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TEST FIRING
OF
A SUPERSONIC PROBE THRUST VECTOR CONTROL CONCEPT

J. R. ELLISON, LT, USAF

TECHNICAL REPORT AFRPL-TR-70-63

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AFRPL-TR-70-63

TEST FIRING OF A SUPERSONIC PROBE THRUST VECTOR CONTROL CONCEPT

John R. Ellison, Lt, USAF

FOREWORD

This report was prepared by the Motor Component Development Branch, Solid Rocket Division, Air Force Rocket Propulsion Laboratory (AFRPL). The subject test was conducted under Project 305903 AMG, Solid Rocket Hardware Evaluation (SRHE), on 12 December 1969. The rocket nozzle was designed and fabricated by the United Technology Center, Sunnyvale, California. The USAF test engineer was Lt Richard K. Strome, and the United Technology Center project engineer was Mr. Joe Spano.

This technical report has been reviewed and approved.

CHARLES R. COOKE
Chief, Solid Rocket Division
Air Force Rocket Propulsion Laboratory

ABSTRACT

The test firing of a rocket nozzle equipped with two fixed exit cone probes was conducted at the Air Force Rocket Propulsion Laboratory on a 36-inch inside diameter uncured propellant solid rocket motor. The exit cone probes were designed to act as shock inducing members, thereby generating side forces for thrust vector control. The probes were of two different configurations, a thin shell of silver infiltrated tungsten, and a thick block of the same material. The thin shell probe was ejected early in the firing, while the thick block version survived satisfactorily. The motor performed as desired, with a 740 psig maximum pressure, 15 second duration firing. LPC 614-A, a 16 percent aluminum, PBAN binder propellant was utilized.

TABLE OF CONTENTS

TABLES

ILLUSTRATIONS

SECTION I

INTRODUCTION

Thrust vector control (TVC) is the primary method of directing a missile in flight along the desired trajectory. Movable nozzles are a currently favored concept for providing TVC forces. Air Force studies (Reference 1) have shown that hydraulic actuation systems presently utilized on contemporary missiles can be replaced by a servo actuator. These servo nozzle control (SNC) systems operate in a manner similar to an aircraft control surface trim tab. A small servo actuation force reacting on a control component provides the power needed for control deflection.

The United Technology Center developed a SNC concept based upon inserting a probe into the supersonic exhaust of a movable solid rocket nozzle. The probe would induce a shock thereby causing a high local pressure on the exit cone surface. This high pressure area would be used as the actuation force for the movable nozzle. The environment for such a probe is very severe. Tungsten was selected by UTC for a candidate probe material. In June 1969 a SNC system utilizing a wire-wound-tungsten (WWW) probe was test fired at the AFRPL (Reference 2). The probe failed and was ejected before meaningful performance data could be obtained. A second test was conducted (reported herein) to verify survivability for a fixed silver infiltrated tungsten probe. Acceptable results would establish a basis for additional probe SNC development.

The objectives of the test were to:

1. Demonstrate the survivability of a thin shell, silver infiltrated tungsten (AgW) probe in the exit cone of a solid rocket nozzle.

2. Demonstrate the survivability of a thick block of AgW in a similar environment.

SECTION II

HARDWARE DESCRIPTION

The test nozzle was a conventional external configuration. A cross-section drawing is shown in Figure 1, and prefire photographs are shown in Figures 2, 3, 4 and 5.

The nozzle entrance section was fabricated from tape wrapped carbon cloth phenolic, MX 4926. The material was cured at 1000 psi and high temperature before being contoured to the final configuration. The nozzle throat insert was a 2.3 inch I.D. piece of G-90 graphite. The nozzle exit cone was a 15 degree half angle cone, fabricated from MX 4926 in the same manner as the entrance cap.

The probes were fabricated from infiltrated tungsten. Ten percent silver was the infiltrant material and 90 percent W formed the matrix. Both spikes were 5.16 inches in diameter, and of a flat end plate/cylindrical configuration. The probes were installed such that their centerlines were at an expansion ratio (A_{local}/A_{throat}) of 5.04:1 (Figure 6), with a total area blockage of 23 percent (Figure 7). Details of the probe designs are considered to be UTC proprietary information.

It was believed that the thick block probe, being solid AgW (Figure 8) would definitely survive the test firing thus providing a firm basis for further concept development. The degree of risk associated with the thin shell probe (Figure 9) was substantially higher, but potential for an ultimately lighter weight, lower cost assembly justified its consideration by UTC.

The gas generator utilized for the test was the AFRPL 36-inch I.D. char motor. The motor was lined with a 1/2-inch wall thickness paper phenolic insulating sleeve. The sleeve was pressed into the backup insulation, Gen Gard V-61. The V-61 I.D. was machined such that it provided structural support for the paper phenolic liner. The char motor aft closure was insulated with silica-filled buna-n-rubber. LPC 614-A uncured propellant was purchased from the Lockheed Propulsion Company for the test. The formulation consisted of 16 percent aluminum, ammonium perchlorate oxidizer, PBAN binder, and traces of other materials. Nominal flame temperature was 5700°F. Exhaust composition and ballistic properties are shown in Table I.

The thrust stand used for the test is a six-component, 20,000-pound thrust capacity unit manufactured by Gilmore Industries, Cleveland, Ohio. Verification tests have confirmed the static accuracy of the stand to be the following:

Axial thrust less than 1/2 percent error
Pitch axis side force less than 1 percent error
Yaw axis side force less than 1 percent error

Dynamic accuracy has not been determined.

SECTION III

TEST RESULTS

A. MOTOR PREPARATION AND PERFORMANCE

The nozzle was received from UTC and installed on the char motor aft closure. The paper phenolic insulating sleeve was coated with LPL-22 polymer 72 hours prior to the scheduled motor loading. The polymer was cured at ambient conditions. The LPL-22 liner was used to act as a wetting agent compatible with both the insulation and the propellant, thus preventing flame propagation down the propellant/insulation interface. The propellant was air-cast into the motor and allowed to settle for a period of 24 hours. Entrapped air was allowed to escape during this time period. A "pancake" igniter consisting of an aluminum mesh coated with a pyrotechnic material was placed on the propellant surface before the aft closure was attached to the motor center chamber. The lead wires were routed through the nozzle orfice. The thrust stand was electrically calibrated after motor loading and prior to the test firing.

The motor was fired, and a smoothly regressive 740-psig maximum chamber pressure trace (Figure 10) was produced. Average chamber pressure was 700 psig over a 15 second effective burn time. A summary of significant motor preparation and performance data is found in Table II, which also contains pertinent nozzle performance information. A prediction of the maximum chamber pressure level had been made using data from an earlier 25-inch char motor firing (Reference 3). The predicted level, 750 psig, correlated well with the actual level, thereby indicating that the propellant performed similarly in the two different motor sizes.

Dynamic performance of the Gilmore thrust stand was almost as good as the static accuracy verification had indicated, in spite of oscillatory vibrations (ringing) in all axes. The stand stabilized in the axial thrust mode immediately after ignition, and thereafter performance was typified by cyclic vibrations of approximately 30-lbf magnitude. The magnitude of the axial ringing, being less than one percent (1%) of the motor thrust was considered to be acceptable for this test. The thrust versus time trace is Figure 11.

Some vibration in the pitch axis (X axis) was also evident. The magnitude of the oscillatory vibrations was approximately ten percent (10%) of the side thrust, but the regularity of the vibrations would readily allow the use of data smoothing techniques if a need for higher accuracy existed. This side force versus time trace is shown in Figure 12.

B. NOZZLE TEST RESULTS

The primary test objective, probe survivability, was not completely achieved. The thin-shell probe was ejected approximately 4-1/2 seconds after ignition (t = 5.7 seconds). The thick block probe survived the test in excellent condition (Figure 13). The exit cone was heavily eroded in an arc upstream of the thick block probe (Figure 14). This severe localized erosion was not expected based on the results of the test described in Reference 1. This could be a problem if future firings are attempted. Parts of the thin shell probe were recovered (Figure 15), and a preliminary post test analysis indicated that a structural failure in the probe retention system had caused the component ejection. The graphite throat insert performed adequately (Figure 16), with an average surface recession rate of 1.4 mil/sec.

C. DATA ANALYSIS

In spite of the thin shell probe failure, some very interesting performance data was obtained. The data included thrust degradation and side force versus time.

The thrust degradation effect of the probes was analyzed by considering the magnitude of the axial thrust immediately before and after the ejection of the thin shell probe. The increase in thrust (Figure 11) was approximately 125 lbf, which indicated that the 11.5 percent area blockage at the expansion ratio of 5:1 had degraded the axial thrust by slightly less than 3 percent.

Pitch side force increased approximately 225 lbf after the probe failure. This indicated that the remaining probe was producing a side force capable of actuating a flexible seal movable nozzle.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

Based on the char motor and test nozzle performance, the following conclusions are made:

1. The probe-actuated servo nozzle control concept is feasible.

2. Tungsten materials can, with the proper design, survive the severe environment experienced by the probe.

3. Char motor performance was satisfactory and in no way contributed to the nozzle failure.

The following recommendations are made:

1. A lighter weight probe configuration should be developed and demonstrated.

2. Another test firing utilizing a probe and movable nozzle should be performed to validate the total system feasibility.

TABLE I. PROPELLANT BALLISTIC PROPERTIES

Combustion Products (LPC 614A)	moles/100 gm
CO	0.7846
HCl	0.5145
Cl	0.0446
H_2O	0.6563
H_2	0.9410
N_2	0.3083
Al_2O_3	0.2820

Propellant Composition	percent
Ammonium Perchlorate	70.5
Aluminum	16.0
Binder	13.5

Performance Characteristics	
Nominal r_b	0.30 in @ 800 psig
Nominal n	0.33 @ 800 psig

TABLE II. MOTOR AND NOZZLE PERFORMANCE DATA

Prefire Throat Diameter	2.302 inches
Postfire Throat Diameter	2.344 inches
Propellant Formulation	LPC 614A
As-Cast Propellant Depth	5.0 inches
Burn Surface Diameter	36.0 inches
Propellant Weight (W_p)	360 pounds
Predicted Maximum P_c	750 psig
Actual Maximum P_c	740 psig
Average P_c	704 psig
Effective Duration	15 seconds
Total Impulse	69,000 lb-sec
*Calculated Specific Impulse	192 seconds
Ambient Temperature	66°F
Ambient Pressure	13.6 psia

*This is delivered $I_{sp} = \frac{\int F d_t}{W_p}$ where F = thrust

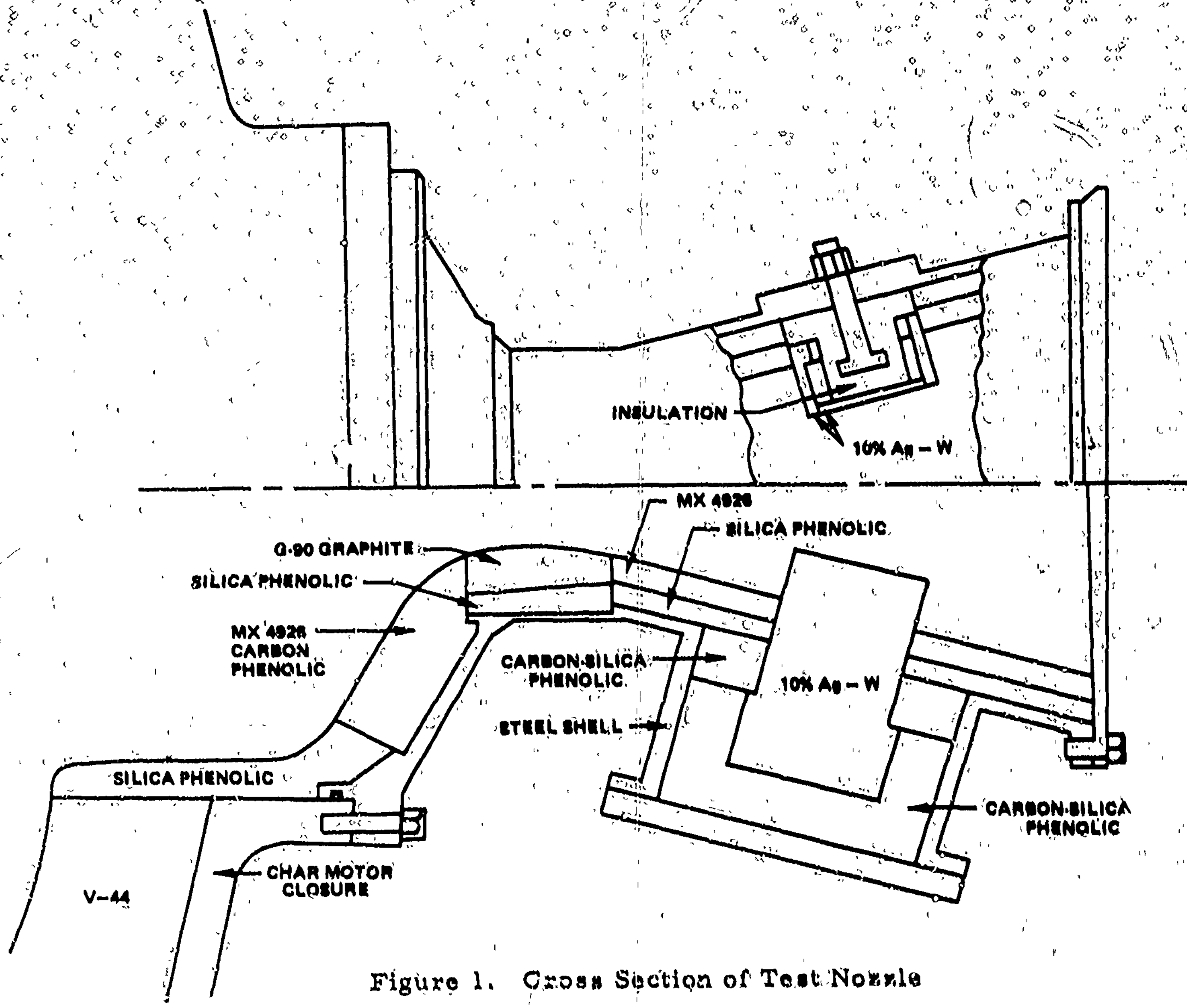

Figure 1. Cross Section of Test Nozzle

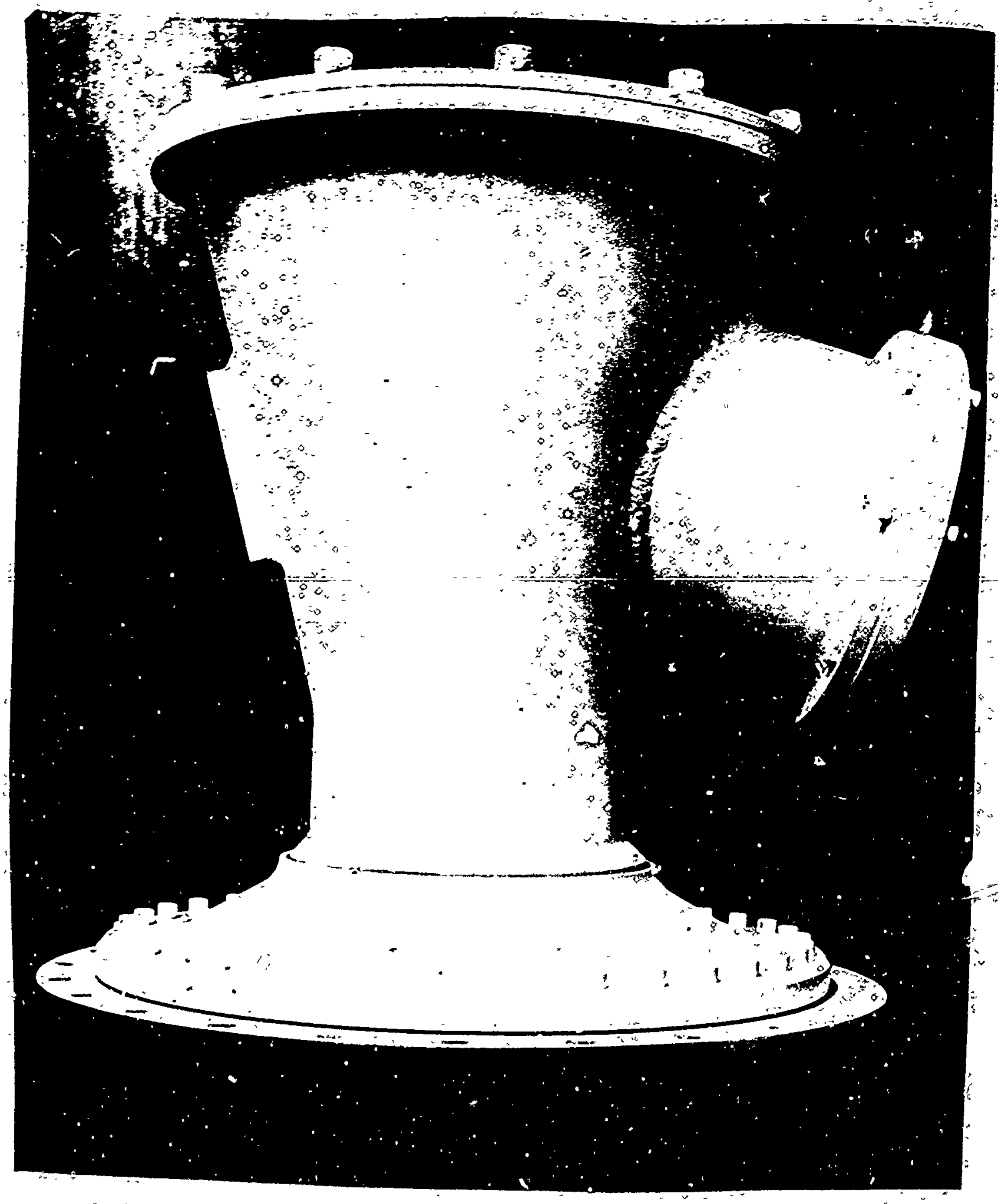

Figure 2. Side View of Test Nozzle

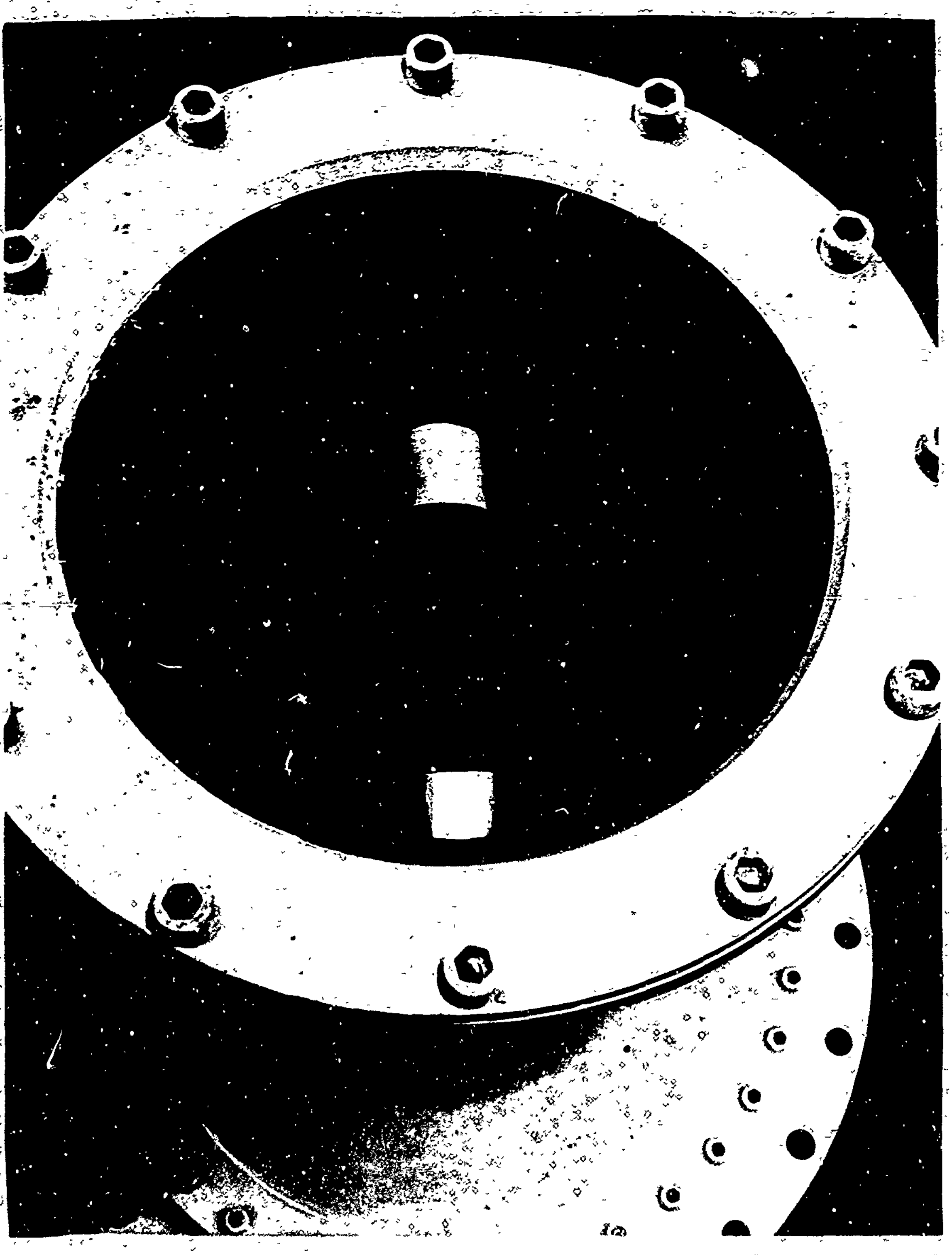

Figure 3. Exit Cone with Solid Block Probe

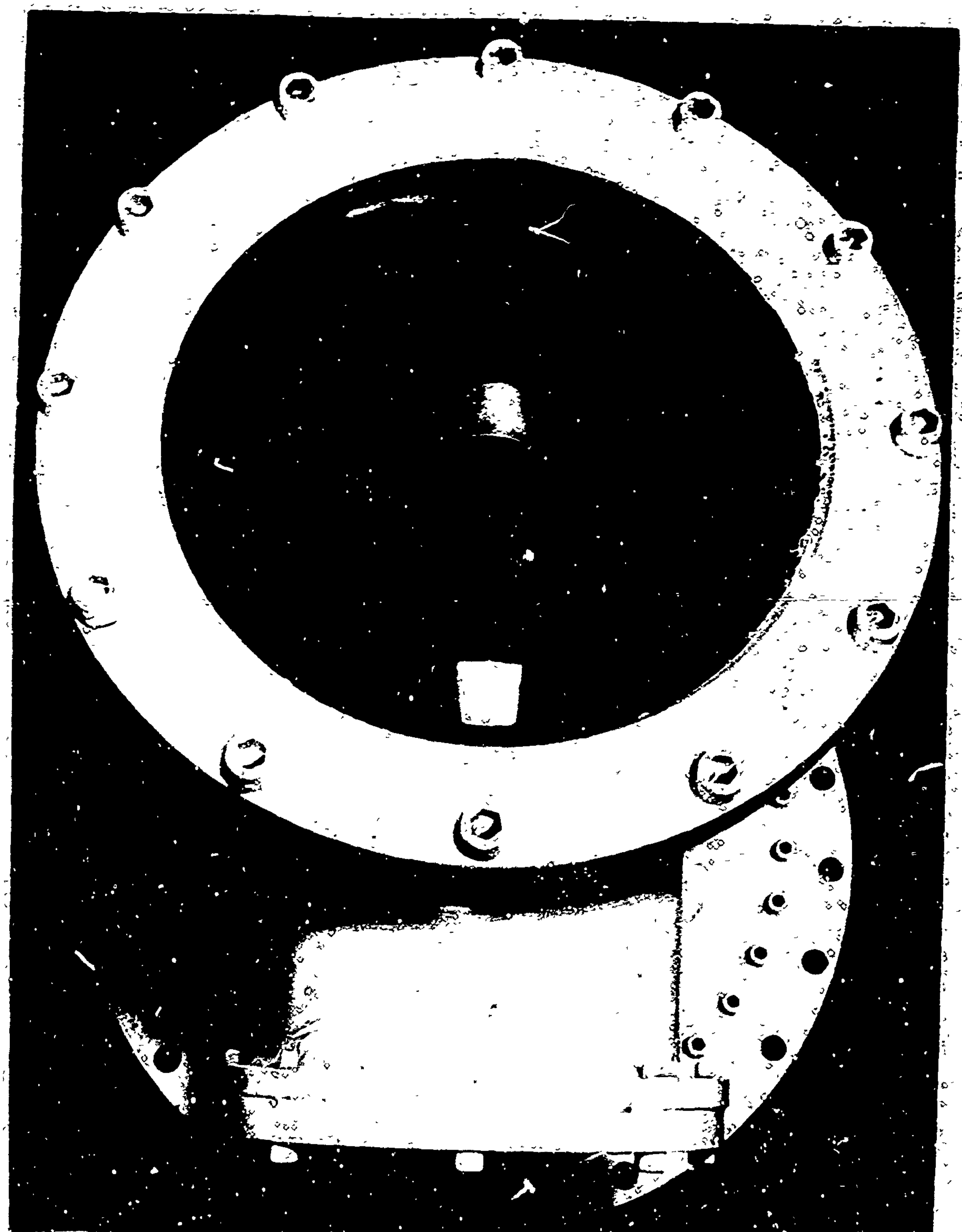

Figure 4. Exit Cone with Thin Shell Probe

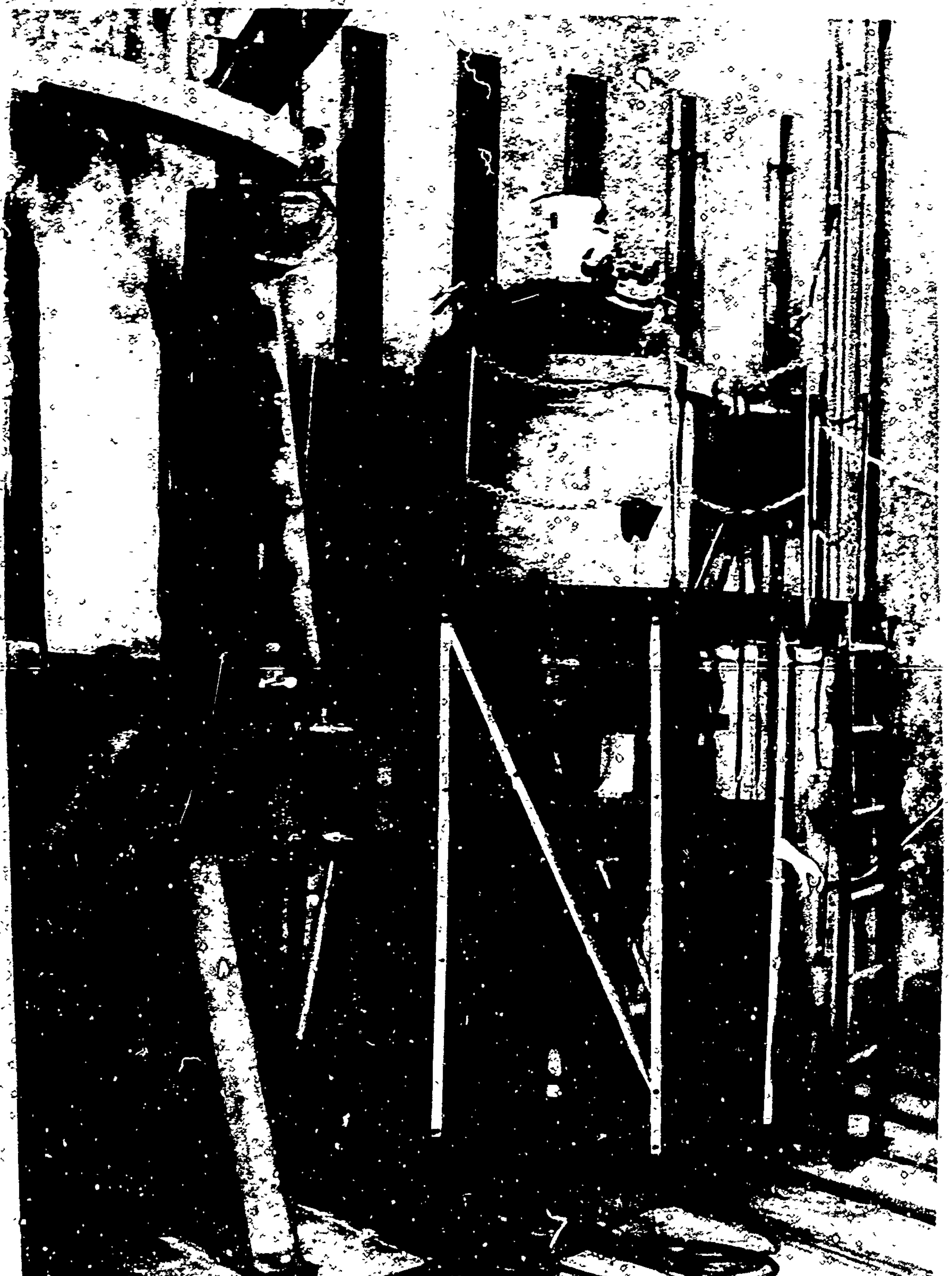

Figure 5. Prefire View of Motor, Nozzle, and Thrust Stand

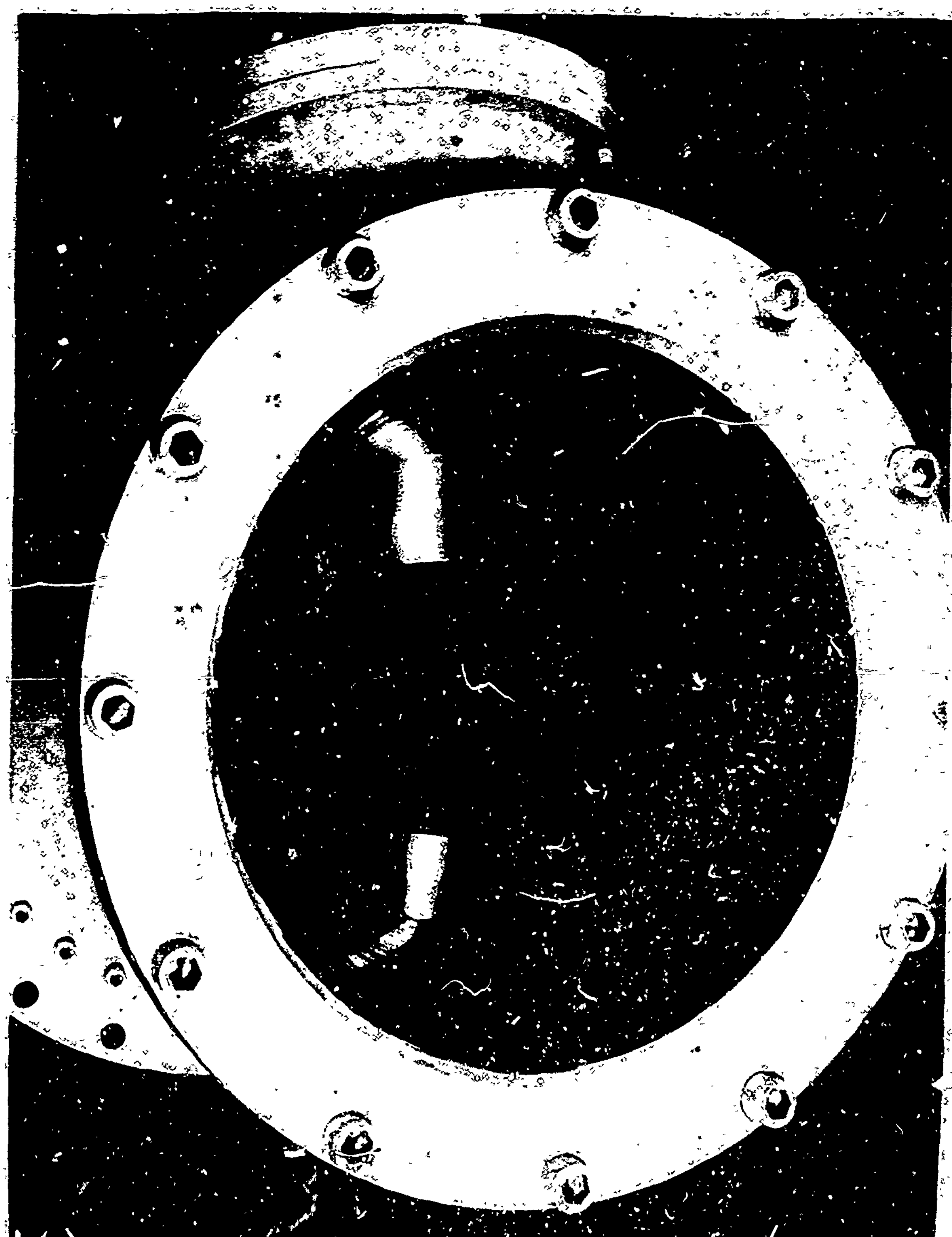

Figure 6. Prefire View, Paired Probes

Figure 7. Prefire View of Entrance Section

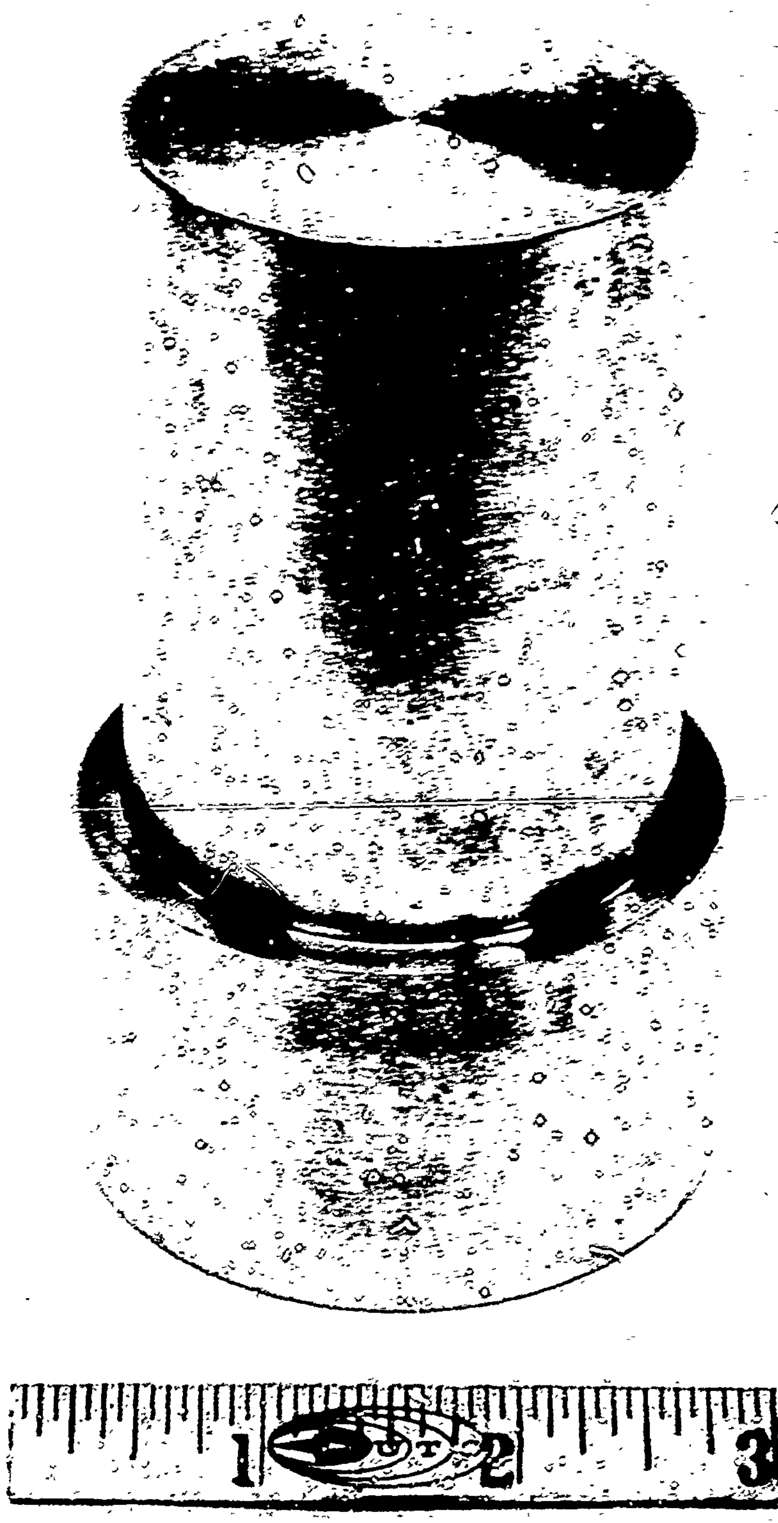

Figure 8. Thick Block Probe

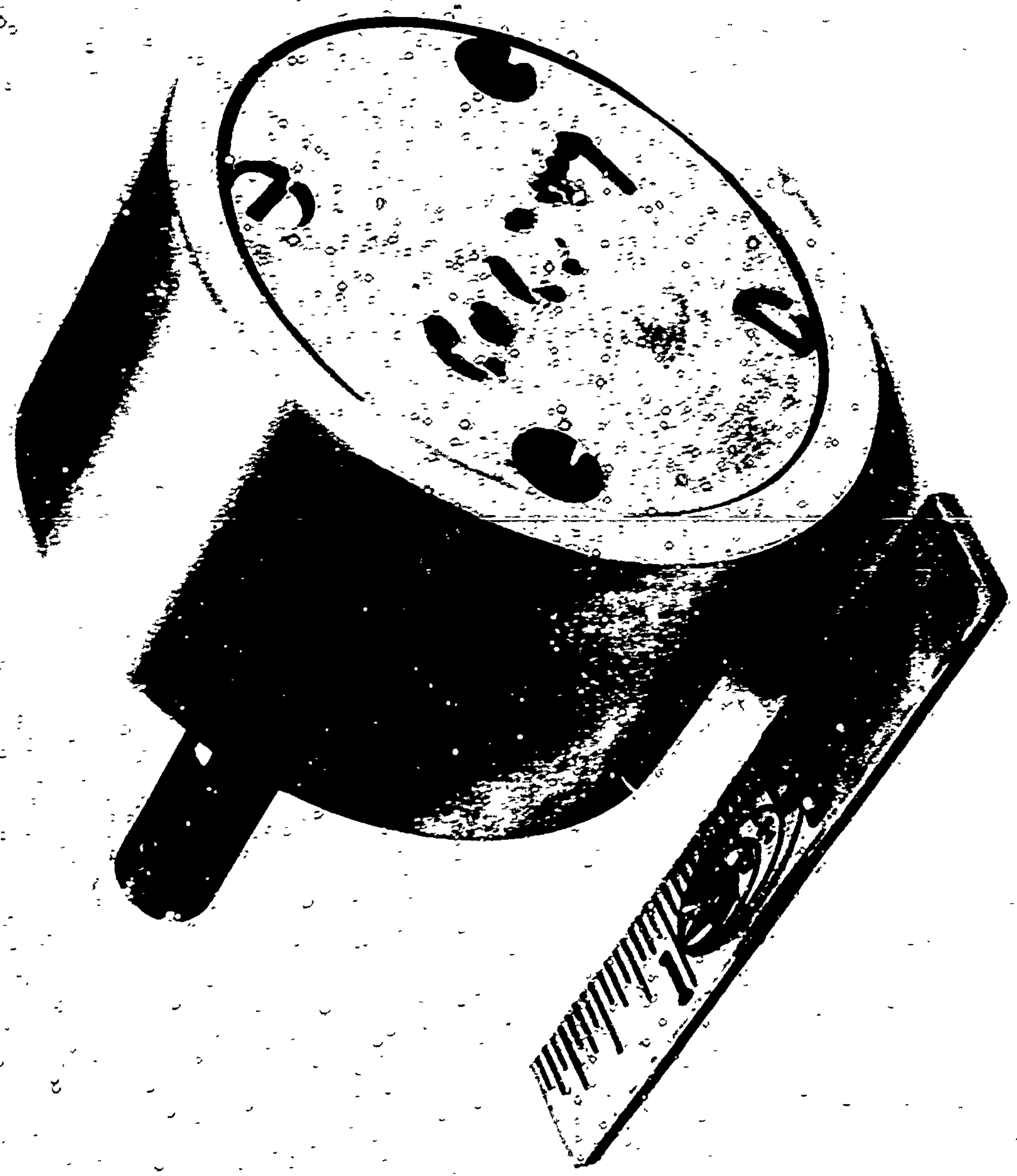

Figure 9. Thin Shell Probe

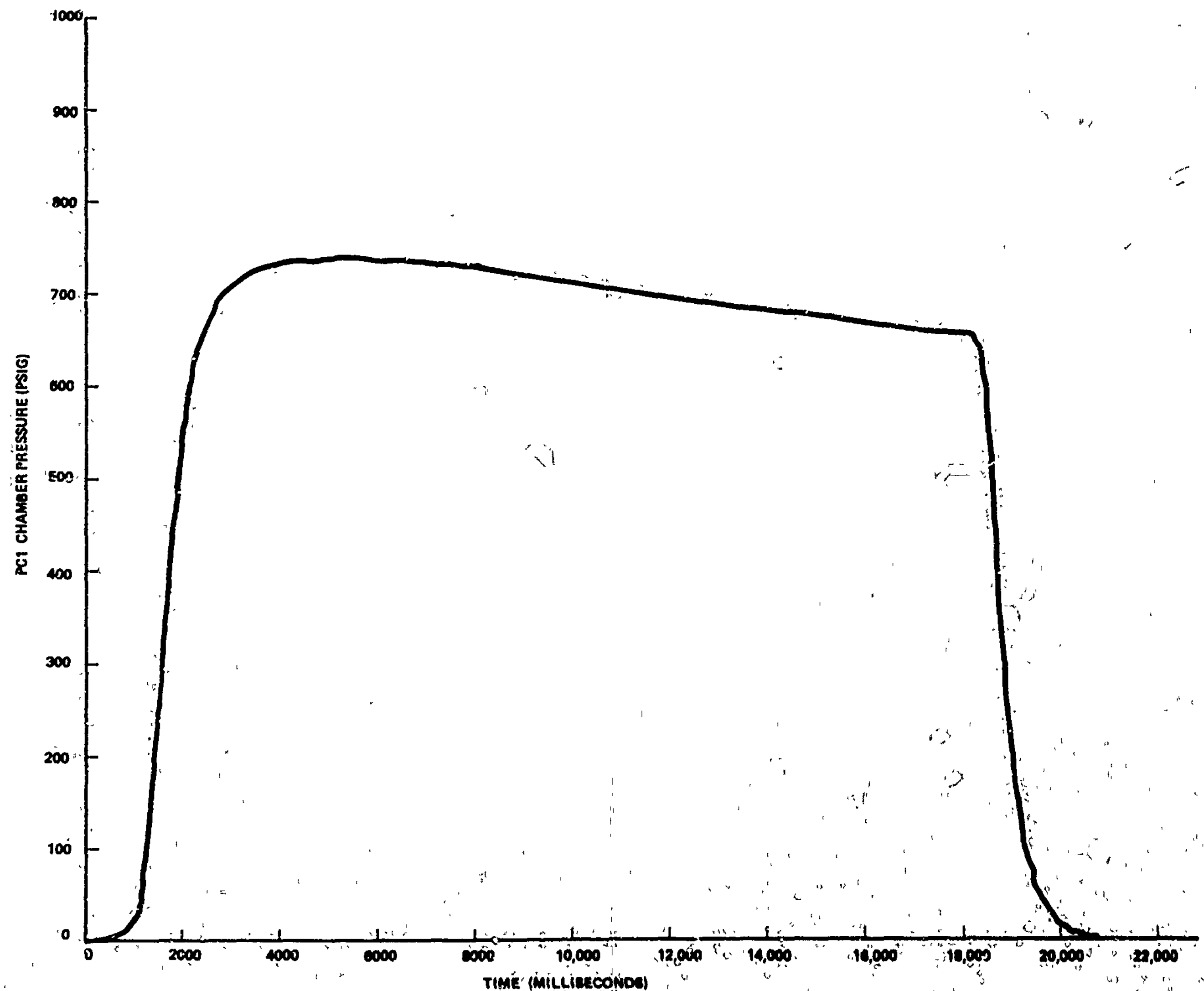

Figure 10. Chamber Pressure versus Time

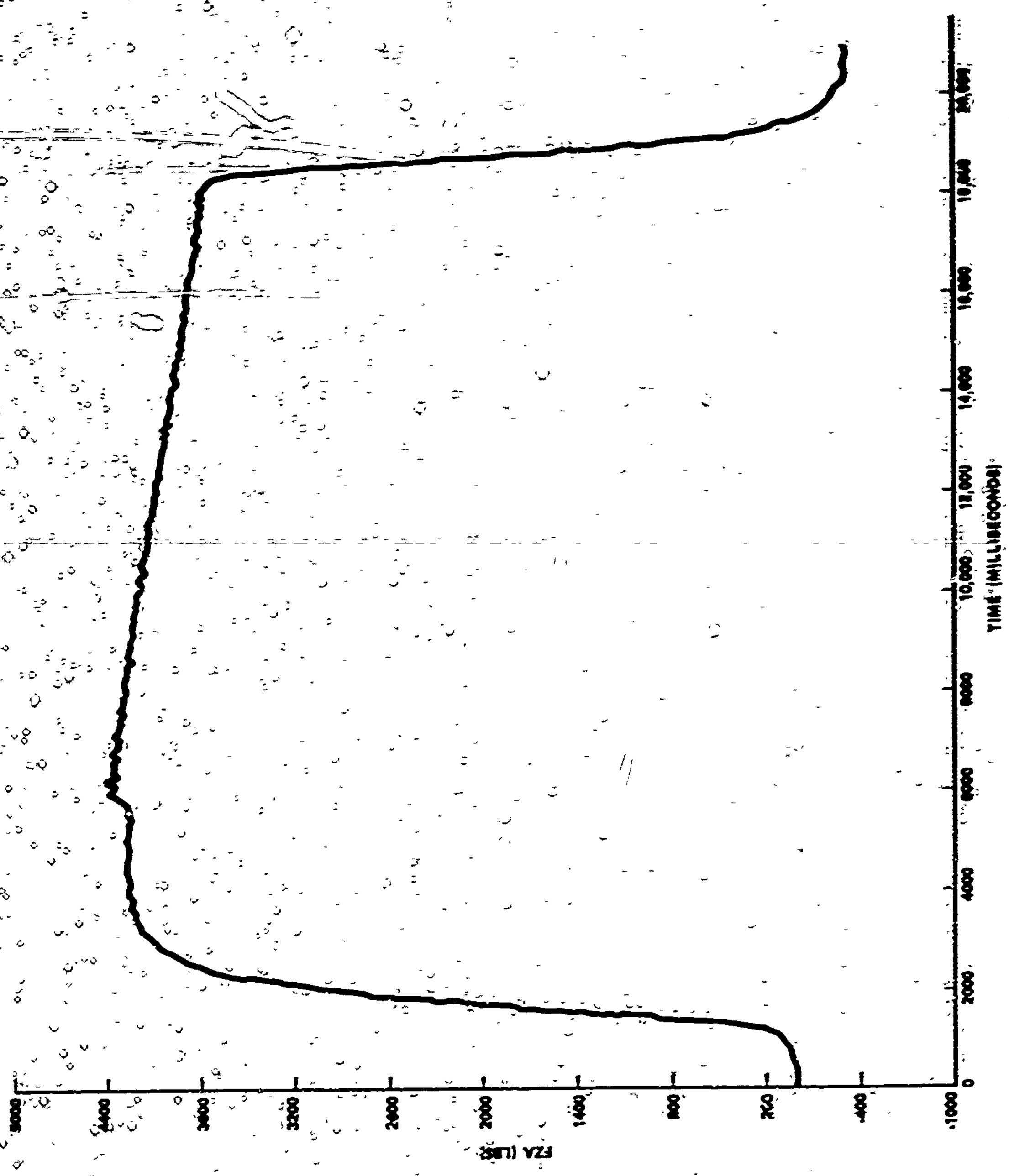

Figure 11. Axial Thrust versus Time

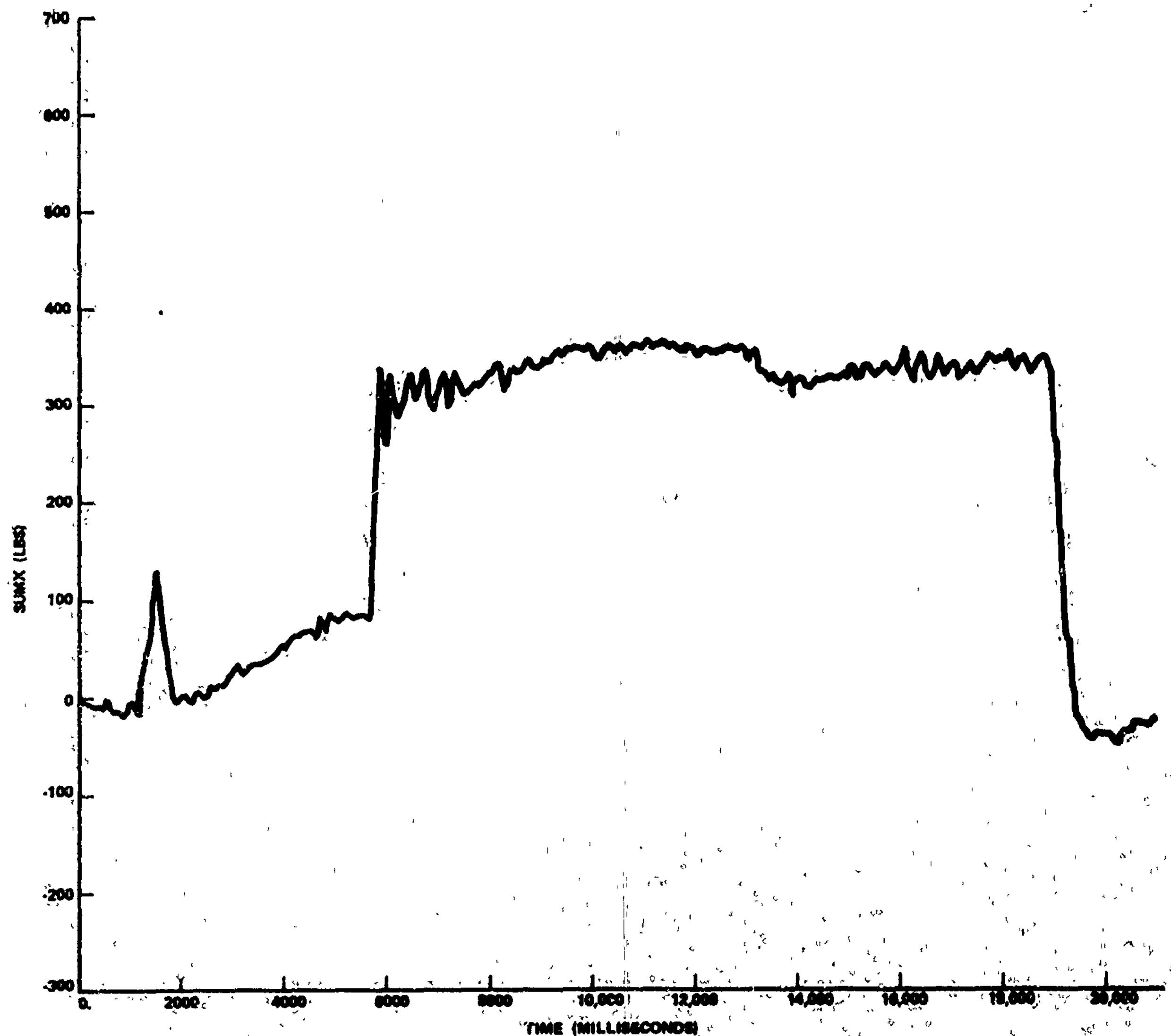

Figure 12. Side Force versus Time

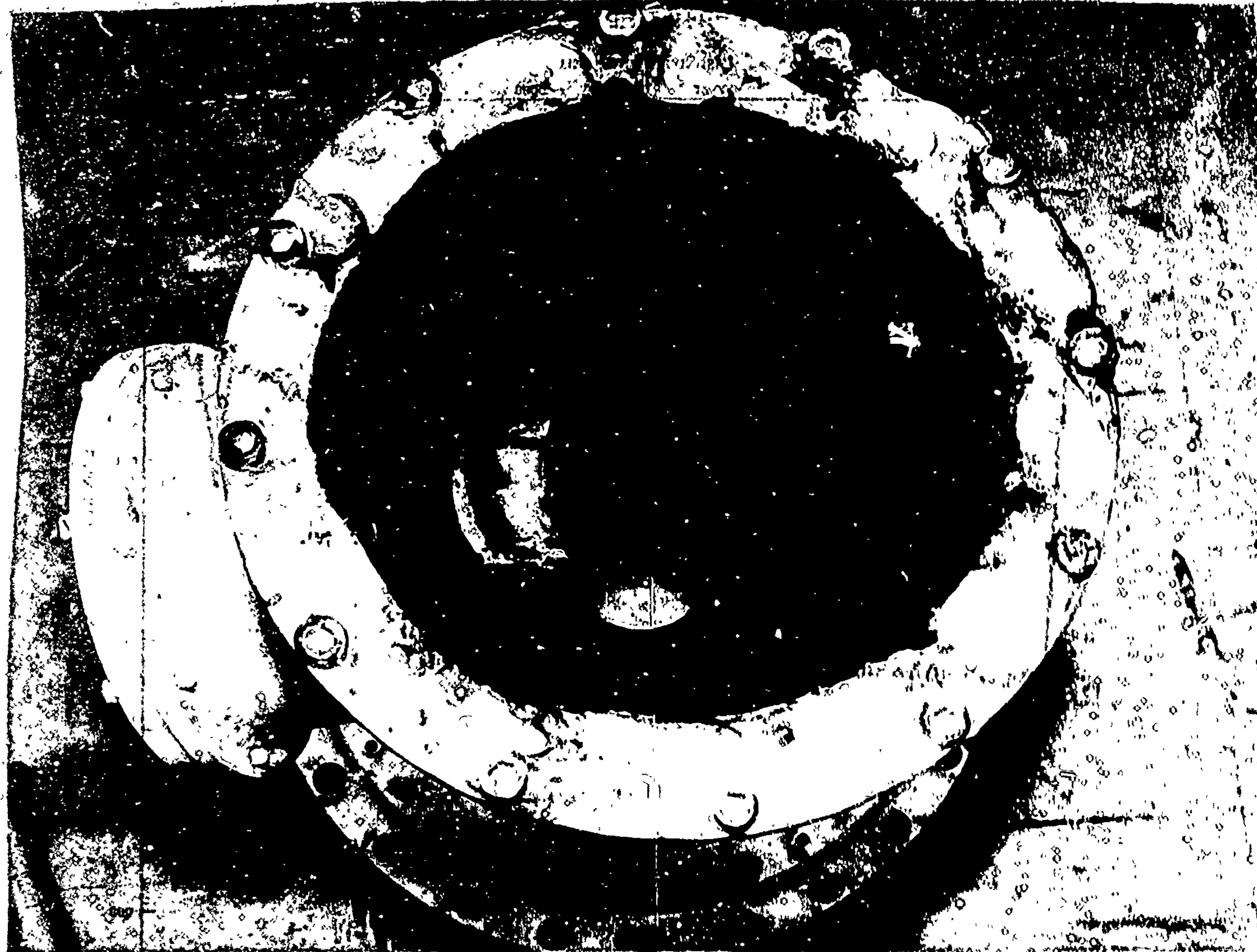

Figure 13. Postfire Top View of Thick Block Probe

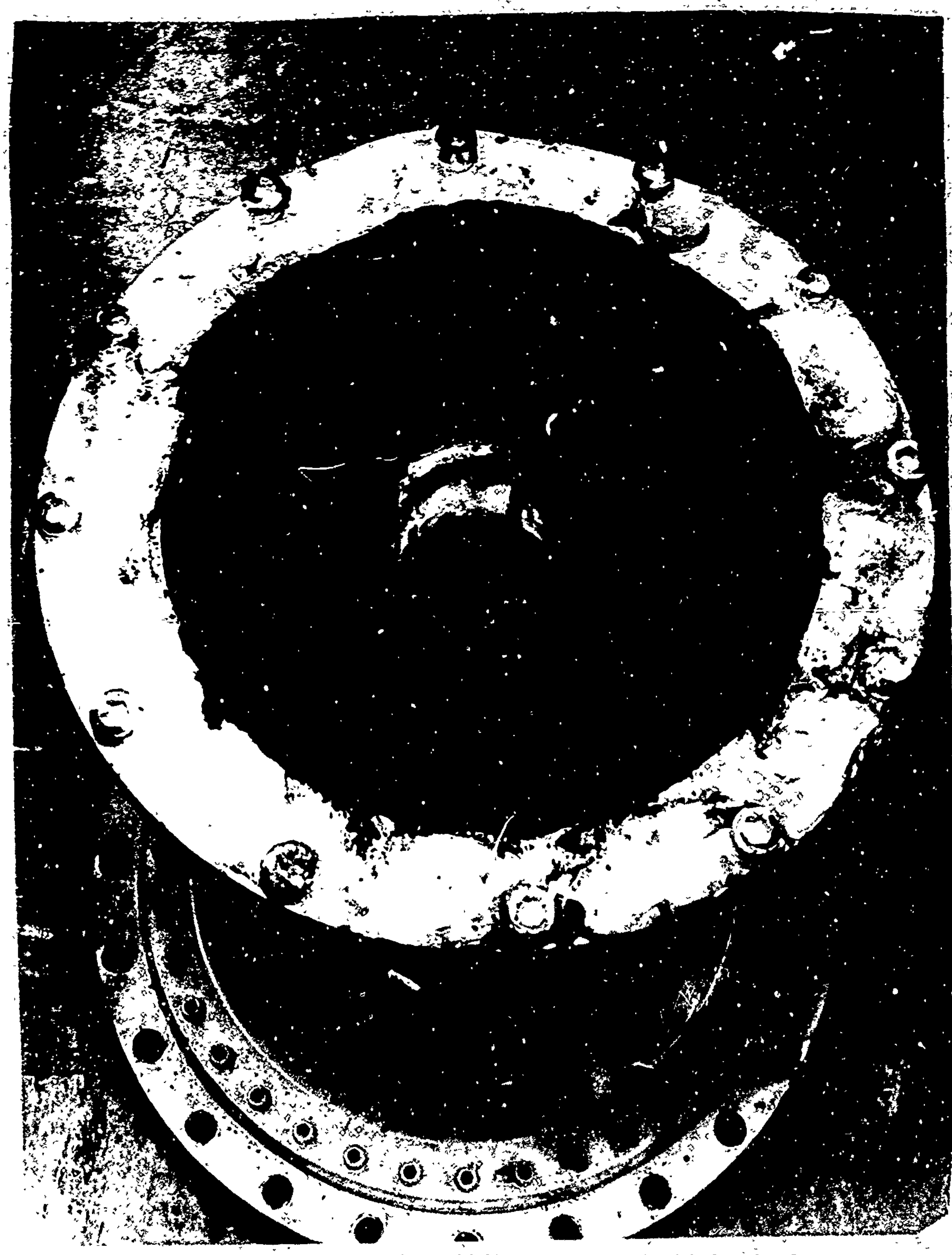

Figure 14. Postfire Oblique View of Thick Block Probe and Exit Cone Erosion

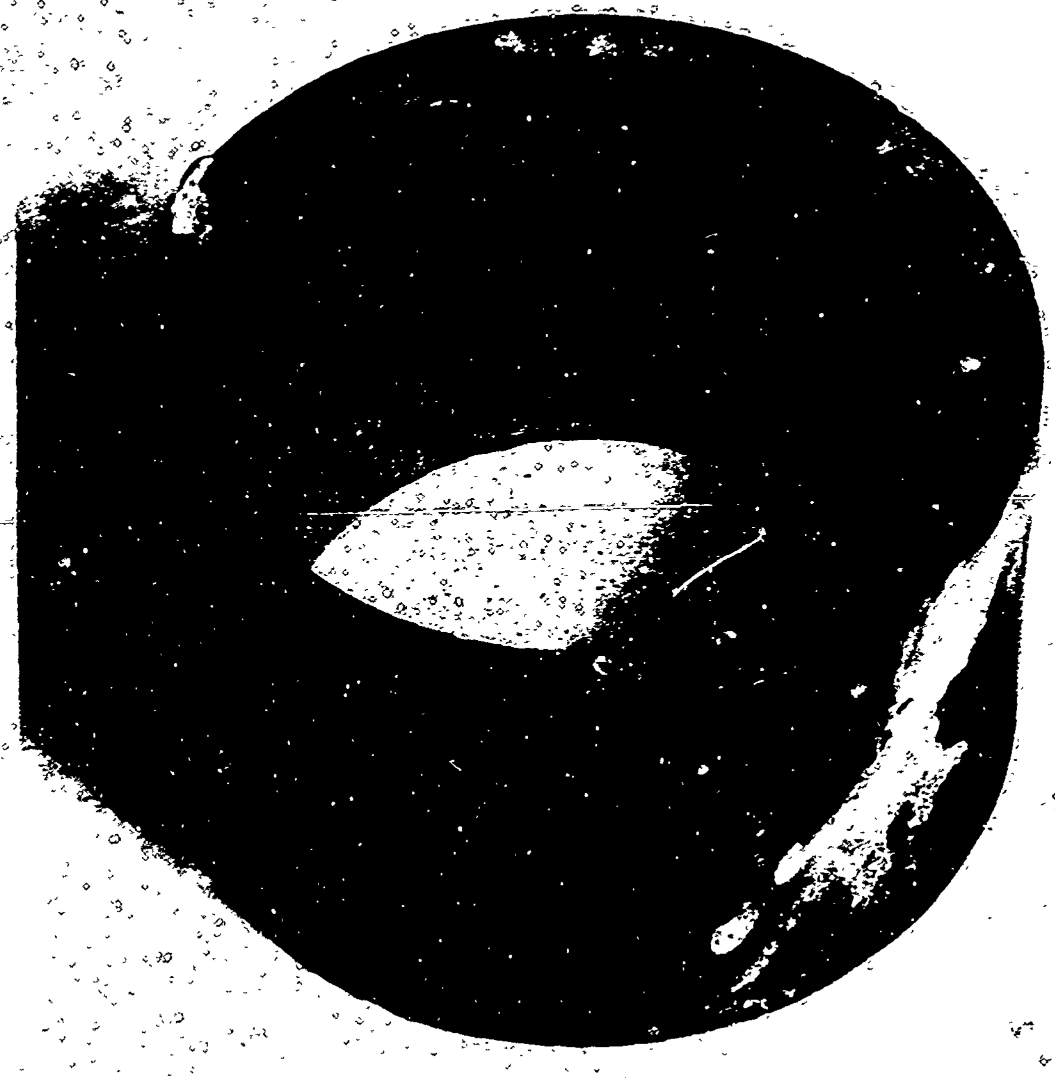

Figure 15. Recovered Parts of Thin Shell Probe

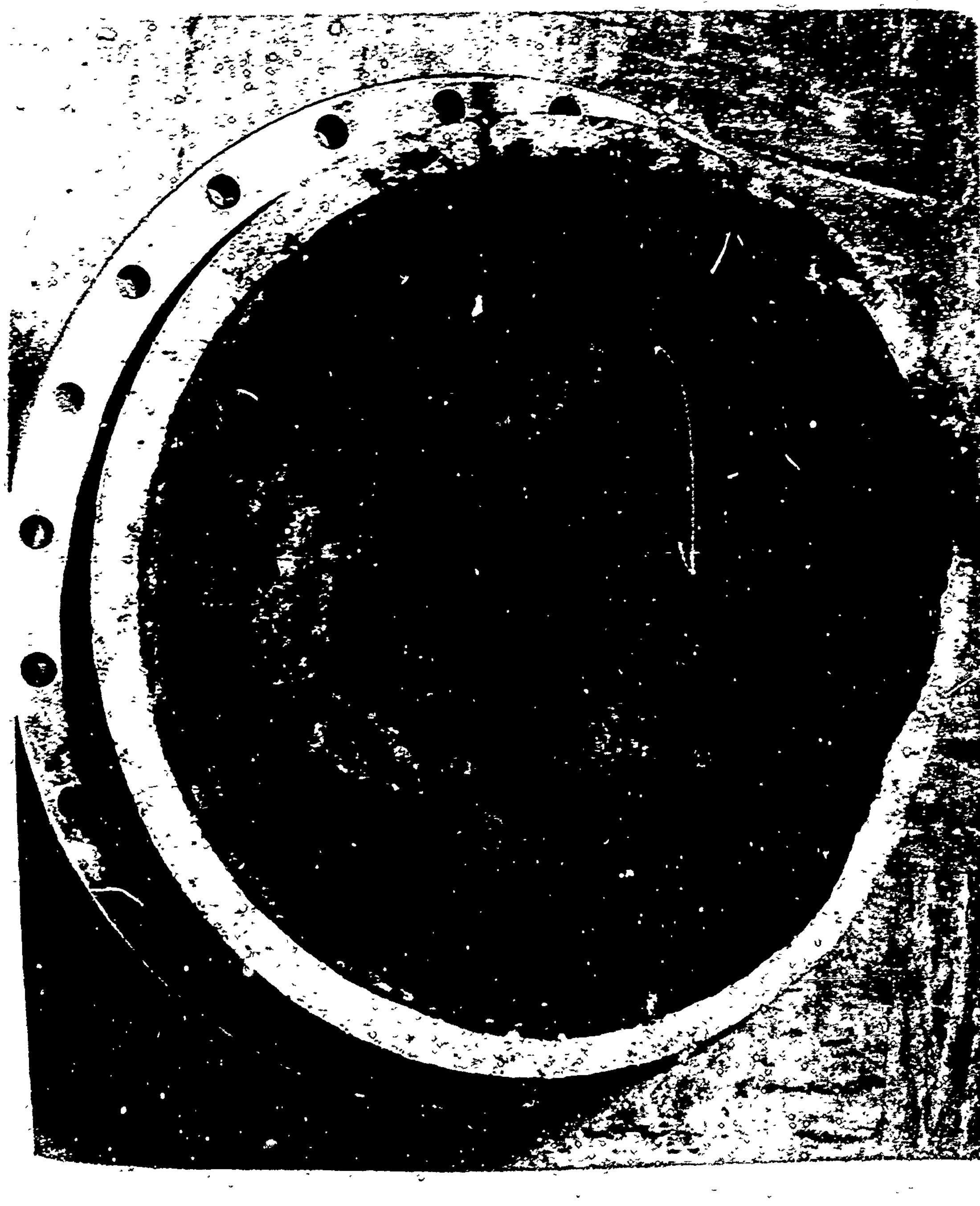

Figure 16. Postfire View of Graphite Throat Insert

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2. J. Ellison; "Test Firing of a Spike-Actuated Flexible Seal Nozzle"; AFRPL-TR-69-191; AD 862282; Air Force Rocket Propulsion Laboratory, Edwards, California; September 1969; Unclassified Report.

3. D. Zorich and J. Ellison; "Evaluation of Pyrolytic Graphite Coated Rocket Nozzle Throat Inserts (Test Nozzles 2 and 3); AFRPL-TR-69-237; AD ; Air Force Rocket Propulsion Laboratory; Edwards, California; November 1969; Unclassified Report.

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13. ABSTRACT

The test firing of a rocket nozzle equipped with two fixed exit cone probes was conducted at the Air Force Rocket Propulsion Laboratory on a 36-inch inside diameter uncured/propellant solid rocket motor. The exit cone probes were designed to act as shock inducing members, thereby generating side forces for thrust vector control. The probes were of two different configurations, a thin shell of silver infiltrated tungsten, and a thick block of the same material. The thin shell probe was ejected early in the firing, while the thick block version survived satisfactorily. The motor performed as desired, with a 740 psig maximum pressure, 15 second duration firing, LPC 614-A, a 16 percent Aluminum, PBAN binder propellant was utilized.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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Char Motor						
Supersonic Nozzle Probe						
Silver Infiltrated Tungsten						
Servo Nozzle Control						