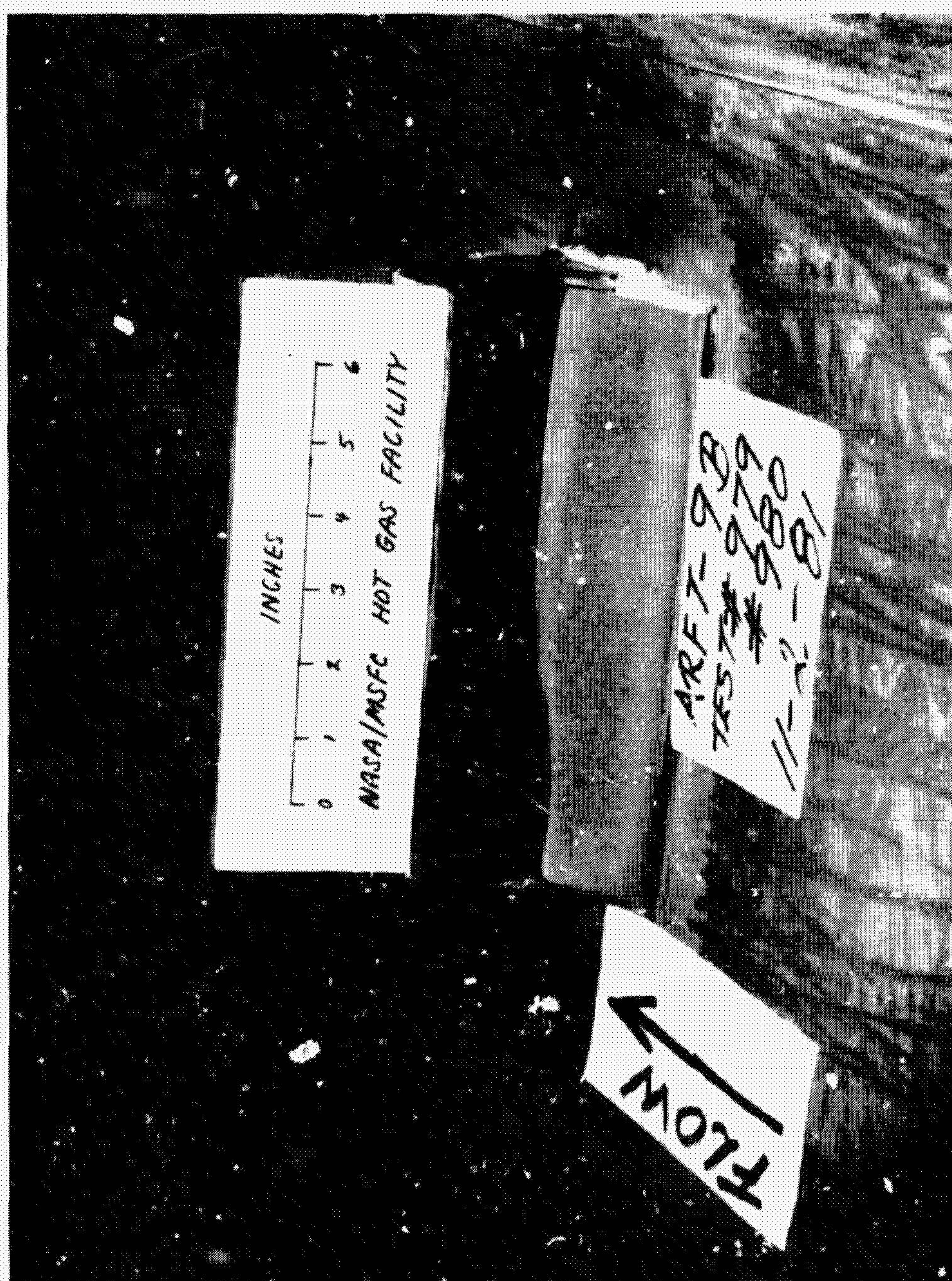

Fig. 29 - Results Identical to Those in Test of Fig. 27

Fig. 30 - Seal (Material Type Class3/Grade 50) is Bonded to the Phenolic at Front of Seal Groove Also in This Test

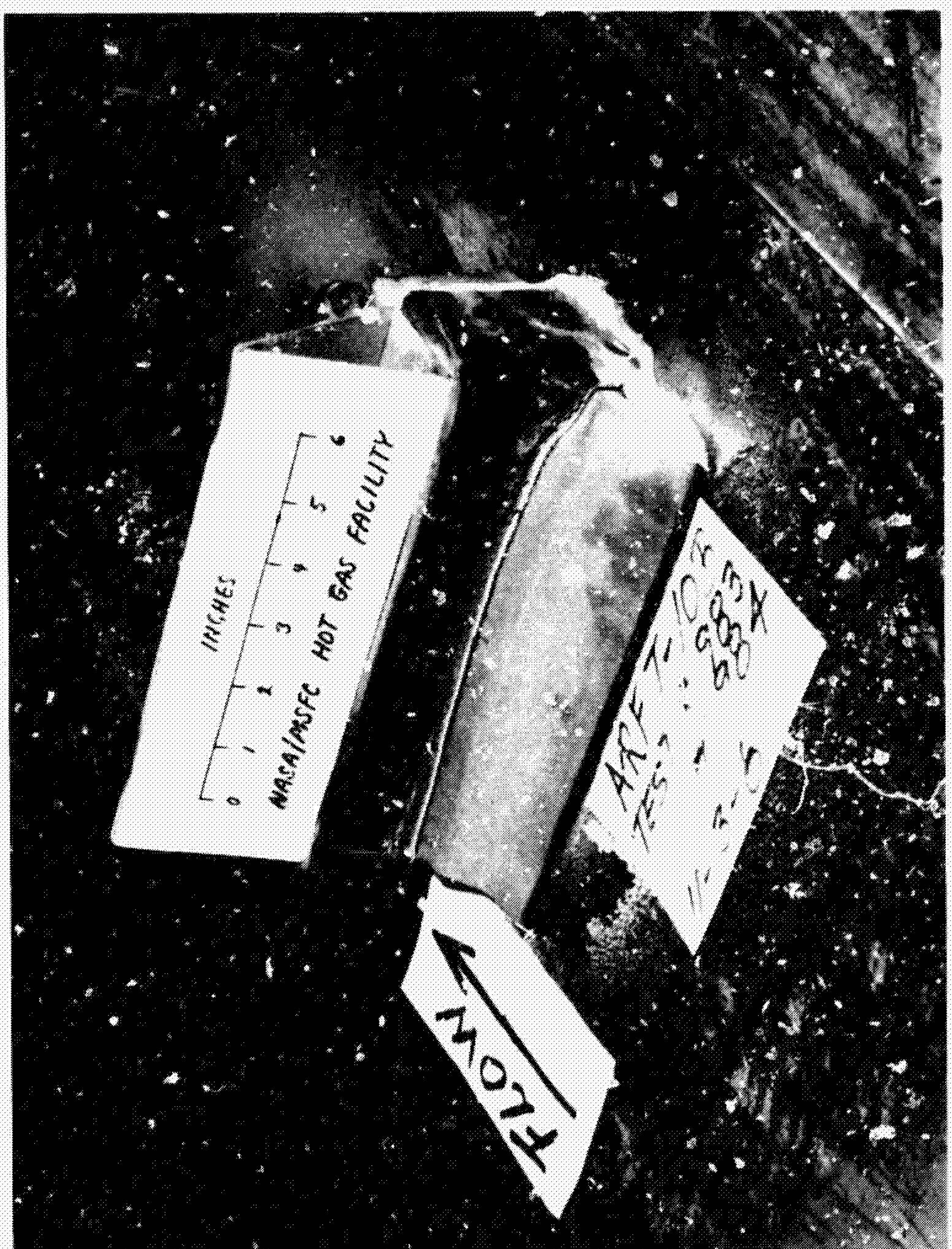

Fig. 31 - Seal Performance Identical to Its Performance When Seal Not Bonded to the Phenolic at the Front of Seal Groove

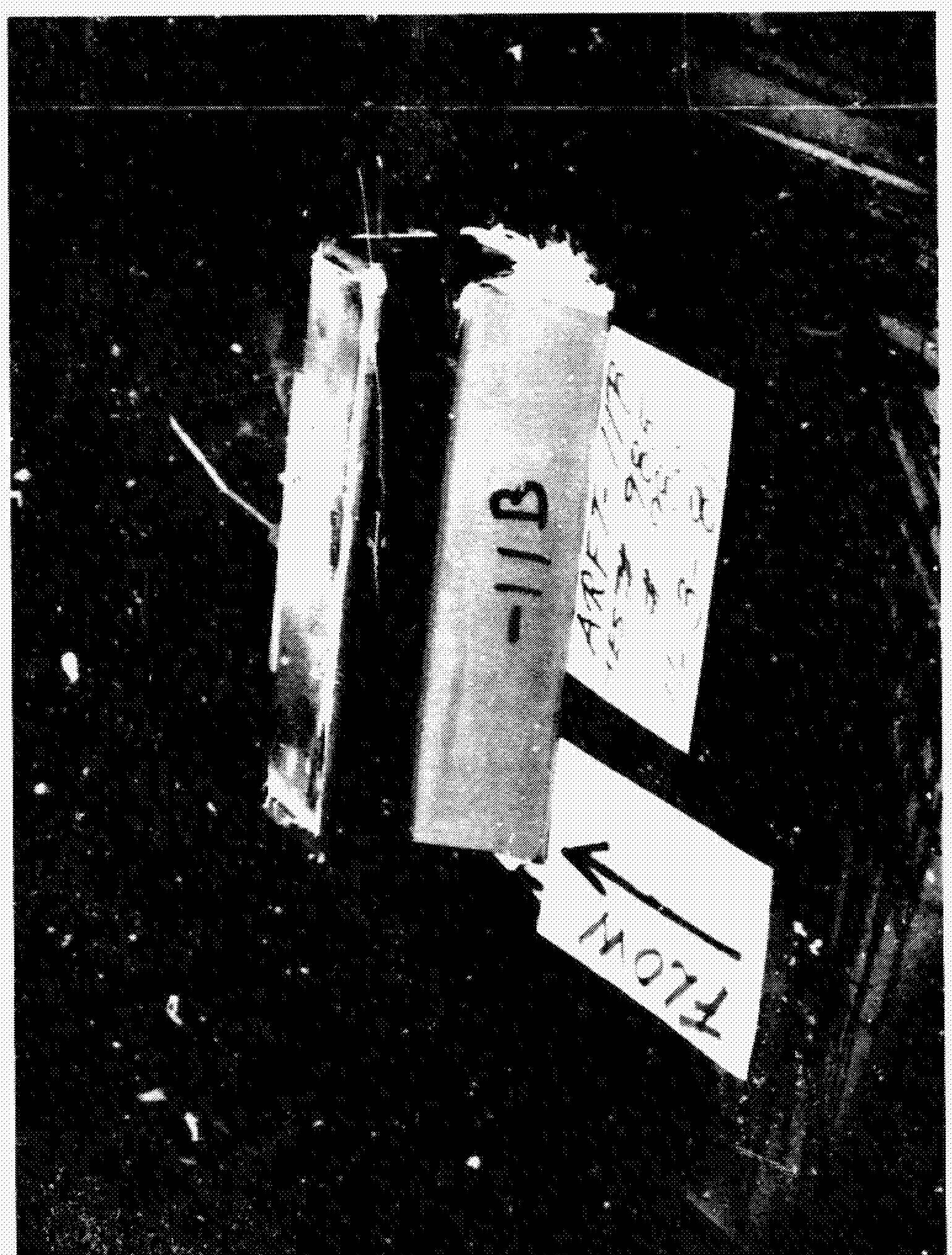

Fig. 32 - Repeat Test of That Shown in Fig. 30

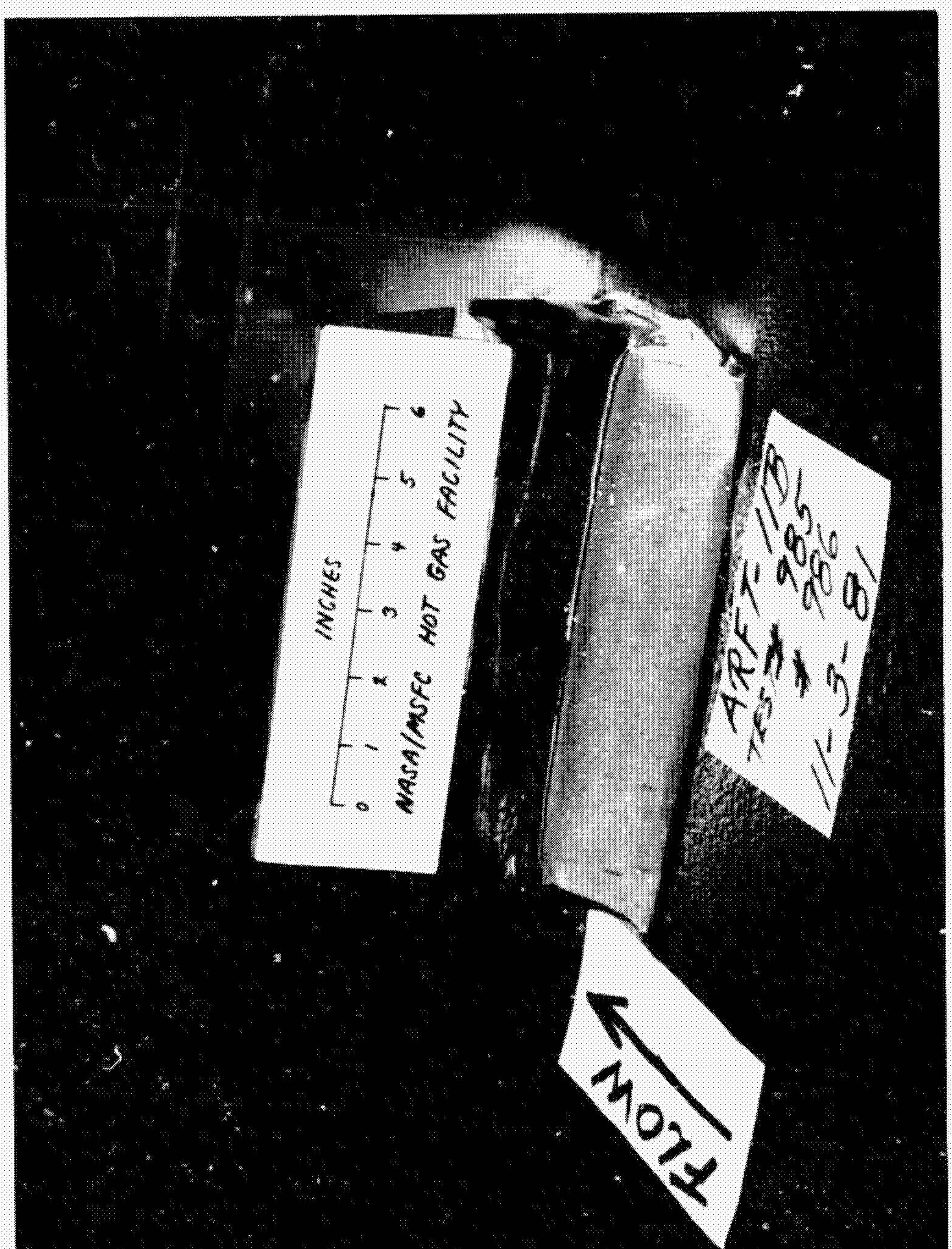

Fig. 33 - Results Identical to Those In Test of Fig. 31

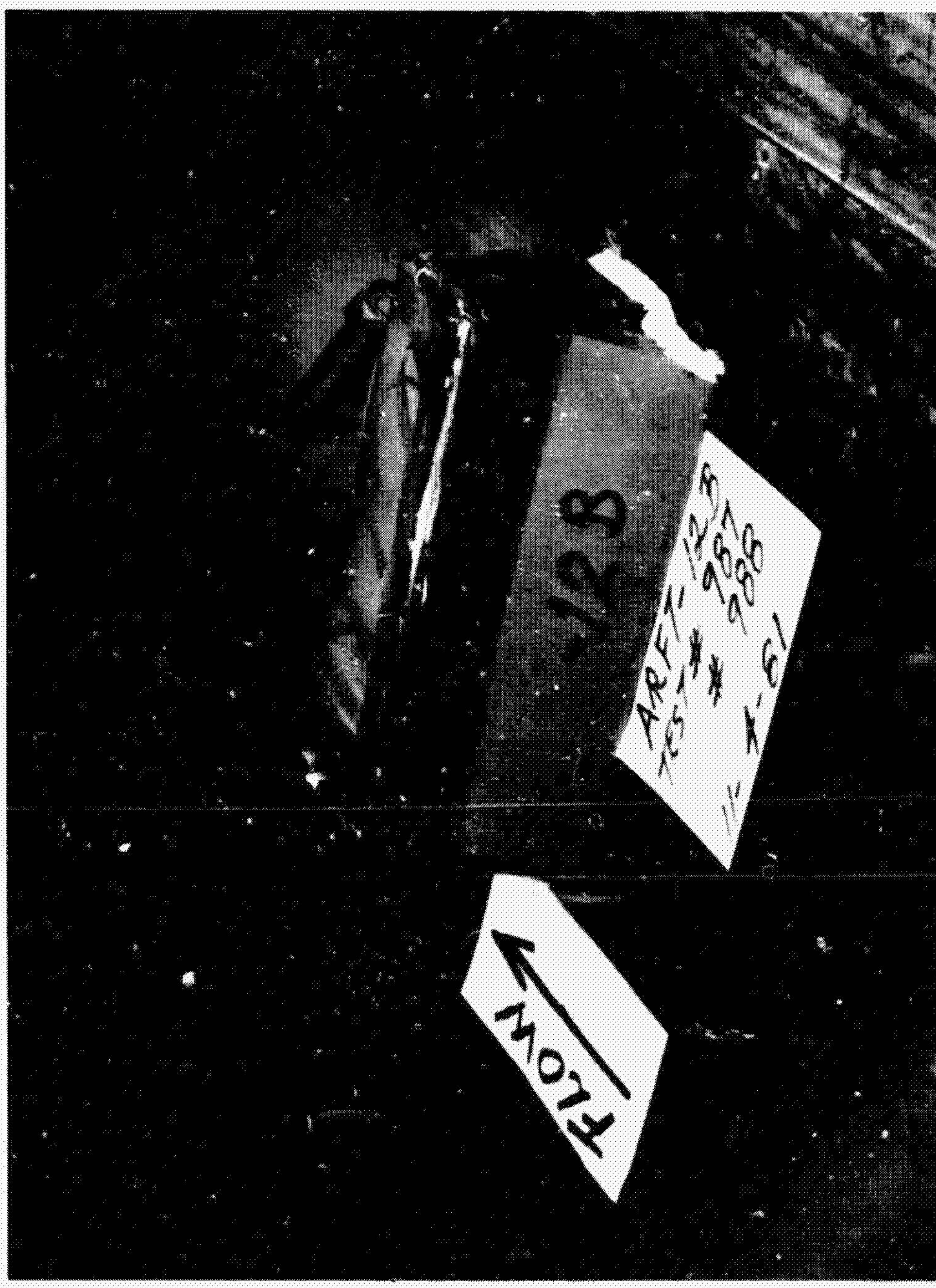

Fig. 34 - Seal (Material Type Class 2B/Grade 40) is Bonded to the Phenolic at the Front of Seal Groove Also in This Test

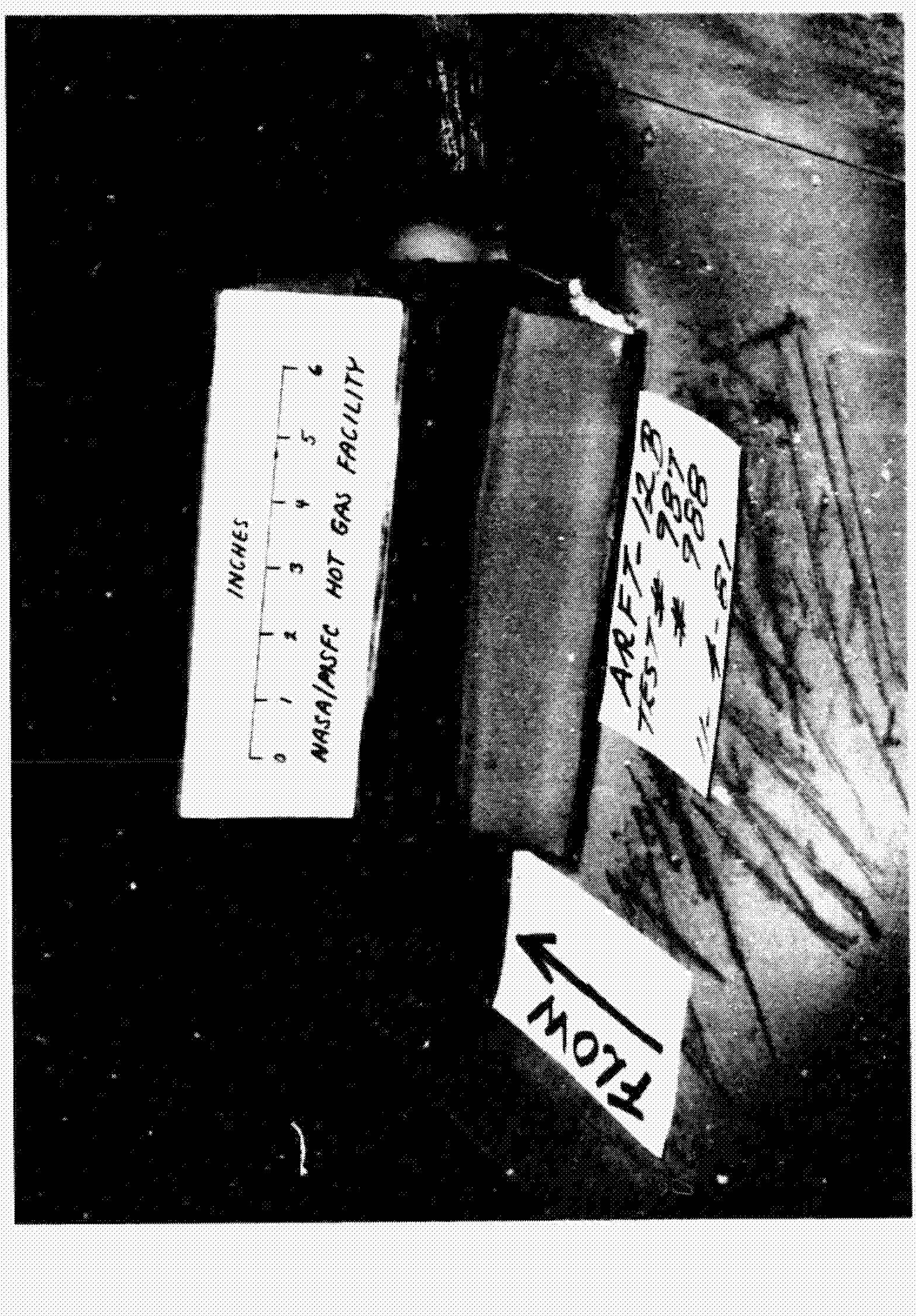

Fig. 35 - Seal Performance Identical to Its Performance When Seal Not Bonded to Phenolic at Front of Seal Groove

Fig. 36 - Repeat Test of That Shown in Fig. 34

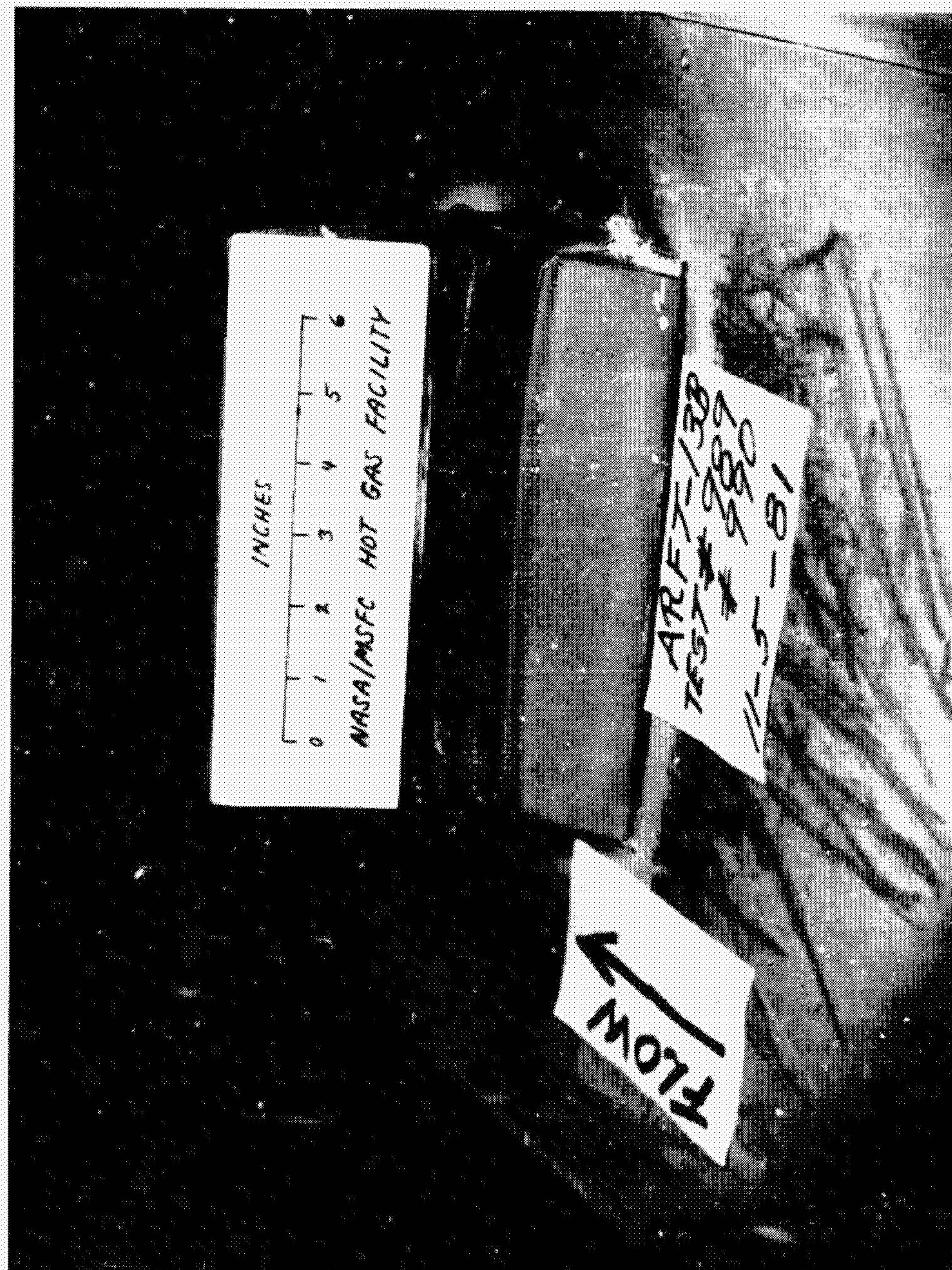

Fig. 37 - Results Identical to Those in Test of Fig. 35

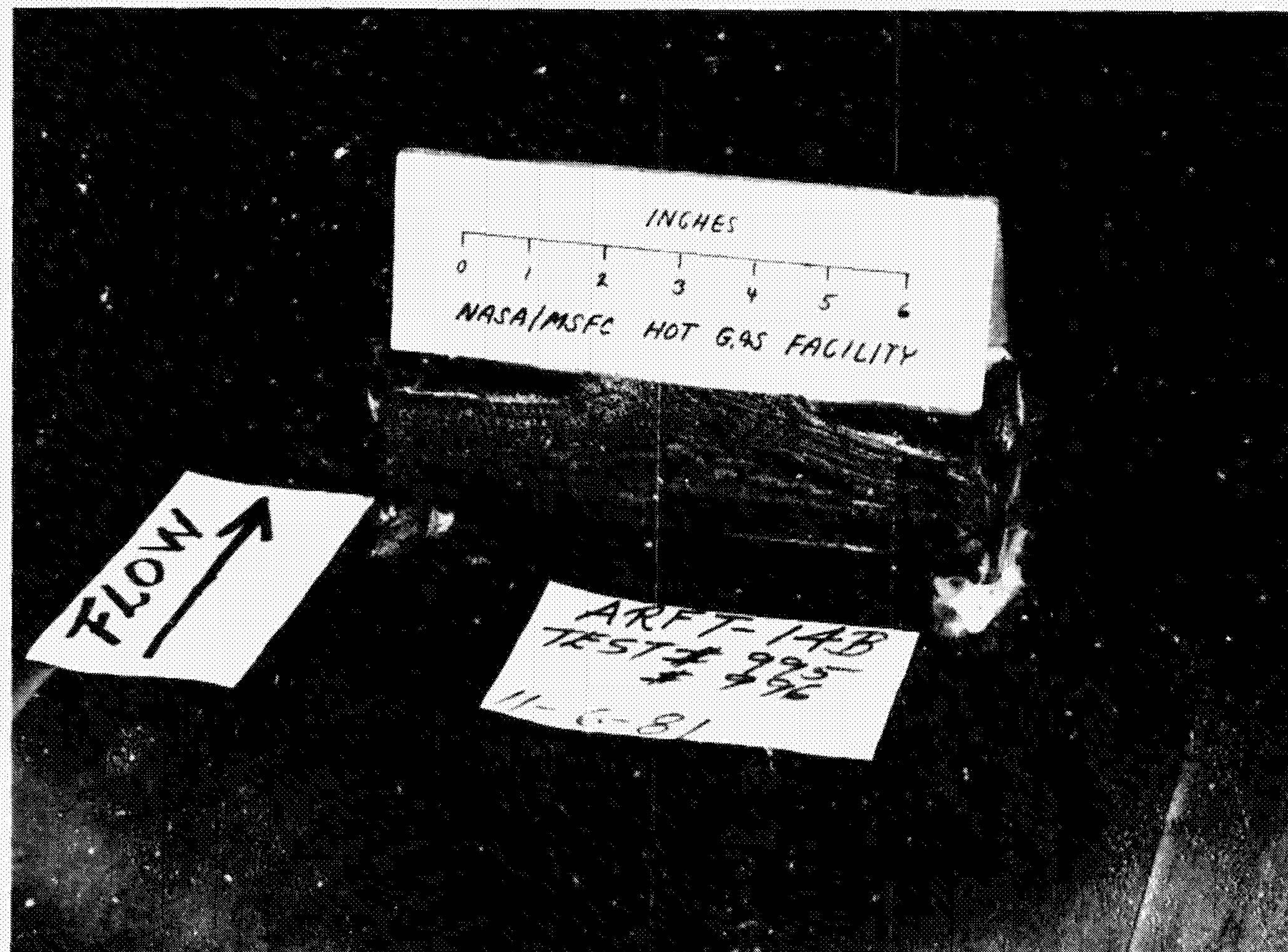

Fig. 38 – Post-Test Photograph of Small Fishtail Seal with 0.60 in. Gap Under Phenolic and Seal Bonded to the Phenolic at Front of Seal Groove Also. As in Tests of Figs. 16 and 17, the Seal Did Not Have Sufficient Compression to Provide Strength Necessary to Withstand Aerodynamic Forces.