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2.75-IN. FOLDING FIN AIRCRAFT ROCKET (U)

FINAL REPORT

VOLUME I

Contract F04611-67-C-0114

Report AFRPL-TR-69-90 April 1969

G. Dolgonas
H. A. Krayenbuhl

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STATEMENT #2 UNCLASSIFIED

~~Prepared for:~~

AIR FORCE ROCKET PROPULSION LABORATORY
Research and Technology Division
Edwards, California. 93523

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

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FOREWORD

This report presents the results of the 2.75-inch Folding Fin Aircraft Rocket improvement program conducted for the Air Force Rocket Propulsion Laboratory by the Aerojet-General Corporation at Sacramento, California, under Contract F04611-67-C-0114. The program was administered under the direction of Captain M. P. Konieczny, RPMMA, and Mr. Lee Meyer, RPMMA, Project Officers.

The Aerojet program managers were T. Bowden and G. Dolgonas. The work reported herein was conducted from July 1967 through October 1968. This report contains no classified information extracted from other classified documents, except for performance parameters quoted from the contract statement of work. The Aerojet report number assigned to this document for local identification is 3297-01F. This technical report has been reviewed and approved by C. R. Cooke, Chief, Solid Rocket Division, Air Force Rocket Propulsion Laboratory.

ABSTRACT

Contract F04611-67-C-0114 covers the design, development, testing and delivery of an improved rocket for the flechette warhead. Work included (1) design, analysis, and component tests; (2) development tests; (3) Preliminary Flight Rating Tests; and (4) delivery of improved rocket motors. Analyses included design trade-off studies, aerodynamics analysis, and manufacturing optimization studies. The improved design was successfully demonstrated through the preliminary flight rating tests and through flight tests, both ground-launched and aircraft-launched. Performance, reliability, and accuracy are within contract requirements.

This final report is in two volumes. Volume I contains the program accomplishments and Volume II contains the Appendixes.

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I. INTRODUCTION AND SUMMARY

A. INTRODUCTION

This final report is submitted by Aerojet-General Corporation in partial fulfillment of the requirements of Contract F04611-67-C-0114. The objective of this program was to design, fabricate, and demonstrate an improved 2.75-in. Folding Fin Aircraft Rocket (FFAR) that will meet the performance requirements for a flechette warhead. The program scope included rocket design, aerodynamic stability analysis and wind tunnel testing, propellant adaptation, manufacturing, motor testing through PFRT, and delivery of 580 units to the Air Force.

B. SUMMARY

The improved 2.75-in. FFAR rocket complies with the performance requirements shown in Exhibit A (amended) of the contract. The design criteria for ease of manufacture and assembly, simplicity, overall cost effectiveness, and maximum utilization of existing 2.75-in. FFAR metal parts were met.

A stability and control analysis was conducted and the analytical results were verified in wind tunnel tests as well as in actual flight tests, both from the ground and from an aircraft.

Production studies were conducted to optimize manufacturing processes for quantities of units ranging from 100,000 to 600,000 per month.

A propellant tailoring program was successfully carried out to obtain optimum burning rate, processing characteristics, mechanical and ballistic properties, and aging stability. Explosive hazard tests verified that the propellant is DOT Class B.

I.B. Summary (cont)

A total of 16 component tests were made, using full-scale motors, to determine igniter, insulation, grain support, and nozzle adequacy. In addition, propellant arc image ignitability tests were conducted to determine ignition requirements, and a total of 66 igniter tests were made in a simulated free-volume chamber to investigate igniter performance.

A total of 36 full-scale development firings were made in accordance with Exhibit A of the contract. Tests conducted on these motors included temperature cycling, vibration, and acceleration/spin tests. Exhibit A of the contract requires testing of three series of 15 motors each. By agreement with the Air Force, the number of motors in series 2 and 3 was reduced to 11 and 6 motors, respectively. In addition, four other development motors were fired.

A 45-motor Preliminary Flight Rating Test program was successfully conducted in accordance with Exhibit A of the contract. Of the 45 motors, 18 were temperature conditioned only firing six each at -65, +70, and +150°F. Twenty of the 45 motors were subjected in sequence to humidity, temperature cycling, vibration, and altitude cycling before firing nine at -65°F, four at +70°F, and seven at +150°F. The remaining seven motors were test fired as follows: three altitude firings; one acceleration firing; one acceleration firing with a temperature gradient across the grain; and three firings with a temperature gradient across the grain. All but one test was successful; this partial failure may have been due in part to improper handling or to a defect in the manufacture of the aft closure.

Forty-four of the 45 PFRT motors were accepted for use in demonstrating that the PFRT motor configuration satisfied the requirement of 95% reliability at a confidence level of 90%. These motors and 14 acceptable R&D motors of the PFRT configuration, together with five flight motors that were recovered, inspected, and accepted for the reliability motor count, totaled

64 of the 76 successful firings required to demonstrate the required reliability level. This quantity of motors (76) reflected the effect of the one failure on the number of motors necessary to demonstrate the specified reliability level. The remaining 12 motors for reliability demonstration were later accepted from the 56 motors successfully fired for acceptance of the 580 production deliveries. The latter were completed in October 1968 with the final shipment of 52 motors to Eglin Air Force Base (EAFB).

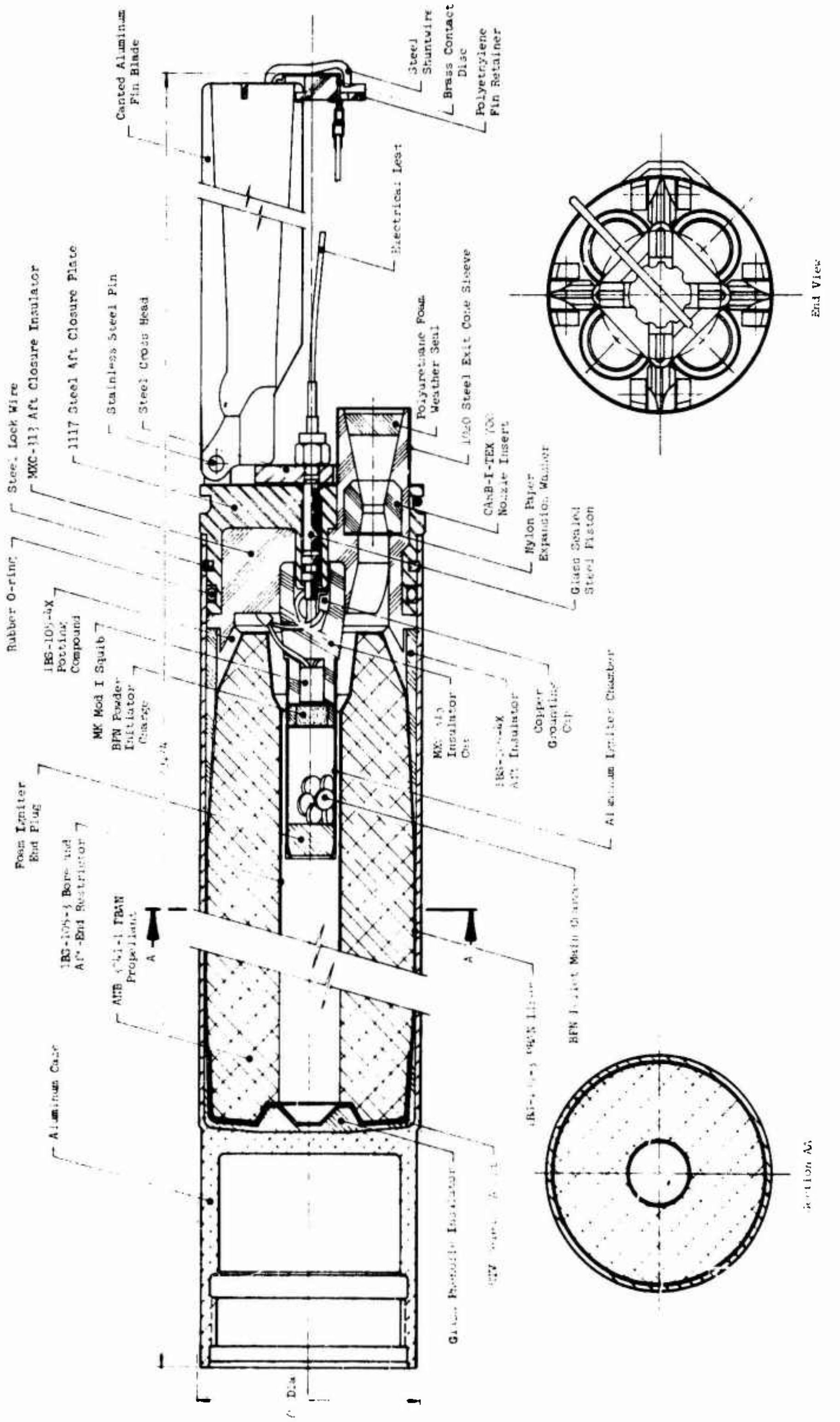
II. TECHNICAL DISCUSSION

A. MOTOR DESIGN AND DESCRIPTION

1. General

The Improved 2.75-in. Folding Fin Aircraft Rocket (FFAR) motor is shown in Figure 1 and described by the fabrication drawings which are tabulated in Figure 2. The design of the Improved 2.75-in. FFAR motor complies with Exhibit A of Contract F0611-67-C-0114.

The basic design objectives successfully achieved by the Improved 2.75-in. motor include (1) maximum usable impulse for deployment of the flechette warhead; (2) envelope and weight limitations of the existing unit for ready motor interchangeability; (3) maximum use of metal parts from the present 2.75-in. motor to retain existing motor/missile/launcher/aircraft interfaces for simplified logistics as well as to provide economy, short development time, and reduced risk; and (4) maximum cost effectiveness for the lowest possible production unit cost consistent with the specified reliability of 0.95 at a 90% confidence level.



Improved 2.75 FFAR PFRT Motor

Figure 1

Component Description	Part No.
Interface Control Envelope - 2.75 FFAR	1146155
Rocket Motor Assembly	1146668-1
Lockwire (GFM Rework)	*1146898-1
O-Ring	*1127114
Igniter and Closure Assembly	1146673-1
Clip Assembly	1146031-1
Shunt Wire	1146336-1
Igniter Assembly	1146693-1
Squib, MK 1, Mod 1	*656714
Chamber, Igniter	1146095-1
End Plug, Igniter	1146096-1
Cap, Insulator	1146370-1
Initiator Charge	1146877-2
Disc	1146876-1
Washer	1146875-1
Fin and Closure Assembly	1146678-1
Cross Head	*456909
Contact Disc	*1253129
Fin Retainer	*1253131
O-Ring	*650950
O-Ring	*650953
Nut	**MS 21044-N3
Pin, Straight	1146056-1
Fin, Blade (GFM Rework)	*1146210-1
Closure Assembly	1146639-4
Plate, Nozzle	1146335-1
Sleeve	1146365-1
Washer	1146613-3
Insert, Throat	1146659-19
Weather Seal	1146913-1
Piston Assy & Wire	1146916-1
Wire	1146915-1
Wire	*1146915-2
Sleeve	1146917-1
Piston	1146932-1
Piston	*9220797
Connector	*9220788
Chamber and Grain Assembly	1146759-1
Chamber, Insulated	1146637-1
Motor Tube	*1569403
Insulator, Released	1146636-1
Insulator, Fwd	1146033-1
Masterline Drawing - 2.75 FFAR	1146103

* GFM

** Government Standard Part

Improved 2.75-in. FFAR Rocket Motor Fabrication Drawings

Figure 2

II.A. Motor Design and Description (cont)

Other requirements in Exhibit A that were successfully met include (1) an ignition interval within 0.100 sec; (2) absence of ejecta; (3) satisfactory safety factor based on empirical data; and (4) capability to withstand the required environmental conditions, either singly or sequentially, followed by successful static firing over the required temperature range of -65 to +150°F.

The approach used in developing the motor was to meet all performance requirements while obtaining the required reliability, maximum producibility, and quality at the lowest possible cost. In achieving this overall objective, the following key design criteria were used:

Maximum structural integrity of the grain through the use of (1) a production propellant with good mechanical properties over the required temperature range and age life; and (2) a grain design and support system that minimizes thermally induced strains, while adequately supporting the grain.

Minimum propellant cost through the use of a well-proven production propellant, which minimizes development costs, and which utilizes low cost materials and processing procedures for minimum production costs.

Simple proven ignition system components to ensure reliable and reproducible ignition at minimum development and production costs.

Nozzle design and materials that provide the required structural and thermal capabilities.

II.A. Motor Design and Description (cont)

The Improved 2.75-in. motor, therefore, features design practices and materials that have been proven capable of operating satisfactorily under the required environmental conditions, including aerodynamic heating, vibration, and the high and low temperature conditions.

Detailed descriptions of the major motor components designed and furnished by Aerojet-General, their performance and material selection, are presented in the following sections. Also included are discussions of our understanding of GFM component configuration, present status of the component, and a definition of any changes required for compatibility with the Aerojet Improved 2.75-in. FFAR rocket motor.

Aerodynamic analyses were previously documented in the Stability and Control Report, Volumes I and II, and are included in this report as Appendix A. Included in this report are discussions of the results of the required full-scale wind tunnel tests.

2. Chamber Insulation System

a. Design Description

The internal insulation of the Improved 2.75-in. motor consists of a premolded glass/phenolic insulator that is bonded in place on the forward head and an asbestos-fiber-filled epoxy insulation (IBS-105-4X*) that is sprayed and spun in place on the aft end of the chamber ID. To release the liner from the forward insulator, the internal surface of the forward insulator is coated with Silastic 587 RTV** silicone rubber before installing in the chamber and bonding in place with IBS-105-3*. After suitable cure time for the forward insulator bond and aft-end insulation, the

* IBS-105-3 and IBS-105-4X, Aerojet-General Corporation, Nimbus, California
** Silastic 587 RTV, Dow-Corning Corporation, Corning, New York

entire chamber is lined with IBS-105-3 which is sprayed, spun, and cured in place. IBS-105-3 functions as liner/insulation and, except where released from the forward head, provides a continuous bond between propellant and insulation, and propellant and chamber.

The forward insulator has a nominal thickness of 0.060 in. with the exception of the center portion, which has a thickness of 0.275 in. This insulator has a centrally-located cone-shaped cavity for centering the forward end of the propellant casting core.

Local material thickness determinations were made on the basis of exposure time to hot gases at predicted weight flow rates and the effect of spin on material erosion rates. In addition to predicted erosion, sufficient material was added to maintain the base temperature at levels that maintain case structural integrity during powered flight. Subsequent adjustments in material thicknesses were made on the basis of inspections of fired hardware.

b. Performance

The internal insulation described above is required to protect the motor case from heat effects when it is exposed to propellant combustion gases during powered flight. The selected insulation materials are capable of withstanding the required environmental conditions over the operating temperature range of -65 to +150°F. In keeping with the design philosophy of maximum cost effectiveness, the materials are suitable for large volume production, while obtaining the design reliability goal of 0.997.

II.A. Motor Design and Description (cont)

(U) The performance of the selected internal insulation has proven satisfactory in recent firings. No hot spots or discoloration of any kind were observed on the chambers. Over 40 other firings, in which the motor contained the above forward insulator and IBS-105-3 sidewall liner, but with SRM 81-15* as aft-end insulation, were conducted without any evidence of chamber over-heating. IBS-105-4X was adopted for its better erosion resistance and lower cost.

(C) A thermal analysis was conducted to evaluate the effects of combined internal and aerodynamic heating on the structural integrity of the case. The analysis shows that, under the most severe flight environment (+150°F), the temperature of the case is not affected by internal heat, and that the case wall temperature reaches +340°F at 2.83 sec (after deployment of the warhead) due to aerodynamic heating. At that time, the nominal motor internal pressure has decayed 86%, while the strength of the case material (2014-T6 aluminum alloy) at 340°F has decreased only 25%, as shown in Figure 3.

(U) The +3-sigma motor pressure for a +150°F firing, the temperature of the case material, and the resulting safety factor are plotted versus time in Figure 3. It can be seen that, despite the loss in strength by the aluminum, the safety factor increases with firing time.

c. Material Selection

(U) The case insulation materials were selected on the basis of satisfactory physical and mechanical properties over the temperature range of -65 to +150°F, demonstrated performance under the required motor operating environments, and lowest cost at high volume production.

* SRM 81-15, Stoner Rubber Co., Orange, Calif.

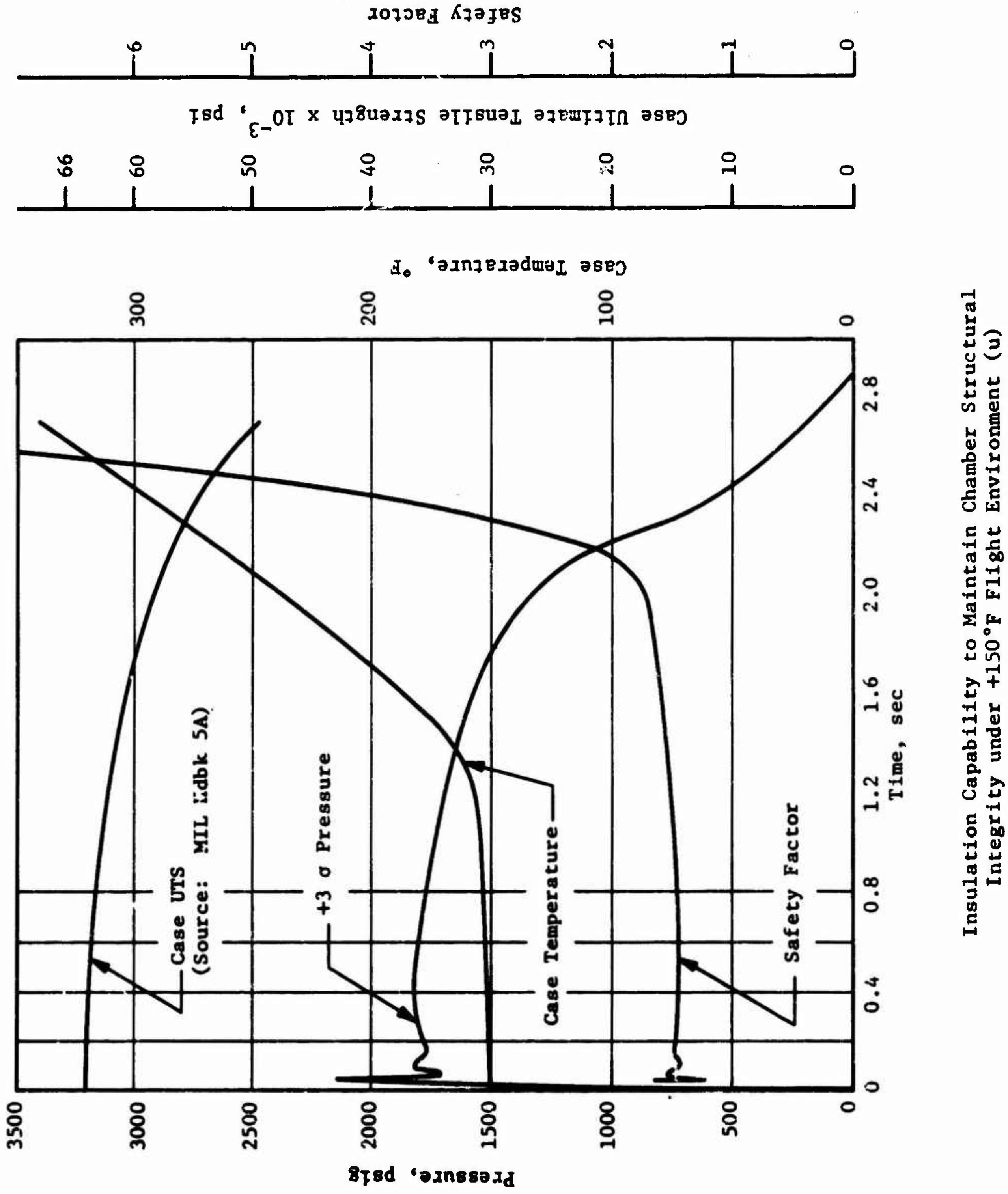

Safety Factor
6
5
4
3
2
1
0
Case Ultimate Tensile Strength x 10^-3, psi
66
60
50
40
30
20
10
0
Case Temperature, °F
300
200
100
0
Case UTS
(Source: MIL Hdbk 5A)
+3 σ Pressure
Case Temperature
Safety Factor
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Time, sec
3500
3000
2500
2000
1500
1000
500
0
Pressure, psig
Insulation Capability to Maintain Chamber Structural
Integrity under +150°F Flight Environment (u)

Figure 3

II.A. Motor Design and Description (cont)

The forward insulator material, chopped glass fabric and phenolic resin, has been successfully used for nozzle entrance sections in other programs. It can be injection molded and cured in short molding cycles. Its thermal and erosion properties are more than adequate for the low gas-flow area at the fore end of the 2.75-in. motor, and its rigidity in the design thickness provides suitable ruggedness to allow the insulator to be used as a positioning device for the casting core.

The liner selected for use in the Improved 2.75-in. motor is designated IBS-105-3 and is compatible with the ANB-3241-2 propellant used in the motor. Tests of the bond strength between IBS-105-3 liner and ANB-3241-2 propellant at -65 and +77°F indicate values of 400 and 80 psi, respectively, which are more than adequate for the motor. In these tests, the characteristic failure mode is cohesive in the propellant. Since IBS-105-3 liner and ANB-3241-2 propellant form a system, a more detailed discussion of liner properties is given as part of the propellant discussion presented in a later section of this report.

For use as aft-end insulation, IBS-105-3 was modified by increasing the asbestos content for improved erosion resistance and the carbon black content was decreased to maintain flow properties for spray application. The modification is designated IBS-105-4X. In PFRT firings of Improved 2.75-in. motors, the performance of IBS-105-4X with respect to erosion resistance was better than the previously used premolded butyl-rubber insulator of SMR-81-15. Additional discussion of IBS-105-4X can be found in a later section of this report.

II.A. Motor Design and Description (cont)

Silastic 587-RTV silicone rubber was selected for use as the agent to release the liner from the forward insulator. Prior to its adoption, alternative release agents were evaluated in double plate tensile specimens prepared to simulate motor conditions (metal plate, release agent, liner, propellant, adhesive, metal plate). The evaluation criterion was the tensile strength required to separate the specimens at the release agent interface. The results, shown in Figure 4, indicate that RTV-587 has the lowest tensile value (5 psi).

3. Aft Closure/Nozzle Design

a. Design Description

The aft-closure/nozzle design of the Improved 2.75-in. motor consists of a machined mild-steel closure, four Carb-I-Tex-700[(1)] throat inserts with consumable Nylon paper[(2)] expansion washers, a molded carbon/phenolic (MXC-313)[(3)] closure insulator with four integral exit cones, and four mild-steel exit cone sleeves. The aft-closure insulator and four exit cones are transfer molded as one piece into the steel closure with the throat inserts, washers, and exit cone sleeves in place. This technique of integrally molding all aft-closure/nozzle components into a single piece in one operation enhances reliability and reproducibility at a substantial cost savings, as compared to more conventional methods of fabrication and assembly.

(1) Carb-I-Tex-700, Carborundum Co., Pittsburgh, Pa.
(2) Nomex 410, Dupont Corp., Wilmington, Del.
(3) MXC-313, Fiberite Corp., Winona, Minn.

Release Agent[1][2]	Tensile Strength Needed for Release, psi at +77°F
Control (no release)	86[3]
Silastic 587-RTV	5
RTV-60	26
Teflon Tape	21
Polyethylene Tape	59[4]
TC-522-1	69

(1) Test specimens consisted of steel plate, release, IBS-105-3 liner, ANB-3241-2 propellant, adhesive, steel plate
(2) All samples cured 24 hr at 180°F prior to casting with ANB-3241-2 propellant
(3) Cohesive failure in propellant
(4) Failure between propellant and adhesive used to bond to steel

Effect of Release Agents on Bond Strength of Propellant/Liner System to Metal

Figure 4

The aft-closure shell is similar dimensionally to the present production component, FTS D-2016. However, the Improved 2.75-in. shell has a shallower detent groove, and the fin-lug corner radii are cut back adjacent to the nozzles to allow clearance for the mold used in molding the insulator into the shell.

The configurations of the entrance and exit sections of each nozzle are molded into the aft-closure insulator. The entrance sections are specifically designed to promote smooth entry of the gases into each throat, thus providing minimum insulator erosion and maximum motor performance. The Carb-I-Tex-700 throat inserts are cylindrical on the OD with a conical aft end and have a cylindrical throat diameter of 0.271 in., extending a nominal axial length of 0.10 in. The cylindrical throat best provides ease of manufacture, dimensional control, and minimum throat erosion for this application when compared to a standard radial throat. Each insert has a consumable Nylon washer at the fore end to permit longitudinal thermal expansion during firing, thereby relieving stresses and preventing insert cracking and possible ejection.

The four throats are equally spaced on a 0.760-in. radius around the closure center line. This placement is the maximum radial position compatible with proper operation of the fins and the GFM launcher detent hook. In this design, the hook determines the length of the exit cone since the hook retains the missile in the launch tube by latching into a groove on the aft closure and extending over the aft end of one of the exit cones. The exit cones have a 11.5° half angle and an expansion ratio of 8.6. Their exit diameter (0.797 in.) is limited by the motor envelope and the requirement for sufficient wall thickness to withstand erosion.

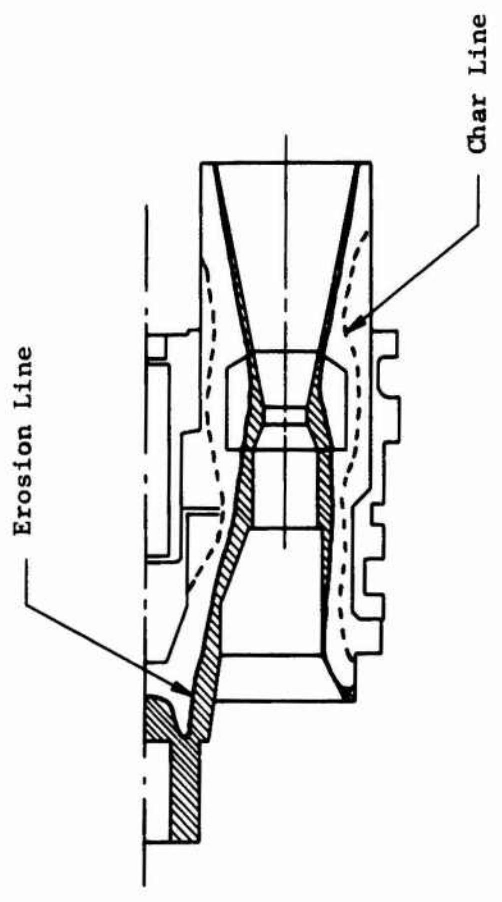
It is our understanding at this time that the shape of the detent hook on future launchers will be changed to accommodate this exit cone design.

The aft closure/nozzle has provisions for mounting the fin assembly, fin actuator piston, and igniter assembly. The resultant aft-closure assembly is attached to the chamber by means of a submerged lockwire and the joint is sealed by an O-ring and IBS-105-4X insulation used as a potting compound. This insulation provides additional protection to the joint and the aft insulator from the erosive effects of gas flow throughout the firing duration.

b. Performance

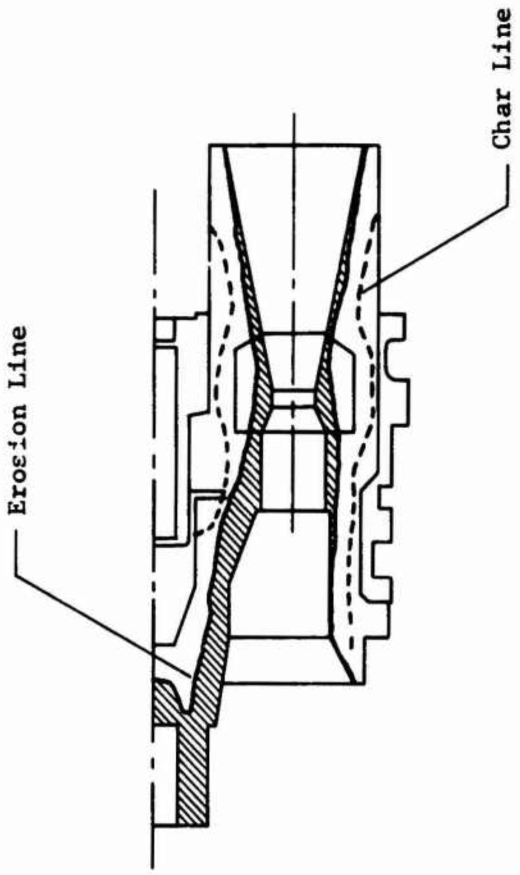
The integrally molded aft closure insulator of MXC-313 maintains shell structural integrity as evidenced by the absence of hot spots of any minor discoloration during post-firing inspections. The material has successfully undergone over 40 other full-scale motor firings. In these firings, the insulator has shown an average erosion rate of 16 mils/sec and an average char depth of 0.120 in. immediately forward of the throat insert. Figures 5 and 6 illustrate typical erosion and char conditions in sectioned closures. A heat transfer analysis shows that the insulator keeps the temperature of the aft-closure shell well within the required 300°F for adequate material strength.

During the first 11 test firings of the integrally molded aft-closure, cracking and/or ejection of the ATJ graphite throat inserts was encountered. Resolution of the difficulty was accomplished by substituting Carb-I-Tex-700 as the throat insert material, since it has the higher compressive strengths required for use in the integrally molded



Typical Aft-Closure Erosion and Char Conditions after -65°F Firing

Figure 5



Typical Aft-Closure Erosion and Char Conditions after +150°F Firing

Figure 6

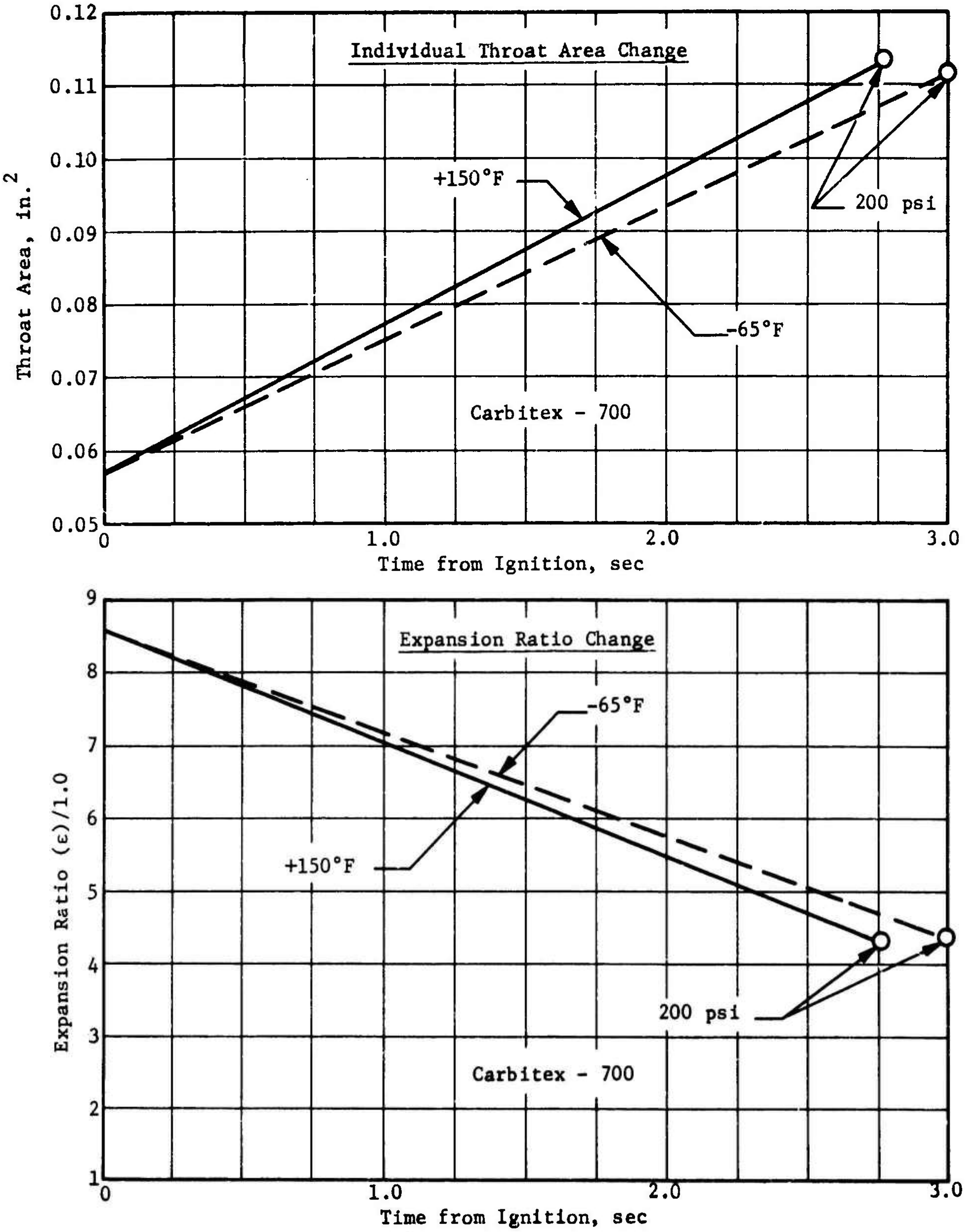
aft-closure design, as discussed in the following section. Based on recent firings with Carb-I-Tex-700 throat inserts, the calculated throat erosion rate is 18 mils/sec, which compares favorably with the 15 mils/sec recorded for ATJ graphite inserts. The individual Carb-I-Tex-700 throat inserts give estimated throat area and expansion ratio changes with time as shown in Figure 7. A structural analysis of the Carb-I-Tex-700 inserts is presented in Appendix B.

c. Material Selection

(1) Aft-Closure Shell or Plate

The selected material for this component is free-machining, low-carbon, cold-drawn steel bar stock, 1117, which is the same material being successfully used in high rate production for the present 2.75-in. FFAR motor. The steel has more than adequate mechanical properties for this application as shown by the positive margins of safety in the inert parts stress analysis in Appendix B. This steel has been successfully used throughout the Aerojet development program and will continue to be used because it best satisfies the requirements for adequate strength, machinability, and low cost in high rate production.

The shell is cadmium plated in accordance with QQ-P-416; Type II, Class 2, to provide the corrosion resistance required for the expected environmental conditions. All finished surfaces are machined in keeping with the intended function and cost effectiveness. In addition, all mating surfaces have sufficient tolerance for required fits, while permitting low-cost machining techniques and minimum inspection.



Changes in Throat Area and Expansion Ratio with Carb-I-Tex Throat Insert

Figure 7

(2) Aft-Closure and Exit Cones

The aft-closure insulation and exit cone material is MXC-313, an ablative carbon fiber/phenolic that has adequate insulating and erosive properties for this application, as well as the physical properties required for satisfactory transfer molding at the desired high production rates. The MXC-313 material has successfully maintained aft-closure integrity by withstanding the stringent erosive conditions of the four-nozzle configuration, while providing satisfactory thermal protection.

(3) Throat Inserts

Carb-I-Tex-700, a pyrolized graphite cloth laminate, was selected for use as the throat insert material. The selection was largely based on its high compressive strength of 21,000 psi across the laminate grain, the plane in which the highest stresses are predicted during firing. In addition, it can readily withstand the 7000 psi molding pressure. The material has a tensile strength of 7600 psi with the laminate grain and 500 psi across the laminate grain. The physical properties of the material are shown in Figure 8 and a structural analysis of the throat inserts is given as part of Appendix B.

Selection of Carb-I-Tex-700 was prompted by the cracking and ejection of ATJ graphite throat inserts that were used in the first firings of the integrally molded aft closure/nozzle. Results of subsequent firings with Carb-I-Tex-700 throat inserts showed that its high strength and inherent toughness eliminated the insert cracking difficulty in integrally molded aft closures.

Compressive strength, psi	
With grain	9,500
Against grain	21,000
Flexural strength	
With grain	10,300
Against grain	2,000
Tesnsile strength, psi	
With grain	9,000
Against grain	500
Thermal conductivity, $\frac{\text{Btu-ft}}{\text{hr-ft}^2\text{-°F}}$	
With grain	35
Against grain	14
Thermal expansion, $\frac{10^{-6}\text{ in.}}{\text{in.-°F}}$	
With grain	0.8
Against grain	3.0
Modulus of elasticity, 10^6 psi	
With grain	2.2
Density, gr/cm^3	1.43

Physical Properties of Carb-I-Tex-700

Figure 8

(4) Expansion Washer

The material selected for this application is Nomex 410 Nylon paper (0.20-in. thick). It is consumed at 700°F to provide a suitable gap for longitudinal thermal expansion of the throat insert during firing. The material has the required properties to withstand the molding temperature of 320°F and the molding pressure of 7000 psi which results in a maximum reduction in thickness of 0.003 in.

Nomex 410 is a combination of two forms of a long chain synthetic polymer, fibrous binder particles and short length (1/4-in.) fibers. After processing on conventional papermaking equipment, the fibrids and short length fibers are permanently bonded to each other by a hot calendering operation.

4. Fins

Four fin blades spaced 90° apart are used to provide missile spin and stability. The fin blades are made of 2014-T6 aluminum alloy, which is the same material used in the chamber. The fin blades utilize the same forged part as the standard GFM fin. To provide the required clockwise spin to the rocket, the fins are canted 0.11° when at the inflight position of 45° to the motor centerline. This fin cant is obtained by machining the mounting faces of the as-forged fin with a 0°9' angle with respect to the fin symmetry plane and drilling the fin bore perpendicular to the mounting faces. To provide the fin cant, tight tolerances are imposed on the fin mounting face, fin bore, fin pin, and fin mounting lugs on the nozzle plate. Clearance between the retracted fins and the nozzle assembly is ensured by maintaining tight tolerances on the nozzle components and nozzle assembly, together with specifying minimum spacing between adjacent nozzles. These close tolerances enable the free fin to maintain a maximum angularity of ± 1/8 of 1 degree.

The fin cant requirement was determined by aerodynamic analysis, wind tunnel tests, and actual flight tests. The final cant-angle adjustment may be based on results from the flight test program. The fins must rotate freely and fall of their own weight when positioned 60° out from the motor centerline. The fin pins must remain in position under a static load of 20 lb. The fin pins are retained in the fin blade by means of a shrink fit at assembly.

5. Ignition System

a. Design Description

The Improved 2.75-in. igniter is a consumable, aft-end mounted, pellet igniter that reproducible and reliably ignites the motor well within the required 0.100 sec. The igniter assembly consists of an insulator cap, aluminum-tube chamber, styrofoam end plug, 0.3-gm BPN IP-10 booster charge, 7-gm BPN-2D pellet main charge, and a Mk I Mod 1 squib. The squib firing circuit utilizes the aft-closure plate as a ground and the piston wire lead as the electrical current conductor from the launcher.

The pyrotechnic train is similar to that of larger igniters in that the squib ignites the booster charge which in turn ignites the BPN pellet main charge, thereby extruding the end plug and allowing the ignition gases to ignite the propellant grain. During igniter action, the igniter end plug and chamber are consumed, thus eliminating igniter debris.

In assembling the igniter, the Mk I Mod 1 squib is installed into the carbon/phenolic insulator cap. The squib electrical leads are led through two holes (180° apart) in the cap, and the squib and its leads are then potted in place with Epon 913. The empty igniter chamber is bonded to the insulator cap with Epon 913. The booster and main charges are then inserted into the igniter chamber, the end-plug cemented in place with DC-92-018, and the end of the tube crimped, thus completing igniter assembly. Prior to final motor assembly, the insulator cap of the igniter assembly is bonded to the aft-closure insulator, the squib circuit shunt is removed, and the squib leads are crimped to the appropriate lead of the piston assembly, thus completing the squib circuit for external application of the firing current.

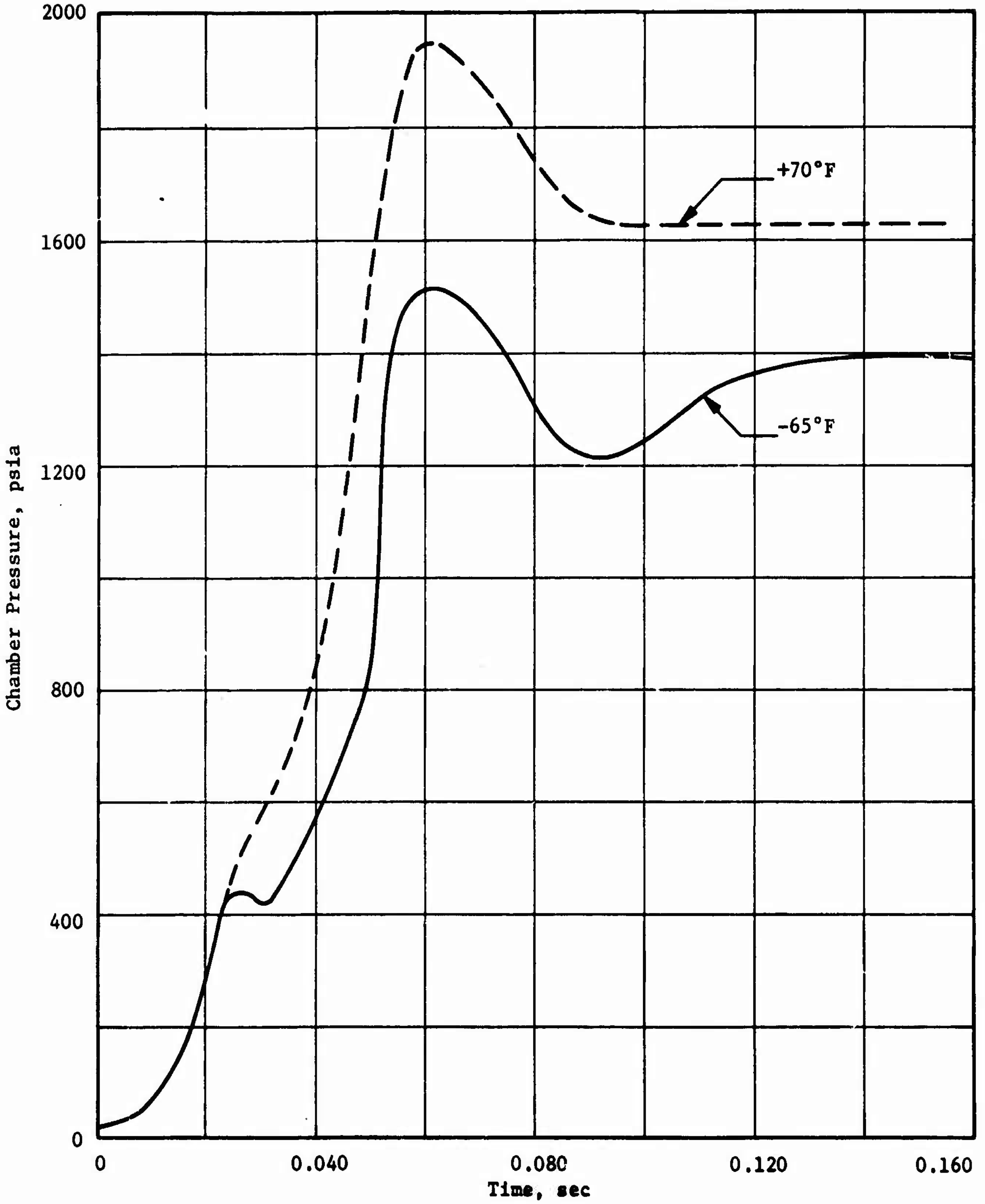
b. Igniter Performance

Figure 9 depicts motor ignition transients at -65 and +70°F when ignited with the igniter described above. It can be seen that motor ignition occurs well within the required 0.100 sec under the most severe environmental conditions of -65°F and 50,000-ft altitude.

c. Material Selection

The insulator cap is formed from MXC-313 molding compound because it has the required strength and erosion resistance for the application. The insulator cap has provisions for mounting the squib, a cavity for the fin-actuating piston and vise, access holes for the ignition wire assembly, and vent holes for pressure flow to the piston.

The igniter chamber is made of drawn 6061-T4 aluminum tubing with a wall thickness of 0.008 in. and an OD of 0.625 in. This type chamber was chosen because it offers ease of igniter manufacture and quality control, provides reproducible igniter performance as compared to other materials, and is rapidly consumed during the ignition transient, thus eliminating ejecta.



Typical Motor Ignition Transients at +70 and -65°F

Figure 9

II.A. Motor Design and Description (cont)

(U) The end plug is made of rigid polystyrene foam and is bonded into the igniter chamber to retain the igniter pyrotechnic charges.

(U) The electrical clip, used to connect the squib and aft-closure ground circuit, is made of copper or brass sheet. The clip is tin-plated to provide good electrical conductivity.

(U) BPN was selected for the igniter pyrotechnic charges because it has reliable and reproducible ignition characteristics at high altitudes and over a wide temperature range. In addition, BPN is supported by a long history of successful use in the rocket industry.

(U) The Mk I Mod 1 squib is retained for use in the Improved 2.75-in. motor to maintain commonality with the present unit. It meets the requirement for a maximum firing current of 0.5 amp per round.

6. Grain Design

a. Design Description

(U) The grain design of the Improved 2.75-in. motor is an internal-burning cylinder (27.7 in. long and 0.750-in. dia bore). The grain is fully case-bonded to the chamber sidewall and is released from the forward head to provide capability of withstanding temperature-induced stresses, especially at the low temperatures. The aft end of the grain is chamfered on the OD to accommodate the insulator of the aft-closure assembly and is chamfered on the ID to provide a gas flow area around the igniter base approximately equivalent to the flow area upstream. The aft end of the grain and the aft 7.5 to 8.0 in. of the bore are restricted with a 0.010-in.-maximum thickness of IBS-105-3 liner to minimize the initial pressure peak.

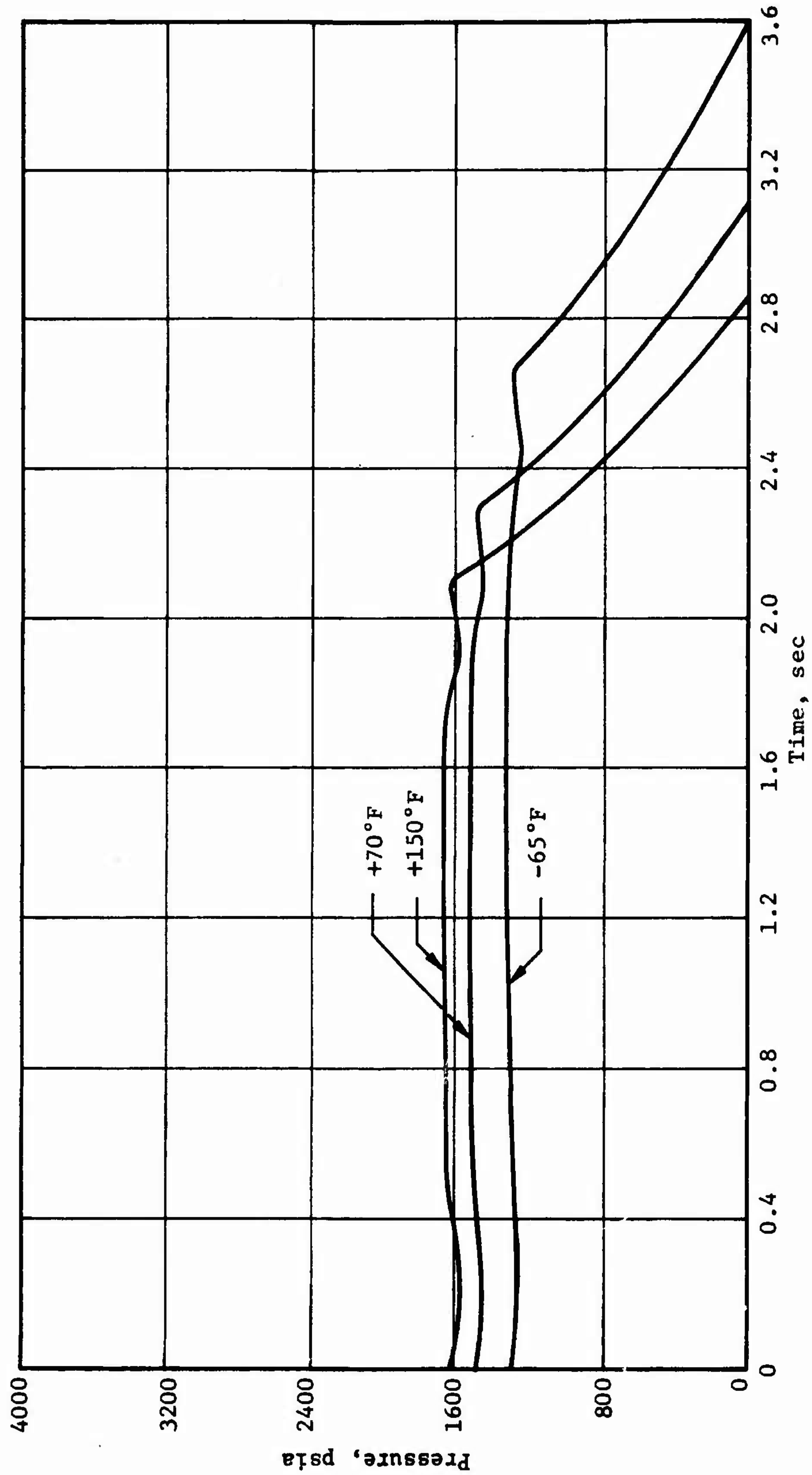
(U) This grain design was selected because (a) it best satisfies the overall performance requirements within the specified weight and envelope of the 2.75-in. motor; (b) it provides high inherent design simplicity and ruggedness for withstanding the specified environmental conditions over the required temperature range, and (c) it is readily adaptable to high-rate production techniques for the lowest possible unit production cost. Early in the program, other variations of this basic grain design were investigated and included a larger bore, a partial release pattern, opposing slots on the aft half of the grain for neutrality, or a combination of these approaches. They were discarded because of lower performance and/or higher processing costs.

b. Performance

(1) Interior Ballistics

(U) A slightly regressive pressure-time curve is obtained from the cylindrical grain because its inherent progressivity is modified by erosive burning in the early portion of the firing and by nozzle erosion throughout the firing. The progressive thrust-time curve results from the nozzle erosion. Typical pressure- and thrust-vs-time curves of the 2.75-in. motor at -65, +70, and +150°F are shown in Figures 10 and 11, respectively, and a summary of motor characteristics, similar in content and format to the CPIA Rocket Motor Manual, is shown in Figure 12.

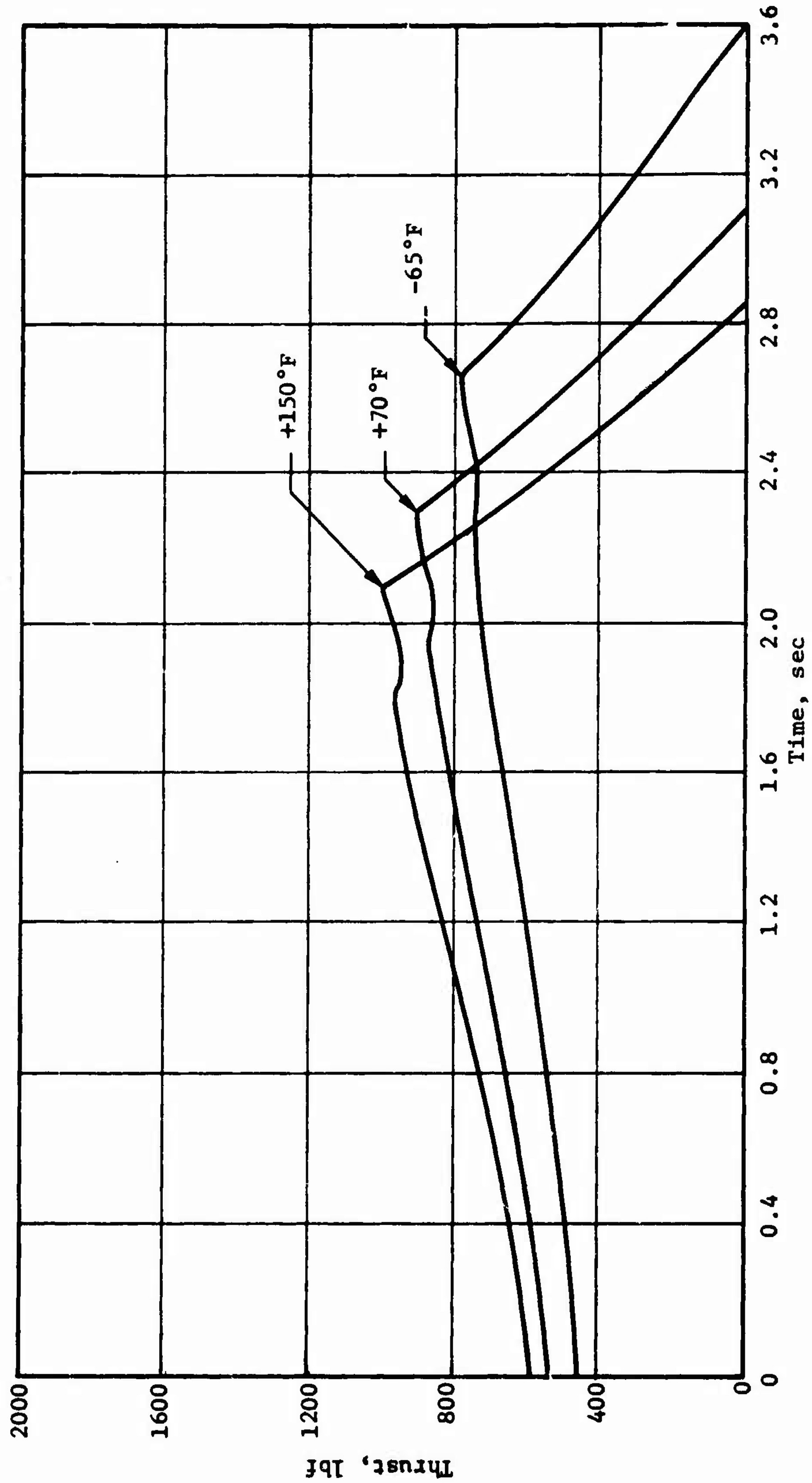
(C) The ballistic performance of the Improved 2.75-in. FFAR motor provides the usable impulse values specified in the technical requirements of Contract Exhibit A, as amended, which requires that the acceptability of motor ballistic performance with respect to missile trajectory performance be based on the usable impulse of the motor at -65, +70, and +150°F.



Pressure-vs-Time Curves (u)

Figure 10

CONFIDENTIAL



Thrust-vs-Time Curves (u)

Figure 11

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Principal Data

Length (including folded fins)	39.34 in.
Diameter	
Principal	2.75 in.
Maximum	2.79 in.
Masses	
Motor tube	2.36 lbm
Closure assembly	1.15 lbm
Fin assembly	0.60 lbm
Insulation and liner	0.48 lbm
Igniter assembly	0.02 lbm
Lockwire and O-ring	0.03 lbm
Total inert masses	4.46 lbm
Propellant masses	8.05 lbm
Total mass	12.69 lbm
Propellant mass fraction	0.63

Nominal Performance (Sea Level)

	-65°F	+70°F	+150°F
Burn time, sec	2.51	2.25	2.13
Action time, sec	3.33	2.96	2.79
Maximum pressure, P_{max}, psia			
Ignition	1697	1879	2047
Steady state	1471	1721	1807
Average pressure, $\overline{P}_b$, burn time, psia	1380	1515	1650
Average pressure, $\overline{P}_a$, action time, psia	1182	1322	1393
Maximum thrust, $\overline{F}_{max}$, lbf	774	873	922
Average thrust, $\overline{F}_b$, burn time, lbf	624	714	762
Average thrust, $\overline{F}_a$, action time, lbf	572	649	693
Action time impulse, I_a, lbf-sec	1901	1917	1931
Propellant specific impulse, I_{spd}, lbf-sec/lbm	237.7	240.0	242.1

Summary of Improved 2.75-in. Motor Characteristics (u)

Figure 12, Sheet 1 of 3

Component Details

Propellant	
Designation	ANB-3241-2
Composition	AP/PBAN/AL
Burning rate at 1500 psia and 70°F	0.395 in./sec
Burning rate pressure exponent (n)	0.32
Grain configuration	Cylindrical bore
Method of manufacture	Cast in case
Grain dimensions	
Length	27.60 in.
Diameter	2.56 in.
Web thickness	0.90 in.
Initial port/throat area ratio	1.92
Case	
Material	Aluminum alloy 2014-T6
Length	31.684 in.
OD	2.750 in.
Thickness, nominal	0.072 in.
Fabrication method	Impact extrusion
Hydrostatic proof pressure	2000 psia
Nozzles	
Exit cone shape	11.5° half angle cone
Throat area, A_t	0.230 in.^{2}
Expansion ratio	8.65
Insert material	Laminated, fibrous graphite, reinforced (Carb-I-Tex-700)
Other materials	Carbon/phenolic, integrally molded exit cone liner and closure insulator; mild steel sleeve OD reinforcement

Summary of Improved 2.75-in. Motor Characteristics (u)

Figure 12, Sheet 2 of 3

Component Details (cont)

Insulations	
Liner	
Composition	PBD (IBS-105-3)
Thickness	0.020 in. min
Restriction	
Composition	PBD (IBS-105-3)
Location	Aft end of propellant and aft end of bore, forward to a distance of 9.03 in. from aft end of motor case
Head end insulation	
Composition	Glass phenolic (Fiberite 4030-190 or Fiberite 8130)
Aft chamber insulation	
Composition	PBD (IBS-105-4X)
Thickness	0.135 in.
Location	Starting 1.065 in. from aft end of case extending to 3.30 in. from aft end of case
Igniter	
Type	Boron potassium nitrate (BPN) pellet system
Description	Main charge consists of 7.0 gm of BPN pellets contained in an aluminum tube; pellets ignited by 0.3 gm of BPN powder, heat is ignited by a MK I, Mod I electric squib
Ignition delay time	100 msec max
Igniter resistance	1.35 ohms
Min current for reliable ignition	1.35 amps

Summary of Improved 2.75-in. Motor Characteristics (u)

Figure 12, Sheet 3 of 3

II.A. Motor Design and Description (cont)

Further, usable impulse is defined as that delivered by the motor from fire switch to the time at which tailoff thrust drops to 430, 511 and 555 lbf at the temperatures of -65, +70, and +150°F, respectively. These three thrust levels are calculated on the basis of the 15-g requirement for flechette warhead deployment, launch conditions of 4000-ft altitude and negative 30° angle, launch velocity of 750 ft/sec, nominal inert motor weight, and drag values from the Tullahoma wind tunnel tests.

(C) The following table lists the specified minimum (-3 sigma) usable impulses and the thrust cutoff levels specified for the Improved 2.75-in. FFAR rocket motors fired at the three temperatures:

Firing Temperature, °F	Thrust Cutoff, lbf	Usable Impulse, lbf-sec Minimum
-65	430	1697
+70	511	1706
+150	555	1709

The 3 sigma variability in usable impulse was obtained from the root-sum-square of the calculated 3 sigma variability in propellant weight and the 3 sigma variability in impulse that were obtained in recent development firings and adjusted to a fixed propellant weight.

(2) Grain Structural Analysis

(U) A structural analysis of the Improved 2.75-in. grain in Appendix B shows that the design has the capability to successfully withstand the following stresses and strains expected to be imposed by the required environmental conditions: grain bore strain of 12.7% versus an allowable greater than 12.7% established by strain cylinder tests; bond shear stress of 413 psi versus the allowable of 560 psi; and bond tensile stress of 32.7 psi versus the allowable of 92 psi. This predicted performance has been verified by the successful PFRT environmental tests, static firings, and flight tests.

(3) Safety Factor

(U) The analyses to determine the safety factors described below are based on worst-on-worst conditions in addition to the very conservative assumptions made throughout the computations here and in Appendix B.

(C) The nominal maximum chamber pressure at +150°F, exclusive of the igniter peak pressure, is 1740 psig, based on three firings at +150°F of motors from three propellant batches. The motors had Carbitex nozzle throat inserts with initial total throat areas of 0.230 in.^{2}. The 3 sigma variability in maximum pressure observed in these three firings is 4.65%. MEOP was calculated as:

$$\text{MEOP} = (1740)\ (1.0465) = 1820 \text{ psig}$$

Since the calculated minimum burst pressure of the chamber at +150°F is 2620 psig (Appendix B), the safety factor is:

$$\text{SF} = \frac{2620}{1820} = 1.44$$

(C) This calculated safety factor is lower than the required 1.5 safety factor based on the ultimate strength of the chamber. However, empirical hydroburst data, as discussed later, indicates that the calculated minimum burst pressure of 2620 psi may well be too conservative.

(C) Restriction is used on the aft end of the propellant grain bore to reduce ignition peak pressure. As shown in Figure 13, six motors were fired with varying amounts of aft-end bore restriction to determine the maximum reduction in ignition peak pressure that can be obtained without adversely affecting motor ignition. In light of these data, it was decided to set the length of bore restriction between 7.75 and 8.0 in. for future motors in order to best provide the desired overall ignition performance, together with ease of processing and control.

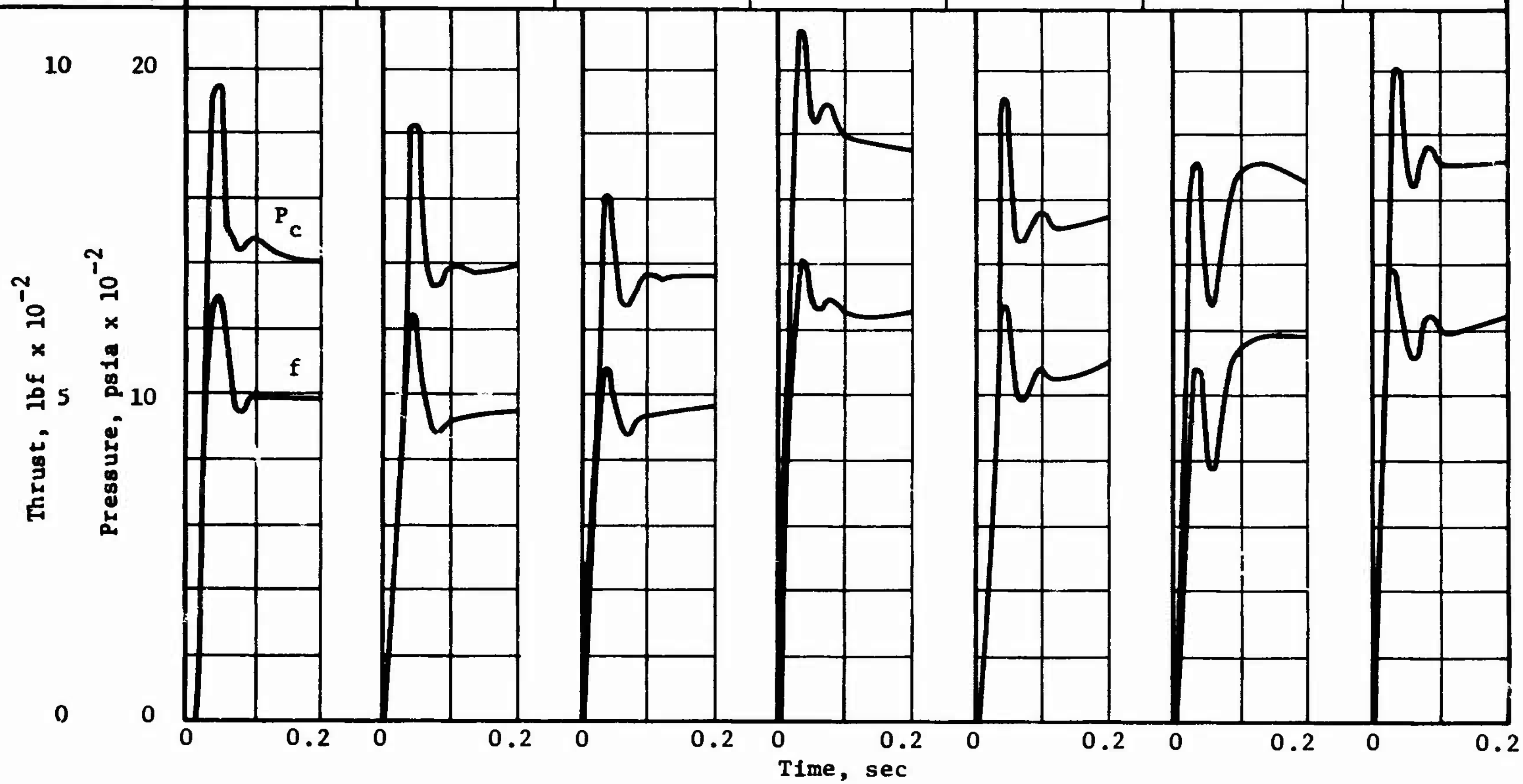
(C) Extrapolating the data in Figure 13 to the +150°F firing condition, the mean value for an ignition peak pressure with the 8.0 in. bore restriction was calculated to be 1927 psia with a 3-sigma variability of 11.7%. Thus, a maximum ignition peak pressure of 2150 psia is predicted for the maximum bore restriction length of 8.0 in. and a maximum ignition peak pressure of 2180 psia is estimated for the minimum bore restriction length of 7.75 in. These ignition pressures result in the following safety factors:

$$\text{(8 in.)} \quad SF = \frac{2620}{2150} = 1.24$$

$$\text{(7.75 in.)} \quad SF = \frac{2620}{2180} = 1.20$$

(U) The conservative results of the above analyses led to an investigation to determine the case strength level as indicated by available empirical data from hydrostatic burst tests. Data from Picatinny Arsenal* shows that the GFM case has a mean hydroburst pressure of 3600 psi, with a high of 3800 psi and a low of 3200 psi. These data are based on hydroburst testing cases. In addition, the grain specification MIL-P-18811 (NORD) for the present

Test No.	II-48	II-22	II-50	CT-11	II-63	II-21	CT-12
Chamber No.	2611	2612	2609	2406	2610	2613	2722
Aft End Restriction	Total	Total	Total	Total	Total	Total	Total
Aft Bore Restriction, in.	0	3	6	6	6	9	8
Firing Temp, °F	-65	-65	-65	+150	+70	+150	+150
Ignition Peak Pressure, psig	1958	1820	1610	2135	1925	1725	2000



Comparison of Bore Restriction and Ignition Peak Pressure (u)

Figure 13

II.A. Motor Design and Description (cont)

Mk 43 2.75-in. motor permits a maximum operating pressure of 2400 psig at +165°F*. Finally, previous tests conducted at the Pico Rivera Military Plant of Norris Industries** indicate burst pressures to be in excess of 3500 psi.

(U) In light of the above empirical data and the specification maximum pressure, Aerojet believes that the GFM case has a more-than-adequate safety factor when used with the Improved 2.75-in. propellant grain.

7. Propellant and Liner

a. Description

(U) The propellant selection for the Improved 2.75-in. FFAR motor is ANB-3241-2, a polybutadiene-acrylic acid-acrylonitrile terpolymer (PBAN) propellant. This propellant is highly reproducible, satisfies the ballistic and mechanical property requirements of the Improved 2.75-in. motor, exhibits good high-temperature stability, and possesses processing characteristics suited to high-volume production. The specification for ANB-3241-2 propellant is AGC-36550. Acceptance specifications are available for all propellant raw materials. The composition of ANB-3241-2 is shown below and a summary of ballistic properties is presented in Figure 14.

* Letter to SMUPA-ND9, Act'g. Ch, 2.75" Rkt Br. from Robert Bradley, Act'g Ch, Complete Round Section, dated 15 July 1967.

** Aerojet-General Corporation, Attn: S. J. Fine from Norris Industries, Pico Rivera Military Plant, D. R. Keener, dtd 9 October 1967.

Ballistic Properties

Standard specific impulse, lbf-sec/lbm at 1000 psia	
Theoretical	264*
Measured, ballistic motor	247.2**
Density, lb/in.^{3}	0.0643
Theoretical chamber flame temperature at 1000 psia, P_C, °F	5895
Theoretical exhaust flame temperature at 1000 psia, P_C, °F	3558
Burning rate, in./sec at 1500 psia	0.395
Pressure exponent	0.32

Mechanical Properties

Temperature	σ_m, psi	ε_m, %	ε_b, %	E_0, psi
-75°F	687	5	6	25,087
+77°F	71	19	22	481
+150°F	36	16	22	330

* Shifting equilibrium

** Specific impulse measured in ballistic (100-lb grain) motor firings conducted on a precision Aeroscience test stand at a chamber pressure of 1000 psia exhausting to 14.7 psia through a nozzle with 15-degree half-angle and optimum expansion. The comparable value at 0-degree half-angle is 251 lbf-sec/lbm.

Ballistic and Mechanical Properties of ANB-3241-2 (u)

Figure 14

II.A. Motor Design and Description (cont)

Ingredient	Wt, %
Ammonium perchlorate	71.00
Aluminum powder	16.00
Binder	13.00
TOTAL	100.00

PBAN propellants have been used extensively in the solid rocket industry. Aerojet has processed and successfully fired PBAN propellants in 44-, 120- (200,000-lb grain), and 260-in.-dia (1,670,000-lb grain) motors. During the 260-Motor Program alone, over 5.5 million lb of PBAN propellants (ANB-3105 and ANB-3254) were processed.

b. Reproducibility

Excellent reproducibility of burning rate and mechanical properties has been achieved with the ANB-3241-2 propellant for the Improved 2.75-in. motor. These desirable characteristics are attributed to the simplicity of the formulation and to the use of mixing procedures and in-process control tests developed and demonstrated for PBAN propellants on the Air Force and NASA 260-in. Motor Programs. The reproducibility of the propellant in-process acceptance tests for seven 450-lb vertical mix batches is shown in Figure 15.

(1) Propellant Burning Rate

The burning rate required for the Improved 2.75-in. motor is achieved through the use of an oxidizer blend containing 80 parts +48 mesh and 20 parts Mikroatomizer ground oxidizer in ANB-3241-2 propellant. Highly reproducible burning rates have been obtained in the 450-lb vertical mix batches processed for the Improved 2.75-in. motor as shown below.

Propellant Component	Acceptance Limit	$\bar{x}$	s	n
Submit				
Acid Equivalents, eq/100 g	0.0510 ± 0.0015	0.0509	0.00046	6
H_2O, wt%	0.20 max	0.065	0.0168	6
Premix				
Liquid Density, g/ml	1.490 ± 0.007	1.489	0.0008	6
Final Fuel				
FeAA, wt%	4.56 ± 0.15	4.52	0.14	5
Uncured Propellant				
Liquid Density, g/ml	1.783 ± 0.007	1.778	0.0019	6
Epoxy Content, wt%	1.05 ± 0.12	1.02	0.033	6
ISRR at 1500 psig, in./sec	0.365 ± 0.010	0.365	0.0034	6

In-Process Control Tests for ANB-3241-2
Propellant

Figure 15

II.A. Motor Design and Description (cont)

	Burning Rate at 1500 psig, +80°F, in./sec	
	Liquid Strand	Cured Strand
$\bar{x}$	0.365	0.305
s	0.0031	0.0051
n	9	8

Liquid strand burning rates are used for acceptance of each propellant batch. The cured strand data were obtained since they agree closely with the burning rate observed in the motor.

(2) Mechanical Properties

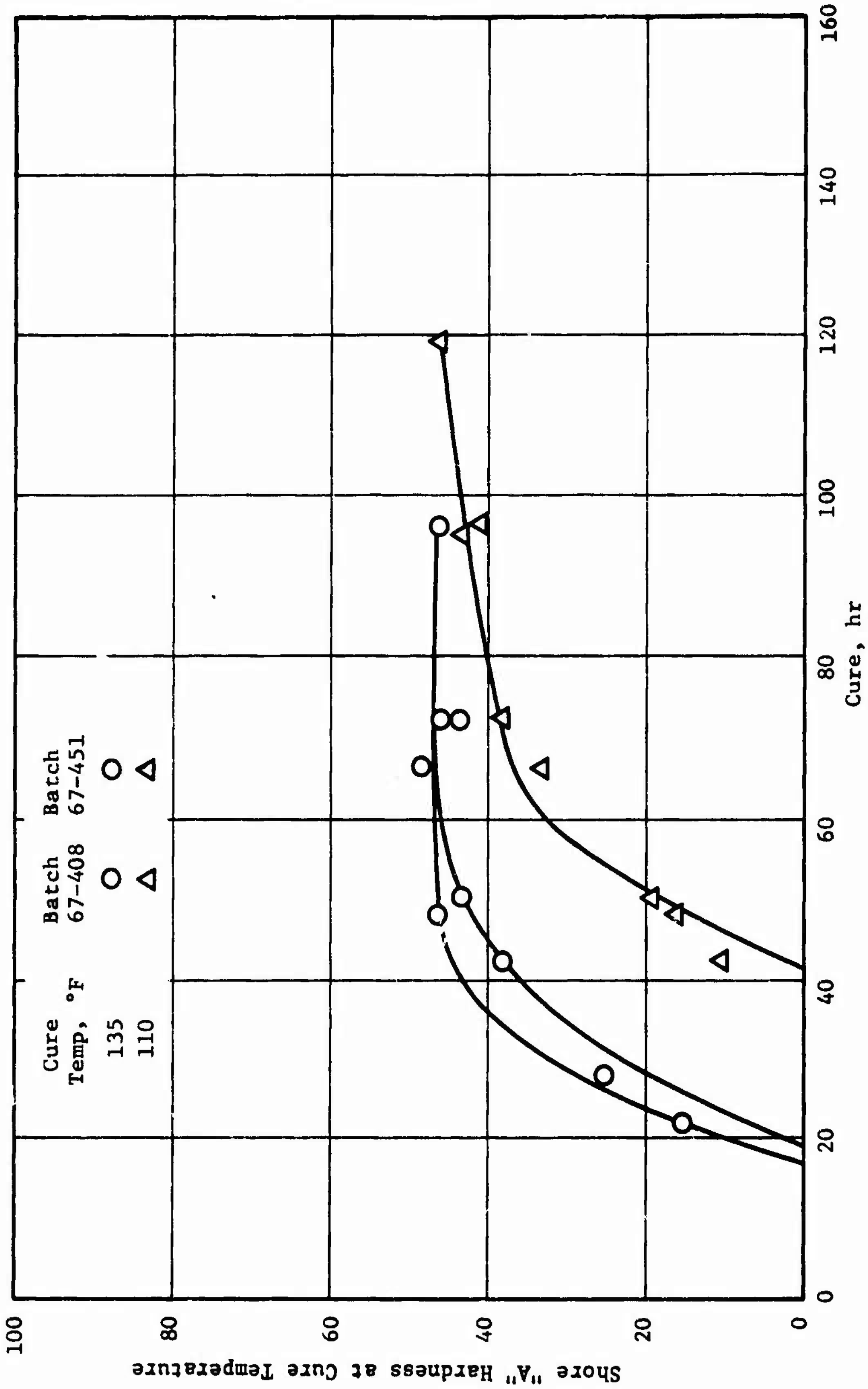
The reproducibility of mechanical properties that were observed in the 450-lb vertical batch mixes processed to date provides assurance of highly reliable motor performance. The mechanical properties at +77°F (2.0 in./min strain rate) of five 450-lb batches cured at +135 °F and one 450-lb batch cured at +110°F are summarized below:

Cure Temp, °F		σ_m, psi	ε_m, %	ε_b, %	E_o, psi
+135	$\bar{x}$	63.4	17.4	25.8	556
	s	4.3	0.89	1.6	30.8
	n	---------------5---------------			
+110	$\bar{x}$	57.3	15.3	23.5	551
	s	3.5	1.5	3.1	54.8
	n	---------------4---------------			

A propellant cure temperature of +135°F was used for motor cast Lots 1 through 5. To reduce the thermal strain in the motor, all subsequent motors were cured at +110°F. As shown, the propellant properties do not differ for the +135 and +110°F cure. The reduced cure temperature, however, increases the time required for the propellant to reach an equilibrium cure state. Figure 16 shows a cure time of five days at 110°F compared to approximately three days at +135°F.

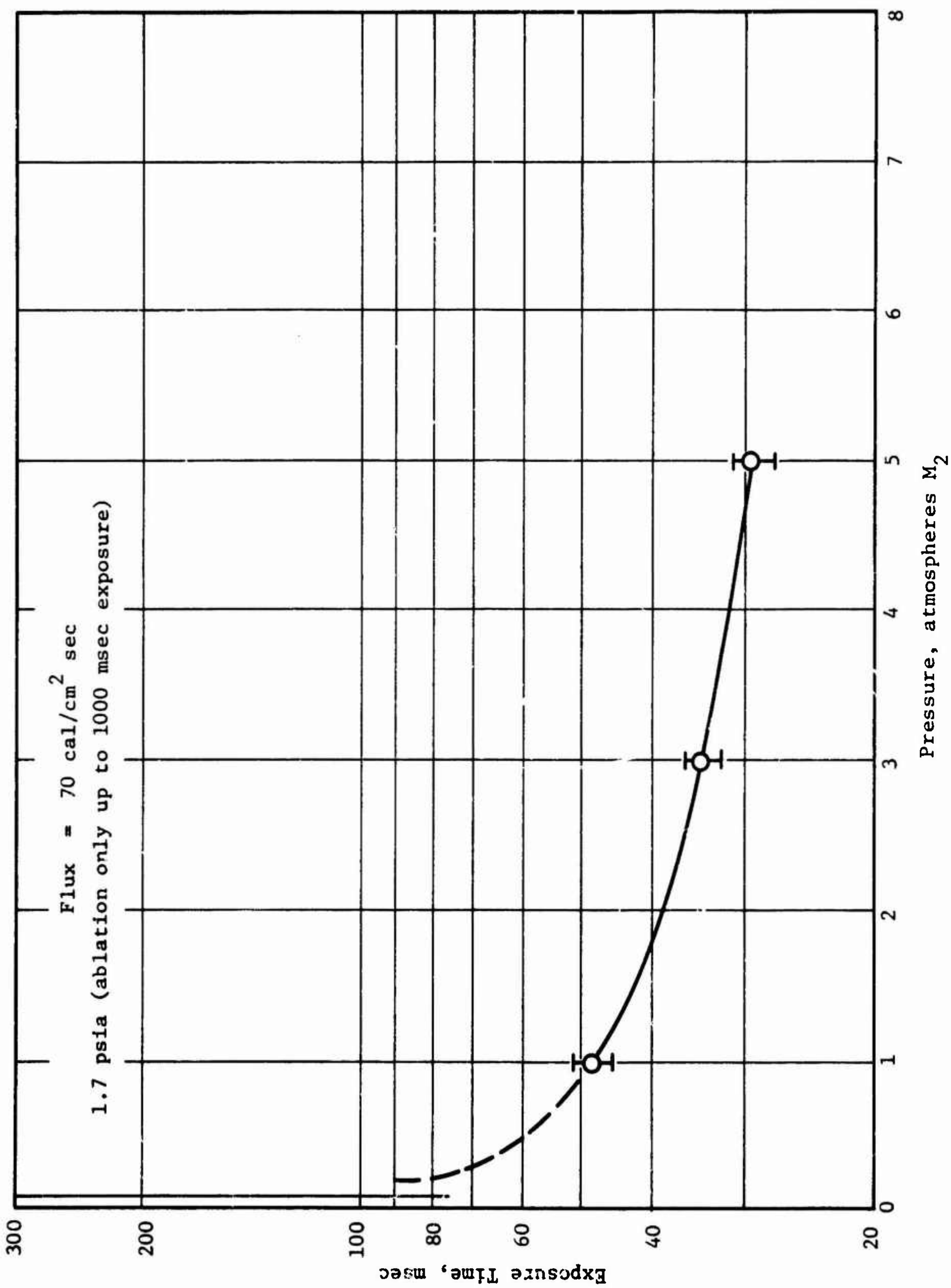
c. Arc-Image Furnace Ignitability Studies

The threshold-ignition energy requirement of a propellant is defined as the radiant energy required to ignite the propellant with a 0.50 probability as determined by visual observation of consecutive fire and no-fire samples with the narrowest possible range or separation of exposure times. The ignitability of ANB-3241-2 was measured at a surface heat flux of 70 cal/cm^2 - sec. The test results are presented in Figure 17. The threshold-ignition energy requirement is approximately 3.5 cal/cm^2 at all atmospheres. This propellant has essentially the same threshold-ignition energy requirement as a similar PBAN propellant, ANP-3105. A typical polybutadiene propellant such as ANB-3066, the Minuteman second-stage propellant, requires 7 to 8 cal/cm^2 at 1 atmosphere. These data also show that the ignitability pressure dependency is small, which is normal for most of the polybutadiene and PBAN propellants tested to date. It is seen that a five-fold increase in pressure decreases the threshold-ignition energy requirement by a factor of only 1.2. Also, these data show that the propellant in a motor at an altitude of 50,000 ft should ignite satisfactorily since the igniter-induced chamber pressure is approximately 8 to 10 atmospheres.



Effect of Temperature on Cure Rate of ANB-3241-2 Propellant

Figure 16



Arc-Image Furnace Ignitability Data Showing Dependence of Exposure Time on Pressure, Propellant ANB-3241-2

Figure 17

II.A. Motor Design and Description (cont)

d. Propellant Processing Characteristics

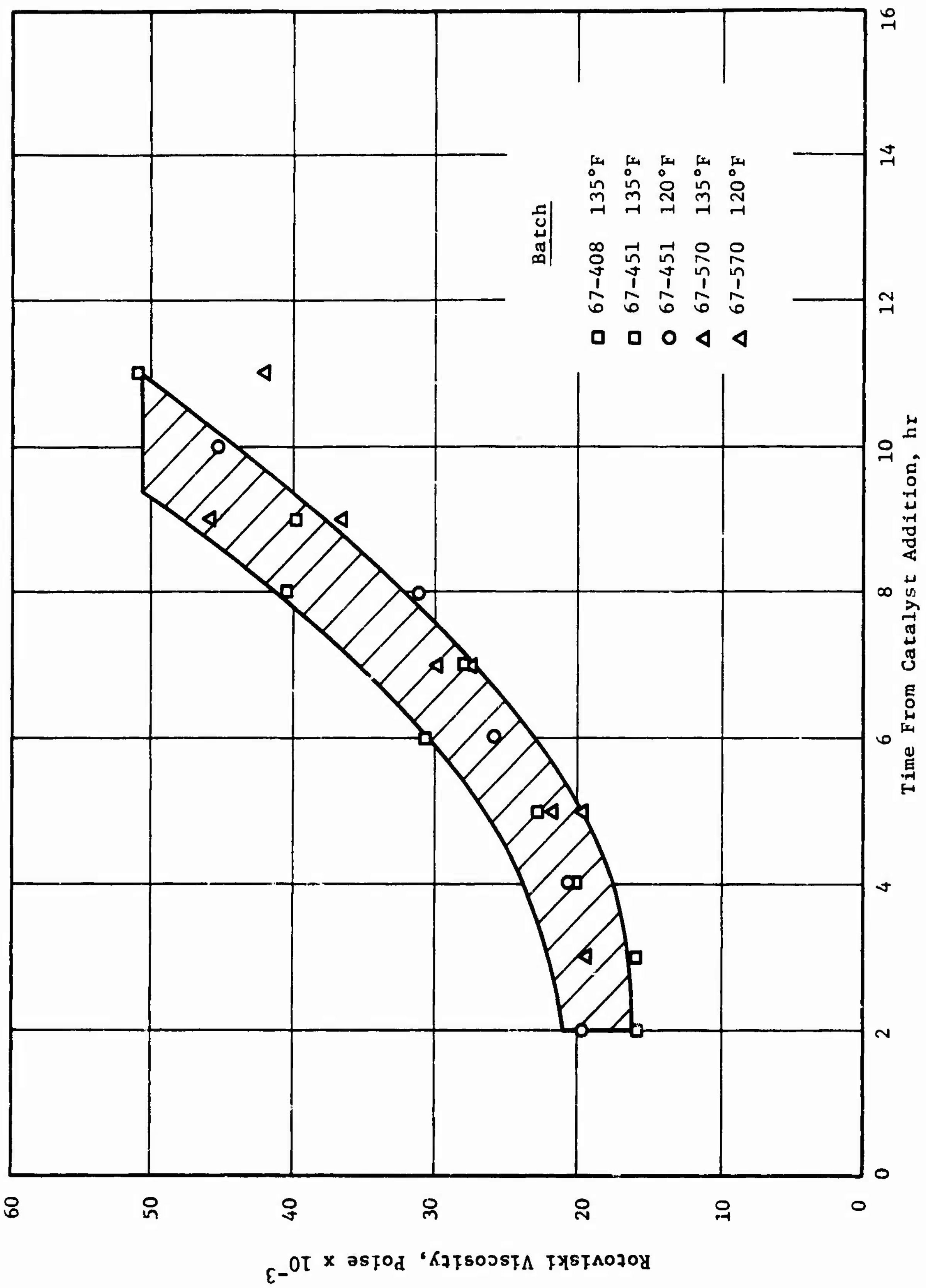
The processing characteristics of ANB-3241, as well as other PBAN propellants, make it ideally suited for high-volume production. The flow characteristics of ANB-3241 are excellent; the as-cast viscosity is only 15,000 poise at +135°F. A comparison of the viscosity buildup from +120 to +135°F of batches prepared for the 2.75-in. FFAR motor program is shown in Figure 18. The close agreement among the various batches is another example of the excellent reproducibility of the Aerojet epoxy-cured PBAN propellant systems.

e. Explosive Classification

The hazard classification tests performed at Aerojet on ANB-3241-2 are listed in Figure 19. More extensive motor testing in accordance with Technical Order T.O. 11A-147 was performed as part of the Improved 2.75-in. FFAR program. As expected, the recommended DOT classification remains Class B.

f. Liner and Insulation

Sprayable liner IBS-105-2 (Specification AGC-36552) was selected to line the chamber sidewall, and insulation IBS-105-4X (Specification AGC-36555) was selected to insulate the chamber aft end which is exposed to propellant combustion and gas flow for almost the full duration of motor operation. Both materials are modifications of liner formulation SD-850-2 that was successfully used and characterized on the 260-in. motor program. The formulations for both materials were specifically tailored to provide (a) flow and cure characteristics required for spray application; (b) good low temperature properties; and (c) high bond strength margins with propellant grain and chamber sidewall. For use as the aft-end insulation material, the asbestos content



Viscosity Profile of ANB-3241-2 Propellant

Figure 18

Item	Test Results
2-in. Cube with No. 8 Blasting Cap (5 tests)	Negative
2-in. Cube with Engineer's Special Blasting Cap (5 tests)	Negative
Ignition and Unconfined Burning Tests	
1-in. cube (1 test)	Burned 8 sec
2-in. cube (2 tests)	Burned 14 sec
4 2-in. cubes (1 test)	Burned 15 sec
Thermal Stability Test (48 hr at 75°C)	
1-in. cube (1 test)	No change
2-in. cube (1 test)	No change
Autoignition Temperature, °F (DTA)	705
Impact Sensitivity, cm/2Kg*	23
NOL Card-Gap Test (6 tests)*	Negative (with no attenuation)

* Not DOT Test

DOT Classification Testing for ANB-3241 Propellant

Figure 19

was increased to provide improved erosion resistance and the carbon black level was decreased to maintain flow properties that permit spray application with the centrifugal applied liner (CAL) process. The compositions of the two materials are presented in Figure 20, together with their respective bond strengths. The excellent bond strengths of both insulation materials reflect the type of failure obtained with the PBAN liner systems in that cohesive failure occurred in the propellant in each test. The bond strength allowables were also determined and are discussed later in this section. The mechanical properties of IBS-105-3 at +77 and -65°F are shown below:

	Mechanical Properties			
Test Temperature, °F	σ_m, psi	ε_m, %	ε_b, %	E_o, psi
+77	183	110	114	383
-65	2966	9	75	58,306

The cure time selected for processing the IBS-105-3 liner is 18 $\pm$ 6 hr at +135°F, which is within the acceptable limits for this system.

Liner Cure		Bond Strength	
Time, hr	Temperature, °F	Peel at +77°F, lb/in.	Tensile at +77°F, psi
8	135	31	84
16	135	33	83
24	135	29	84

Components	Equivalents Ratio	Composition, wt% IBS-105-3	IBS-105-4X
PBAN	45	50.49	49.04
MNA	45	2.67	2.62
LD-124	10	3.36	3.26
DER-332	110	12.96	12.58
FeAA		0.50	0.50
P-33		10.00	5.00
Sb_2O_3		10.00	10.00
Asbestos		10.00	17.00
Bond Strength at +77°F			
Peel Strength, lb/in.		24	20
Tensile Strength, psi		64	65

Comparison of 2.75-in. FFAR Motor
Insulation and Bond Systems

Figure 20

g. Structural Integrity Evaluation of Propellant/Liner System

A laboratory test and analytical program has been completed having as its primary objective the verification of the structural adequacy of the propellant/liner system selected for use in the Improved 2.75-in. motor. The specific objectives were the following:

(1) Fully characterize the physical and mechanical properties of ANB-3241-2.

(2) Determine propellant and bond allowables for critical motor operating conditions.

(3) Conduct cumulative damage analysis for the thermal cycling condition (150 to -65°F).

(4) Verify analytical prediction by cycling full-scale motors to failure.

Laboratory tests conducted with samples from two propellant batches (68-46 and VBM-1-67-001), and the type of data obtained are summarized below:

Test	Data Obtained
1. Specific volume vs temperature	Coefficient of thermal expansion
2. Stress relaxation	Long term modulus (storage)
3. Broad spectrum constant rate tensile	Modulus, strength and elongation parameters vs rate and temperature
4. Full-scale and analogue motor thermal cycling	Allowable number of motor thermal cycles (-65 to 150°F)
5. Constant rate tensile with pressure	Allowable strain for firing
6. Constant rate bond tension	Allowable tensile stress for storage
7. Constant rate bond shear with pressure	Allowable shear stress for firing

II.A. Motor Design and Description (cont)

In addition, a cumulative damage analysis of the motor cycling condition was conducted to provide analytical support to the experimental observation which indicated that ANB-3241-2 propellant has adequate capability to successfully withstand the required three cycles between the temperature extremes of -65 and 150°F in the full-scale motor configuration.

The results of the constant rate tests, which were remarkably consistent between the two batches, showed that the propellant properties are highly rate and temperature dependent. This characteristic was shown to be the major factor accounting for the successful thermal cycling performance despite low elongations measured at low temperatures at standard test rates.

Comparison of allowable strains and stresses with calculated requirements showed positive safety margins for all motor operating conditions. The validity of this analysis is confirmed by more than 50 static test firings of motors subjected to thermal cycling and vibrational environments and >600 flight tests.

Cumulative damage analyses for both shock and step-wise thermal cycling between the extremes of -65 and 150°F were conducted using recently developed techniques and propellant properties obtained from the laboratory testing. The results indicated no significant difference between the two types of cycle and predicted the earliest failures at about 11 cycles and 50% failures by the 34th cycle. Full-scale motor cycling results were in good agreement with these predictions.

Based on the results of the laboratory and analytical work it is concluded that the propellant and propellant-liner system selected for use in the 2.75-in. FFAR motor will satisfactorily meet all structural requirements.

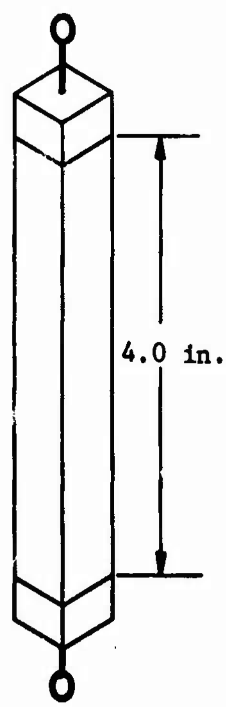
(1) Physical Properties and Response Characterization

(a) Coefficient of Thermal Expansion

The volume coefficient of thermal expansion was determined by means of measurements of propellant density at various temperatures over the range -80 to +80°F. The slope of a density - temperature plot provides the desired value. The linear coefficient is taken to be one third of the volumetric. The average linear value for ANB-3241-2 determined from tests of specimens from four batches is $6.0 \times 10^{-5}\,°F^{-1}$.

(b) Response Characterization

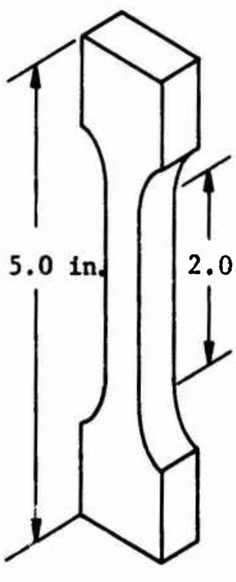
Stress relaxation tests were performed with end-bonded uniaxial specimens at -75, -40, 0, 40, 77, 110 and 150°F.



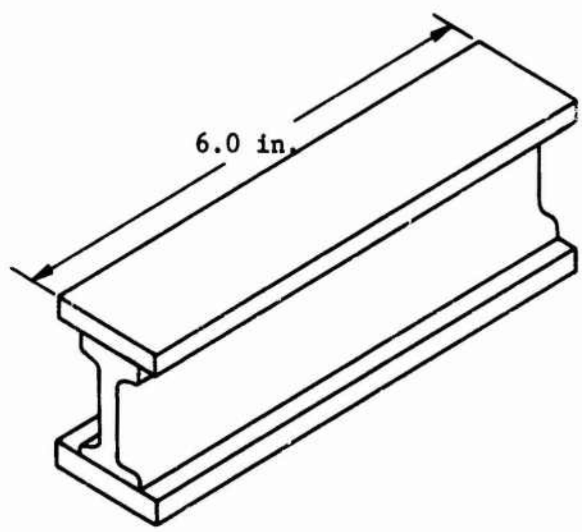
End-Bonded Uniaxial

Strains of 0.5 - 1.0% were applied at a rate of 0.25 min^{-1} and held for 10 minutes while the decay in stress was measured. The data obtained were plotted in the form of relaxation modulus versus time for each test temperature. Superposition of the data was accomplished by correcting the modulus by the ratio, T_s/T, (T_s = reference temperature = 209°K (77°F), T = test temperature in °K) and manually shifting the curves along the time axis until they superimposed at the reference temperature. The resulting "master curve," shown in Figure 21, provides the modulus data needed for the thermoviscoelastic analysis. The shift factors required to superpose the data are shown in Figure 22.

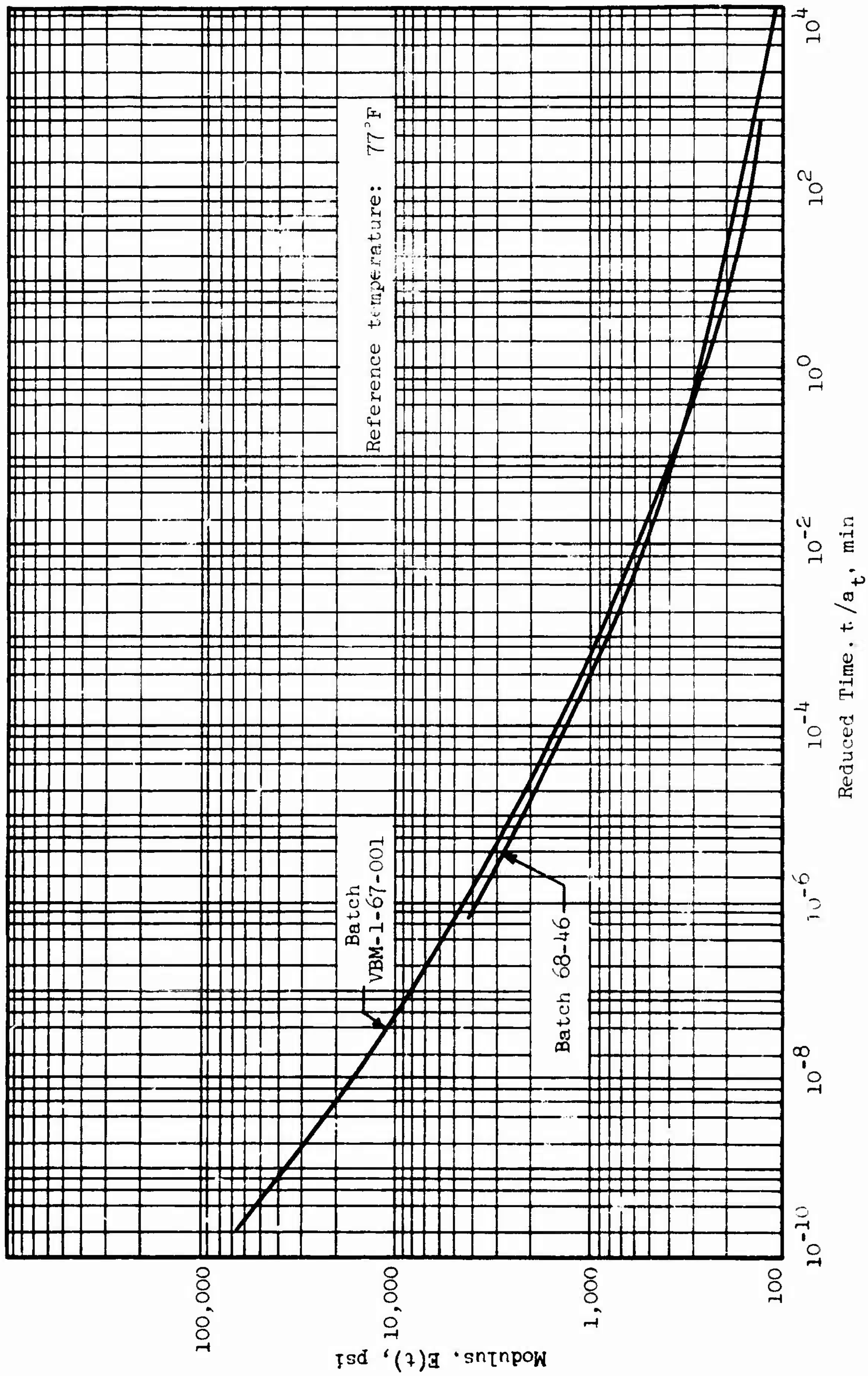
Constant rate tensile tests of uniaxial and biaxial specimens were conducted under conditions specified by the test plan shown below:



ICRPG Dumbbell

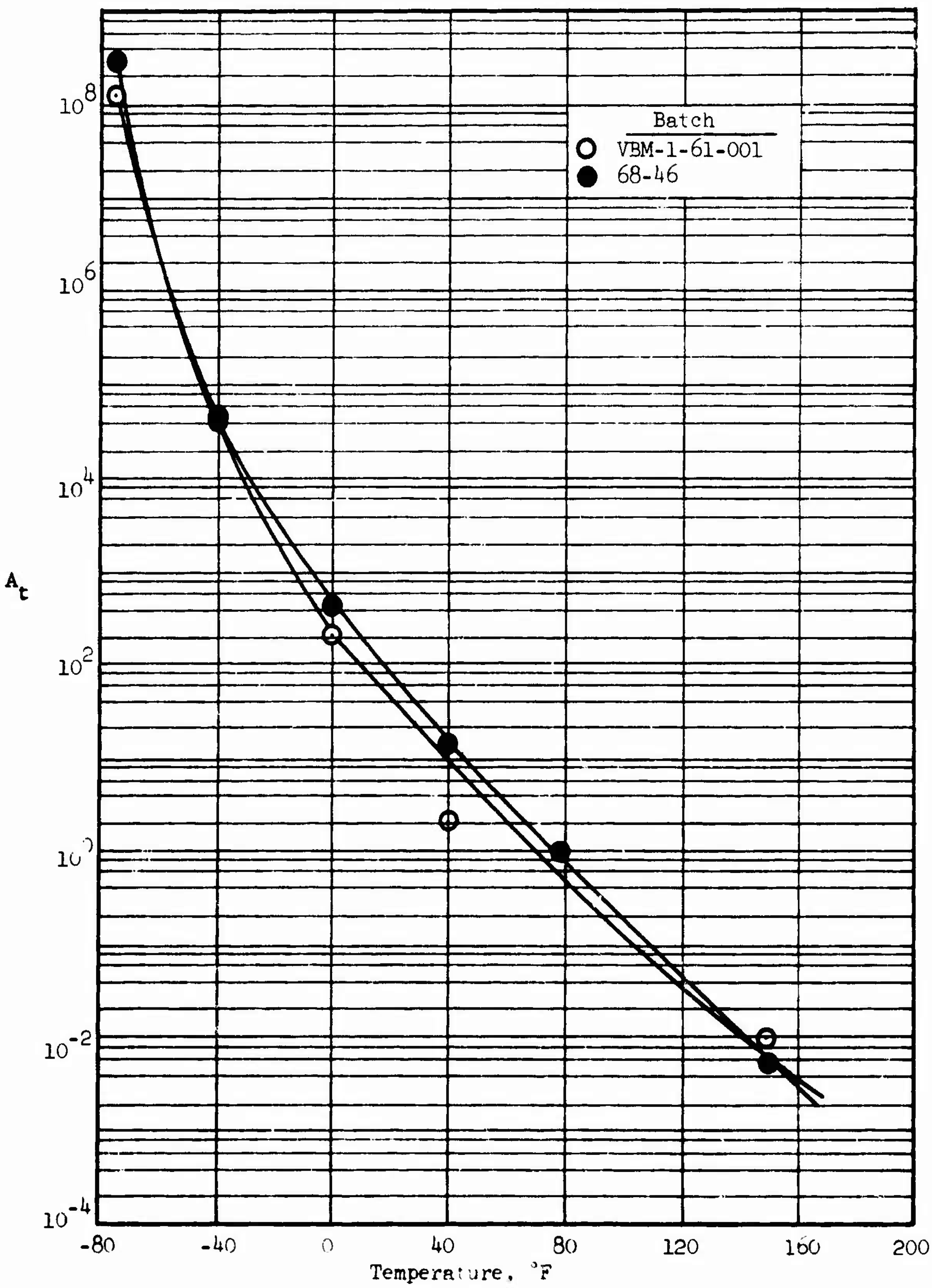


Biaxial Strip



Master Relaxation Curve for ANB-3241-2

Figure 21



Time-Temperature Shift Factor for ANB-3241-2

Figure 22

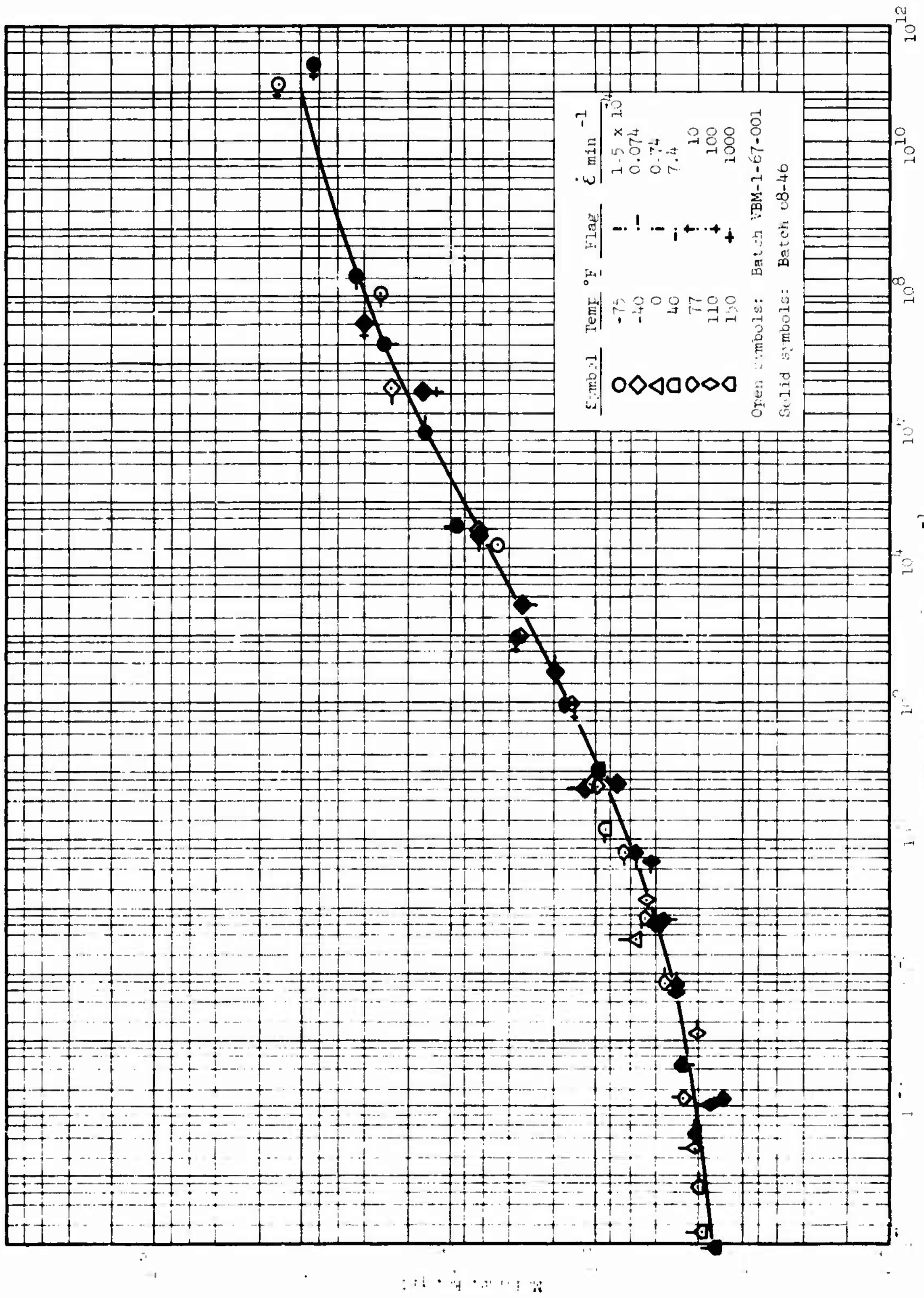
II.A. Motor Design and Description (cont)

Rate min^{-1}	-75	-65	-40	0	40	77	110	150
0.00015	X		X	X		X	X	X
0.0074						X$^{(3)}$	X	X$^{(3)}$
0.074						X$^{(3)}$	X$^{(1)}$	
0.74	X$^{(1)(3)}$		X$^{(1)(3)}$		X$^{(1)(3)}$	X$^{(1)(3)}$	X$^{(3)}$	
7.4						X$^{(3)}$		
10		X$^{(2)}$						
100		X$^{(2)}$	X			X		
1000	X	X$^{(2)}$				X		

(1) Indicates conditions for biaxial tests
(2) Tests with 1000 psig pressure and 12% pre-strain
(3) Uniaxial strains measured by extensometer

This matrix was designed to characterize the tensile behavior over a wide range of rate and temperature. It also includes the testing needed to determine the allowable strain for firing.

Modulus values pertinent to the analysis of high rate loading conditions, such as handling, acceleration and firing, are obtained from a plot of modulus vs reduced strain rate ($\dot{\varepsilon}\ a_T$) as shown in Figure 23 for a reference temperature of 77°F. Moduli for other temperatures can be simply determined from this plot by multiplying the strain rate of interest by the appropriate a_T from Figure 22 and entering the curve of Figure 23 at that point.



Modulus vs Reduced Strain Rate for ANB-3241-2 Propellant

Figure 23

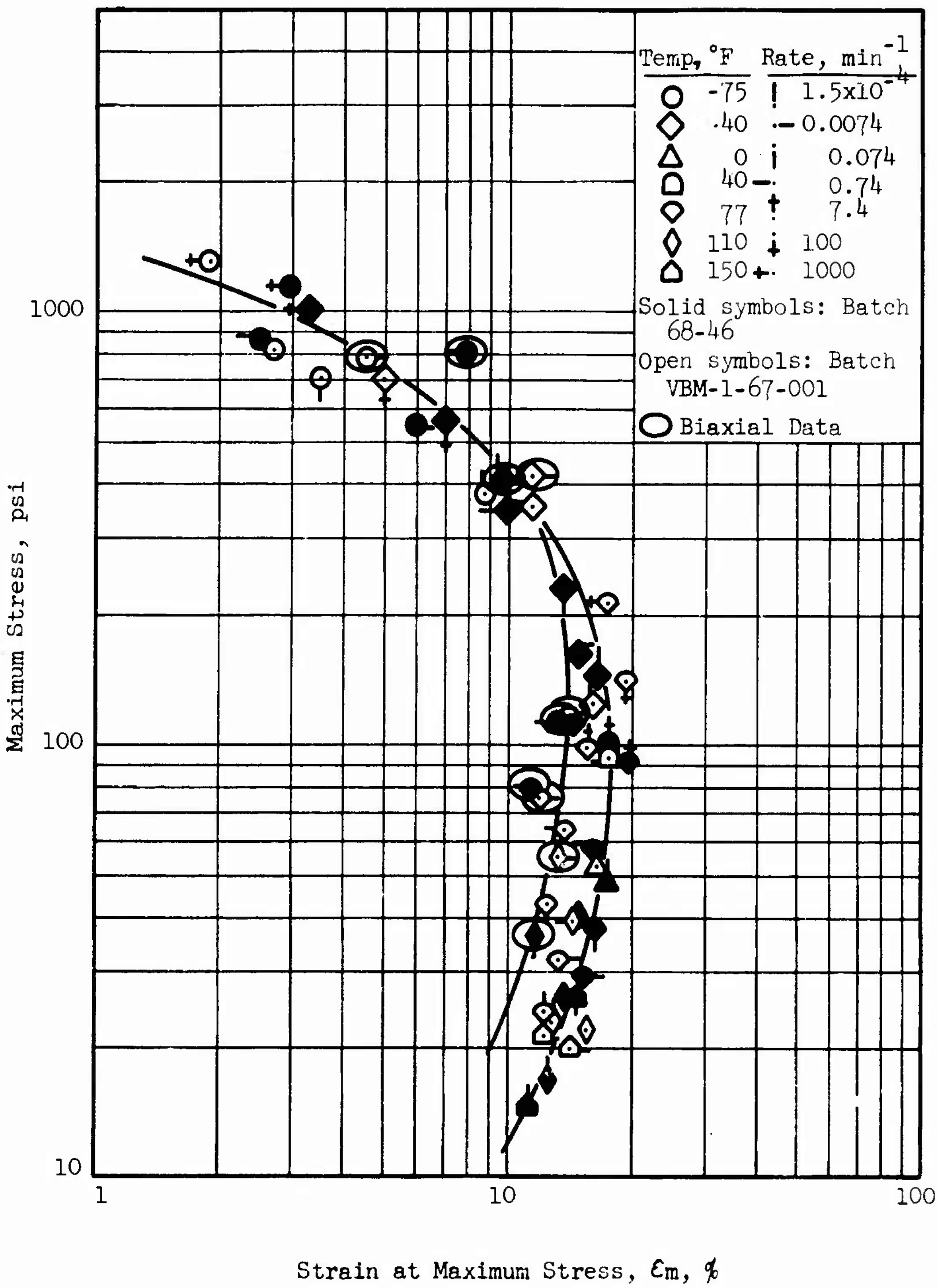
A "Smith-type" failure envelope for ANB-3241-2 is shown plotted in Figure 24 with both the uniaxial and limited biaxial strip data shown. At the lower stress values, corresponding to the lower strain rates and higher temperatures, the biaxial elongations are about 70% of those from the uniaxial tests. At the higher stress values, however, there appears to be no significant difference.

Figures 25, 26, and 27 show the elongation parameters ε_m, ε_b, and σ_m/E plotted vs reduced strain rate for reference temperatures of 77°F and -65°F. It will be noted that the elongation is quite rate sensitive and passes through a maximum at 77°F at a rate between 10 and 100 min^{-1}. The maximum strain rate application to the cooling of a full-scale 2.75-in. motor from 150 to -65°F can be simply estimated since it is known that the maximum strain at the inner bore at -65°F is 12.7% and the minimum time required to reach thermal equilibrium at -65°F is about 2.5 hours. Thus:

$$\dot{\varepsilon} = \frac{0.127}{2.5 \times 60} = 8.5 \times 10^{-4} \ \text{min}^{-1}$$

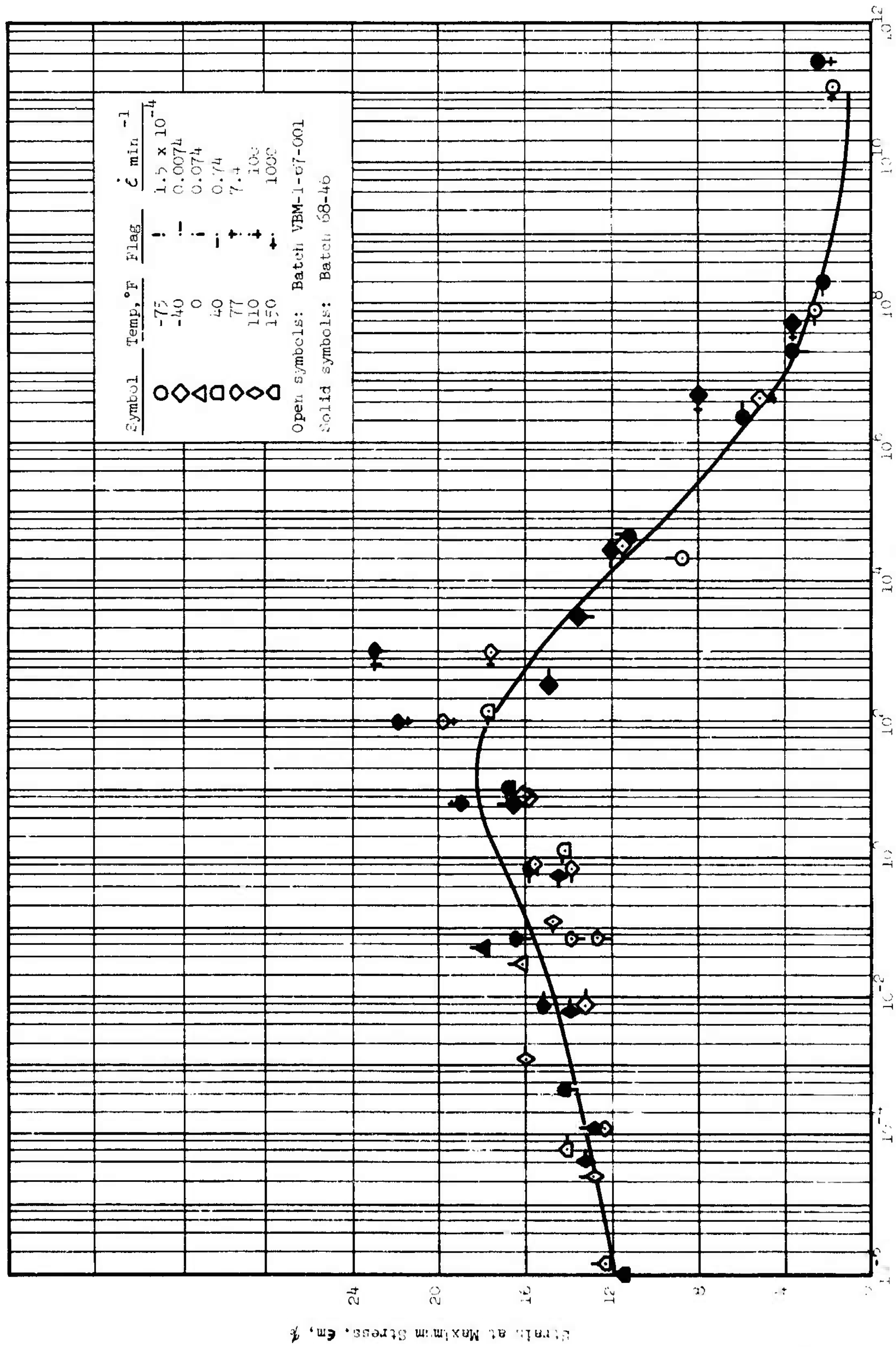
It can be seen from Figure 25, by referring to the strain rate scale representing a reference temperature of -65°F, that the elongation corresponding to the motor strain rate is about 13% compared to about 5% at the standard rate of 0.74 min^{-1}. Further, on that part of the curve any reduction in the rate of cooling would lower the strain rate and result in even higher elongations.

This example is presented to emphasize that elongation values obtained from standard rate tests at low temperatures are not necessarily indicative of the propellant's capability, or lack of same, to perform satisfactorily under a given motor condition. A proper assessment must take into account the rate and temperature dependence of the propellant and relate these to the particular motor condition being analyzed.



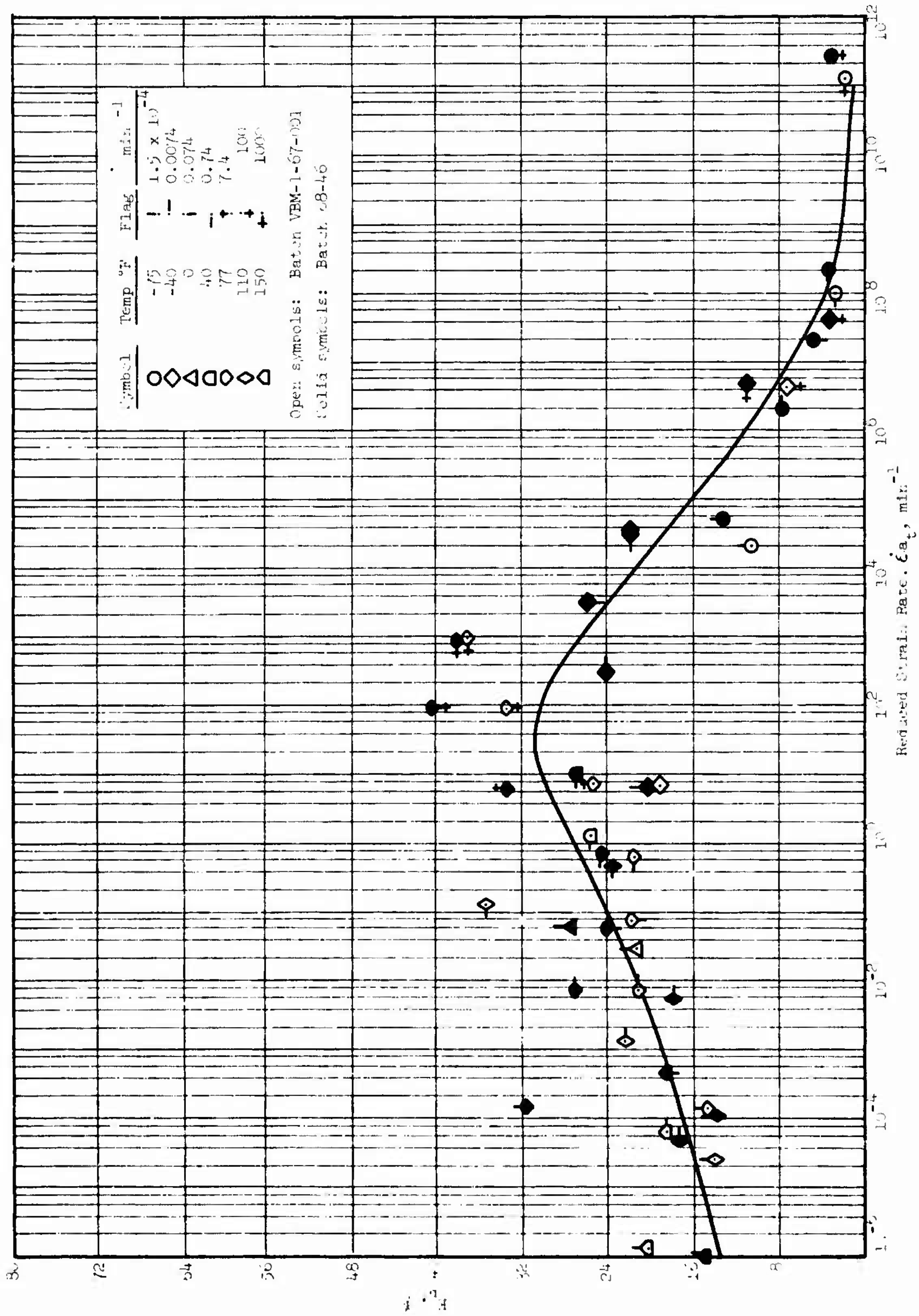
"Smith-Type" Failure Envelope for ANB-3241-2

Figure 24



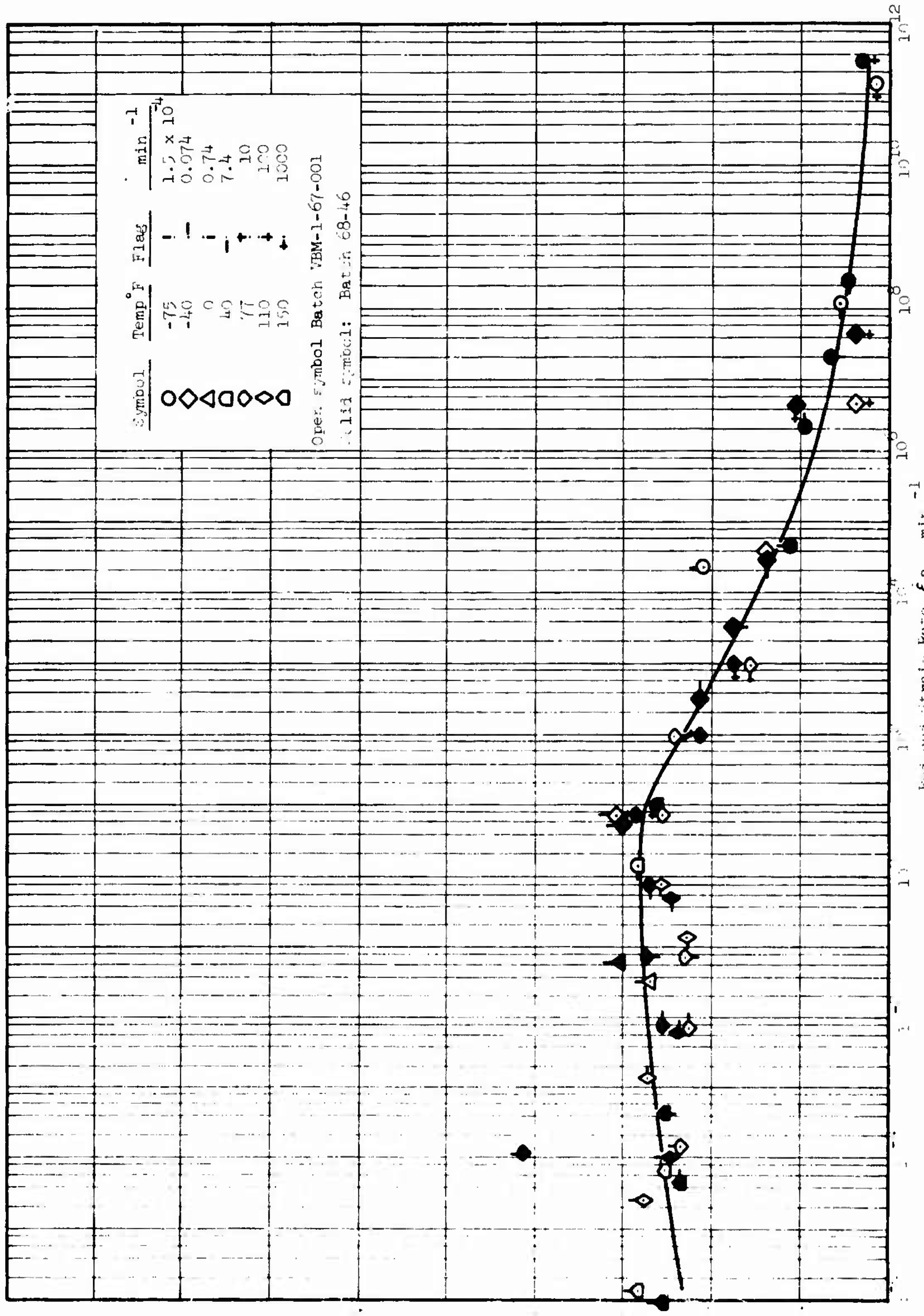
Strain at Maximum Stress vs Reduced Strain Rate for ANB-3241-2 Propellant

Figure 25



Strain at Break vs Reduced Strain Rate for ANB-3241-2 Propellant

Figure 26



Strain Parameter ϵ_m / E_o vs Reduced Strain Rate for ANB-3241-2 Propellant

Figure 27

To further demonstrate the path dependency effects two specimens each were strained at 77°F to 5, 7.5, 10, 12.5, and 15% held for 24 hours, then cooled while under strain to -65°F. No failures occurred after six weeks. The specimens were brought up to 77°F, strained an additional 5% and then cooled again to -65°F. No failures occurred after four weeks. Similar tests were conducted with specimens from Batch VBM-1-67-001 at strain levels of 15, 17.5, 20, 22.5, 25 and 30%. All specimens held at the latter three strain levels failed within one day. The rest have resisted failure for six weeks.

(2) Propellant and Bond Allowables

The methods used to estimate the allowable strains and stresses for the propellant and bonds are based on simulating the critical motor conditions in the laboratory, by means of careful specimen design and environmental control, and treating the resulting data to account for the expected variability in properties. The basic relation used in calculating the allowables is given below:

$$X_a = \bar{X}K\,[1 - (3 + a)\quad V] \qquad (1)$$

Where

X_a = allowable stress or strain

$\bar{X}$ = mean measured property obtained under appropriate test conditions

K = stress concentration of multiaxiality correction factor

a = statistical parameter which depends upon number of samples tested and level of confidence required

V = coefficient of variation for property being measured

II.A. Motor Design and Description (cont)

(a) Strain Allowables

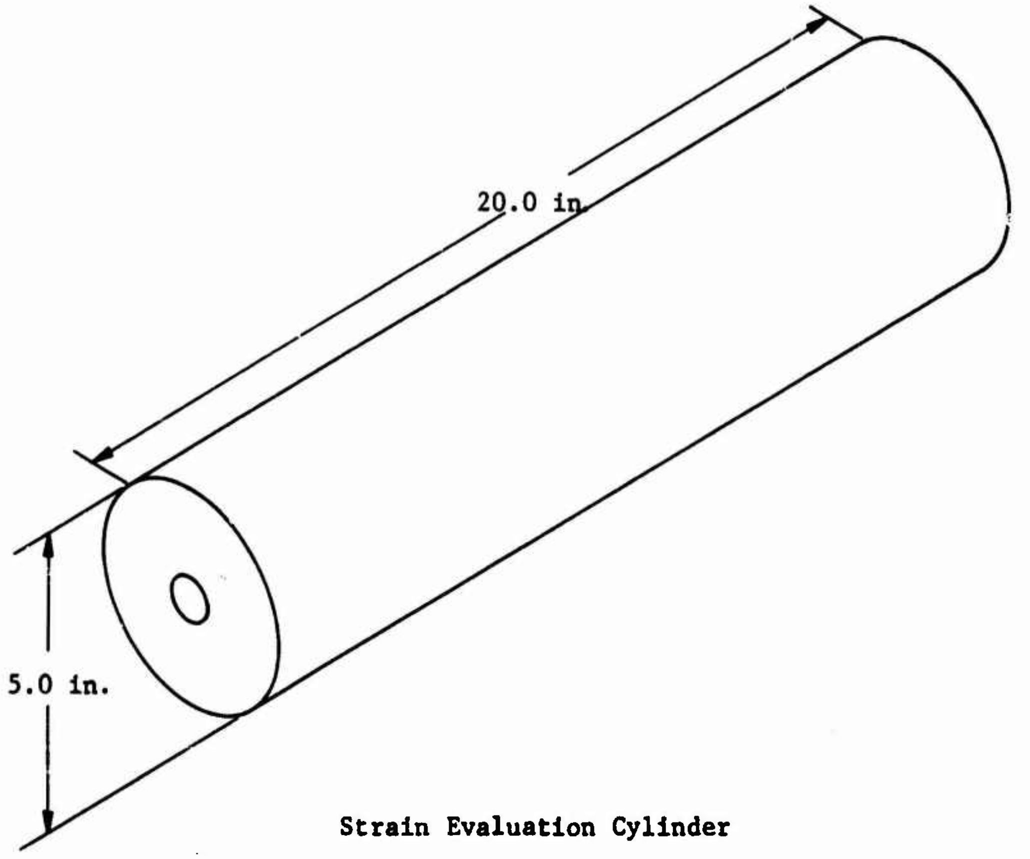
1 Thermal Cycling

Because of the complications presented by factors such as path dependency, the evaluation of thermal cycling capability cannot be handled simply using uniaxial or biaxial tests. The best approach has been the use of analogue motors, with cylindrical bores of various sizes, thermally cycled to failure. In the case of the 2.75-in. motor the small size makes it convenient to test the full-scale article. Data for 16 full-scale motors from five different cast lots cycled between 150 and -65°F are presented below.

Cast Lot	Measured Strain, %	Cycles Completed* Without Failure	Remarks
6	12.4	10	Failed
	12.3	27	Failed
	12.4	27	Failed
	12.1	16	Failed
	12.1	28	Failed
7	11.7	20	No failure. Test discontinued
	10.2	20	No failure. Test discontined
9	11.3	10	No failure. Test discontinued
	10.8	10	No failure. Test discontinued
	10.5	5	Failed (scratch on bore)
10	11.8	4	Failed (scratch on bore)
	10.8	9	Failed
12	13.0	10	No failure. Test discontinued
	12.9	10	No failure. Test discontinued
	12.8	10	No failure. Test discontinued
	12.9	10	No failure. Test discontinued

* - 65 to +150°F

Numerous strain cylinders prepared from half length 2.75-in. motor cases with different bore sizes have been tested.



Strain Evaluation Cylinder

The results from 20 cylinders from four cast lots summarized below indicate a satisfactory safety margin for the specification requirements of three cycles.

II.A. Motor Design and Description (cont)

Cast Lot	Measured Strain, %	Cycles Completed[1] Without Failure	Remarks
6	13.6	5	Failed
	13.9	18	Failed
	13.4	12	Failed
	14.4	6	Failed
8	12.3	17	Failed
	12.0	11	Failed
	12.6	14	Failed
	11.4	21	Failed
	15.7[2]	11	Failed
	15.3[2]	9	Failed
10	12.4	6	Failed
	12.3	9	Failed
	15.7[2]	9	Failed
	15.7[2]	6	Failed
12	12.4	6	Failed
	12.1	10	Failed
	12.2	6	Failed
	11.9	5	Failed
	15.5[2]	5	Failed
	15.4[2]	5	Failed

2 Firing

The allowable inner bore hoop strain for firing at -65°F was estimated from the results of high rate tensile tests of pre-strained specimens. The tests were conducted in a high pressure (1000 psig) environment to simulate the conditions at the inner bore during motor ignition. The pre-strain on the specimens was about 12% corresponding to the

(1) -65 to +150°F
(2) Core size: 0.60-in. diameter; all others 0.70-in. diameter

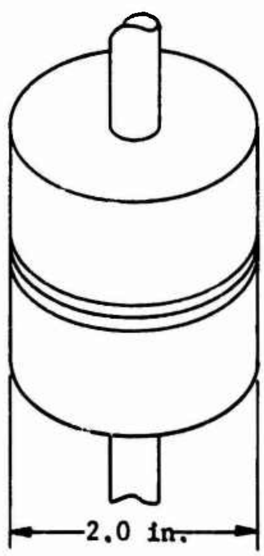
expected maximum thermal strain at the inner bore at -65°F. Of primary interest for this condition is the propellants' capability to withstand the additional strain, over and above the thermal strain already present, imposed by motor pressurization. These allowable incremental strains, calculated using Equation (1), are shown in Figure 28. A K value of 0.83 was used to correct the uniaxial values to equivalent biaxial elongations.

The allowable obtained for the time corresponding to time to peak ignition pressure (150 msec) would be 3%. This compares with a calculated requirement of 2.7%. Thus, an adequate margin of safety exists for the firing condition.

(b) Bond Stress Allowables

1 Storage

An evaluation of the bond capability for storage was made from the results of constant rate tension tests of poker-chip sandwich specimens. The specimens made from Batch 68-46 used IBS-105-4X



Poker-Chip

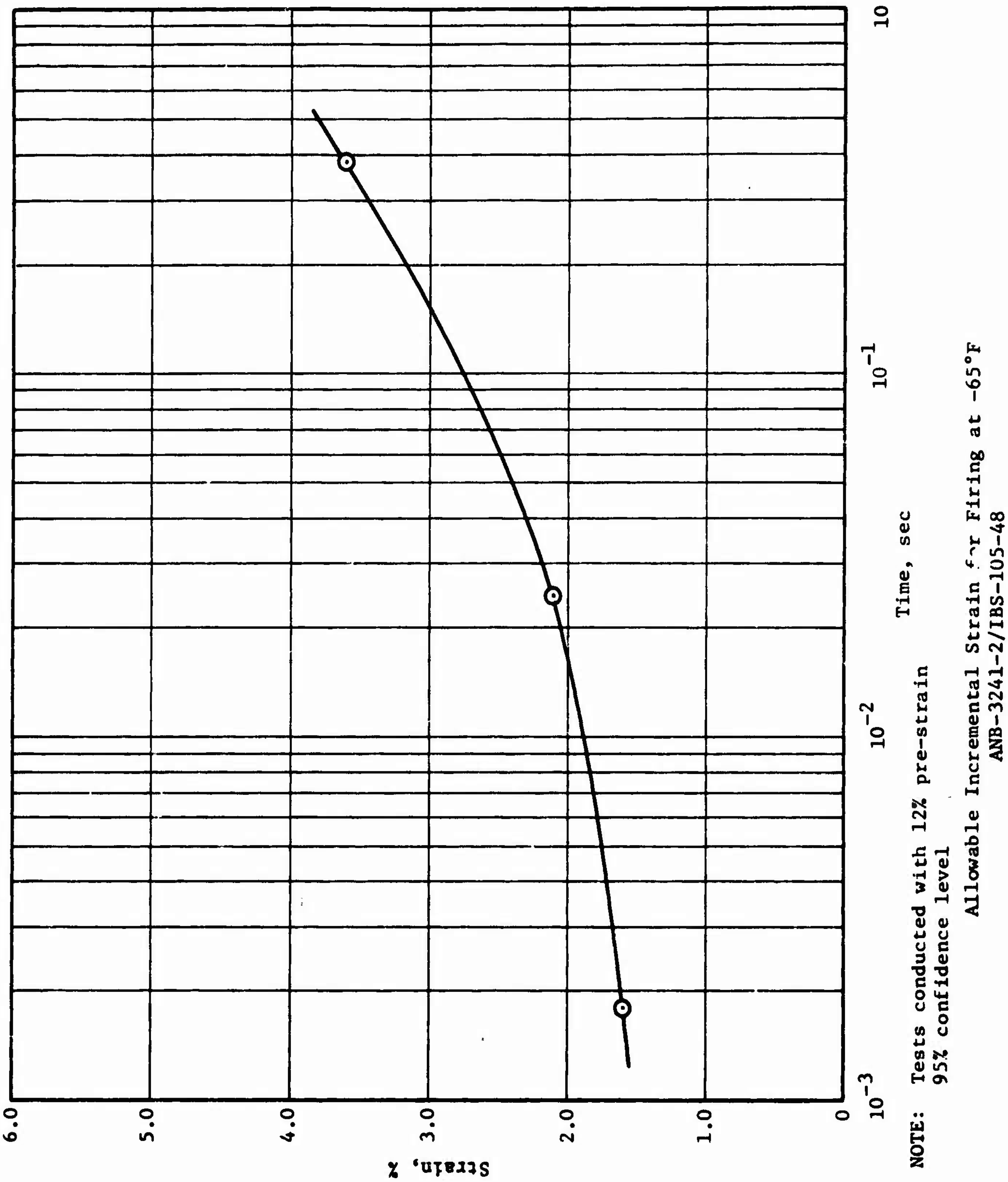

Allowable Incremental Strain for Firing at -65°F
ANB-3241-2/IBS-105-48
Strain, %
Time, sec
6.0
5.0
4.0
3.0
2.0
1.0
0
10^{-3}
10^{-2}
10^{-1}
10
NOTE: Tests conducted with 12% pre-strain
95% confidence level

Figure 28

insulation while those prepared with propellant from VBM-1-67-001 contained IBS-105-3 insulation. Tests were conducted at crosshead rates of 0.02, 0.2 and 2.0 inches per minute and temperatures of -65, 77 and 150°F. The results plotted in the form of stress vs reduced time to failure for a reference temperature of -65°F are presented in Figure 29. The estimated allowable stress was obtained from these data by use of Equation (1) with K taken to be 1.4. In addition the time values were corrected by a factor A = 0.1, to account for the fact that during the constant rate test the maximum stress is not applied to the specimen for the full duration of the test.

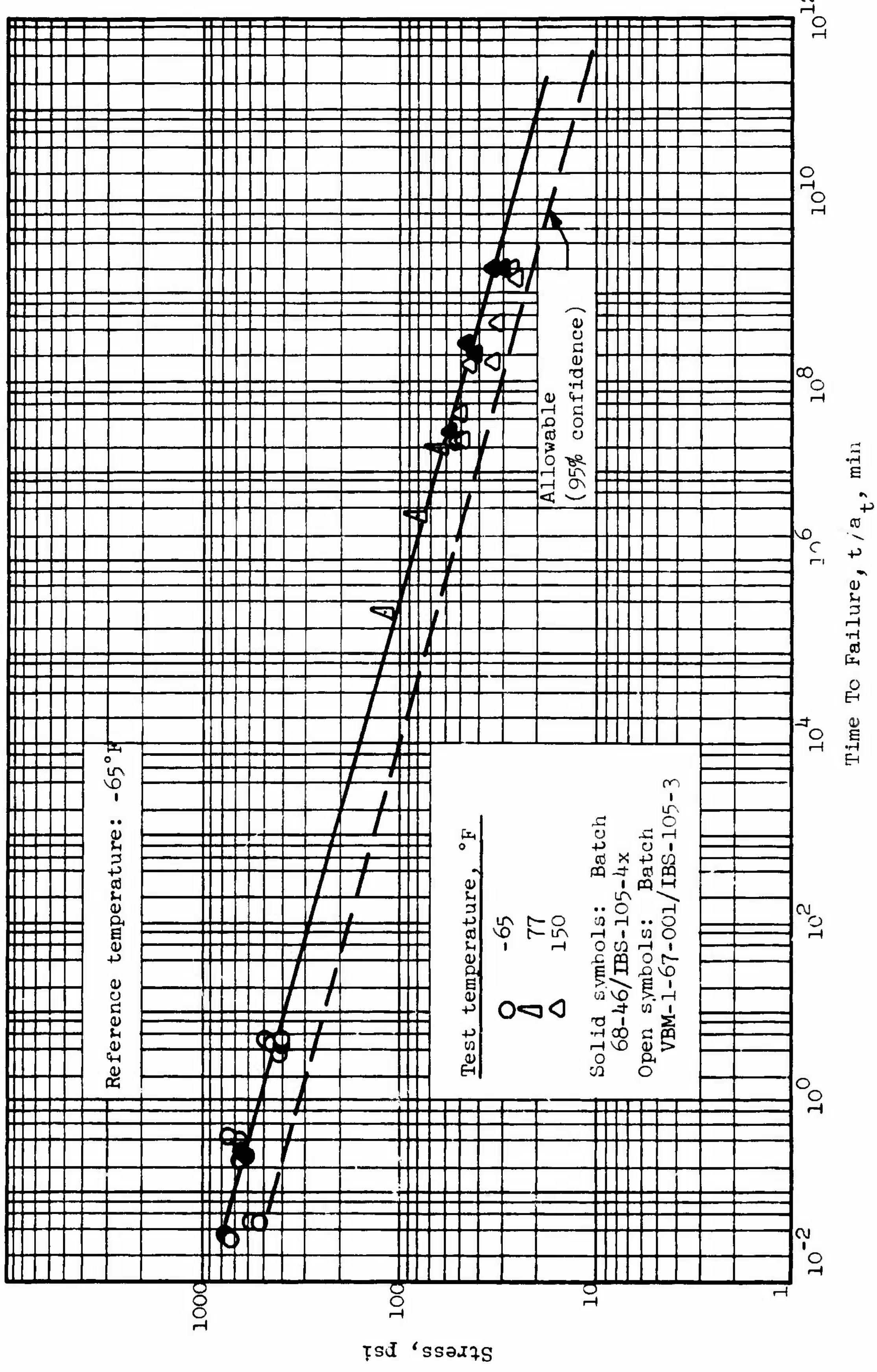
Comparison of the allowables thus obtained,out to storage time in excess of one year, indicate large margins of safety.

2 Firing

Poker-chip bond specimens tested in shear at several rates, and with superimposed pressure, provide the data needed for calculation of the allowable bond shear stresses for motor firing. Again Equation (1) was used with a K factor of 1.2. The results for firing temperatures of -65 and 150°F are shown in Figure 30. The calculated requirements for these temperatures are 465 and 10.6 psi, respectively. These compare with allowable values taken at 150 msec of 980 and 110 psi. Again adequate safety margins are indicated.

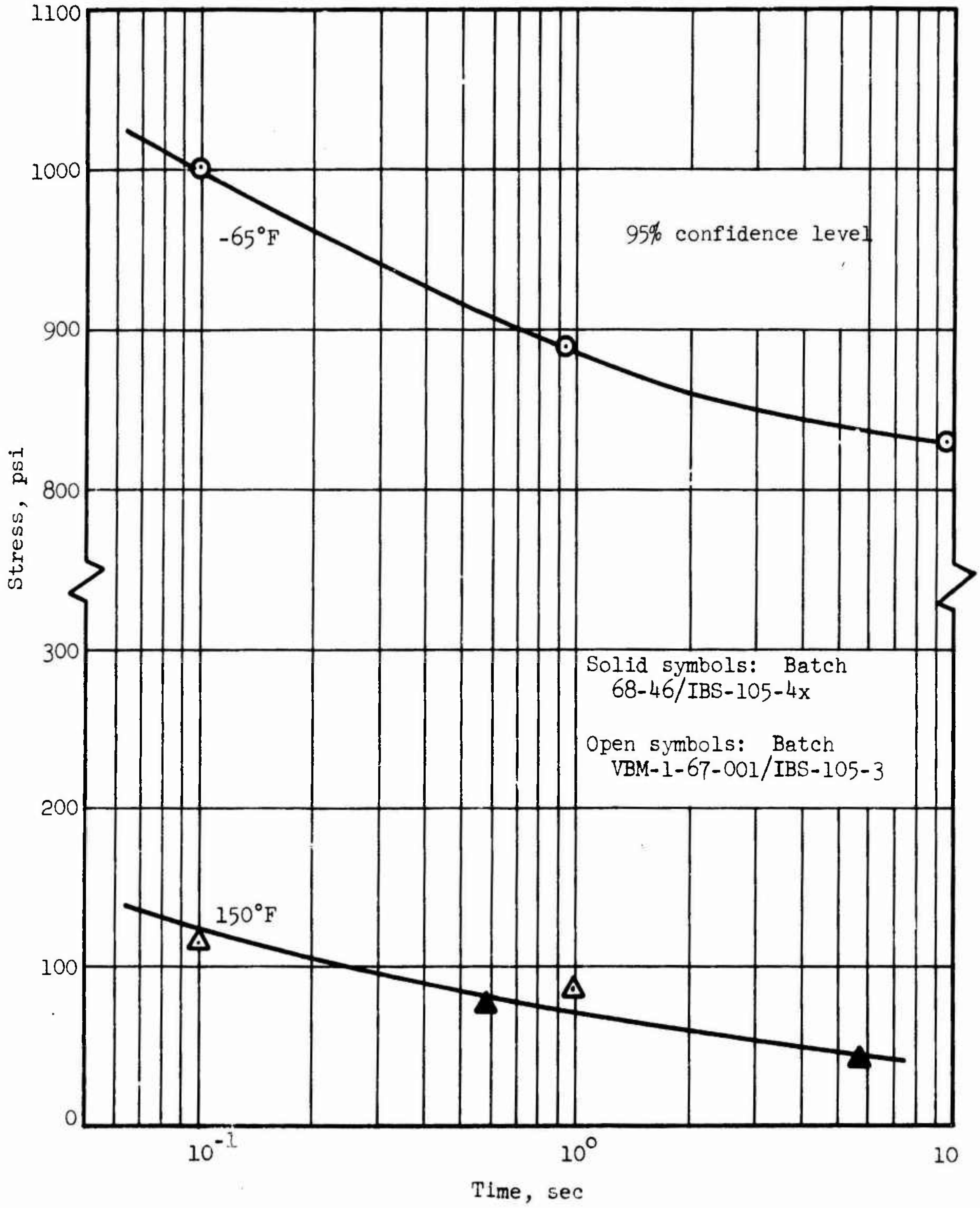
(3) Cumulative Damage Analysis

The 2.75-in. motor was subjected to analyses of transient heat conduction, thermoviscoelasticity, and cumulative damage using the properties obtained from laboratory tests of propellant ANB-3241-2, Batch 68-46. The pertinent properties used are presented in Figure 31.



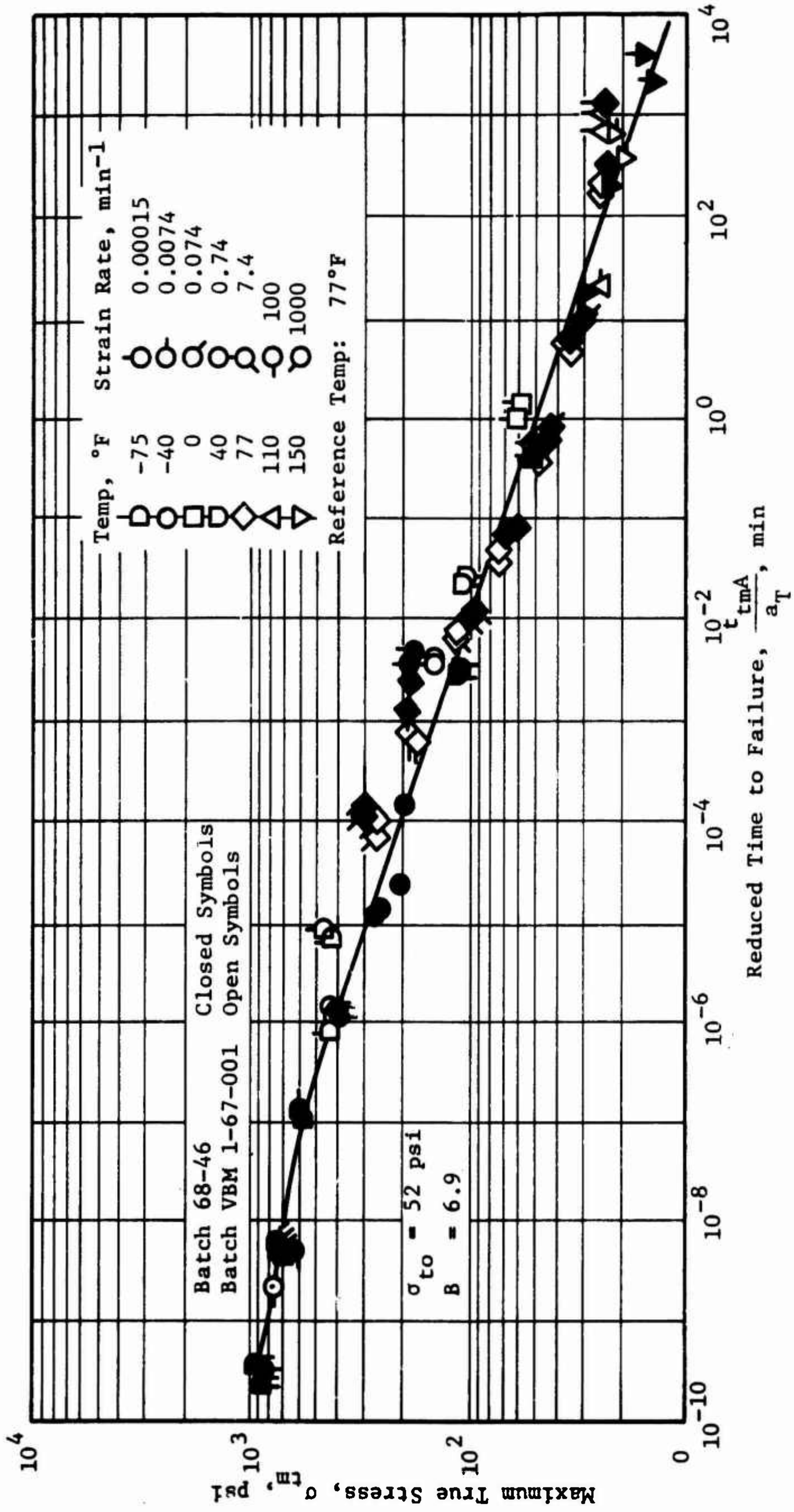
Allowable Tensile Stress for Storage of 2.75-in. Motor Propellant-to-Liner Bond

Figure 29



Allowable Bond Shear Stress for Firing of 2.75-in. Motor Propellant-to-Liner Bonds

Figure 30



Maximum True Stress vs Reduced Time to Failure for ANB-3241-2 Propellant

Figure 31

The three analyses ware programed as an integrated computer routine with a relatively simple format for the data print-out. Two thermal histories for the motor were analyzed: (1) for shock thermal cycling, where the motors are transferred rapidly from a hot (+150°F) to a cold (-65°F) conditioning cell, and vice versa; and (2) for step-wise cooling of the motors where they are exposed sequentially to the following temperatures: +110, +77, +40, 0, -40, -65, and +150°F. The analyses involved five shock thermal cycles (Case 1) and three step-wise thermal cycles (Case 2). A 24-hr period was allowed for equilibration of all temperatures.

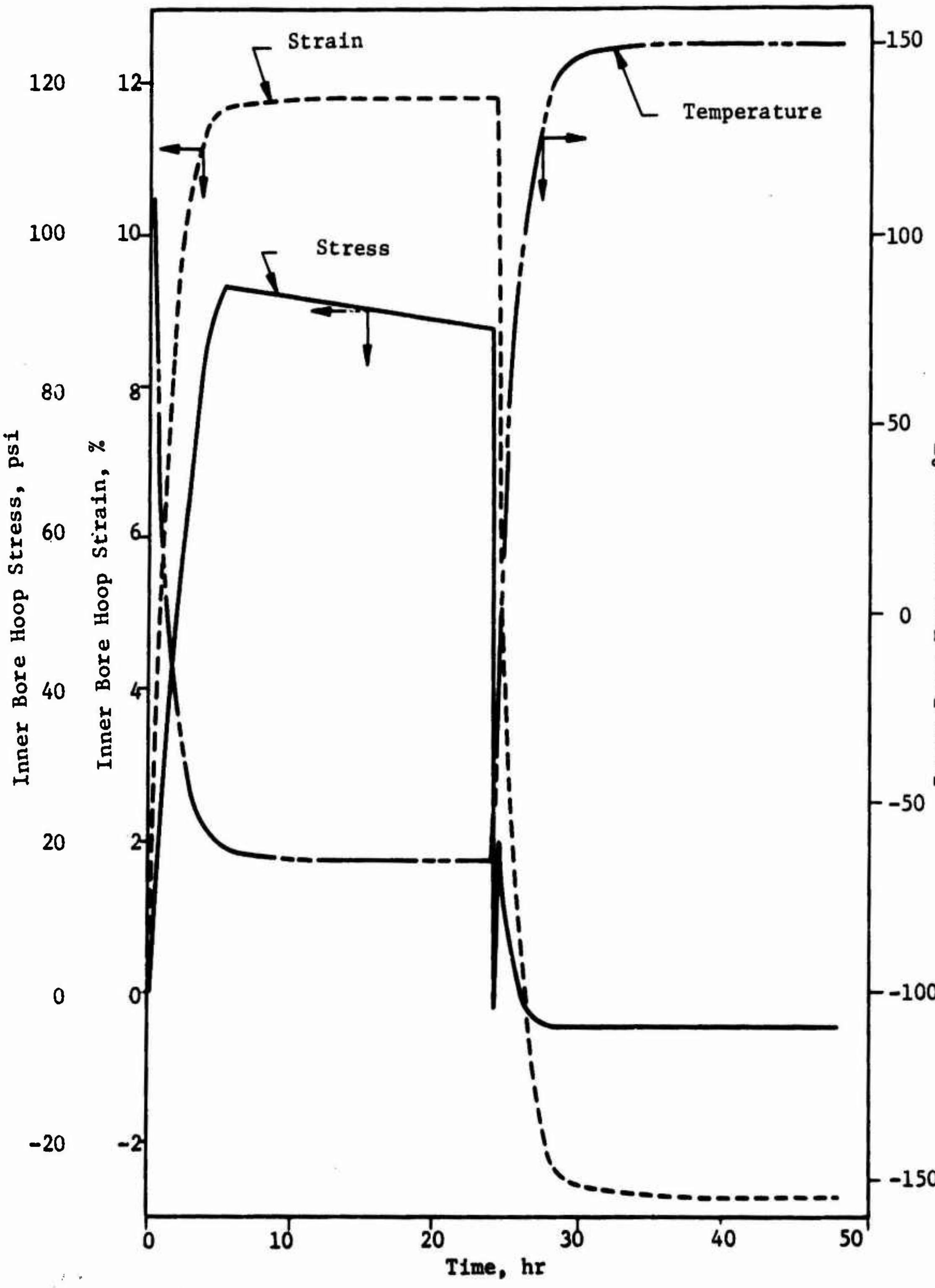
(a) Case 1 - Shock Thermal Cycling

Temperatures and calculated inner-bore hoop stress and strain, for the first thermal cycle are summarized in Figure 32. No significant stress buildup was observed on subsequent cycles. The cumulative damage analysis for the inner-bore is summarized in Figure 33, which shows that after five cycles a significant margin exists.

The damage fraction* at the end of three cycles is 0.082 and at the end of the fifth cycle is 0.144. Extrapolation of the damage calculations indicates that 50% of the motors from these batches would be expected to fail before the 34th cycle. Also, the lower tolerance limit would be exceeded after about 11 or 12 thermal cycles. Thus, the analytical predictions are consistent with full-scale motor cycling tests.

The radial stress-vs-temperature analyses for the propellant-to-liner bond line are given in Figure 34. The corresponding damage analysis is given in Figure 35. The damage fraction (5.46×10^{-4}) after five cycles falls far short of that required to predict bond failures in these motors.

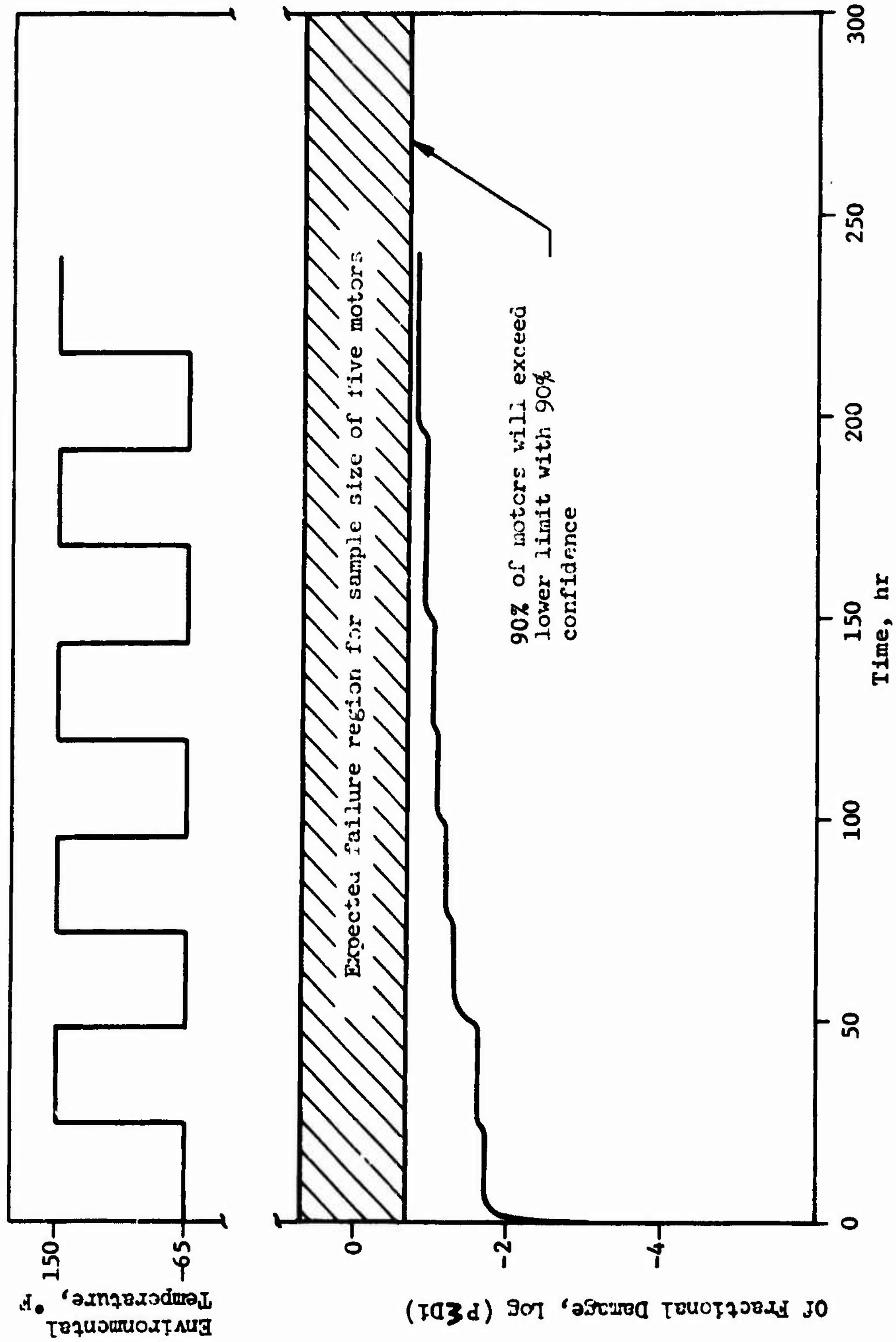
*The percent of damage that has occurred, compared to the estimated nominal amount of damage required to cause failure.



Inner Bore Temperature and Calculated Hoop Stress
and Strain During First Shock Thermal Cycle

Figure 32

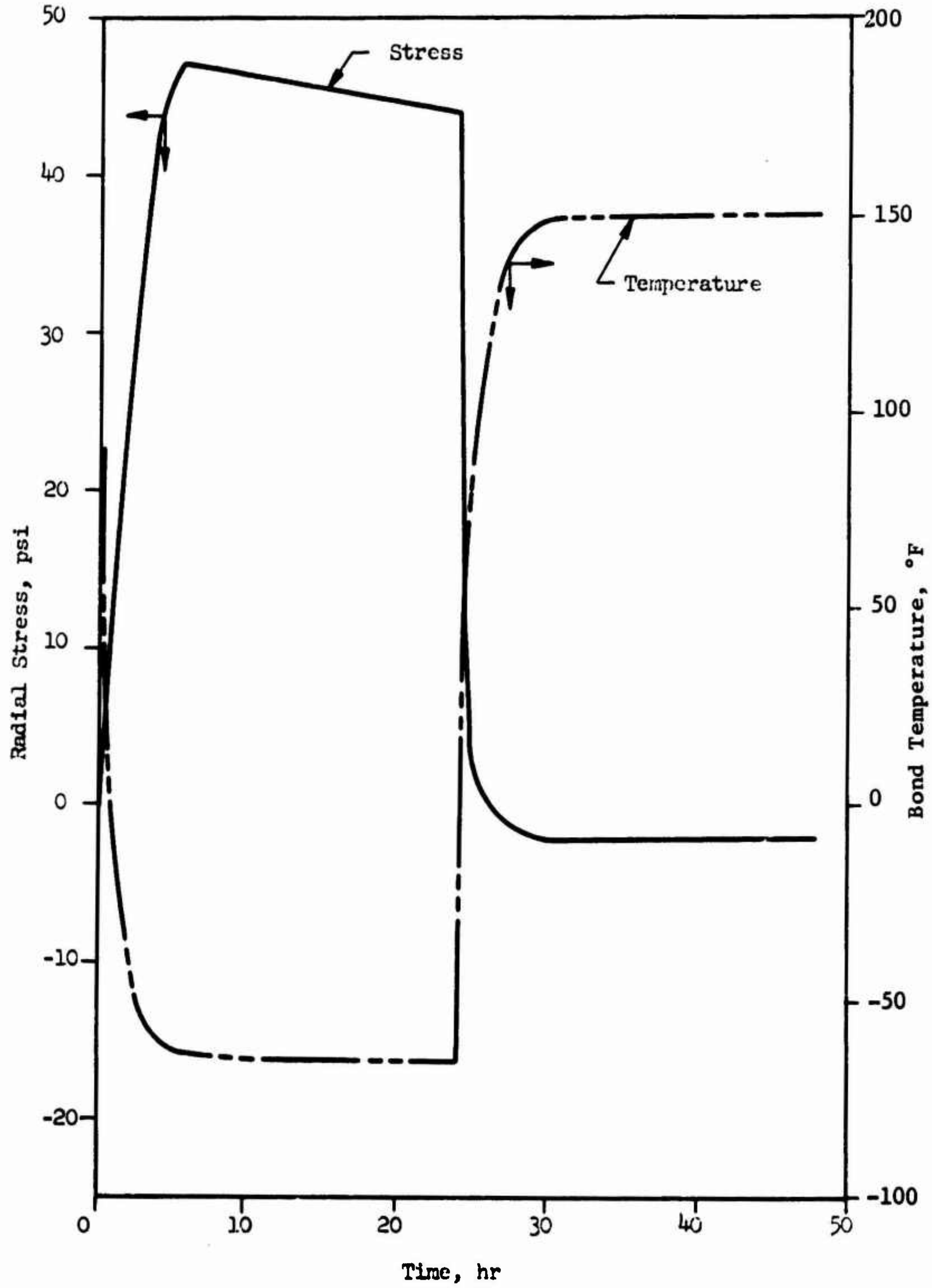
UNCLASSIFIED



Calculated Cumulative Damage at the Inner Bore for Shock Thermal Cycling

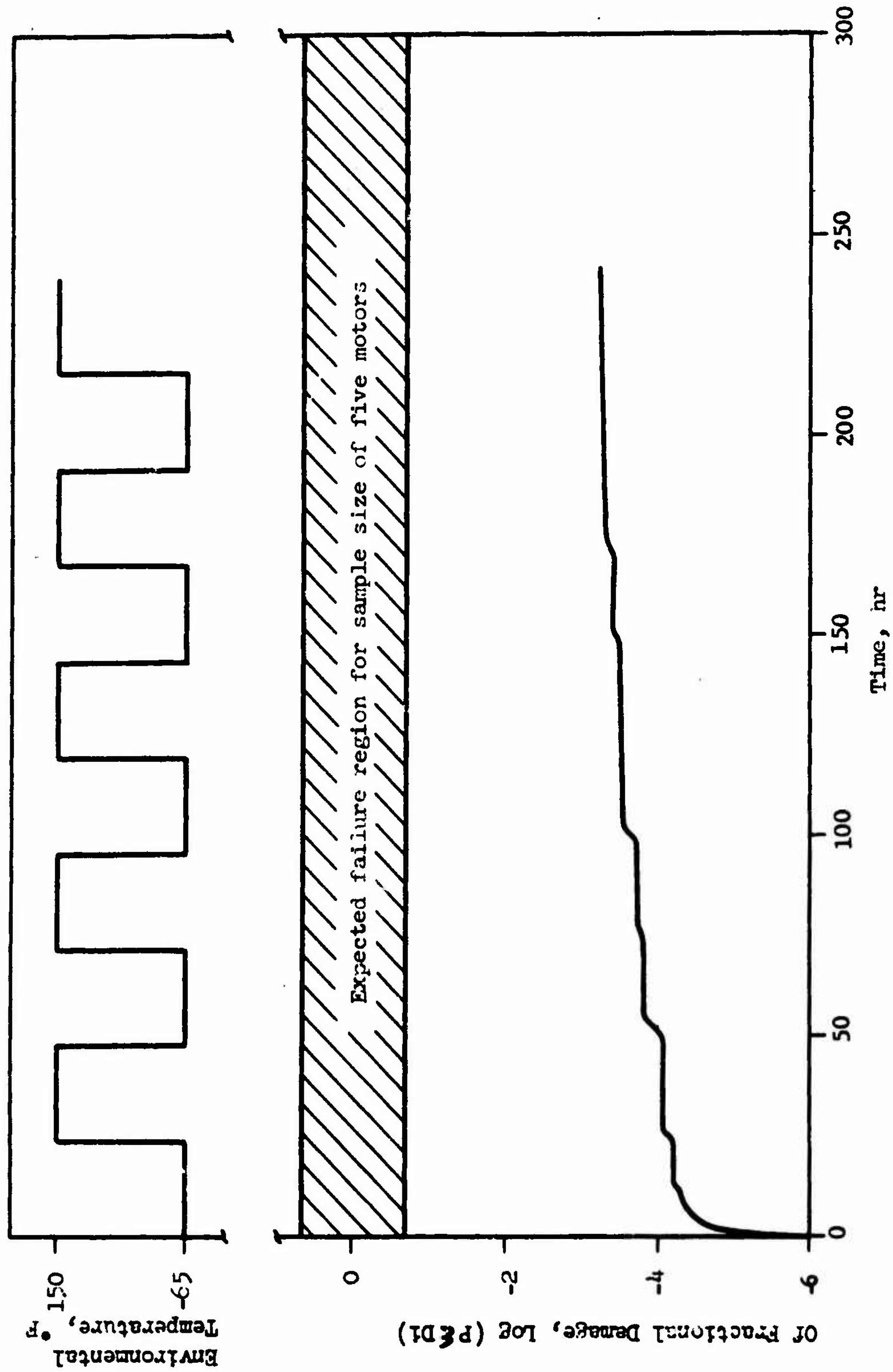
Figure 33

UNCLASSIFIED



Propellant/Liner Bond Temperature and Calculated Radial Stress During First Shock Thermal Cycle

Figure 34



Calculated Cumulative Damage of the Propellant/Liner Bond During Shock Thermal Cycling

Figure 35

(b) Case 2 - Step-Wise Thermal Cycling

The bore temperature and calculated inner-bore hoop stress and strain are summarized in Figure 36. Cumulative damage for the first three cycles is summarized in Figure 37. The total damage fraction at the end of the third cycle is 0.089, which compares with the value of 0.082 predicted for the shock thermal cycling. Therefore, it appears that no significant difference would occur in motor failure behavior for the two thermal cycling histories.

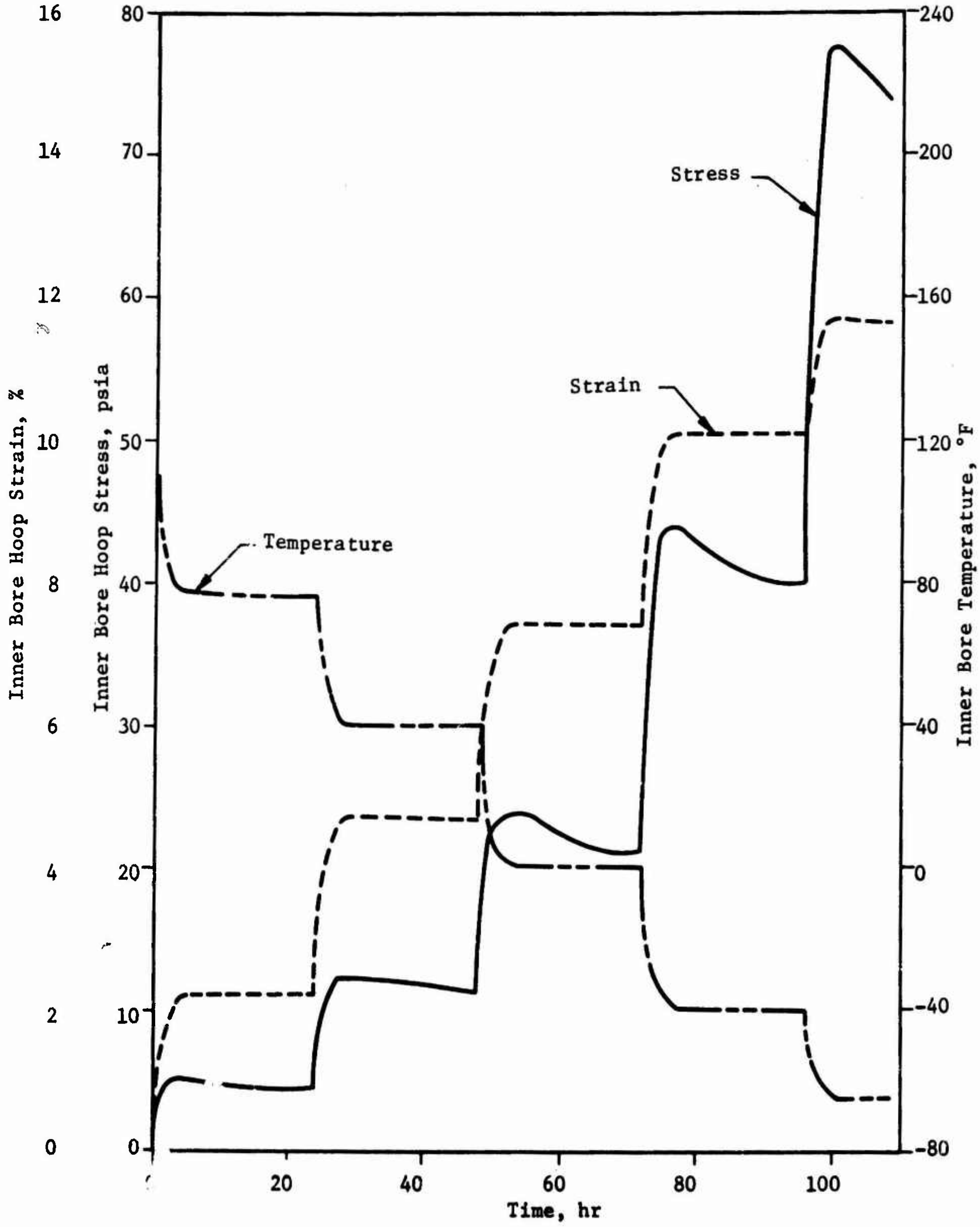
The propellant-to-liner bond radial stress analysis and bond temperature are summarized in Figure 38 while the damage analysis is given in Figure 39. As in Case 1, the damage fraction is negligible at the bond (6.42×10^{-4}) at the end of three thermal cycles.

h. Propellant Storage Tests

In compliance with the Contract Work Statement storage tests were conducted to determine the effects of relative humidity exposure and high temperature on the mechanical properties of ANB-3241-2 propellant.

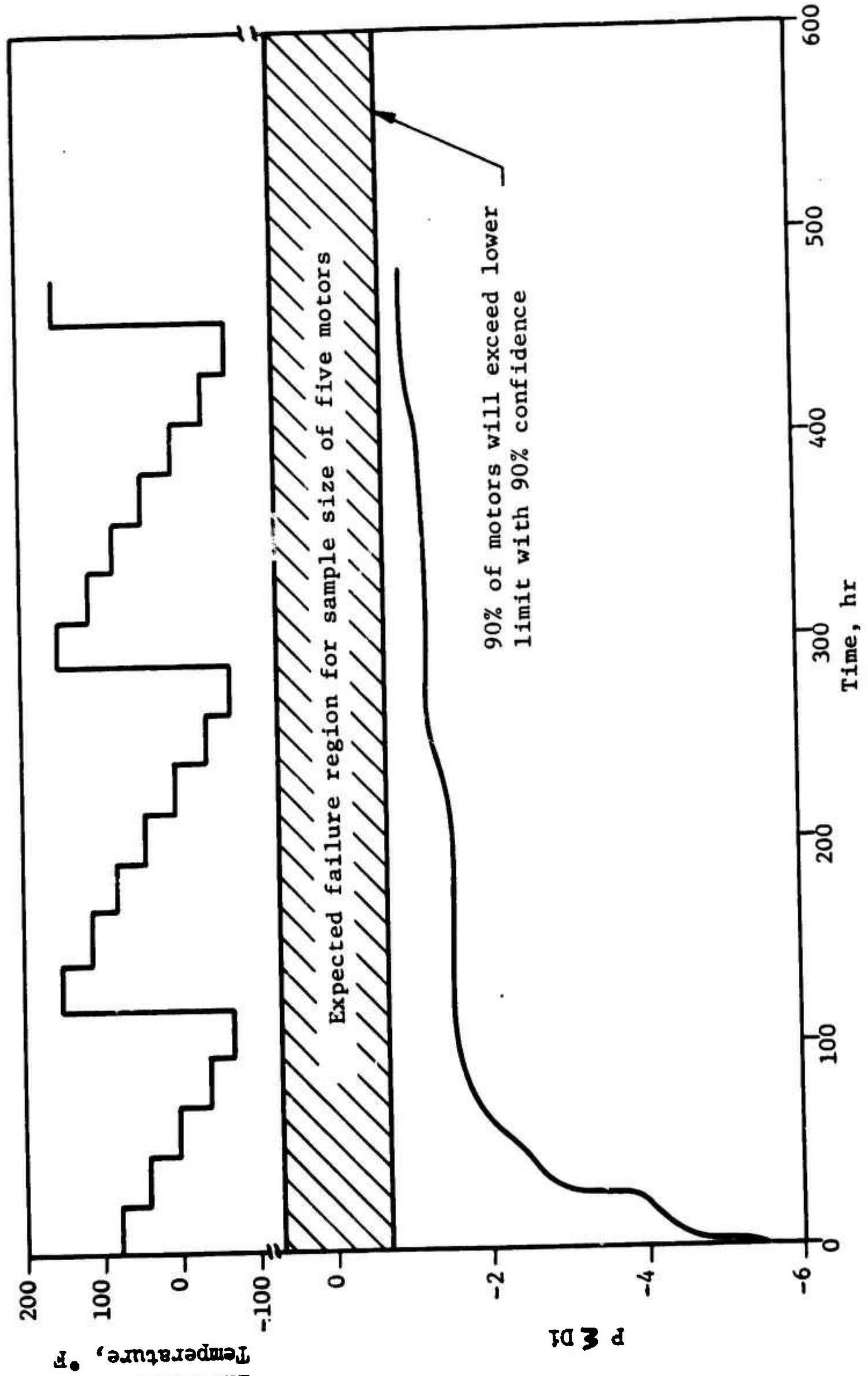
(1) Relative Humidity Storage Tests

The storage tests to determine the effects of long term exposure to various relative humidities on the propellant mechanical properties are not complete at this time. The available test data are shown in Figure 40. Low temperature properties show no change on exposure to 90, 70, 35 and 0 percent relative humidity while the ambient and +150°F test properties show the expected decrease in propellant tensile strength and



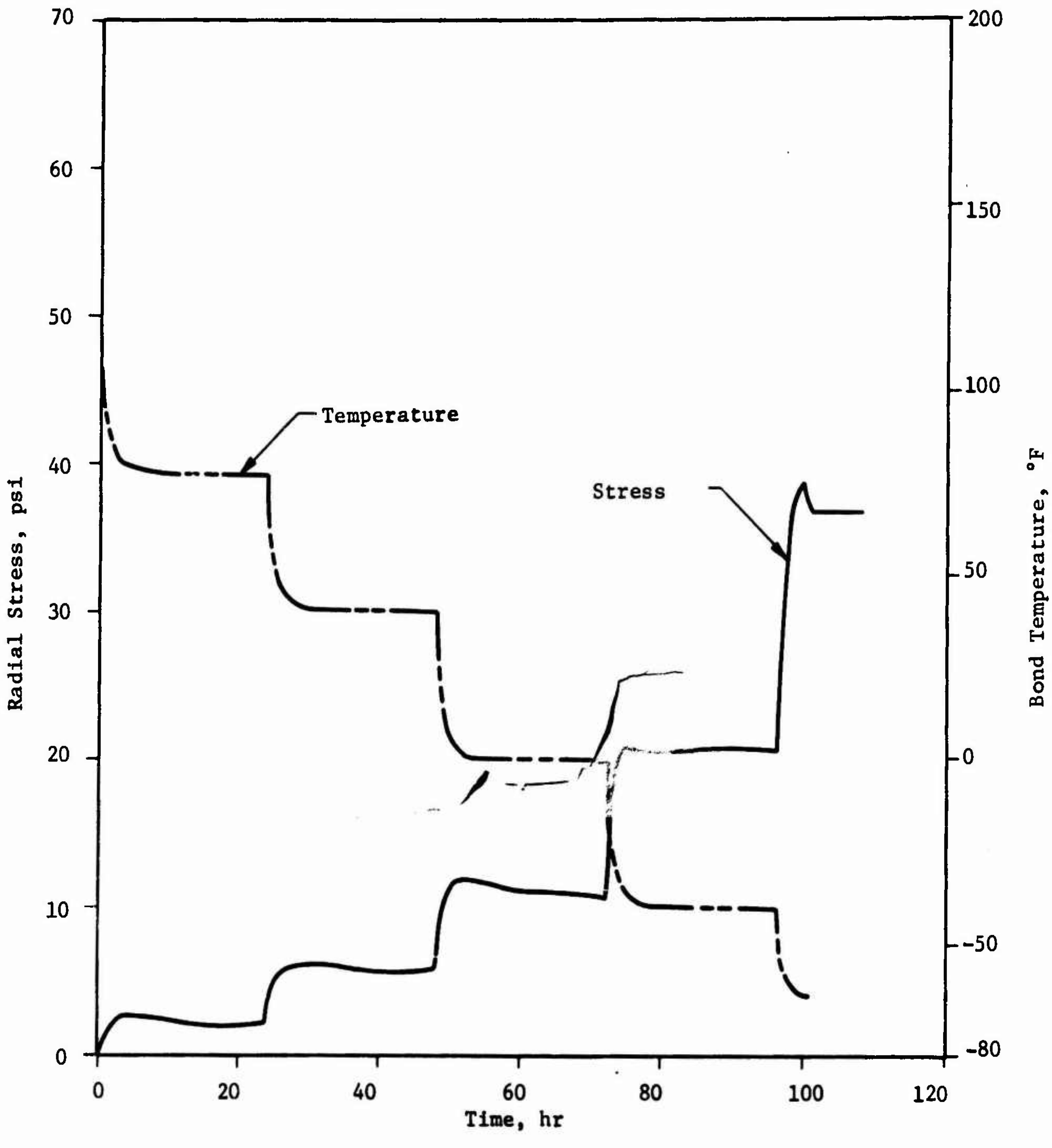
Inner Bore Temperature and Calculated Hoop Stress and Strain During First Step-Wise Thermal Cycle

Figure 36



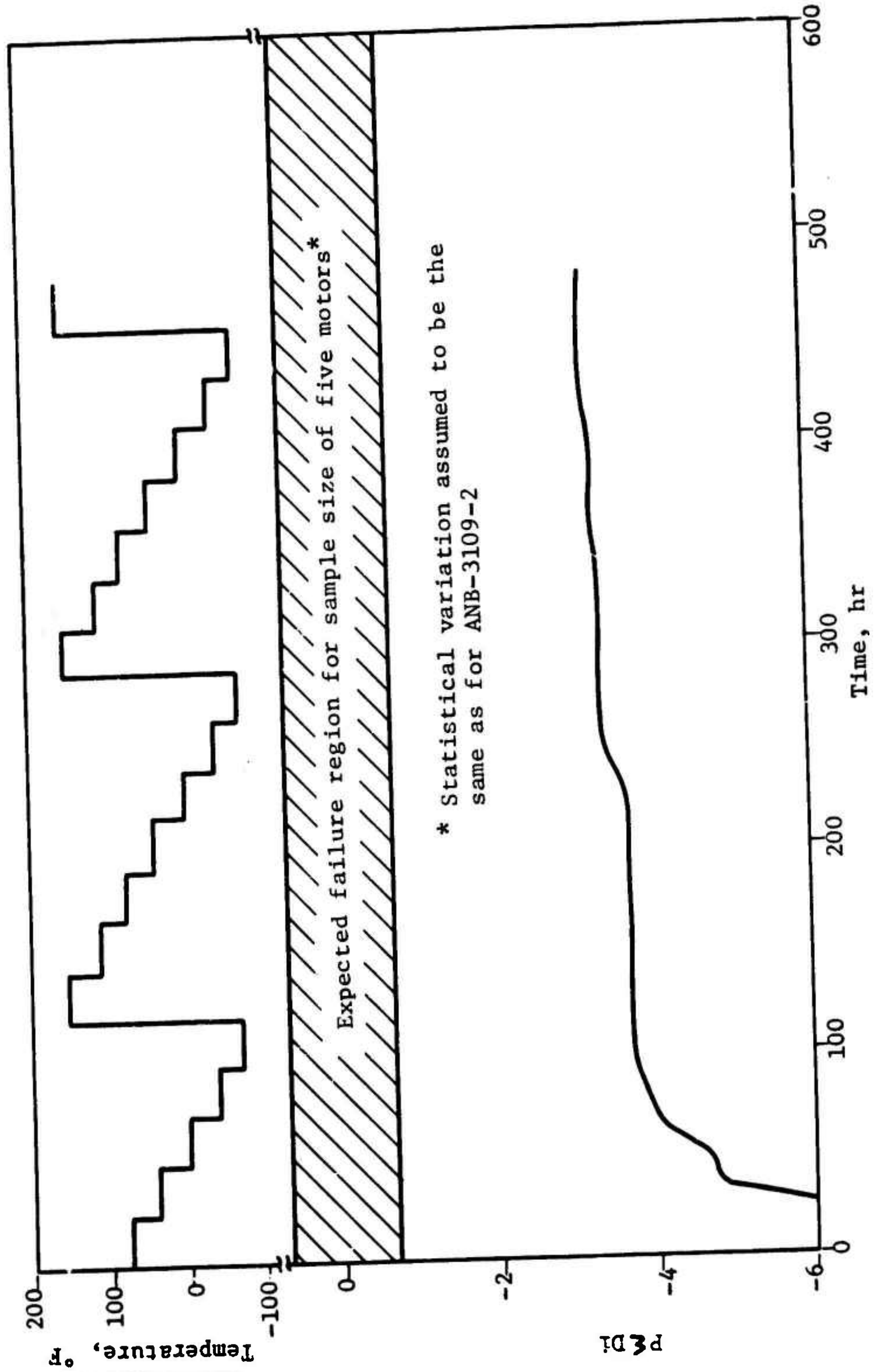
Calculated Cumulative Damage at Inner Bore for Step-Wise Thermal Cycling

Figure 37



Propellant/Liner Bond Temperature and Calculated Radial Stress During First Step-Wise Thermal Cycle

Figure 38



Calculated Cumulative Damage of the Propellant/Liner Bond during Step-Wise Thermal Cycling

Figure 39

Relative Humidity, %	Test Temp, °F	Strain Rate min^{-1}	Ambient Shore "A" Hardness	Mechanical Properties: 0 Storage Time*: σ_m, psi	ε_m, %	ε_b, %	E_o, psi	6 Weeks Storage: σ_m, psi	ε_m, %	ε_b, %	E_o, psi
0	+150	0.0074	35	23	12	16	259				
		0.074	56	27	14	21	307				
		0.74	57	39	13	20	430	41	12	18	533
	77	0.0074	58	34	15	19	382				
		0.074	56	45	14	22	483				
		0.74	55	71	15	22	695	84	16	23	800
	-75	0.0074	56	509	7	8	11,836				
		0.074	57	657	4	4	22,427				
		0.74	55	829	3	3	38,892	793	3	4	31,359
35	+150	0.0074	51	20	15	19	204				
		0.074	51	26	12	16	294				
		0.74	47	36	12	16	416	34	12	18	413
	77	0.0074	48	28	13	17	344				
		0.074	51	36	13	21	407				
		0.74	50	52	13	23	555	55	15	25	562
	-75	0.0074	50	529	6	8	13,310				
		0.074	48	643	4	5	21,029				
		0.74	50	778	3	3	34,263	721	4	4	26,642
70	+150	0.0074	36	13	19	25	149				
		0.074	35	15	13	30	175				
		0.74	36	21	13	27	235	20	12	24	254
	77	0.0074	36	17	14	28	192				
		0.074	37	19	14	30	219				
		0.74	39	32	13	28	380	26	12	29	318
	-75	0.0074	37	501	8	10	10,941				
		0.074	35	625	5	5	18,955				
		0.74	40	757	3	3	31,708	692	4	5	25,222
90	+150	0.0074	14	8	33	39	72				
		0.074	14	9	28	43	87				
		0.74	14	11	20	41	93	12	19	32	109
	77	0.0074	12	10	26	46	96				
		0.074	13	11	20	43	104				
		0.74	15	15	17	45	175	16	16	35	198
	-75	0.0074	17	420	7	11	10,198				
		0.074	15	571	5	5	16,597				
		0.74	15	737	3	3	29,634	659	4	5	22,297

* * 20% constant strain held at all humidities

Effect of Relative Humidity on the Mechanical Properties of ANB-3241-2 Propellant (VBM-1-67-001)

Figure 40

modulus with increasing relative humidity. However, constant strain tests conducted at 77°F indicate the propellant will hold 20% strain (highest strain level tested) at each humidity level tested.

(2) High Temperature Storage Tests

Propellant used to prepare the cast Lot 6 motors (the first cast lot with fully case bonded design) were stored at 200, 180, 160, and 77°F for various lengths of time to assess the shelf life of ANB-3241-2. Test data for these storage temperatures are summarized in Figures 41 through 44. Although some hardening of the propellant was observed at storage temperatures of 200 and 180°F; little change in properties of the propellant resulted from 150 and 77°F storage. These data are consistent with other Aerojet PBAN propellant storage experience.

Propellant-liner bond aging tests are in progress but the initial test intervals have not been reached. The data will be provided when available.

8. Motor Assembly

The overall motor assembly conforms to the envelope and interface requirements outlined in the interface control envelope Drawing 1146155, listed as part of the Improved 2.75-in. drawing package in Figure 2. The nominal overall motor assembly length is 39.34 in. which extends from the forward threaded end of the chamber to the aft end of the fin retainer. The maximum OD of the motor, 2.790 in., occurs at the aft closure; the OD of the chamber is a maximum of 2.750 in. along its entire length. The chamber is a GFM component fabricated from 2014-T6 aluminum alloy. The motor assembly is

Test Temp., °F	Strain Rate, min^{-1}	Storage Time at 77°F, weeks: 0 (Control) σ_m, psi	0 (Control) ϵ_m, %	0 (Control) ϵ_b, %	0 (Control) E_o, psi	12 σ_m, psi	12 ϵ_m, %	12 ϵ_b, %	12 E_o, psi	20 σ_m, psi	20 ϵ_m, %	20 ϵ_b, %	20 E_o, psi
150	0.0074	21	13	17	219					21	10	13	271
	0.074	27	15	19	265					22	12	18	279
	0.74	33	15	24	348	34	13	16	366	32	12	17	382
77	0.0074	29	15	22	288					30	11	18	372
	0.074	38	17	24	351					39	12	17	481
	0.74	56	16	25	527	56	14	21	570	58	13	19	653
-40	0.0074	164	15	24	1922					173	14	22	2217
	0.074	224	14	26	3178					233	14	24	3538
	0.74	342	10	22	6268					336	12	24	6519
-75	0.0074	554	6	8	14,130					485	8	12	11,618
	0.074	682	4	5	25,740					625	4	6	21,859
	0.74	844	3	3	37,538	756	3	3	36,588	784	3	3	35,944

Storage Stability of ANB-3241-2 Propellant at 77°F (Batch 68-46)

Figure 41

Test Temp, °F	Strain Rate, min^{-1}	0 (Control)				4				8				12				16			
		σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	σ_m, psi	ϵ_m, %	ϵ_b, %	E_c, psi	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi	σ_m, psi	ϵ_m, %	ϵ_b, %	E_o, psi
150	0.0074	21	13	17	219													20	9	12	305
	0.074	27	15	19	265													27	8	9	425
	0.74	33	15	24	348	31	10	14	420	29	11	16	399	34	9	13	511	31	10	13	456
77	0.0074	29	15	22	288													30	9	13	450
	0.074	38	17	24	351													38	11	17	542
	0.74	56	16	25	527	51	13	21	546	55	12	19	645	52	12	17	670	50	13	20	608
-40	0.0074	164	15	24	1922													162	14	23	2108
	0.074	224	14	26	3178													191	15	28	2594
	0.74	342	10	22	6268													257	13	27	4674
-75	0.0074	554	6	8	14,130													393	8	13	9008
	0.074	682	4	5	25,740													544	6	10	14,653
	0.74	844	3	3	37,538	946	2	3	57,300	698	3	5	26,460	674	4	4	27,198	751	3	4	31,118

Storage Stability of ANB-3241-2 Propellant at 150°F (Batch 68-46)

Figure 42

Test Temp, °F	Strain Rate, min^{-1}	0 (Control) σ_m, psi	ε_m, %	ε_b, %	E_o, psi	2 σ_m, psi	ε_m, %	ε_b, %	E_o, psi	6 σ_m, psi	ε_m, %	ε_b, %	E_o, psi	11 σ_m, psi	ε_m, %	ε_b, %	E_o, psi	14 σ_m, psi	ε_m, %	ε_b, %	E_o, psi
150	0.0074	21	13	17	219																
	0.074	27	15	19	265																
	0.74	33	15	24	348	29	10	14	408	34	9	13	517	33	8	12	575	35	8	11	629
77	0.0074	29	15	22	288																
	0.074	38	17	24	351																
	0.74	56	16	25	527	47	13	17	572	50	11	17	666	56	10	15	765	60	10	13	822
-40	0.0074	164	15	24	1922													150	15	22	1900
	0.074	224	14	26	3178													226	11	20	4157
	0.74	342	10	22	6268													342	10	19	7753
-75	0.0074	554	6	8	14,130													529	5	7	17,306
	0.074	682	4	5	25,740																
	0.74	844	3	3	37,538	701	3	4	25,201	736	3	4	30,664	825	2	3	41,972	941	2	3	26,521

(Storage Time at 180°F, weeks)

Storage Stability of ANB-3241-2 Propellant at 180°F (Batch 68-46)

Figure 43

Test Temp, °F	Strain Rate, min^{-1}	0 (Control) σ_m, psi	0 (Control) ε_m, %	0 (Control) ε_b, %	0 (Control) E_o, psi	2 σ_m, psi	2 ε_m, %	2 ε_b, %	2 E_o, psi	4 σ_m, psi	4 ε_m, %	4 ε_b, %	4 E_o, psi	6 σ_m, psi	6 ε_m, %	6 ε_b, %	6 E_o, psi
150	0.0074	21	13	17	219												
	0.074	27	15	19	265												
	0.74	33	15	24	348	33	9	12	494	32	9	13	483	38	9	10	590
77	0.0074	29	15	22	288												
	0.074	38	17	24	351												
	0.74	56	16	25	527	47	14	17	546	48	12	19	601	49	12	20	594
-40	0.0074	164	15	24	1922												
	0.074	224	14	26	3178												
	0.74	342	10	22	6268												
-75	0.0074	554	6	8	14,130												
	0.074	682	4	5	25,740												
	0.74	844	3	3	37,538	725	3	3	27,843	933	2	2	45,072	929	2	3	41,577

Storage Time at 200°F, weeks

Storage Stability of ANB-3241-2 Propellant at 200°F (Batch 68-46)

Figure 44

made up of a series of subassmeblies for ease of assembly, storage, and handling. The weight and balance data of the various components are given in Appendix C. These subassemblies are final assembled as described in the following paragraphs.

The piston assembly consists of the GFM piston with a wire lead-through that is sealed with a fused glass bead at the exit points from the piston. Each end of the wire lead-through is crimped to an extension electrical lead. The exposed wire and fused glass bead seals are covered with silicone rubber to prevent electrical shorts. All connections and bare wire are covered with an insulating sleeve. This assembly is incorporated into the aft closure assembly as described in the next paragraph.

The aft-closure assembly has four aerodynamic fins assembled to the aft-closure lugs with solid, corrosion-resistant steel pins. The pins have an interference shrink fit with the fins and a minimal clearance fit with the closure lugs to provide a ± 1/8° maximum angular tolerance conditions to the fin assemblies. After assembly to the closure, the four fins are held in the folded position by a plastic fin retainer, which locks into a slot in the aft end of each fins. The fin retainer also contains the electrical contact disk by which igniter-to-launcher electrical contact is made. The foam weather seals are bonded into the nozzles with Epon 913, and the piston assembly and cross head are installed and retained in the aft closure assembly and the contact disk is then completed by crimping the extended electrical lead to the contact disk and covering the connection with an insulating sleeve.

The igniter assembly is removed from the storage area and bonded to the aft-closure assembly after the grounding clip is installed. Squib wires are connected to the matching ground and contact wires of the grounding clip and piston to complete the igniter-to-launcher circuitry.

II.A. Motor Design and Description (cont)

An electrical continuity check is performed between the aft-closure plate ground and the electrical contact disk at the fin ends. The maximum allowable circuit resistance is 1.35 ohms at ambient temperature. Electrical connections are capable of withstanding a 10-lb pull.

Upon completion of chamber insulation and lining, the propellant is cast at +110°F and the grain core is positioned in the chamber, thus displacing the propellant. The propellant is cured at +110°F for 5 days and then trimmed at the aft end. The motors are X-rayed and prepared for final assembly.

During final motor assembly, the O-ring is lubricated and installed in the aft closure groove, and the area of the joint between the aft-closure insulator and the chamber-grain assembly is potted with 12-gm of IBS-105-4X insulation material. This amount is sufficient to completely fill the void between the aft-closure and the aft-end of the grain, thereby providing additional protection to the aft-end of the chamber wall. The aft-closure assembly with the igniter in place is positioned within the motor chamber such that the lockwire grooves are aligned. During this operation, the aft end of the cured IBS-105-4X chamber insulation is compressed by the interference fit at the interface with the closure, thus providing an additional protective seal for the aft joint.

The lockwire is lubricated with silicone lubricant, and the hook end of the lockwire is inserted through the elongated hole in the motor chamber and into the hole of the lockwire groove of the closure. The aft-closure assembly is rotated clockwise until the raised notched end of the lockwire snaps into the elongated hole in the chamber. An electrical shorting clip is installed between the contact disk of the fin retainer and a groove in the nozzle closure. The motor is then placed in an oven to cure the IBS-105-4X insulation used for potting.

II.A. Motor Design and Description (cont)

A 2.0 in.-wide circumferential band of brown lacquer is applied 3.0 in. aft of the forward end of the chamber to designate the proper ammunition color coding.

A stencil is applied designating motor part number, code identification, contract number, manufacture date, lot number, firing and storage temperature range and warranty date. A stencil is applied with black ink near the front end with the following designation: "Torque head to 55 to 65 ft/lb."

9. Government-Furnished Material (GFM)

The listing of GFM items is given below, followed by appropriate Aerojet design recommendations to improve performance and/or manufacturability of selected items.

	Component Description	Part No.
1.	Lockwire	1146924-1 or 1146898-1
2.	O-ring	1127114
3.	Shunt Wire	1146336-1
4.	Squib, Mk I, Mod 1	656714
5.	Cross Head	456909
6.	Contact Disk	1253129
7.	Fin Retainer	1253131
8.	O-ring	650950
9.	O-ring	650953
10.	Nut	MS 20365-1032
11.	Pin, Straight	1146056-1
12.	Fin Blade	1146210-1
13.	Plate, Nozzle	1146916-1
14.	Piston Assy	1146721-1
15.	Motor Tube	1569403

Our understanding of the configuration, present status of the component, and definition of changes to the above GFM items for compatibility with the Aerojet Improved 2.75-in. motor are discussed in the following paragraphs for the selected items.

Item 1. To meet the requirements for dispersion, it is necessary to spin the rocket. The spin imparted by the fins is transmitted to the rocket through the closure and step-latch design of the lockwire. The current GFM lockwire requires modification to ensure positive retention under these spin-imposed loads, and will be reworked for the current contract to incorporate a reformed shape. This modification is also adaptable to the standard current round where its use would provide additional flight safety.

Item 3. The samples of GFM shunt wire that were received at Aerojet on several furnished closure assemblies were designed to anchor into the end of the fin-attach roll pin. The recommended Aerojet-revised design requires a solid steel pin in order to restrict the fin misalignment to $\pm$ 1/8 of a degree; therefore, a modification was made to the shunt wire to provide a spring-tight fit around the aft closure detent groove.

Item 4. The Mk 1 Mod 1 squib meets the specified firing current of 0.5 amp per round and maintains commonality with the present unit. However, to achieve the required high altitude capability, it is necessary to use a pyrotechnic booster charge in conjunction with the squib.

Item 11. The GFM pin was a hollow roll-pin. The new fin-pin design requires very tight tolerances in both the fin and aft-closure mounting lugs. This product improvement design is the result of the request for a $\pm$ 1/8° fin tolerance during assembly to the aft closure.

Item 12. The current-round fin-blade was modified to provide a 0.11° cant angle to the fins to impart a rotation of less than 7-1/2 rps to the rocket during flight to achieve improved stability and accuracy. The cant angle is slight enough to allow use of the current fin forgings by machining the same width hub at an angle, and drilling a new hole at a right angle to the hub face.

Item 13. Only the interior portion of the aft closure shall require any major modification from the current round. The exterior retains the same lockwire, O-ring groove, closure length, and bearing ring OD with only a small diameter and radius change to the detect retention groove. Spacing is unchanged at the aft-face fin-pin location and fin tab. Other small tool cutter radii and tolerance changes to make up the deviations from the GFM machined part. The interior retains the piston bore, four holed, and the same closure wall thickness; only the cavity, piston sleeves OD, hole size, and location are changed.

Item 15. Although the GFM motor case (1569403) is unchanged for the Improved 2.75-in. motor, minor within-tolerance variations occur from one fabricator to another. These variations vary the motor weight and propellant loading capability. In addition, the current chamber lockwire groove tolerances can allow less than 1.5 factor on yield under the worst-on-worst tolerance buildup.

B. STABILITY AND CONTROL

An investigation was conducted to determine the optimum configuration for the Improved 2.75 FFAR from the standpoint of simultaneously achieving a one-standard-deviation dispersion less than 9.5 mils, minimal probability of pit-roll resonance, minimum change in existing tooling, and no alteration of existing launchers. This optimum configuration is identical to the present 2.75 FFAR in external configuration, except for the addition of a 0.11° differential fin cant.

A complete description of the analytical and test results of this investigation is presented in Appendix A.

C. DEVELOPMENT TEST RESULTS

1. Igniter Tests

The purpose of the 2.75-in. ignition testing program was to develop an igniter that would function reliably from sea level to 50,000 ft altitude over the temperature range of -65 to 150°F. In addition, the igniter must be simple to manufacture and reliable. Accordingly, igniter testing was conducted with a variety of charge weights, squib-to-pellet initiators, and charge containers. The Mark I squib, used in the current 2.75-in. motor, was used as the primary initiator in all tests.

a. Main Charge

During initial testing early in the program, the main charges were varied from 7 to 9 gm of Type 2D BPN pellets. Based on arc-image furnace propellant ignitability test results, together with results from the ignition simulation test chamber firings, a main charge of 7 gm of Type 2D BPN pellets was selected to provide reliable and reproducible ignition over the specified pressure and temperature ranges.

b. Pyrotechnic Container

This phase of igniter testing was devoted to igniter container development. Several container materials were evaluated, including cellulose-acetate-butyrate, Kraft paper, aluminum foil, and commercial aluminum tubing. Five tests were conducted using containers of hand-fabricated Kraft paper, five with containers of hand-fabricated aluminum foil, six with cellulose-acetate-butyrate commercially formed tubes, and 41 with commercially-fabricated aluminum tubes. It was found early in the testing program that the commerical aluminum tubing (0.61 in. ID; 0.007 in. wall thickness; 2.35 in long) provided consistently reproducible igniter performance as compared to the other materials and fabrication techniques. For this reason, as well as for its capability to provide ease of igniter manufacture and quality control, the aluminum tube was selected as the main charge container.

c. Igniter Test Firings

The first 18 ignition tests were conducted with the 7-gm main charge and the Mark I squib all housed in the aluminum containers. The tests were made in the ignition simulation chamber over the temperature range of -65 to 150°F and at one atmosphere pressure. Test results showed an average peak pressure of 222 psi and an average time-to-peak pressure of 0.022 sec. Both the average peak pressure and the time-to-peak pressure was considered normal. However, when an additional five tests were conducted at +75°F under simulated altitude conditions of 50,000 feet, extended times-to-peak pressure and complete hangfires were observed. These results indicated that the Mark I squib is not adequate to initiate the main pellet charge at altitude. Accordingly, it was decided to add a booster charge between the squib and main charge to aid in obtaining satisfactory igniter operation at altitude.

II.C. Development Test Results (cont)

Nine additional igniter tests were conducted in the ignition simulation test chamber at a simulated 50,000-ft altitude, with a booster charge of 0.5 gm of BPN powder (IP-10 granulation or particle size). Three tests each were conducted at -65, +75, and +150°F. In these nine tests, the igniters exhibited peak pressures and times-to-peak pressures that closely approximated the satisfactory performance previously obtained at one atmosphere.

To optimize the granulation size and weight of the BPN booster charge, an additional seven altitude tests were conducted in the ignition simulation chamber. All igniters had the 7-gm BPN pellet main charge, Mark I squib, and aluminum container; only the booster charge was varied in weight and particle size. One igniter contained 0.1 gm of IP-10 granulation, three igniters had 0.2 gm of the same powder, and three igniters had 0.2 gm of 2C granules. Based on test results, it is evident that the granulation of the BPN initiator powder (IP-10 vs 2C) has no effect on performance. Further, at -65°F, a booster charge of 0.1 gm is unacceptable, and a charge of 0.2 gm is marginal.

Nine additional tests were conducted with a 0.3-gm charge at a simulated altitude of 50,000 ft, three each at -65, +70, and +150°F. The results of these tests, when compared with the tests using 0.1, 0.2, and 0.5-gm booster charges, indicate that the 0.3-gm booster charge yields the shortest ignition delay over the temperature range and at altitude and is compatible with the requirement of no significant increase in test chamber pressurization.

A summary of the design, test conditions, and results of all ignition tests conducted are presented in Figure 45. Statistical data are given in Figure 46 for tests with a 7-gm charge in a commercial aluminum charge container, for sea level tests with no booster charge, and for altitude tests with 0.3 and 0.5-gm booster charges. Since obviously poor performance was obtained with 0.1 and 0.2-gm booster charges, no further data reduction from these tests was justified.

	No. of Tests	Avg. Pressure and standard Dev. at -65°F, psia	Avg. Pressure and standard Dev. at +70°F, psia	Avg. Pressure and standard Dev. at +150°F, psia	Avg. Time to Peak Pressure & Standard Dev. at -65°F, msecs	Avg. Time to Peak Pressure & Standard Dev. at +70°F, msecs	Avg. Time to Peak Pressure & Standard Dev. at +150°F, msecs
Sea level firings, No booster charge	14	232 - 16.5	232 - 23.1	233 - 31.4	25.2 - 3.86	20.0 - 0	21.6 - 5.2
Altitude (50,000 ft) firings, 0.3 gm BPN booster charge	11	220 - 18.7	253 - 21	253 - 32.6	26.3 - 5.92	21 - 4.95	13.3 - 3.42
Altitude (50,000 ft) firings, 0.5 gm BPN booster charge	9	219 - 12.7	225 - 16.8	360 - 18.5	20.3 - 1.2	15.2 - 1.93	12.2 - 2.22

Average Values of Pressure and Time-to-Peak Pressure
(Commercial aluminum tube and 7 gm
Type 2D-BPN pellet main charge)

Figure 45

Run Number and Date Fired	Conditioning Temp, °F	Amb Pressure, mmHg	Squib Delay Time, msec	Time-to-Peak Press, msec	Function Time, msec	Peak Pressure, psia	BPN-Powder Initiation Charge Wt, gm	BPN-2D Charge Wt, gm	Remarks
3460A 12/1/67	+70	760	3	23	82.5	393	0.5-1P-10	9.0	Initiator in soda straw. Cellulose acetate butyrate chamber, tube.
3464 12/4/67	+70		3	23	87	290	none		#850 Mylar over tape over end of CAB tube.
3465 12/4/67	+70		2	28	95	240			#850 Mylar over tape over end of CAB tube.
3467 12/5/67	-65		3	22	84	201		9.0	#850 Mylar over tape over end of CAB tube.
3492 12/13/67	+70		2	26	80	283		7.0	Kraft paper tube, one wrap.
3493 12/13/67	+70		2	26	79	239			Kraft paper tube, one wrap.
3495 12/14/67	-65		2	26	76	225			Kraft paper tube, one wrap.
3501 12/15/67	+150		2	33	83	172			Kraft paper tube, one wrap.
3503 12/18/67	-65		3.5	34	83	140			Kraft paper tube, one wrap.
3543 1/11/68	+70		2	23	76	184			Kraft paper tube, two wraps.
3490 12/12/67	+70		2	24	83	323			Aluminum foil, one wrap, 0.001-in. thick.
3494 12/13/67	-65		2	28	79	229			Aluminum foil, one wrap, 0.001-in. thick.
3502 12/18/67	+150		12	27	79	169			Aluminum foil, one wrap, 0.001-in. thick.
3506 12/20/27	-65		3.5	31	83	122		7.0	Aluminum foil, one wrap, 0.001-in. thick.
3473 12/6/67	+70		2	33	84	251		9.0	Seamless Al tube, 0.007-in. wall.
3476 12/6/67	-65			22.5	78	194		9.0	Seamless Al tube, 0.007-in. wall.
3485 12/11/67	-65			20	80	364		8.0	Seamless Al tube, 0.007-in. wall.
3486 12/11/67	+70			20	80	256		7.0	Seamless Al tube, 0.007-in. wall.
3496 12/14/67	-65			25	80	249			Seamless Al tube, 0.007-in. wall.
3497 12/14/67	+70			20	73.5	212			Seamlesa Al tube, 0.007-in. wall.
3491 12/14/67	+150			25	72	231			Seamless Al tube, 0.007-in. wall.
3504 12/19/67	+70			20	66	227			Seamless Al tube, 0.007-in. wall.
3505 12/19/67	-65			22	76	237			Seamless Al tube, 0.007-in. wall.
3528 1/3/68	+70		2	19	69	264			Seamless Al tube, 0.007-in. wall, 4 gm CPR 2036foam over pellets.
3529 1/3/68	+70		40	51	110	164			Seamless Al tube, 0.007-in. wall, 4 gm CPR 2036 foam over pellets.
3531 1/5/68	+70		2	21.5	69	246			Seamless Al tube, 0.007-in. wall, 4 gm CPR 2036 foam over pellets.
3534 1/8/68	+70		2	30	87	230			Seamless Al tube, 0.007-in. wall. Interstices filled with 8 ml CAB-o-Sil.
3593 2/29/68	-65		3	24	78	261			Seamless Al tube, 0.007-in. wall.
3598 3/1/68	-65		1	30	82	180			Seamless Al tube, 0.007-in. wall.
3605 3/4/68	+150	760	1	19	66	253			Seamless Al tube, 0.007-in. wall.
3608 3/7/68	+70	84	2	35	80	185	none	7.0	Seamless Al tube, 0.007-in. wall.

Summary of Igniter Development Tests

Figure 46, Sheet 1 of 2

Run Number and Date Fired	Conditioning Temp, °F	Amb. Pressure, mmHg	Squib Delay Time, msec	Time-to-Peak Press, msec	Function Time, msec	Peak Pressure, psia	BPN-Powder Initiation Charge Wt, gm	BPN-2D Charge Wt, gm	Remarks
3611 3/7/68		88	1	32	77	184	none	7.0	Seamless Al tube, 0.007-in. wall.
3612 3/8/68		87	1	400	78	137			Seamless Al tube, 0.007-in. wall
3613 3/8/68		88	1	-	-	-			Hang fire.
3614 3/11/68		87	1	32	90	211			Hang fire.
3615 3/11/68		87	1	-	-	-	none		Hang fire.
3617 3/12/68		87	1	15	76	244	0.5 IP-10		Seamless Al tube.
3618 3/12/68		88	2	16	80	208			
3619 3/12/68	+70		1	13	87	229			
3620 3/12/68	-65		1	20	82	229			
3621 3/13/68	-65		19	20	83	201			
3622 3/13/68	-65		1	21	83	227			
3632 3/20/68	+150		2	13	73	360			
3633 3/20/68	+150		1	11	66	366			
3634 3/20/68	+150		1	10	69	375	0.5 IP-10		
3636 3/21/68	+70		1	31	78	360	0.1 IP-10		
3637 3/22/68	+150		1	15	82	247	0.5 IP-10		
3638 3/25/68	+70		1	17	64	226	0.5 IP-10		
3659 3/29/68	+70		1	15	66	291	0.2 IP-10		
3663 4/1/68	+150		2	17	70	311	0.2 IP-10		
3664 4/2/68	+150		1	13	71	294	0.2-2C granules		
3665 4/3/68	+150		1	15	71	276	0.2-2C granules		
3667 4/4/68	-65		1	510	86	96	0.2-2C granules		
3671 4/5/68			1	33	86	167	0.2 IP-10		
3673 4/8/68			1	24	79	208			
3676 4/11/68			1	28	87	266			
3678 4/11/68			1	25	75	268	0.2 IP-10		
3681 4/17/68	-65		1	20	78	229	0.3 IP-10		
3682 4/18/68	+150		6	9	66	291			
3683 4/19/68	+150		1	17	50	251			
3685 4/19/68	+70		1	14	69	281			
3686 4/19/68	+70		1	25	87	221			
3686A 4/19/68	+70		1	24	81	256			
3687 4/22/68	-65		2	34	86	236			
3689 4/22/68	+150		1	14	75	218			
3690 4/23/68	-65	88	1	25	85	196	0.3 IP-10	7.0	Seamless Al tube.

Summary of Igniter Development Tests

Figure 46, Sheet 2 of 2

II.C. Development Test Results (cont)

2. Motor Component Tests (Phase I)

Motor component tests were those used to verify component performance without regard to the specific test requirements of Exhibit A to the contract. A total of 16 such tests were made. Ballistic data, test objectives, and results are summarized in Figure 47.

The first four component tests (CT-1 through -4) were made with the chamber and grain assembly in Figure 48 to evaluate grain ballistics and insulation performance. The four-slot grain configuration was adopted in lieu of the two-slot proposal grain design for easier processing and lower cost. The initial burning surface of the four-slot configuration was the same as the two-slot proposal configuration and was achieved by shortening the length of the slots from 14.8 in. to 9.0 in. The grain support system is also shown in Figure 48.

The first two tests were conducted with a single-nozzle heavyweight test aft closure to expedite early start of the development program. The third and fourth motors incorporated the proposed aft closure with four canted nozzles as shown in Figure 49 as Configuration A. In these four firings, a bag-type igniter installed in the forward end was used to expedite testing.

Based on results from these four firings, the chamber and grain assembly was modified to incorporate a heavy bead of insulation at the grain/aft-closure interface to protect the chamber sidewall at that point, and the four-slot grain configuration in Figure 48 was replaced by a simple tube grain design (ID and aft-end burning) because throat erosion data showed that the inherent progressivity of the tube design was offset by the increase in nozzle throat area during motor operation. Use of the tube grain design

Test No.	Chamber S/N	Date Fired	Firing Temp, °F	Action Time Total Impulse, lbf-sec	Burn Time Total Impulse, lbf-sec	Specific Impulse lbf-sec/lbm	Max Thrust, lbf	Max Ignition Thrust, lbf	Avg Thrust, lbf
CT-1	2-004	10-5-67	+70	N/A	N/A	N/A	N/A	N/A	N/A
CT-2	2-001	10-9-67	+70	N/A	N/A	N/A	N/A	N/A	N/A
CT-3	2-002	10-12-67	+70	N/A	N/A	N/A	N/A	N/A	N/A
CT-4	2-005	10-18-67	+70	N/A	N/A	N/A	N/A	N/A	N/A
CT-5	2-003	10-18-67	+70	N/A	N/A	N/A	N/A	N/A	N/A
CT-6	2324	12-21-67	-65	N/A	N/A	N/A	N/A	510	N/A
CT-7	2302	1-22-68	+70	N/A	N/A	N/A	N/A	540	N/A
CT-8	2306	1-22-68	+70	N/A	N/A	N/A	N/A	645	N/A
CT-9	2301	1-27-68	+150	N/A	N/A	N/A	N/A	735	N/A
CT-10	2322	1-30-68	+150	N/A	N/A	N/A	N/A	694	N/A
CT-11	2406	4-30-68	+150	1913	1519	240.6	892	712	684
CT-12	2722	5-20-63	+150	1871	1572	-	868	684	680
CT-13	2713	5-24-68	-65	N/A	N/A	N/A	687	425	N/A
CT-14	2711	6-10-68	+150	1897	1619	237.5	904	517	672
CT-15	2712	7-19-68	+70	1915	1547	239.5	908	581	665
CT-16	2703	7-19-68	+150	1925	1578	241.2	958	618	717

2.75-in. FFAR CT Ballistic Data Summary (u)

Figure 47, Sheet 1 of 3

Test No.	Max Chamber Pressure, psig	Max Ignition Pressure, psig	Avg Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Propellant Burn Rate, in./sec	Remarks
CT-1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Test objectives: evaluate grain ballistics and insulation performance; single nozzle test aft closure; at 0.15 sec chamber burnthrough at grain/aft closure interface.
CT-2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Test objectives: evaluate grain ballistics and insulation performance; grain/aft-closure interface protected by a heavy bond of IBS-105-4 insulation; pressure taps eroded away; grain/aft-closure interface intact.
CT-3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Test objectives: evaluate grain ballistics and proposed aft-closure with four threaded canted nozzles; aft closure areas at pressure tap and center piston eroded away.
CT-4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Test objectives: evaluate tube grain ballistics and insulation performance; four slots filled with potting material resulting in a tube grain; pressure tap eliminated; carbon phenolic insulator cap over piston; aft-closure insulator intact; all four exit cone insulators ejected. Based on these tests, this chamber-grain assembly was used to start development tests; aft closure was also modified to include additional insulation and exit cone insulator changes to ensure retention; this aft closure design used to start development tests.
CT-6	N/A	1236	N/A	N/A	N/A	0.052	0.033	N/A	Test objectives: demonstrate inadequacy of fore end insulation as cause of burnthrough in development Tests II-08 and -19; chamber burnthrough occurred like Test II-08 and -09 (at aft edge of forward insulator); forward insulator lengthened to provide increased coverage along chamber sidewall.
CT-7	1420	1373	N/A	N/A	N/A	0.038	0.034	N/A	Test objectives: evaluate performance of flatted exit cones fabricated from carbon phenolic; exit cones eroded away; design discarded.
CT-8	1680	1810	N/A	N/A	N/A	0.051	0.022	N/A	Test objectives: evaluate performance of integrally molded aft-closure; molding material was MXC-313 carbon phenolic; all exit cones and three ATJ inserts ejected due to insert thermal expansion causing cracking at junction of inserts and exit cones; 40 mil expansion gap incorporated as solution
CT-9	1580	1680	N/A	N/A	N/A	0.053	0.010	N/A	Test objectives: evaluate integrally molded aft closure with silica phenolic as insulation material; 40 mil expansion gap for ATJ throat inserts; closure burnthrough at expansion gap.
CT-10	1545	1804	N/A	N/A	N/A	0.040	0.024	N/A	Test objectives: evaluate integrally molded aft closure with silica phenolic as insulation material; 40 mil expansion gap filled with potting material; closure burnthrough at expansion gap.

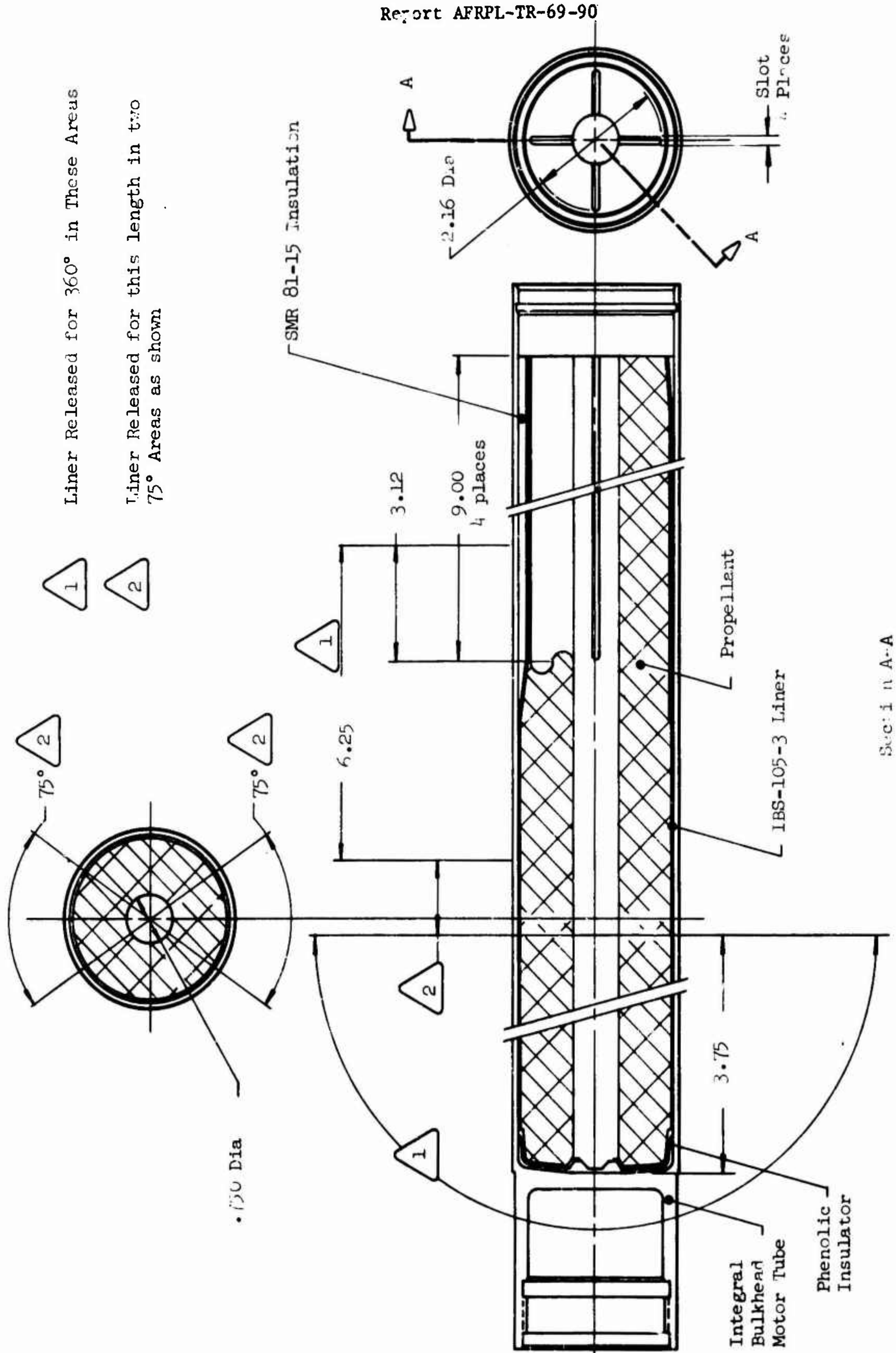
2.75-in. FFAR CT Ballistic Data Summary (u)

Figure 47, Sheet 2 of 3

Test No.	Max Chamber Pressure, psig	Max Ignition Pressure, psig	Avg Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Propellant Burn Rate, in./sec	Remarks
CT-11	1748	2135	1360	2.80	2.00	0.005	0.040	0.449	Test objectives: (1) Demonstrate chamber-grain integrity after temperature cycling from -65 to +150°F; (2) Evaluate Carb-I-Tex 700 as throat insert material at +150°F; firing successful; inserts intact; throat erosion acceptable.
CT-12	1762	2000	1314	2.75	2.10	0.004	0.038	N/A	Test objectives: (1) Demonstrate chamber-grain integrity after temperature conditioning at +150°F; (2) Evaluate Carb-I-Tex 700 throat insert material at +150°F; fin actuation piston (GFM, swaged) failed during firing allowing external erosion of the exit cones.
CT-13	[illegible]	1304	N/A	2.71	1.71	0.021	0.029	N/A	Test objectives: (1) Evaluate Durez as an alternate net molding material at -65°F; (2) Evaluate Carb-I-Tex 700 throat insert material at -65°F; one Durez exit cone failed, thereby causing one throat insert to eject.
CT-14	[illegible]	1575	1349	2.82	2.19	0.007	0.020	0.410	Test objectives: (1) Evaluate MXC-313 aft-closure insulation cured for 30 min instead of 60 min; post-fire condition similar to 60-min-cure insulation; (2) Evaluate Carb-I-Tex 700 throat inserts at +150°F; firing successful; all hardware remained intact; throat erosion acceptable.
CT-15	1675	1692	1344	2.86	2.24	0.004	0.007	0.400	Test objectives: (1) Evaluate MXC-313 aft-closure insulation cured for 30 min. instead of 60 min; post-fire condition similar to 60-min-cure insulation; (2) Check out PFRT test procedures, test facility, and digital data recording, and computer data reduction system.
CT-16	[illegible]	1780	1423	2.66	2.05	0.005	[illegible]	0.439	Test objectives: (1) Evaluate MXC-313 aft-closure insulation cured for 30 min. instead of 60 min; post-fire condition similar to 60-min-cure insulation; (2) Check out PFRT test procedures, test facility, and digital data recording, and computer data reduction system.

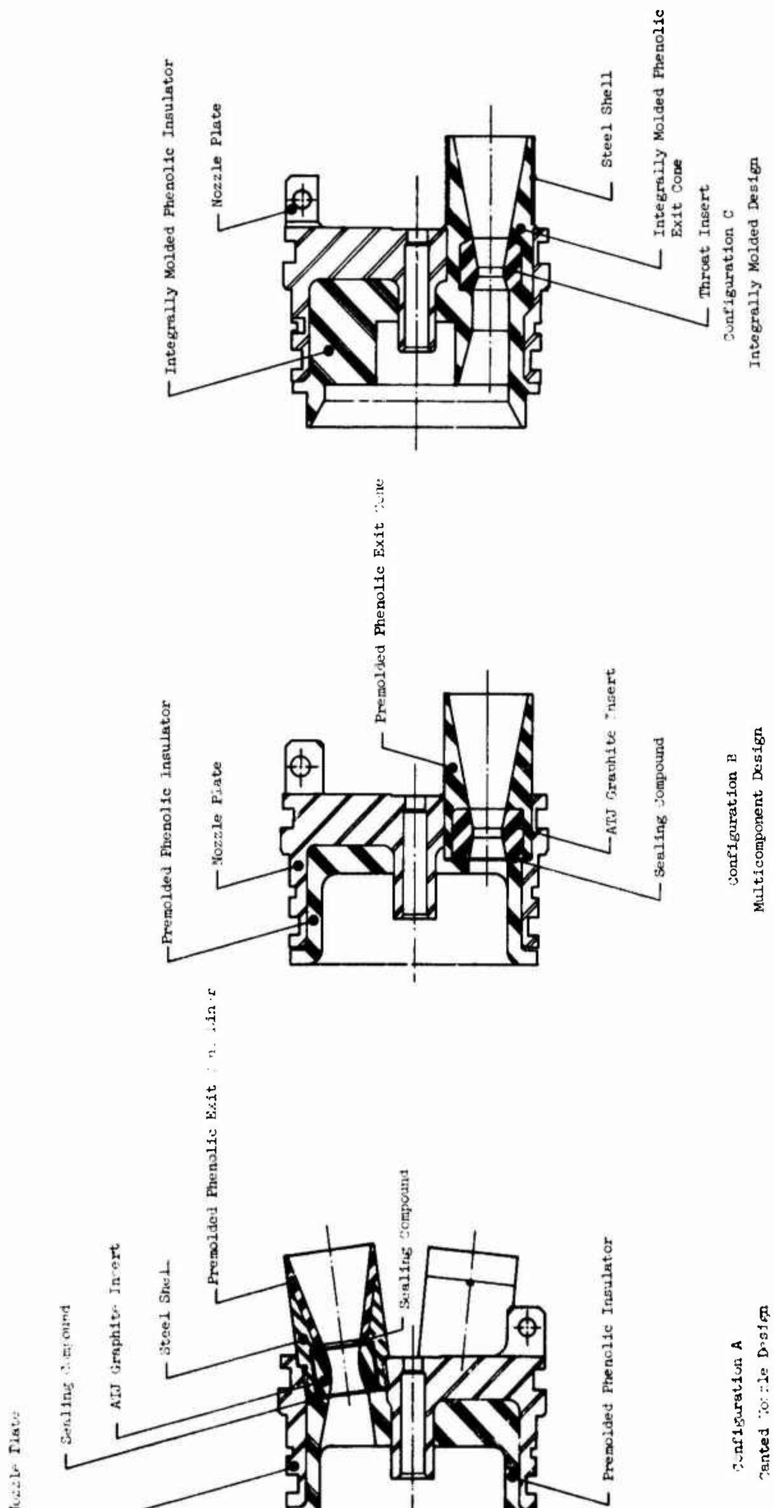
2.75-in. FFAR CT Ballistic Data Summary (u)

Figure 47, Sheet 3 of 3



Chamber and Grain Design (Configuration A)

Figure 48



Development Aft Closure Designs

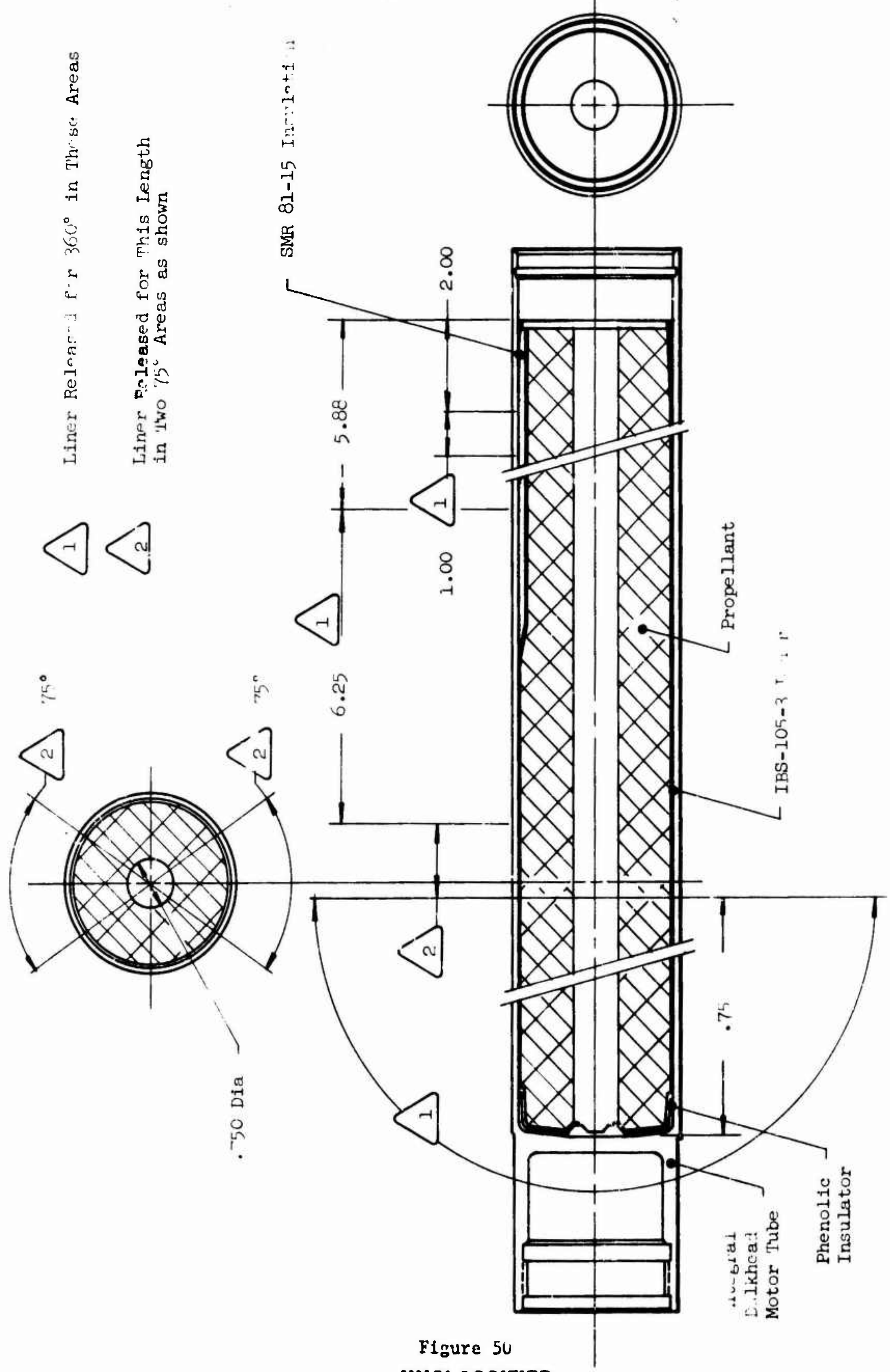
Figure 49

also permitted elimination of the extra insulation beneath the slots for additional design simplicity. The circular aft-end portion of the insulator, however, was retained, but with dimensional changes to provide better protection at the grain/aft-closure interface. The grain support system remained unchanged from that shown in Figure 48. The resultant chamber and grain assembly is illustrated in Figure 50.

In addition to the above, the proposal aft closure was modified to incorporate a carbon phenolic insulator installed over the centrally-located piston, the four exit-cone insulators were slightly changed for better retention, and the pressure tap was removed and installed in the forward head, as shown in Figure 51. This location and pressure tap configuration were used in all subsequent component and development test motors. The modified aft-closure assembly and the above chamber and grain assembly were used to initiate the required development testing.

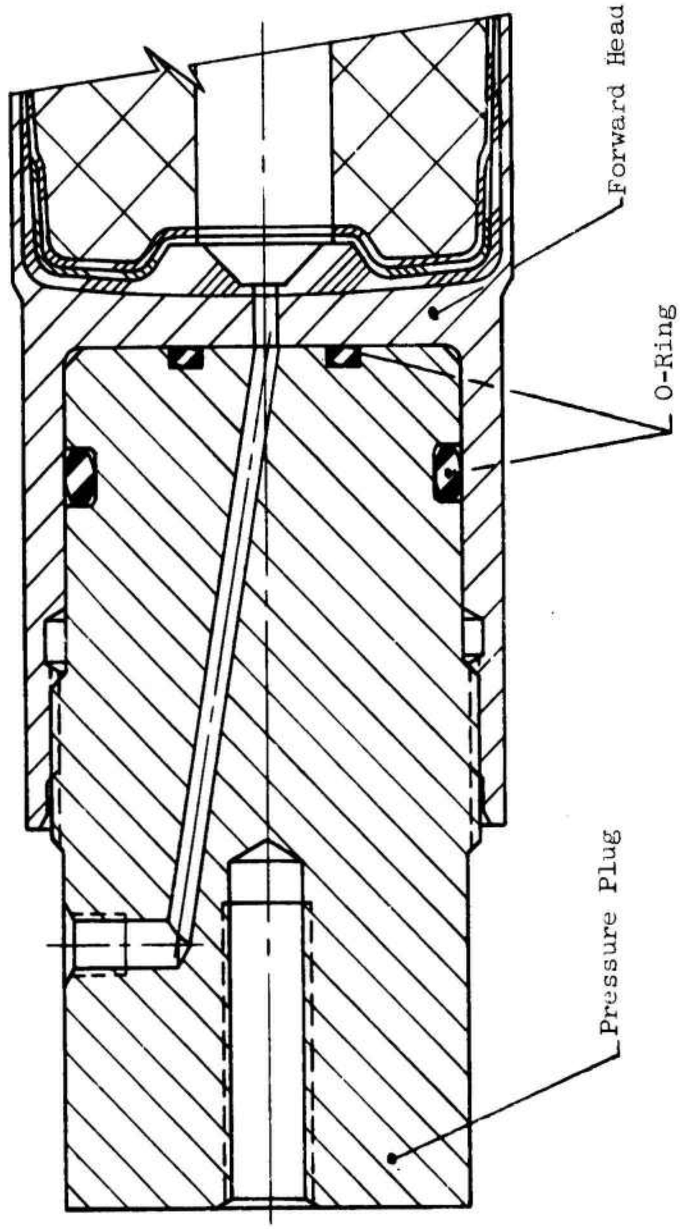
CT-6 was conducted to demonstrate that insufficient insulation at the forward end of the motor caused the burn-through experienced in the firing of development motors in Tests II-08 and -09. As a result, the length of the forward closure insulator along the chamber sidewall was lengthened from 0.61 to 1.12 in. to prevent a recurrence of this type failure.

The remaining component tests (CT-7 through -16) were made primarily as materials evaluation tests for the multicomponent aft-closure design and later the integrally-molded design shown in Figure 49 as configurations B and C, respectively.



Chamber and Grain Design (Configuration B)

Figure 50



Forward Head Pressure Tap Configuration

Figure 51

II.C. Development Test Results (cont)

a. Component Test 1

The test objective was to evaluate grain ballistics and chamber insulation performance. This was the first full-scale motor test in the program and was conducted at ambient. The motor was cast with a four-slot grain configuration. At the bottom of each slot, the chamber side-wall insulation of SMR-18 was increased to 0.090 in. to withstand exposure to the erosive gases for almost the full firing duration. A heavyweight test aft closure with a single nozzle and a bag-type igniter with a charge of 12 gm of BPN pellets were used to expedite early start of component testing.

Upon ignition, a higher-than-anticipated peak pressure of 2800 psi was recorded. At approximately 0.15 sec duration, the erosive gases cut through the chamber at the grain/aft-closure interface and the entire aft-closure assembly and aft-chamber ring were ejected intact. Erosion was also noted on the chamber sidewall in the vicinity of the four propellant slots.

The cause of failure was inadequate insulation at the grain/aft-closure interface. In addition, erosive burning occurred which contributed to the higher-than-anticipated initial pressure.

b. Component Test 2

The motor configuration for this test was virtually the same as CT-1, except that a reduced igniter charge (6 gm) was used and the grain/aft-closure interface was modified. The modification consisted of trimming the aft end of the propellant grain adjacent to the aft-chamber insulation and of molding into the trimmed area a heavy bead of IBS-105-4 insulation to interlock the aft closure and protect the grain/aft-closure interface.

Upon ignition at ambient, a high initial peak pressure similar to the first test was obtained. At 0.9 and 1.2 sec, respectively, the two pressure instrumentation taps on the aft closure were eroded off causing the burnout of the aft-closure assembly.

These firing results demonstrated the adequacy of the grain/aft-closure interface modification but revealed the inadequacy of the aft pressure-tap port insulation under erosive conditions. The firing results also indicated that the ignition spike was not significantly decreased by a reduction in igniter charge weight from 12 to 6 gm of BPN.

c. Component Test 3

This motor, fired at ambient, was the first to incorporate the proposal four-nozzle aft-closure configuration (Figure 49). The aft closure/grain joint modification was further improved by using a pre-machined insulator ring. The motor was satisfactorily ignited without an excessive ignition peak pressure from the 4-gm bag igniter. After approximately 0.4 sec, the aft closure burned through, first in the pressure tap area, then at the center piston area, eventually eroding out most of the aft closure, except for two nozzles. Again, the aft-closure insulation proved insufficient to withstand the erosive conditions. In addition, it was apparent that obtaining pressure measurements at the aft closure was detrimental to aft-closure integrity.

d. Component Test 4

To reduce the high initial pressures, this motor was reworked to reduce the burning surface by filling the aft-grain slots with a modified IBS-105 liner material, thus resulting in a tube grain configuration.

Throat erosion data indicated that the progressivity of a tube grain design would be offset by the change in the nozzle area. In addition, the central area of the aft-closure insulation was reinforced by adding a carbon-phenolic insulator over the piston to resist the direct impingement of erosive gases from the motor bore.

The motor was fired at ambient with a 5-gm bag igniter. The aft closure remained intact for approximately 1.9 sec, at which time the center piston assembly area burned out. In addition, the insulators of all four exit cones ejected between 1.5 and 1.7 sec after fire switch. This test confirmed the desirability of eliminating the grain slots and adding more insulation in the central area of the aft closure.

Based on the results of this test, the designs of the aft-closure insulator and the exit cones were modified for future tests. The cylindrical bore grain design was also adopted. Phase II development tests were initiated with this design.

e. Component Test 6

This motor was conditioned and fired at -65°F to demonstrate that the failures of development Tests II-08 and 09 were due to insufficient insulation at the forward end and not from vibration at -65°F. The motor had the same forward insulation and release pattern as the motors from Tests II-08 and -09. Like these two motors, this motor also burned through at the forward end where the forward insulator terminates. As a result, the length of the forward insulator was changed from 0.60 to 1.12 in. to increase its average of the sidewall and, thus, prevent a recurrence of this type failure.

f. Component Test 7

The motor was fired at +70°F primarily to evaluate the performance of flatted exit cones fabricated from carbon phenolic. Secondary objectives included fin actuation and evaluation of carbon phenolic as an insulation material for the aft closure. The chamber and grain assembly (Figure 50) was like that used in CT-6 above, but with a 3-in. long tapered aft-end insulator of SMR-81-15 (butyl rubber).

During firing, the flatted exit cones of carbon phenolic eroded away resulting in loss of throat insert at 1.17 sec, while the carbon phenolic material as the aft-closure insulator performed satisfactorily. Fins actuated successfully and withstood the exhaust well.

g. Component Test 8

This was the first unit to incorporate an integrally molded aft-closure insulator, nozzle inserts, and exit cones. The throat inserts were cylinders (0.75 in. dia by 0.75 in. long) of ATJ graphite, and, after molding, the throat diameter was machined to 0.28 in. dia.

The motor was fired at 70°F. All four exit cones and three throat inserts were ejected at 0.5 sec duration. The expansion of the graphite throat inserts during firing cracked the exit cones at the weakest point, the junction of the exit cones and plate.

II.C. Development Test Results (cont)

h. Component Test 9

This test was conducted after development Test II-28 and was made to evaluate silica exit cones assembled with the 40 mil throat insert relief gap potted with silicone rubber. The test firing was conducted at +150°F and lasted 2.5 sec. At that time, the aft closure burned through at the bottom of the exit cone circle at the expansion gap and the closure separated from the motor.

i. Component Test 10

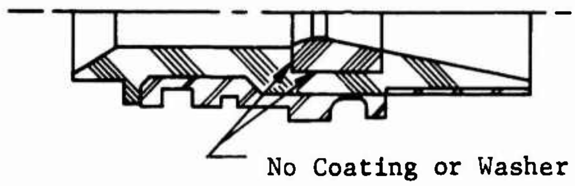
This test motor was fired to evaluate silica phenolic as an insulation material for the integrally molded aft closure. The throat insert and relief gap and potting material were the same as used in Test II-33. When the motor was fired at +150°F, one exit cone was ejected at 0.24 sec with subsequent erosion through closure and chamber at the insert expansion gap.

j. Component Test 11

This firing at +150°F was a materials evaluation test conducted with throat insert material Carbitex-700. The test was prompted by the previous acceptable performance of Carbitex at -65°F in development Test II-22 and the requirement for further verification of its acceptability at the high temperature. Again Design A-2 was used with a Nylon paper washer and uncoated insert (Figure 52). All inserts remained in place and no evidence of cracking was observed. Throat erosion at +150°F showed the same acceptable amount as at -65°F.

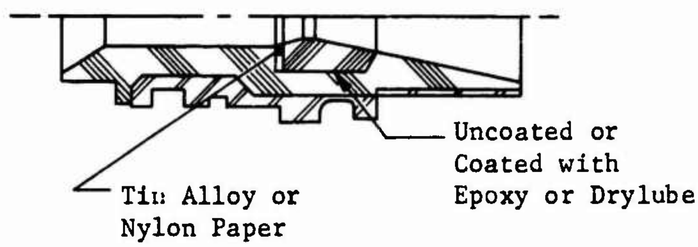
Throat Materials

Design A-1 One Piece Net Molded with Ablative Throat



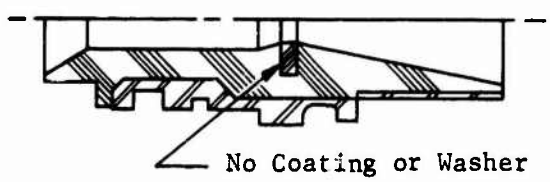
MX 4926

Design A-2 One Piece Net Molded with Graphite Inserts



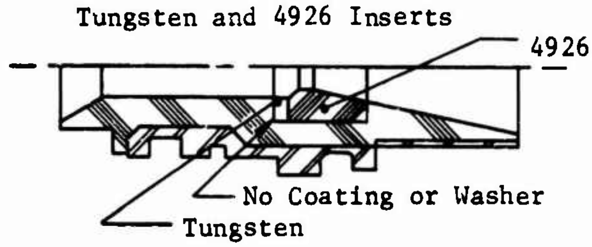
ATJ
(Baseline)
POCO AXF-QB
RVD
G-90
Pyrocarb 458
Carbitex-700
TS 902

Design A-3 One Piece Net Molded with Pyrolitic Graphite Washer



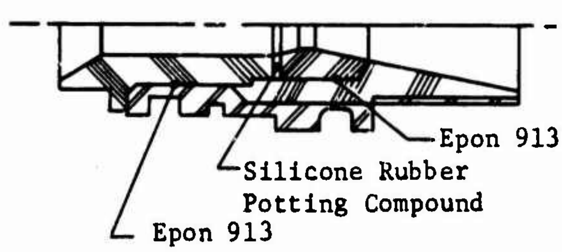
Pyrolitic
Graphite Washer

Design A-4 One Piece Net Molded with Tungsten and 4926 Inserts



Tungsten Insert and
MX 4926 Insert

Design B-1 Two Piece with Bonded Graphite Inserts



ATJ
POCO AXF-QB
RVD
G-90
Pyrocarb 458
Carbitex
TS 902

Candidate Aft Closure and Throat Insert Designs

Figure 52

II.C. Development Test Results (cont)

The chamber and grain assembly, including restriction, was identical to that for development Test II-31. The assembly was temperature conditioned to +150°F before firing. Test data showed that the ignition peak pressure was 2120 psig vs the design peak pressure of 1990 psig. The bore restriction was therefore extended in later motors to reduce the ignition peak pressure to an acceptable level.

For this firing, the aft end of the grain was potted with IBS-105-4X, which replaced the previous potting material, CS-3802 silicone rubber. IBS-105-4X was expected to reduce erosion of the aft-end insulation (SMR 81-15), while providing aft-end grain restriction and closure-joint sealing. Examination of the chamber after firing showed that IBS-105-4X, as an insulation potting material, substantially reduced the amount of erosion on the aft-end insulation.

k. Component Test 12

This firing was a materials evaluation test conducted at +150°F with an integrally-molded aft closure of the same design as used in development Test II-21 below. The GFM fin-actuating piston, however, developed a leak at the seal between the wire and piston, thus causing the center of the aft closure to erode away. To eliminate a recurrence, subsequent aft-closures will use fin-actuating pistons having fused-glass-bead seals where the electrical wire lead enters into and exits from the piston. The average throat erosion was about 19 mils/sec despite the piston burnthrough.

II.C. Development Test Results (cont)

l. Component Test 13

This firing made with a PFRT configuration was also a materials evaluation test conducted at -65°F with an integrally molded aft closure containing Carbitex-700 throat inserts, but with Durez insulation material instead of MXC-313. The insulator had the same configuration as used in the previous tests. The Durez material was tested in the interest of providing a second material source. During the firing, one Durez exit cone cracked and failed, thereby allowing its throat insert to eject. Inspection of the fired aft closure revealed that material porosity combined with lack of close contact with the aft closure shell had caused the cracking. No further test of this material was performed.

m. Component Test 14

This motor was temperature conditioned to +150°F and then successfully fired as a continuation of the nozzle material evaluation tests. The test objective was to evaluate the performance of MXC-313 aft-closure insulation material when transfer-molded with a cure time of 30 min vs the present cure time of 60 min. In all other respects, the motor was the same as the PFRT design (Figure 1). Postfiring examination of the aft closure indicated that the amount of erosion and the general condition of the insulator were similar to those exhibited by the insulation when cured for 60 min.

n. Component Tests 15 and 16

Two additional motors of the PFRT configuration were conditioned to +70 and +150°F, respectively, and successfully static fired as a continuation of the materials evaluation testing of the MXC-313 aft-closure insulation material. Both motors had aft closures containing MXC-313 transfer-molded with a cure time of 30 min. Postfiring inspection showed that the condition of the aft-closure insulation material cured for 30 min continues to compare well with aft-closure insulation material cured for 60 min. The firings were satisfactory.

In addition to material evaluation, the tests served to check the PFRT test procedures, the Beckman analogue digital computer (ADC) for recording performance data, and its data reduction capability. Results were satisfactory.

3. Motor Development Tests (Phase II)

Exhibit A of the contract specified three series of 15 motors each to be fired in Phase II. By agreement with the Air Force, series 2 was reduced to 11 tests and series 3 was reduced to six tests. Four additional tests were made. Descriptions of the motors and testing are presented below. Tests were in accordance with MIL-R-25535A, as required. Ballistic data, test objectives, and results are summarized in Figure 53. Typical firing curves at -65, +70, and +150°F are shown in Figures 10 and 11.

Thirty-six development motors were test-fired, 12 at -65°F, 10 at +70°F, and 8 at +150°F. The six remaining motors were successfully subjected to spin tests at Langley. As shown in Figure 54, environmental testing included temperature cycling from -65 to +150°F and endurance vibration testing at the temperature extremes prior to firing.

Test No. II-	Chamber S/N	Propellant Batch Number	Date Fired	Firing Temp., °F	Action Time Total Impulse, lbf-sec	Burn Time Total Impulse, lbf-sec	Specific Impulse lbf-sec/lbm	Max Thrust, lbf	Max Ignition Thrust, lbf	Average Thrust, lbf
01	2-020	67-506	11-9-67	+70	1775	1160	223.2	810	620	674
02	2-006	67-506	11-14-67	+70	1772	1634	222.9	811	662	542
03	2-007	67-506	11-30-67	+70	N/A	N/A	N/A	N/A	670	N/A
04	2-012	67-506	11-14-67	-65	N/A	N/A	N/A	N/A	620	N/A
05	2-015	67-506	11-21-67	-65	1696	1566	213.3	651	658	575
06	2-013	67-506	11-17-67	+150	1766	1613	222.1	851	753	699
07	2-011	67-506	12-20-67	+150	1788	1645	224.9	905	747	710
08	2-09	67-506	12-14-67	-65	N/A	N/A	N/A	N/A	N/A	N/A
09	2-08	67-506	12-14-67	-65	N/A	N/A	N/A	N/A	N/A	N/A
10	2316	67-570	1-15-68	-65	N/A	N/A	N/A	N/A	N/A	N/A
11	2-017	67-506	1-5-68	+150	1808.9	1679	227.5	905	730	660
12	2-015	67-506	1-8-68	+150	1736	1614	218.4	885	655	633
13	2-019	67-506	1-10-68	+150	1817.7	1678.9	228.6	921	696	611.8
14	2305		1-23-68	+70			Successful spin test at Langley			
15	2315		1-24-68	+70			Successful spin test at Langley			
16	2-010	67-506	12-7-67	+70	1760	1627	221.3	834	798	661
17	2304		12-12-67	+70	1914	1602	240.7	855	674	667
18	2412	68-1	1-23-68	-65	1819.6	1514.5	226.8	707	535	510.4
19	2411	68-1	1-26-68	-65	1809.6	1558.7	227.6	707	530	507.2
20	2410	68-1	1-2-68	+150	1861.6	1677.6	234.1	840	685	614.4
21	2613	68-46	5-13-68	+150	1919	1642	241.2	892	543	673
22	2612	68-46	4-22-68	-65	1873	1573	230.3	739	622	551
23	2607	68-46	3-4-68	-65	N/A	N/A	N/A	N/A	N/A	N/A

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 1 of 7

Test No. II-	Chamber S/N	Propellant Batch Number	Date Fired	Firing Temp., °F	Action Time Total Impulse, lbf-sec	Burn Time Total Impulse, lbf-sec	Specific Impulse, lbf-sec/lbm	Max Thrust, lbf	Max Ignition Thrust, lbf	Average Thrust, lbf
24	2320		1-24-68	+70			Successful spin test at Langley			
25	2323		1-24-68	+70			Successful spin test at Langley			
26	2309		1-26-68	+70			Successful spin test at Langley			
27	2502	68-21	1-25-68	+70	N/A	N/A	N/A	N/A	735	N/A
28	2503	68-21	1-26-68	+70	N/A	N/A	N/A	N/A	700	N/A
29	2615	68-46	3-11-68	+70	1912	1607	240.5	896	695	676
30	2611	68-46	4-16-68	-65	1831	1524	230.3	656	657	539
31	2609	68-46	4-25-68	-65	1837	1525	231.0	675	542	540
32	2310		1-26-68	+70			Successful spin test at Langley			
33	2319	67-570	1-27-68	+150	1888.9	160.15	237.5	895	625	665.6
34	2318	67-570	1-31-68	+150	1921.6	1630.7	241.7	898	710	693.2
35	2404	68-1	1-7-68	+70	1940	1680	244.0	878	610	658
36	2610	68-46	5-8-68	+70	1896	1600	239.6	842	639	643

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 2 of 7

Test No. II-	Max. Chamber Pressure, psig	Max. Ignition Pressure, psig	Avg. Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Remarks
01	1350	1490	1328	3.368	1.721	0.02	0.05	Test objectives: Evaluate (1) basic design of chambers and grain assembly; (2) grain ballistics and insulation performance; (3) four canted-nozzle aft closure (tape-wrapped MX 4926 for insulator and exit cones). Full duration firing; satisfactory ballistics; no hot spots, some delamination of exit cones noted.
02	1437	1593	1232	3.270	2.461	0.014	0.036	Test objectives: Same as above plus evaluate use of steel sleeves to control exit-cone delamination. Full duration firing; no delamination noted.
03	N/A	1610	N/A	N/A	N/A	0.045	0.032	Test objectives: Evaluate (1) ballistic and insulation performance; (2) aft closure with four straight nozzles (WB [illegible], Avceram as insulator and silica phenolic exit cones). Aft closure ejected at 0.05 sec due to combination of chamber ovality and shallow lockwire groove; test inconclusive.
04	N/A	1418	N/A	N/A	N/A	0.069	0.007	Test objectives: Evaluate performance of grain, insulation, and canted four nozzle aft closure with tape wrapped MX 4926 insulator and exit cones; steel sleeves on exit cones. Motor malfunctioned at 0.5 sec due to O-ring leak in pressure tap adapter.
05	1560	1560	1107	3.270	2.722	0.037	0.017	Test objectives: Same as above; motor constructed as for Test II-04 above. Motor temperature cycled; full duration firing; regressive curve due to grain cracking; lack of adequate release; additional release agent to be applied in future motors.
06	1515	1705	1286	2.813	2.308	0.029	0.014	Test objectives: Same as above; motor constructed as for Tests II-04 and -05. Good full duration firing; ballistics and insulation performance satisfactory.
07	1532	1652	1318	2.768	2.315	0.030	0.010	Test objectives: Same as above, but under environmental and firing conditions; also evaluate gas flow effects on fins; motor constructed as for Tests II-04, -05, and -06, but with MX 4925 as aft closure insulation and exit cones. Vibrated and cycled; good full duration firing; no adverse effects noted on fins.
08	N/A	1368	N/A	N/A	N/A	0.051	0.037	Test objectives: Same as for Test II-07, but no fins; motor constructed as for Tests II-04 to -07. Vibrated and cycled; chamber sidewall burnthrough at aft edge of forward insulator.

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 3 of 7

Test No. II-	Max. Chamber Pressure, psig	Max. Ignition Pressure, psig	Avg. Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Remarks
09	N/A	N/A	N/A	N/A	N/A	0.054	0.031	Test objectives: Evaluate motor performance under environmental and firing conditions; motor constructed as for Tests II-04 thru -08. Vibrated; rupture at ignition; cracked grain due to inadequate release area; apply more release agent in future motors.
10	N/A	958	N/A	N/A	N/A	0.051	0.035	Test objectives: Same as above; motor constructed as for Tests II-04 thru -09, but MX 4296 for aft closure insulator and exit cones. Vibrated; chamber burnthrough at 0.5 se[illegible] aft edge of forward insulator.
11	1640	1765	1471.5	2.739	2.294	0.039	0.013	Test objectives: Same as above; motor constructed as for Tests II-04 thru -10, but with MX 4925 for aft closure insulator and exit cones. Vibrated; good full duration firing [illegible] successful simulated launch tube set up.
12	1400	1540	1343.8	2.741	2.291	0.045	0.026	Test objectives: Same as above; motor constructed as for Test II-11. Vibrated; good full duration firing under successful simulated launch tube set up.
13	1700	2130	1464.9	2.832	2.302	0.048	0.023	Test objective: Evaluate grain and chamber assembly; canted nozzle aft closure; insulator and exit cones of silica phenolic. Vibrated; good full duration firing; si[illegible] phenolic satisfactory.
14								Test objective: Evaluate motor performance under spin conditions at Langley; motor constructed as for Test II-11. Successful spin test.
15								Test objective: Same as Test II-1[illegible]. Successful spin test.
16	1561	211[illegible]	1345	2.906	2.461	0.025	0.015	Test objectives: Evaluate grain ballistics and insulation performance; evaluate exit cones with short throat inserts and exit cones with long inserts and with and without steel sleeves; exit cones fabricated from silica phenolic and aft closure insulator from MX 4925. Full duration firing; exit cone with long insert and steel sleeve showed excellent post firing condition; remainder fair to poor condition.

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 4 of 7

Test No. II-	Max. Chamber Pressure, psig	Max. Ignition Pressure, psig	Avg. Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Remarks
17	1668	1766	1350	2.868	2.184	0.048	0.030	Test objectives: Same as above; motor constructed as for II-16 above, except exit cones fabricated of MX 4925. Full duration firing; exit-cone post-fire condition same as II-16.
18	1170	1325	1088	3.565	[illegible].395	0.051	0.036	Test objectives: Evaluate case-bonded grain design with forward head fully released; aft-closure insulator and exit cones of MX 4926. Temperature cycled; good full duration firing; ballistics and insulator performance good.
19	1155	1312	1067	3.568	2.678	0.054	0.032	Test objectives: Same as II-18 above; motor constructed as for II-18 above. Temperature cycled; good full duration firing; excessive throat erosion.
20	1370	1625	1293.1	3.030	2.270	0.045	0.025	Test objectives: Same as II-18 and -19 above; motor constructed as for II-18 and -19 above. Temperature cycled; firing normal except for excessive throat erosion.
21	1710	1725	1336	2.84	2.215	0.005	0.035	Test objectives: Evaluate motor performance after vibration and temperature cycling; evaluate MXC-313 as transfer-molding insulation material for integrally molded aft closure; evaluate +150°F performance of Carb-I-Tex 700 as throat insert material in PFRT design; motor of PFRT configuration. Normal firing; MXC-313 was satisfactory and throat erosion of Carb-I-Tex acceptable.
22	1412	1820	1127	3.4	2.58	0.005	0.045	Test objectives: demonstrate chamber-grain integrity after temperature cycling and endurance vibration at -65°F for 60 hr (30 hr each in longitudinal and vertical axes); Carb-I-Tex 700 as throat insert material. Firing successful; inserts intact; throat erosion acceptable.
23	N/A	1556	N/A	N/A	N/A	0.028	0.036	Test objectives: Evaluate grain and chamber performance; evaluate Durez as insulation material for integrally molded aft closure; ATJ throat inserts. One nozzle cracked and ejected at 0.235 sec.
24								Test objectives: Evaluate motor performance under spin conditions at Langley; motor constructed as for Test II-11, except that IBS-105-4X was used as the aft end insulator instead of SMR-81-15. Successful spin test.

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 5 of 7

Test No. II-	Max. Chamber Pressure, psig	Max. Ignition Pressure, psig	Avg. Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Remarks
25								Test objectives: Same as for Test II-24; motor was constructed same as for II-24. Successful spin test.
26								Test objectives: Same as for Tests II-24 and -25; motor constructed as for Test II-11. Successful spin test.
27	1312	1600	N/A	3.382	N/A	0.041	0.023	Test objectives: Evaluate ballistic and insulation performance; evaluate performance of aft closure insulator and exit cones of MX 4925, plus aft end insulator of IBS-1C5-4X; ATJ inserts. One insert ejected at 0.55 sec and another at 1.3 sec.
28	1625	1810	N/A	3.20	N/A	0.051	0.014	Test objectives: Same as Test II-27 above; motor constructed same as for Test II-27. Ejected two exit cones at 1 sec.
29	1741	2046	1464	2.829	2.183	0.017	0.018	Test objectives: Evaluate grain and insulation performance; evaluate Durez for integrally molded insulator and exit cones and ATJ inserts; chamber and grain assembly of PFRT design. Normal firing for full duration.
30	1466	1958	894	3.4	2.55	0.010	0.036	Test objectives: Demonstrate chamber-grain integrity after temperature cycling from -65 to +150°F; evaluate MX 4926 material for throat insert use. Firing successful; throat inserts intact; throat erosion too high.
31	1370	1610	992	3.4	2.55	0.005	0.045	Test objectives: Same as II-22 above; environmental testing consisted only of temperature cycling; Pyrocarb 548 as throat insert material. Firing successful; inserts intact; throat erosion unacceptable.
32								Test objective: Evaluate motor performance under spin test conditions; motor constructed the same as for Test II-11. Successful spin test.

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 6 of 7

Test No. II-	Max. Chamber Pressure, psig	Max. Ignition Pressure, psig	Avg. Chamber Pressure, psig	Action Time, sec	Burn Time, sec	Ignition Delay, sec	Ignition Rise Time, sec	Remarks
33	1535	1530	1453.3	2.838	2.163	0.052	0.030	Test objective: Evaluate ballistic and insulation performance; evaluate WB 8517 (carbon phenolic) as transfer-molded aft closure insulator and exit cones plus ATJ inserts; chamber grain assembly like II-11, except for IBS-105-4X as aft end insulator. Vibrated; normal firing; aft-closure insulation satisfactory.
34	1645	1855	1556	2.772	2.117	0.042	0.016	Test objective: Same as for II-33; motor constructed as for II-33, except that MXC-313 was integrally molded insulation material with ATJ graphite inserts and SMR 90K-18 as the aft-end insulator material.
35	1615	1519	1365	2.946	2.323	0.022	0.039	Test objective: Evaluate fully bonded grain performance; evaluate aft closure integrally molded with MXC-313 and ATJ inserts. Full duration firing; inserts in excellent condition probably due to molded entrance section.
36	1622	1925	1293	2.95	2.285	0.005	0.044	Test objective: Evaluate ballistic and insulation performance of PFRT design; evaluate MXC-313 as aft-closure insulation and Carb-I-Tex throat inserts; determine igniter peak with 6-in. aft end of bore restriction. Vibrated; temperature cycled; firing successful; igniter pressure too high; 7.75 to 8.0 in. bore restriction set for PFRT motors.

2.75-in. FFAR Development Ballistic Data Summary (u)

Figure 53, Sheet 7 of 7

Motor for Test II- No.	Temp. Cycle	Vibrate, °F -65	Vibrate, °F +150	Fire, °F -65	Fire, °F +70	Fire, °F +150
1					x	
2					x	
3					x	
4	x			x		
5	x			x		
6	x					x
7	x	x				x
8		x		x		
9		x		x		
10		x		x		
11			x			x
12			x			x
13			x			x
14					x*	
15					x*	
16					x	
17	x				x	
18	x			x		
19	x			x		
20	x			x		
21	x		x			x
22		x		x		
23				x		
24					x*	
25					x*	
26	x				x*	
27					x	
28					x	
29					x	
30	x		x	x		
31	x			x		
32					x*	
33	x	x				x
34						x
35					x	
36	x		x		x	

*Spin Test at Langley

Phase-II Test Sequence

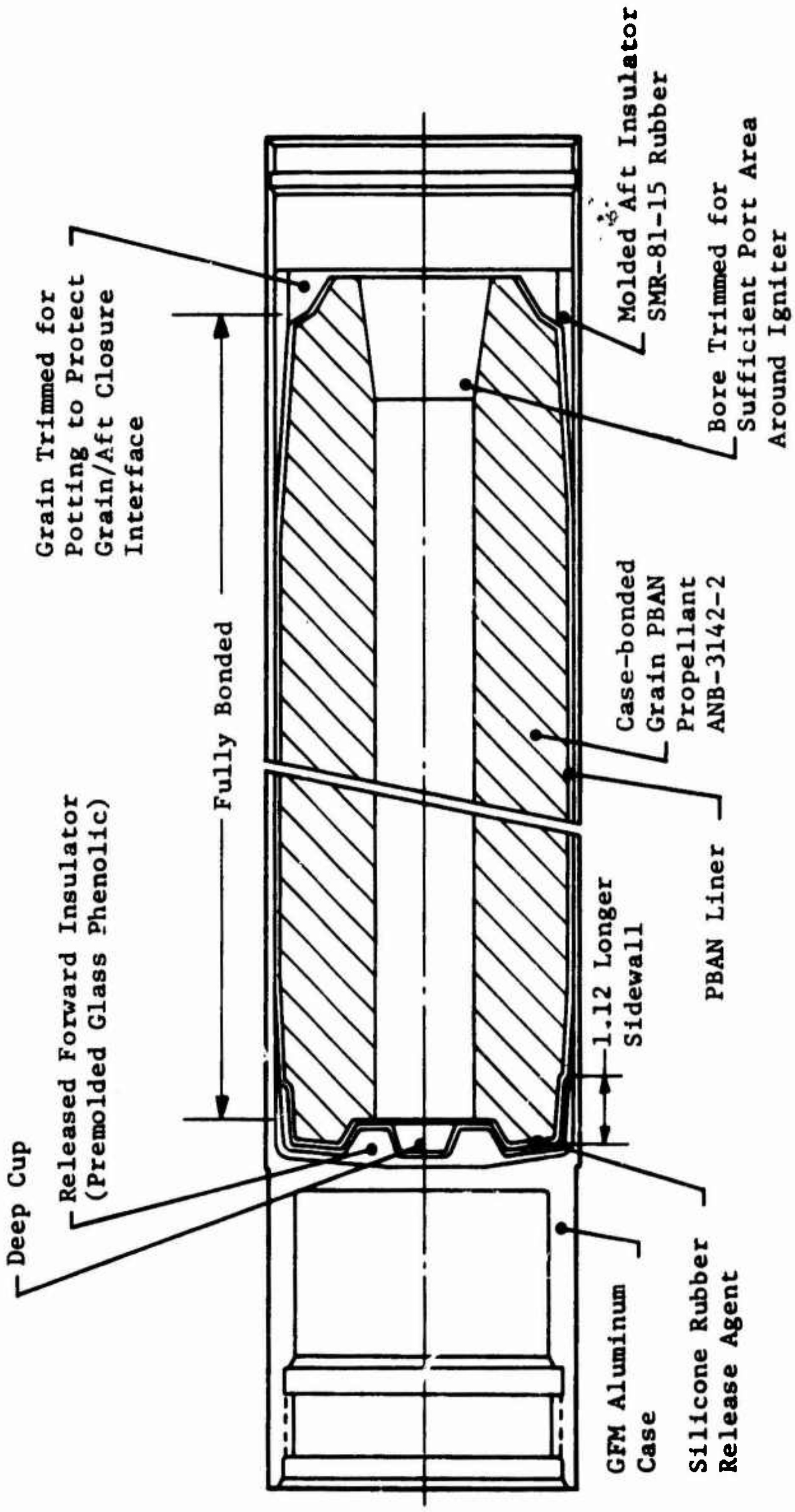
Figure 54

II.C. Development Test Results (cont)

The chamber and grain assembly for Tests II-1 through II-17 had a grain support system wherein the forward head was fully released and the sidewall was partially released in two 75 degree strips which led into a 6-in. wide band circumferentially released at the center of the motor as shown in Figure 50. The motor for Test II-18 incorporated a grain support system that consisted of fully bonding the grain to the chamber sidewall and completely releasing the grain from the forward closure. Except for the four motors for the acceleration tests at Langley (Tests II-24 through -26 and II-32) and a fully bonded motor for Test II-36, all remaining development motors had this grain support system. The grain support system was incorporated into the PFRT design shown in Figure 1.

The aft end insulator of SMR-81-15 (ethylene propylene rubber) in 13 development motors (Tests II-1 through -9, II-11 through -13, and II-16) was 10-in. long and was increased from the proposal thickness of 0.10 in. by adding 0.04-in. thick layer of SMR-81-15. In subsequent motors, the insulator was set at 3 in. in length and tapering from an aft end thickness of 0.125 in. to 0.25 in. at the forward end. Two other insulation materials (SMR-90K-18 rubber and sprayed-on IB-105-4X) were tested in this configuration to evaluate alternative aft-end insulation materials. A comparison of the performance of SMR-90K-18 in Tests II-10, -13, and -34; IBS-105-4X in Tests II-24, -25, -29, -31, -33, and -36; and SMR-81-15 in previous tests showed that IBS-104-4X provided improved erosion resistance at lower cost. This material in the above insulator configuration was incorporated into the PFRT motor (Figure 1).

In addition to the above changes to the chamber and grain assembly shown in Figure 50, three other changes were made as illustration in Figure 55. The first consisted of lengthening the forward insulator to provide more coverage along the chamber sidewall. This change resulted from the chamber burn-through at the aft end of the insulator during Test II-08.



Chamber and Grain Assembly Design
(Configuration C)

Figure 55

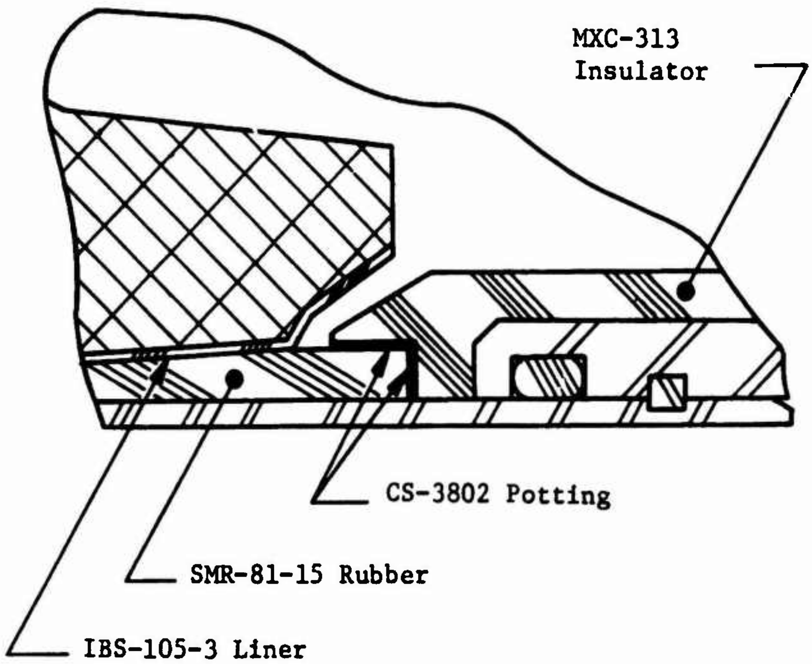
II.C. Development Test Results (cont)

Inadequacy of the fore-end insulation was confirmed by a similar burn-through in CT-6 previously discussed. Further, the insulator cup was deepened to permit easier and more positive centering of the casting core and the material thickness was increased for added ruggedness.

The other two changes involved the aft-end configuration of the grain. The bore was trimmed to provide adequate post area for gas flow around the aft-end igniter, and the aft-end of the grain O D was trimmed to accept sufficient potting materia to better protect the grain/aft-closure interface, as shown in Figure 55.

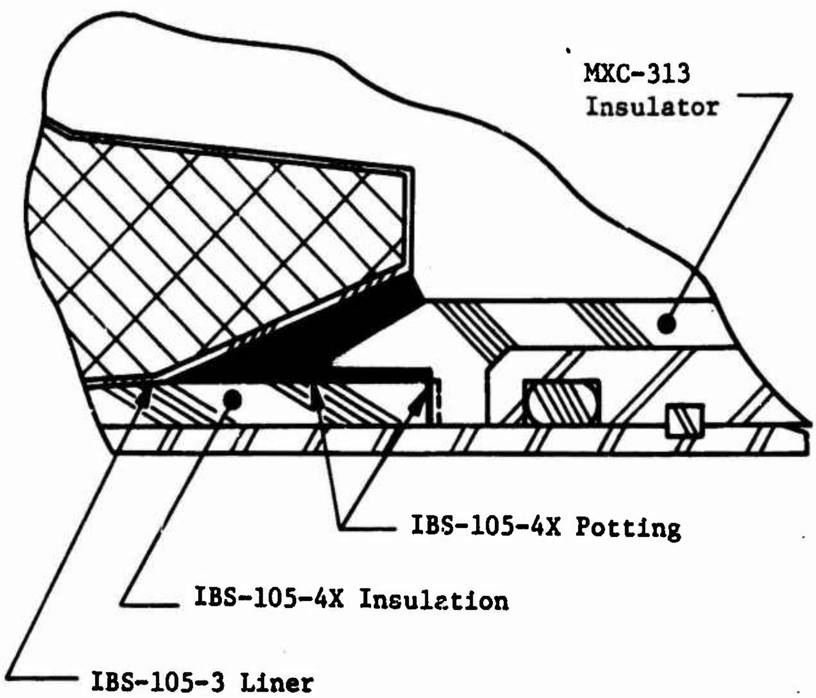
As a result of excessive erosion of the aft-end insulator observed in Tests II-22, II-30, and -31, the grain/aft closure interface in Figures 55 and 56 were changed to that shown in Figure 57, the PFRT design, wherein the IBS-105-4X potting compound completely fills the gap between grain and closure to fully protect the grain/aft-closure interface. This configuration was successfully tested in Test II-21 and in 45 PFRT motors, as described later.

During the development firings, the prime insulation candidates for the multicomponent aft-closure (Figure 49, Configuration B) were MX 4926 and MX 4925, with one unsatisfactory test each of WB 8251 and silica phenolic. Exit cone materials included MX 4926, MX 4925, and silica phenolic. When the integrally-molded aft-closure design (Figure 49, Configuration C) was adopted, MXC-313 insulation material was used successfully for transfer molding the aft-closure insulator and exit cones as a unit. Performance of the material in test firings rates highly satisfactory. Other insulation materials for the integrally molded aft closure included WB-8517 in one unsuccessful test firing and Durez in four inconclusive test firings.



Old Design Aft Joint

Figure 56



New Design Aft Joint

Figure 57

For throat inserts, ATJ graphite was used in both the multi-component and integrally molded aft closure because of its low erosion rate and low cost. In the integrally molded aft closure, its compressive strength, however, was too low to withstand the high pressures of the transfer-molding process, as evidenced by insert cracking and ejection during firing. At that time, various candiate throat insert configurations and materials (Figure 52) were investigated to overcome the insert cracking and ejection difficulty and to obtain a material with satisfactory compressive strength for withstanding the transfer-molding process. Both Pyrocarb and MX 4926 were tested but exhibited unacceptable rates of erosion. Subsequently, Carbitex was selected based on its compressive strength of 21,000 lb and its acceptable rate of erosion (about 18 mils/sec) which compares favorably to ATJ graphite (about 15 mils/sec). The design, shown as Design A2 in Figure 52, was incorporated into the PFRT motor (Figure 1).

Except for the first five firings, wherein a bag-type igniter installed at the fore end of the motor was used to expedite start of testing, all remaining development motors had igniters with the basic aft-end igniter configuration shown in Figure 1 and previously described in Section II. C. 1.

a. Series 1

(1) Ambient Temperature Firings

(a) Test II-01

The motor was fired successfully at ambient temperature to confirm basic component design and ballistic performance. Nozzle exit-cone delamination was noted. A bag igniter was used containing 6 gm of BPN and located in the forward end of the motor.

The motor was insulated with a forward insulator (Fiberite 4030-190) and an aft-end chamber sidewall insulator (SMR-81-15) rubber modified with an extra layer of SMR 81-15. It was assembled with a closure having four threaded canted nozzles (Figure 49, Configuration A). The chamber and grain assembly for this motor was essentially as shown in Figure 50, but with the thickness of the SMR 81-15 aft-end insulator increased by an extra layer of SMR 81-15.

(b) Test II-02

This motor, fired at ambient, was of the same configuration as used in Test II-01 above, except that a steel sleeve was placed around each exit cone to control the delamination noted above. The motor was successfully fired at ambient to evaluate grain ballistics and insulation performance. The exit-cone delamination was apparently corrected by the steel sleeves.

(c) Test II-03

This motor was the first to incorporate an aft-closure assembly with four straight nozzles (Figure 49, Configuration B). The aft-closure insulator was fabricated from WB 8251 (Avceram) material, the exit cones from silica phenolic, and the throat inserts from ATJ graphite. The igniter was the first aft-end model to be used in this test series. It was bonded to a piston cap made of MX4926 and contained 9 gm of BPN pellets.

The motor was fired at ambient to evaluate grain ballistics and insulation performance. At ignition, the aft closure was ejected at 1500 psi during ignition because of a shallow lockwire groove combined with chamber ovality.

(2) Temperature Cycling Tests

A total of four motors (Figure 50) were temperature cycled. Subsequently, two motors each were fired at -65 and +150°F.

(a) Test II-04

This motor was constructed like the motor for Test II-02 above. It was fired at -65°F and failed shortly after ignition because of a leak at the O-ring in the adapter used for pressure measurement. This motor operated normally for approximately 0.5 sec before loss of the adapter seal and subsequent burn through the forward portion of the chamber and bulkhead.

(b) Test II-05

This motor was tested at the cold temperature (-65°F). Reduced test data showed the test curve to be regressive. This regressivity is believed to have been the result of the grain cracking in the aft end, possibly on initial pressurization. The X-rays taken after temperature cycling had indicated no cracks. However, the grain had not contracted from the chamber wall in the released areas as much as desired. A process change was made to apply more release agent in future motors.

(c) Test II-06

This motor was insulated like the prior motors of this series and assembled with a canted nozzle closure assembly which incorporated steel sleeves on the exit cones (Test II-02 above). It operated well for the full duration at 150°F.

(d) Test II-07

This motor was of the same configuration as the motor for Tests II-08 and II-09, was vibrated with them, and was intended for Test II-10. Based on the firing failures of II-08 and II-09, which occurred prior to this test, it was decided to fire the motor at +150°F after temperature cycling in agreement with the test plan for the motor for Test II-07. Fins attached in the normal open position were tested to evaluate the effect of the exhaust gas stream on the fin blades. The motor fired successfully, with no adverse effects on the fins.

(3) Vibration Tests

Six motors (Figure 50) were subjected to vibration tests, subsequently three were fired at -65°F and three were fired at +150°F.

(a) Test II-08

This motor was assembled like the motor for Test II-17 (see below), except that the nozzles were all the same configuration. The motor was vibrated at -65°F for 60 hr prior to firing at -65°F. The chamber burned through the sidewall after 0.275 sec of burning, at a point where the forward head insulator ends.

(b) Test II-09

This motor was of the same configuration as the motor for Test II-08 and received the same vibration treatment prior to firing at -65°F. The motor chamber ruptured at ignition. Examination of the X-rays taken before firing and of the hardware and unburned propellant indicated that the grain cracked longitudinally during ignition. The cause of failure was assigned to the lack of bond-release at -65°F. A program of laboratory evaluation of various release agents and grain release design was initiated. Component Test 6 (see above) was conducted to verify that the failure of this motor and of the motor for Test II-08 was not due to the vibration to which they were exposed.

(c) Test II-10

The chamber and grain assembly of this motor was the same as that for Tests II-08 and -09 (Figure 50), except that two coats of release material were applied to obtain satisfactory release in the released areas.

(d) Test II-11

This motor was insulated as shown in Figure 50, but with the insulator (10-in. band of SMR 81-15 rubber) modified with an extra layer of 0.04-in.-thick rubber. It was released with one coat of TC-522-1 on the forward end in two 70-degree wide strips in a pattern like that shown in Figure 50. This pattern provides for fore-end venting as well as pressure equilibrium in the vented area. The chamber assembly was vibrated at +150°F.

II.C. Development Test Results (cont)

The motor was fired at +150°F in a rigid tube to simulate launcher eject. It ran full duration with good ballistic data. The motor had a straight nozzle closure. The aft-closure insulator was made of carbon phenolic and the exit cones of silica phenolic. The igniter was an aft end model which consisted of an aluminum tube plugged with plastic foam on one end, a Mk 1 Mod 1 squib, and 7 gm of BPN pellets. The loaded igniter tube was bonded to a carbon phenolic cap covering the piston. The igniter circuit to the squib was completed through a wired piston. The silica phenolic exit cones remained intact, the piston functioned properly, and the simulated launcher eject made indicated no damage to the launch tube. The igniter was used in all subsequent test motors and was incorporated into the PFRT motor with the added initiator charge as discussed previously.

(e) Test II-12

This motor was of the same chamber and grain design as the motor for Test II-11 and was vibrated at +150°F. It was assembled with the "work horse" aft closure. The closure was built with four threaded canted nozzles, with 0.312-in.-dia throat inserts. The aft-closure insulator and exit cones were of carbon phenolic. It was successfully fired at +150°F and again simulated launch tube ejection was accomplished with no damage to the launch tube.

(f) Test II-13

This chamber was vibrated at +150°F. The motor was fired using straight nozzles. The aft-closure insulator was silica phenolic instead of the previously used carbon phenolic, and the steel nozzle sleeves were reduced from 0.050 to 0.008-in. thick. The silica insulator functioned properly for the full duration as did the silica exit cones with the 0.008 in. sleeves.

(4) Flight Acceleration and Spin Tests

Two motors (Tests II-14 and -15) were temperature cycled and subsequently fired successfully at ambient temperature in the spin fixture at Langley Research Center.

(a) Tests II-14 and -15

The chamber and grain configuration of both motors is shown in Figure 50 with the long aft-end insulator of SMR 81-15 insulation. The aft-closure insulator, exit cones, and piston cap were made of carbon phenolic. The throat inserts were ATJ graphite machined to 0.28 in. ID.

b. Series 2

(1) Ambient Temperature Firings

(a) Test II-16

The chamber and grain assembly for this motor is shown in Figure 50, but with the aft end insulator modified with an extra layer of SMR 81-15. It was assembled with a straight nozzle aft-closure (Figure 49, Configuration B). The aft-closure insulator was made of MX 4925 and the exit cones of silica phenolic. Two of the ATJ graphite throat inserts were 0.5-in. long and two inserts were 0.75-in. long. The steel sleeve was installed on one each of the exit cones containing the short and long inserts. The igniter with 9 gm of BPN pellets was an aft-end model bonded to a piston cap made of MX 4926. The motor operated successfully at +70°F for full duration. The motor hardware remained intact. The one exit cone with a long throat insert and no steel sleeve showed some delamination. However, the short insert with no steel sleeve had burned off.

(b) Test II-17

This motor (Figure 50) was the first to be tested from propellant Cast Lot 3. This motor lot was fabricated with 3-in.-long aft-end insulator in contrast to the previous motor lot which was made with 10-in.-long insulators. As a result of this modification, the characteristic dip plateau in the pressure-time curve of previous tests was eliminated. The igniter charge was reduced to 7 gm for this and subsequent tests. Like motor Test II-16, Test II-17 also had two short and two long nozzle inserts and the same steel sleeve set-up. The exit cones, however, were made of carbon fiber phenolic (MX 4925) instead of silica phenolic. Postfiring examination gave results similar to Test II-16, namely, the long insert plus sleeve combination was best, the short insert plus sleeve was next best, the long insert without sleeve next, while the short insert without sleeve was the least desirable.

(2) Temperature Cycling Tests

Four motors were temperature cycled and fired, two at each temperature extreme.

II.C. Development Test Results (cont)

(a) Test II-18

The chamber and grain assembly for this test is shown in Figure 55. The forward insulator was extended to provide additional sidewall coverage and the cup was made deeper. The aft insulator was molded of SMR-81-15 into a 3-in. wide band 0.125-in. thick at the aft end tapered to 0.025 in. at the forward end. Only the forward insulator was released with RTV 587 Silastic, thus making this unit essentially case bonded, as shown in Figure 55. The motor was assembled with the "work horse" type aft closure. It was temperature cycled from ambient to -65°F three times, followed by cycling from +150 to -65°F three times. The motor was successfully fired at -65°F.

(b) Test II-19

This unit was a duplicate of Test Motor II-18, above, received identical environmental treatment, and was also successfully fired at -65°F. This confirmed the capabilities of the case-bonded design at the low temperature extreme.

(c) Test II-20

This motor had a case-bonded grain and was released only at the forward insulator head. The chamber was insulated with the forward insulator and with an aft insulator molded of SMR 81-15 into a 3-in. wide band 0.125-in. thick at the aft edge tapered to 0.025 in. at the forward edge. It was released at the forward insulator only, using RTV 587.

The motor was temperature cycled three times from 150 to -65°F in the following 24 hr program: 7 hr up to temperature, 5 hr soak, 7 hr down to the cold extreme, and 5 hr soak cold. The motor was conditioned at +150°F and test fired. The motor ran full duration; however, a nozzle insert in the "work horse" closure with canted nozzles eroded through and the resulting gas flow burned off an adjacent exit cone.

Because of the nozzle failure on this and other motors fired at about the same time an investigation was initiated to improve the nozzle design. Tests of improved nozzle designs were made in component tests described in the previous section. Eight tests were conducted subsequent to this test (II-20). Descriptions of following tests that were conducted prior to this improved nozzle test will be noted.

(d) Test II-21

This motor was temperature cycled from -65 to +150°F and test fired at +150°F in accordance with the original test plan. No grain cracking, unbond, or other propellant abnormalities were observed during visual and X-ray examination subsequent to temperature cycling. This motor was also used as a nozzle materials evaluation test for an integrally molded aft closure. Throat inserts were Carbitex-700 and the insulation was MCX-313 (Design A-2, Figure 52). The throat inserts were not coated and a consumable Nylon paper expansion washer was used. Postfire examination showed no evidence of insert ejection or cracking and erosion (about 19 mils/sec) was considered acceptable.

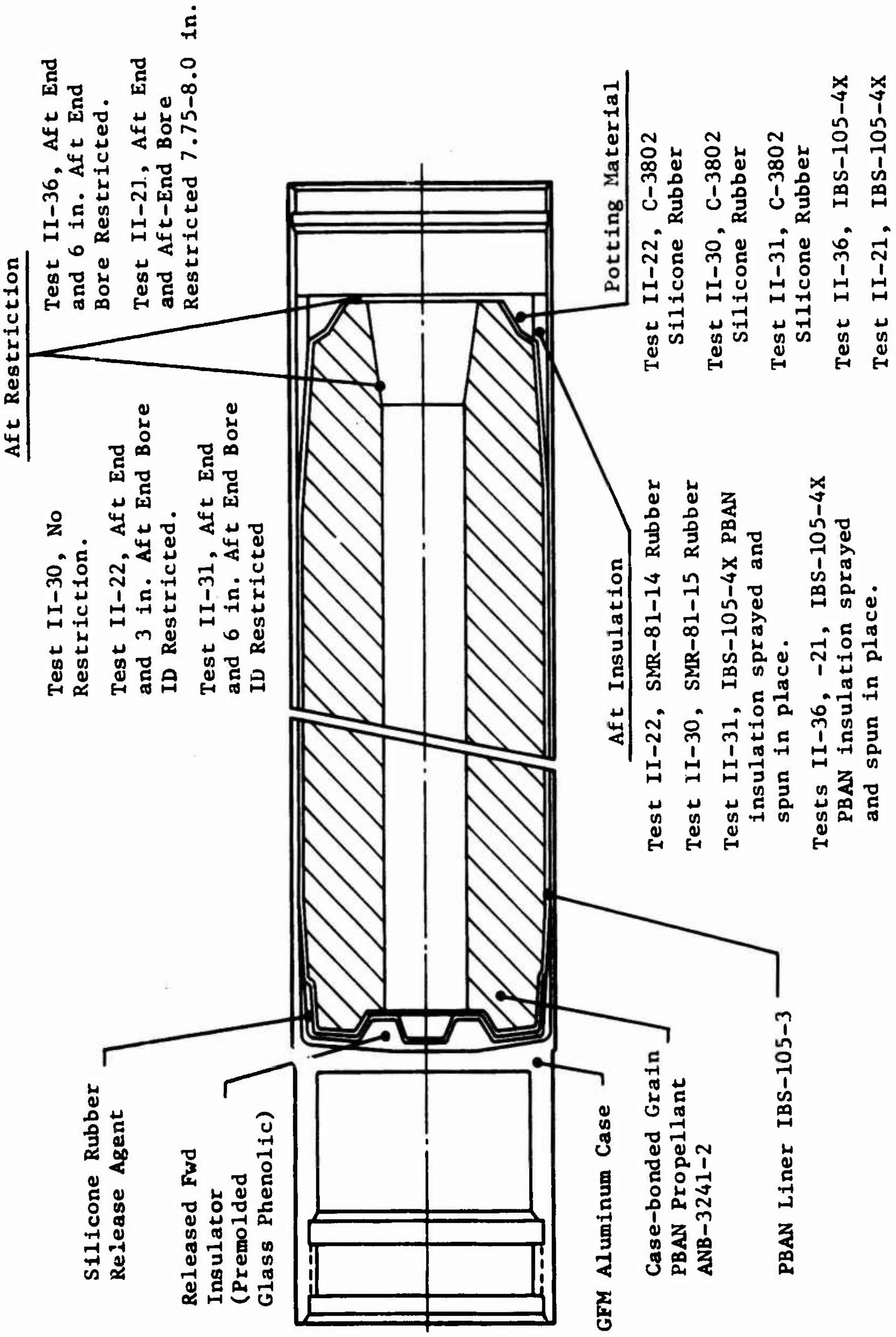
(3) Vibration Tests

Six motors were originally scheduled for vibration tests. As a result of agreements with the Air Force, this quantity was reduced to two, both tests at -65°F.

(a) Test II-22

The chamber and grain assembly for this firing at -65°F (Figure 58) included restriction (0.01 in. thick) on the aft face of the grain and on 3 in. of the bore ID at the aft end. Sidewall liner, IBS-105-3, was used as the restriction material. Prior to firing, the chamber and grain assembly was temperature cycled from -65 to +150°F and then vibrated at -65°F for 60 hr as follows: 30 hr total in the longitudinal axis (15 hr at each of resonant frequencies of 200 and 20 cps) and 30 hr in the vertical axis (15 hr at each of the resonant frequencies of 200 and 20 cps). Visual and X-ray inspection revealed no bond separations, propellant cracking, or other abnormalities. The test aft-closure was installed; the motor was conditioned to -65°F and successfully fired. Test results showed that an additional reduction in ignition peak pressure was needed when the data was extrapolated to the peak pressure for a +150°F firing.

This motor was also utilized as a materials evaluation test. It used a net-molded aft closure containing Carbitex-700 throat inserts. This aft closure is shown as Design A-2 in Figure 52; the throat inserts were uncoated and a Nylon paper expansion washer was used. Postfiring examination showed no evidence of insert ejection or cracking. Further, the calculated erosion rate was 17 mils/sec which compares favorably with the 15 mils/sec for inserts of ATJ graphite. The calculated loss in velocity is very slight with no apparent loss in range.



2.75 in. Chamber and Grain Assembly

Figure 58

(b) Test II-23

During firing of this motor at -65°F the expended squib case came loose from the slotted insulator and was expelled through one of the nozzles at 0.235 seconds after ignition. The nozzle throat insert was ejected at 0.92 seconds apparently as a result of damage caused by the squib case.

(4) Flight Acceleration and Spin Tests

Three motors were fired at ambient temperature in the spin fixture at Langley Research Center. Two were temperature cycled prior to the firing. The chamber and grain assembly for Tests II-28 and -29 was the same as shown in Figure 58, except that the aft end insulator was IBS-105-4X material sprayed in place while the aft-closure configuration was the same as shown in Figure 52 Configuration B. Test II-26 was conducted with the chamber grain assembly shown in Figure 50.

(a) Test II-24

The chamber and grain assembly was the same as shown in Figure 57 except that IBS-105-4X insulation was used on the aft end insulator. It was considered necessary to add a 0.005-in. thick shim to the lock wire, because of chamber ovality. The motor functioned well in the spin fixture.

(b) Test II-25

The test was identical to the one above, including the lock wire shim. The motor was temperature cycled prior to firing.

(c) Test II-26

The chamber and grain configuration was like that shown in Figure 50. This motor was tested in the centrifuge at ambient conditions and performed well. It was also temperature cycled prior to firing.

c. Series 3

(1) Ambient Temperature Firing

(a) Test II-27

This unit was assembled with the longer (1.12 in.) forward insulator (Figure 55). This motor like motor II-18 above, was released on the forward end only, approximately 0.75 in. up the inside of the forward insulator. The motor was fired at +70°F and was intended to be the Batch Acceptance firing of Cast Lot 5 which included the motors for shipment to Eglin. However, on firing, one nozzle was ejected at 0.55 sec and a second at 1.3 sec. Postfiring examination revealed that the carbon phenolic parts and the mating graphite insert were assembled to such a tight tolerance that the expansion of the throat inserts during firing cracked the carbon phenolic parts as in the net molded case cited above.

(b) Test II-28

This motor was assembled the same as for Test II-27 above, except that a 40 mil relief or expansion gap was machined into the carbon phenolic aft-closure insulator abutting the forward face of the throat insert. The relief gap was potted with a soft silicone rubber. This relief was to fix the Eglin aft closures already assembled like that used for Test II-27. On firing at +70°F, however, two exit cones were ejected at 1 sec. The motor continued for a total duration of approximately 3 sec, but at a reduced pressure of 825 psig. Apparently the 40-mil machined gap provided a path for heat transfer sufficient to overcome the insulation barrier. Both carbon phenolic and silica phenolic behaved the same way. (See Component Test 9.)

(c) Test II-29

This motor was fired successfully at 70°F for full duration.

(2) Temperature Cycling Tests

Five motors were originally scheduled for temperature cycling tests, by agreement with the Air Force this quantity was reduced to two, both fired at -65°F.

(a) Test II-30

The chamber and grain assembly (Figure 58) was successfully temperature cycled from -65 to +150°F, then assembled with the test aft closure, and fired at -65°F. Performance of the propellant grain and igniter was generally satisfactory; however, improved tailoff performance and reduction of the ignition peak pressure were considered necessary. A lower ignition peak pressure was required to avoid exceeding the maximum operating pressure (MEOP) of 1990 psig during firing at +150°F.

II.C. Development Test Results (cont)

This firing was also utilized to evaluate nozzle materials. A net-molded nozzle, Design A-1, with throat inserts of MX 4926 (Figure 52) was used in this with the grain and chamber assembly shown in Figure 58. Early selection and testing were made to demonstrate grain and aft-closure integrity in order to provide flight delivery motors in time to meet critical flight test dates. Examination of the fired aft closure showed that the throat inserts were retained, but that some cracking was evident. As expected, the throat insert material exhibited excessive erosion (about 30 mil/sec compared to 15 mil/sec for ATJ). It was calculated that 30 mil/sec would cause a reduction in burnout velocity of 175 ft/sec, which is not satisfactory from a performance standpoint.

(b) Test II-31

The ID bore restriction for this test motor was increased to 6 in. as a result of the data gained from Test II-22 (Figure 58). The motor was temperature cycled and then fired at -65°F. Ignition peak pressure was deemed satisfactory when extrapolated to the peak pressure for a +150°F firing.

This motor was also used for a materials evaluation test for throat-insert material Pyrocarb 458, which is similar to Carbitex-700. The material was evaluated in the interest of providing a second material source and lower cost. Design A-2 of Figure 52 (Nylon washer and uncoated insert) was used.

(3) Vibration Tests

By agreement with the Air Force, these six tests were deleted.

(4) Flight Acceleration and Spin Tests

(a) Test II-32

This test and motor configuration (Figure 50) was identical to the one used in Test II-26. The trailing sidewall of the chamber on both the motors tested in the centrifuge had a small burn through during tail-off because of the Coriolis force effect of planar rotation. This was a function of the test apparatus and not the insulation design and manufacture.

d. Additional Tests

A total of four additional tests were made to verify performance and evaluate components.

(1) Test II-33

The chamber and grain assembly for this motor is shown in Figure 50, except that the aft insulator was IBS-105-4X sprayed and cured in the chamber. The aft closure was transfer molded of WB 8517 carbon phenolic, with a 0.6 in. diameter tapered graphite insert later machined to a 0.28 in. throat with a 40 mil expansion gap as described before. This was the first closure using tapered inserts. The motor was fired for full duration at +150°F. The hardware remained intact and in good condition.

This design provides more insulation; also the tapered throat inserts have more bearing surface to resist ejection, and cause less load on the shell portion of the nozzle.

II.C. Development Test Results (cont)

(2) Test II-34

This motor was like that for Test II-33, except that the carbon phenolic transfer-molding material was MXC-313. It was tested for full duration at +150°F. All hardware was in good condition after firing. This configuration is similar to the candidate for PFRT and gave additional confidence for the motors shipped to Eglin AFB for flight tests.

(3) Test II-35

This chamber was insulated like that shown in Figure 50, but was fully case bonded. It was assembled with a net molded closure. Carbon phenolic, MXC-313, was used. A built-in relief was provided for the graphite throat insert. This was accomplished by painting and curing Epon 913 0.25-in. thick on the forward face of the tapered insert. The motor was fired at ambient condition, ran for full duration, and all hardware remained intact. Postfiring examination showed the throat erosion to be very uniform. This was attributed to the tunnel entrance section leading to the throats.

(4) Test II-36 - Chamber 2610

This was largely a materials evaluation test conducted at +70°F with an integrally-molded aft closure containing Carbitex-700 throat inserts and MXC-313 insulation (Design A-2 of Figure 52). The throat inserts were uncoated and a consumable Nylon paper expansion washer was used. Postfiring examination showed no evidence of insert ejection or cracking. Carbitex-700 exhibited the same acceptable amount of throat erosion (about 18 mils/sec) as previously experienced at -65 and +150°F. Prior to firing, the chamber and grain assembly was temperature cycled from -65 to +150°F.

D. PRELIMINARY FLIGHT RATING TESTS - PHASE III

1. General

The test plan shown in Figure 59 is in general accordance with Specification MIL-R-25535 and consists of 45 motors. Of the 45 motors, 18 were only temperature conditioned before firing; six each were fired at -65, +70, and +150°F. Twenty of the 45 motors were sequentially environmentally tested and fired; eight at -65°F, four at +70°F, and eight at +150°F. The remaining seven motors were tested as follows: three altitude firings, one acceleration firing, one acceleration firing with a temperature gradient across the grain, and two firings with a temperature gradient across the grain. Successful completion of this testing demonstrated motor readiness to enter qualification.

Shortly after the start of the PFRT environmental testing, temperature cycling of four other Improved 2.75-in. motors from Cast Lot 7 was initiated as part of the propellant characterization work. Routine inspection of the motors showed that the grains in Motors 2706 and 2707 had cracked at gouges and/or deep scratches on the bore surface after one cycle over the required temperature range of -65 to +150°F. Investigation revealed that the defects were caused by a trim tool, which was inserted into the bore to cut and remove the liner on the forward head insulator exposed to the bore. Liner removal in this area is necessary so that the liner release boot on the forward end of the grain will be pressurized upon motor ignition.

Improved 2.75-in. FFAR PFRT Motor Test Plan

Figure 59

(U) Steps taken to eliminate a recurrence of this difficulty included the design of a new liner trim tool. The design incorporates a protective sleeve to shield the tool edges from the adjacent bore surface curing tool insertion, liner cutting, and tool removal. Further, all PFRT motors, including the 20 motors in environmental testing, were bore inspected and replacements were made for the units exhibiting cracks, gouges and/or scratches.

(U) All motor environmental tests and static firings were successful, with the exception of one motor fired at -65°F wherein one integrally molded exit cone separated from the aft-closure and allowed the loss of the Carbitex throat insert. Subsequent investigation indicated that this partial failure may have been partially due to improper handling of the motor or to a defect in the manufacture of the aft closure.

(U) Ballistic data from 40 to the 45 motors provided valid usable impulse values. The remaining five motors were excluded because four were either temperature grandient or acceleration firings, and the fifth motor was invalidated by the exit-cone malfunction. Analysis of the data from the 40 motors shows that the usable impulse comfortably exceeds the specified usable impulse values at -65, +70, and +150°F.

(U) A description of the environmental tests is given in Appendix D. A computer summary of the ballistic data, together with calculated nominal and minus one-sigma values, is given in Figures 60 through 63, and computer printouts of the ballistic tabulations and performance curves of 43 of the 45 motors are presented in Figures 64 through 106. The remaining two motors were acceleration firings at Edwards Air Force Base. Figures 107 through 109 show typical motor conditions before and after firings.

2.75 PEAK -65 DEG.F

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-E01-0A-	DATE FIRED	DELTA TD SEC	DELTA TR SEC	DELTA TA SEC	DELTA TB SEC	W DOT LB/SEC	CW	PIGN MAX PSIA	PC MAX PSIA	PC AVG PSIA
10-35	5	002	072568	.018	.022	3.422	2.565	2.34	.00658	1824	1505	1174
12-21	20	011	080868	.021	.017	3.257	2.445	2.50	.00609	1795	1484	1204
12-24	21	012	080868	.023	.016	3.233	2.397	2.50	.00601	1845	1465	1180
12-19	6	013	080868	.020	.019	3.261	2.453	2.49	.00598	1590	1463	1162
12-49	9	018	081568	.016	.019	3.204	2.503	2.52	.00603	1592	1530	1227
12-65	44	019	081568	.024	.009	3.199	2.455	2.52	.00614	1565	1530	1227
12-13	35	022	081568	.013	.015	3.234	2.426	2.49	.00596	1830	1501	1206
12-63	36	029	081568	.020	.035	3.240	2.518	2.50	.00602	1480	1512	1210
11-11	42	034	081768	.021	.025	3.257	2.505	2.48	.00598	1773	1489	1203
11-37	27	035	081768	.020	.023	3.300	2.465	2.44	.00605	1829	1473	1160
11-30	43	037	081768	.026	.024	3.350	2.530	2.38	.00574	1565	1471	1173
10-12	12	038	081768	.018	.020	3.502	2.550	2.29	.00597	1569	1400	1135
10-07	41	042	082768	.013	.028	3.501	2.500	2.29	.00596	1441	1428	1145
10-77	13	043	082768	.026	.027	3.489	2.637	2.29	.00594	1666	1404	1132
10-85	28	044	082768	.015	.020	3.459	2.640	2.31	.00584	1739	1412	1141
OPERATION LOCATIONS			1 1	1 2	1 3	1 4	1 5	1 6	1 7	1 8	1 9	1 10

Legend:

DELTA TD	Ignition delay time
DELTA TR	Ignition rise time
DELTA TA	Action time
DELTA TB	Seb burn time
W DOT	Mass flow rate
CW	Mass flow coefficient
PIGN MAX	Maximum ignition pressure
PC MAX	Maximum pressure
PC AVG	Average action time pressure

Ballistic Data Summary for -65°F (u)

Figure 60, Sheet 1 of 4

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-B01-0A-	I 15G LB-SEC	IA LB-SEC	ID LB-SEC	ISP	ISP(DA)	FY MAX LB	FIGN MAX LB	FYA AVG LB	FYB AVG LB	RB IN/SEC
10-35	5	002	1821	1930	1944	243.2	152.0	762	602	564	623	.350
12-21	20	011	1800	1903	1913	236.2	150.6	793	609	588	643	.367
12-24	21	012	1805	1904	1918	237.8	151.6	783	599	589	637	.375
12-19	6	013	1800	1902	1912	235.7	150.8	795	509	583	631	.360
12-49	9	018	1803	1901	1910	236.0	150.7	802	518	593	650	.359
12-65	44	019	1806	1903	1912	237.4	150.6	806	505	595	639	.366
12-13	35	022	1801	1900	1909	236.9	150.9	796	592	586	643	.370
12-63	36	029	1813	1907	1916	236.4	150.6	794	462	589	642	.357
11-11	42	034	1800	1893	1913	237.2	151.2	783	583	581	634	.358
11-37	27	035	1780	1886	1897	235.5	150.2	776	592	572	627	.356
11-30	43	037	1775	1887	1896	237.5	150.1	774	521	562	610	.355
10-12	12	038	1787	1910	1917	239.1	151.2	741	501	545	596	.347
10-07	41	042	1774	1894	1902	237.5	150.0	740	450	541	590	.359
10-77	13	043	1788	1901	1910	239.2	150.9	742	547	545	600	.341
10-85	28	044	1781	1890	1904	238.0	150.2	728	568	546	593	.340
OPERATIONSLOCATIONS			1 11	1 12	1 13	1 14	1 15	1 16	1 17	1 18	1 19	1 20

Legend:

I 15G	Impulse at 15 g
IA	Action time impulse
ID	Total impulse
ISP	Specific impulse
ISP(DA)	Total impulse / Motor weight
FY MAX	Maximum thrust
FIGN MAX	Maximum ignition thrust
FYA AVG	Average action time thrust
FYB AVG	Average burn time thrust
RB	Burning rate

Ballistic Data Summary for -65°F (u)

Figure 60, Sheet 2 of 4

Parameter	Statistic	Value	Extreme	Value	Run	No.	Sum	Value	Location	No.
DELTA TO SEC	SIGMA =	0.0042					SUM	= 0.294000092894D 00	LOC A	2
	XBAR =	0.0196	MINIMUM =	0.0130	12-13	022	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	0.0260	11-30	037	SQUARES	= 0.600600376451D-02	LOC B	0
DELTA TR SEC	SIGMA =	0.0061					SUM	= 0.321000102907D 00	LOC A	3
	XBAR =	0.0214	MINIMUM =	0.0090	12-65	019	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	0.0350	12-63	029	SQUARES	= 0.739300475937D-02	LOC B	0
DELTA TA SEC	SIGMA =	0.1163					SUM	= 0.498960123062D 02	LOC A	4
	XBAR =	3.3264	MINIMUM =	3.1990	12-65	019	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	3.5020	10-12	038	SQUARES	= 0.166165333874D 03	LOC B	0
DELTA TB SEC	SIGMA =	0.0734					SUM	= 0.376290073395D 02	LOC A	5
	XBAR =	2.5086	MINIMUM =	2.3970	12-24	012	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	2.6400	10-85	044	SQUARES	= 0.944715579204D 02	LOC B	0
W OUT LB/SEC	SIGMA =	0.0963					SUM	= 0.363369979858D 02	LOC A	6
	XBAR =	2.4225	MINIMUM =	2.2900	10-12	038	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	2.5200	12-49	018	SQUARES	= 0.881495368773D 02	LOC B	0
CW	SIGMA =	0.0002					SUM	= 0.902900435030D-01	LOC A	7
	XBAR =	0.0060	MINIMUM =	0.0057	11-30	037	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	0.0066	10-35	002	SQUARES	= 0.543950224740D-03	LOC B	0
PIGN MAX PSIA	SIGMA =	137.6776					SUM	= 0.251430000000D 05	LOC A	8
	XBAR =	1676.2000	MINIMUM =	1441.0000	10-07	042	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	1845.0000	12-24	012	SQUARES	= 0.424100690000D 08	LOC B	0
PC MAX PSIA	SIGMA =	43.1755					SUM	= 0.220720000000D 05	LOC A	9
	XBAR =	1471.4667	MINIMUM =	1400.0000	10-12	038	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	1530.0000	12-49	018	SQUARES	= 0.325043100000D 08	LOC B	0
PC AVG PSIA	SIGMA =	31.5791					SUM	= 0.177250000000D 05	LOC A	10
	XBAR =	1181.6667	MINIMUM =	1135.0000	10-12	038	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	1227.0000	12-49	018	SQUARES	= 0.209590030000D 08	LOC B	0
I TSG LB-SEC	SIGMA =	14.0550					SUM	= 0.269340000000D 05	LOC A	11
	XBAR =	1795.6000	MINIMUM =	1774.0000	10-07	042	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	1821.0000	10-35	002	SQUARES	= 0.483654560000D 08	LOC B	0
IA LB-SEC	SIGMA =	16.7933					SUM	= 0.265110000000D 05	LOC A	12
	XBAR =	1900.7333	MINIMUM =	1866.0000	11-37	035	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	1730.0000	10-35	002	SQUARES	= 0.541934390000D 08	LOC B	0
IU LB-SEC	SIGMA =	11.2176					SUM	= 0.286730000000D 05	LOC A	13
	XBAR =	1911.5333	MINIMUM =	1896.0000	11-30	037	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	1944.0000	10-35	002	SQUARES	= 0.548111570000D 08	LOC B	0
ISP	SIGMA =	1.8954					SUM	= 0.356480073547D 04	LOC A	14
	XBAR =	237.6534	MINIMUM =	235.5000	11-37	035	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	243.2001	10-35	002	SQUARES	= 0.847237249701D 06	LOC B	0
ISPIDAL	SIGMA =	0.5599					SUM	= 0.226160038757D 04	LOC A	15
	XBAR =	150.7734	MINIMUM =	150.0000	10-07	042	SUM OF		OPER.	1
	NUMBER =	15	MAXIMUM =	152.0000	10-35	002	SQUARES	= 0.340993476377D 06	LOC B	0
		171					SUM	= 0.116150000000D 05	LOC A	16
		333	MINIMUM =	720.0000	10-85	044	SUM OF		OPER.	1
			MAXIMUM =	800.0000	12-65	019	SQUARES	= 0.900306900000D 07	LOC B	0

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Ballistic Data Summary for -65°F (u)

Figure 60, Sheet 3 of 4

FIGN MAX	SIGMA =	22.5581					SUM	= 0.8158000000000D 04	LOC A 17
LB	XBAR =	543.8667	MINIMUM =	450.0000	10-07	042	SUM OF		OPER. 1
	NUMBER =	15	MAXIMUM =	609.0000	12-21	011	SQUARES	= 0.4475552000000D 07	LOC B 0
FVA AVG	SIGMA =	19.8581					SUM	= 0.8581000000000D 04	LOC A 18
LB	XBAR =	572.0667	MINIMUM =	541.0000	10-07	042	SUM OF		OPER. 1
	NUMBER =	15	MAXIMUM =	595.0000	12-65	019	SQUARES	= 0.4914425000000D 07	LOC B 0
FVB AVG	SIGMA =	20.4241					SUM	= 0.9360000000000D 04	LOC A 19
LB	XBAR =	624.0000	MINIMUM =	590.0000	10-07	042	SUM OF		OPER. 1
	NUMBER =	15	MAXIMUM =	650.0000	12-49	018	SQUARES	= 0.5846480000000D 07	LOC B 0
RB	SIGMA =	0.0102					SUM	= 0.5366001605999D 01	LOC A 20
IN/SEC	XBAR =	0.3577	MINIMUM =	0.3400	10-85	044	SUM OF		OPER. 1
	NUMBER =	15	MAXIMUM =	0.3750	12-24	012	SQUARES	= 0.1921053151180D 01	LOC B 0

Ballistic Data Summary for -65°F (u)

Figure 60, Sheet 4 of 4

2.75 FFAR — +70 DEG.F

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-E01-OA-	DATE FIRED	DELTA TD SEC	DELTA TR SEC	DELTA TA SEC	DELTA TB SEC	W DOT LB/SEC	CW	PIGN MAX PSIA	PC MAX PSIA	PC AVG PSIA
11-10	3	001	072568	.010	.010	2.766	2.205	2.89	.00612	2201	1708	1412
31-06	19	004	080868	.014	.021	3.044	2.220	2.65	.00594	1866	1838	1302
27-26	18	005	080868	.015	.034	2.906	2.273	2.78	.00597	1667	1736	1328
27-27	4	006	080868	.009	.020	2.896	2.251	2.79	.00599	2258	1728	1349
12-85	29	014	081468	.016	.021	2.860	2.208	2.63	.00607	1686	1769	1340
31-37	31	015	081468	.016	.026	3.078	2.276	2.60	.00612	1681	1772	1258
31-43	34	016	081468	.018	.026	3.074	2.175	2.61	.00609	1580	1743	1274
10-31	40	030	081768	.036	.018	3.027	2.380	2.65	.00604	1669	1622	1295
11-31	10	031	081768	.012	.014	2.890	2.208	2.76	.00597	2215	1703	1363
11-36	11	032	081768	.016	.022	2.920	2.212	2.74	.00605	1983	1681	1329
10-03	25	033	081768	.018	.028	3.038	2.323	2.63	.00593	1672	1627	1269
OPERATION LOCATIONS			1 1	1 2	1 3	1 4	1 5	1 6	1 7	1 8	1 9	1 10

Legend:

DELTA TD	Ignition delay time
DELTA TR	Ignition rise time
DELTA TA	Action time
DELTA TB	Web burn time
W DOT	Mass flow rate
CW	Mass flow coefficient
PIGN MAX	Maximum ignition pressure
PC MAX	Maximum pressure
PC AVG	Average action time pressure

Ballistic Data Summary for +70°F (u)

Figure 61, Sheet 1 of 4

2.75 PEAK +70 DEG.F

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-E01-OA-	I 15G LB-SEC	IA LB-SEC	ID LB-SEC	ISP	ISP(DA)	FY MAX LB	FIGN MAX LB	FYA AVG LB	FYB AVG LB	RB IN/SEC
11-10	3	001	1829	1923	1947	243.4	152.8	894	740	695	738	.407
31-08	19	004	1775	1908	1916	237.4	151.2	830	561	626	680	.403
27-26	18	005	1814	1926	1937	240.1	152.5	938	506	662	725	.395
27-27	4	006	1811	1924	1934	239.4	152.6	907	684	664	727	.399
12-65	29	014	1820	1946	1943	239.9	153.2	895	552	676	740	.407
31-37	31	015	1745	1904	1915	239.8	150.8	845	540	619	692	.395
31-43	34	016	1761	1900	1910	236.3	150.7	841	551	618	680	.413
10-33	40	030	1801	1924	1933	240.7	152.8	851	559	636	697	.376
11-31	10	031	1803	1914	1924	239.4	152.3	893	726	682	720	.407
11-36	11	032	1792	1910	1920	239.9	152.3	885	650	654	720	.400
10-03	25	033	1799	1921	1931	241.5	152.1	850	545	632	715	.386
OPERATION+LOCATIONS			1 11	1 12	1 13	1 14	1 15	1 16	1 17	1 18	1 19	1 20

Legend:

I 15G	Impulse at 15 g
IA	Action time impulse
ID	Total impulse
ISP	Specific impulse
ISP(DA)	Total Impulse / Motor Weight
FY MAX	Maximum thrust
FIGN MAX	Maximum ignition thrust
FYA AVG	Average action time thrust
FYB AVG	Average burn time thrust
RB	Burning rate

Ballistic Data Summary for +70°F (u)

Figure 61, Sheet 2 of 4

DELTA TO SEC	SIGMA =	0.0067					SUM	= 0.174000050873D 00	LOC A 2
	XBAR =	0.0156	MINIMUM =	0.0090	27-27	006	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	0.0340	10-33	030	SQUARES	= 0.319800203186D-02	LOC B 0
DELTA TR SEC	SIGMA =	0.0066					SUM	= 0.240000072867D 00	LOC A 3
	XBAR =	0.0218	MINIMUM =	0.0100	11-10	001	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	0.0340	27-26	005	SQUARES	= 0.567800356758D-02	LOC B 0
DELTA TA SEC	SIGMA =	0.1026					SUM	= 0.325010080338D 02	LOC A 4
	XBAR =	2.9546	MINIMUM =	2.7660	11-10	001	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	3.0780	31-37	015	SQUARES	= 0.961338524593D 02	LOC B 0
DELTA TB SEC	SIGMA =	0.0618					SUM	= 0.247430047989D 02	LOC A 5
	XBAR =	2.2494	MINIMUM =	2.1750	31-43	016	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	2.3860	10-33	030	SQUARES	= 0.556942507802D 02	LOC B 0
W DOT LB/SEC	SIGMA =	0.0989					SUM	= 0.299499968556D 02	LOC A 6
	XBAR =	2.7227	MINIMUM =	2.6000	31-37	015	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	2.8900	11-10	001	SQUARES	= 0.816434938660D 02	LOC B 0
CW	SIGMA =	0.0001					SUM	= 0.662900283933D-01	LOC A 7
	XBAR =	0.0060	MINIMUM =	0.0059	10-03	033	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	0.0061	11-10	001	SQUARES	= 0.399530664333D-03	LOC B 0
PIGN MAX PSIA	SIGMA =	257.9993					SUM	= 0.204780000000D 05	LOC A 8
	XBAR =	1861.6364	MINIMUM =	1560.0000	31-43	016	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	2258.0000	27-27	006	SQUARES	= 0.387682260000D 08	LOC B 0
PC MAX PSIA	SIGMA =	63.3092					SUM	= 0.189270000000D 05	LOC A 9
	XBAR =	1720.6364	MINIMUM =	1622.0000	10-33	030	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	1838.0000	31-06	004	SQUARES	= 0.326065650000D 08	LOC B 0
PC AVG PSIA	SIGMA =	44.1998					SUM	= 0.145390000000D 05	LOC A 10
	XBAR =	1321.7273	MINIMUM =	1258.0000	31-37	015	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	1412.0000	11-10	001	SQUARES	= 0.192361290000D 08	LOC B 0
I ISG LB-SEC	SIGMA =	25.6451					SUM	= 0.197500000000D 05	LOC A 11
	XBAR =	1795.4545	MINIMUM =	1745.0000	31-37	015	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	1829.0000	11-10	001	SQUARES	= 0.354668040000D 08	LOC B 0
IA LB-SEC	SIGMA =	10.6941					SUM	= 0.210650000000D 05	LOC A 12
	XBAR =	1910.8182	MINIMUM =	1900.0000	31-43	016	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	1934.0000	12-85	014	SQUARES	= 0.404172550000D 08	LOC B 0
IG LB-SEC	SIGMA =	12.0567					SUM	= 0.212100000000D 05	LOC A 13
	XBAR =	1928.1818	MINIMUM =	1910.0000	31-43	016	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	1947.0000	11-10	001	SQUARES	= 0.408981900000D 08	LOC B 0
ISP	SIGMA =	1.5728					SUM	= 0.263980056763D 04	LOC A 14
	XBAR =	239.9819	MINIMUM =	237.4001	31-06	004	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	243.4001	11-10	001	SQUARES	= 0.633529012417D 06	LOC B 0
ISPIDAL	SIGMA =	0.8432					SUM	= 0.167300032043D 04	LOC A 15
	XBAR =	152.0909	MINIMUM =	150.7000	31-43	016	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	153.2000	12-85	014	SQUARES	= 0.254455297470D 06	LOC B 0
		...665					SUM	= 0.959900000000D 04	LOC A 16
		...364	MINIMUM =	830.0000	31-06	004	SUM OF		OPER. 1
			MAXIMUM =	908.0000	27-26	005	SQUARES	= 0.836495500000D 07	LOC B 0

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Ballistic Data Summary for +70°F (u)

Figure 61, Sheet 3 of 4

FIGN MAX	SIGMA =	84.2296					SUM	= 0.6596000000000D 04	LOC A 17
LB	XBAR =	599.6364	MINIMUM =	506.0000	27-26	005	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	740.0000	11-10	001	SQUARES	= 0.4026148000000D 07	LOC B 0
FVA AVG	SIGMA =	25.0574					SUM	= 0.7144000000000D 04	LOC A 16
LB	XBAR =	649.4545	MINIMUM =	618.0000	31-43	016	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	695.0000	11-10	001	SQUARES	= 0.4645982000000D 07	LOC B 0
FVR AVG	SIGMA =	19.9672					SUM	= 0.7853000000000D 04	LOC A 19
LB	XBAR =	713.9091	MINIMUM =	686.0000	31-06	004	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	740.0000	12-65	014	SQUARES	= 0.5610315000000D 07	LOC B 0
RB	SIGMA =	0.0109					SUM	= 0.4394001245500D 01	LOC A 20
IN/SEC	XBAR =	0.3995	MINIMUM =	0.3760	10-33	030	SUM OF		OPER. 1
	NUMBER =	11	MAXIMUM =	0.4130	31-43	016	SQUARES	= 0.1756384996720D 01	LOC B 0

Ballistic Data Summary for +70°F (u)

Figure 61, Sheet 4 of 4

2.75 FFAR +150 DEG.F

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-E01-OA-	DATE FIRED	DELTA TD SEC	DELTA TR SEC	DELTA TA SEC	DELTA TB SEC	W DOT LB/SEC	CW	PIGN MAX PSIA	PC MAX PSIA	PC AVG PSIA
10-18	1	003	073068	.016	.019	2.829	2.167	2.80	.00594	2126	1858	1391
12-07	17	007	080868	.026	.021	2.692	2.027	2.99	.00602	2116	1637	1412
12-44	2	008	080868	.015	.010	2.685	2.037	3.00	.00609	2152	1657	1431
12-03	16	009	080868	.008	.018	2.678	2.084	3.02	.00801	1709	1857	1420
12-39	31	010	080868	.010	.014	2.704	2.045	2.98	.00600	2173	1671	1421
12-41	32	017	081468			2.705	2.058	2.98	.00600		1844	1437
10-48	37	023	081568	.027	.038	3.009	2.253	2.67	.00615	1463	1670	1266
10-88	7	024	081568	.011	.014	2.816	2.192	2.81	.00597	1899	1871	139[illegible]
10-92	8	025	081568	.012	.018	2.848	2.149	2.81	.00598	2454	1824	1382
11-35	39	026	081568	.016	.018	2.776	2.110	2.89	.00615	2300	1713	1366
11-21	23	027	081568	.017	.011	2.696	2.050	2.97	.00596	2293	1891	1457
10-51	38	028	081568	.022	.026	2.847	2.129	2.81	.00590	2490	1755	1374
10-09	22	039	082768	.026	.038	2.864	2.212	2.80	.00600	1848	1751	1367
10-44	24	040	082768	.021	.018	2.880	2.241	2.78	.00598	1563	1696	1354
OPERATIONS+LOCATIONS			1 1	1 2	1 3	1 4	1 5	1 6	1 7	1 8	1 9	1 10

Legend:

DELTA TD	Ignition delay time
DELTA TR	Ignition rise time
DELTA TA	Action time
DELTA TB	Web burn time
W DOT	Mass flow rate
CW	Mass flow coefficient
PIGN MAX	Maximum ignition pressure
PC MAX	Maximum pressure
PC AVG	Average action time pressure

Ballistic Data Summary for +150°F (u)

Figure 62, Sheet 1 of 4

2.75 FFAR +150 DEG.F

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-E01-0A-	I 15G LB-SEC	IA LB-SEC	ID LB-SEC	ISP	ISP(DA)	FY MAX LB	FIGN MAX LB	FYA AVG LB	FYB AVG LB	RB IN/SEC
10-18	1	003	1813	1938	1947	245.6	153.5	906	675	665	756	.411
12-C7	17	007	1821	1938	1948	241.7	153.7	962	704	720	787	.443
12-44	2	008	1812	1924	1941	241.1	153.1	956	689	718	788	.441
12-03	16	009	1814	1930	1941	239.8	153.1	967	549	721	780	.431
12-39	31	010	1812	1940	1951	241.9	153.0	962	746	717	775	.439
12-41	32	017	1830	1937	1946	241.6	153.5	966	540	717	799	.436
10-48	37	023	1762	1906	1928	240.5	152.1	901	469	633	708	.399
10-86	7	024	1814	1933	1946	243.1	153.2	915	585	666	751	.410
10-92	8	025	1811	1936	1940	243.5	153.5	902	791	660	744	.418
11-35	39	026	1778	1907	1922	239.3	151.9	934	760	667	766	.426
11-21	23	027	1811	1923	1937	241.9	153.0	942	733	713	773	.436
10-51	38	028	1808	1936	1946	243.0	153.5	912	791	660	745	.422
10-09	22	039	1803	1932	1943	242.5	153.3	911	591	675	741	.406
10-44	24	040	1797	1942	1956	244.6	154.3	906	496	674	741	.401
OPERATION LOCATIONS			I 11	I 12	I 13	I 14	I 15	I 16	I 17	I 16	I 19	I 20

Legend:

I 15G	Impulse at 15 g
IA	Action time impulse
ID	Total impulse
ISP	Specific impulse
ISP(DA)	Total Impulse / Motor Weight
FY MAX	Maximum thrust
FIGN MAX	Maximum ignition thrust
FYA AVG	Average action time thrust
FYB AVG	Average burn time thrust
RB	Burning rate

Ballistic Data Summary for +150°F (u)

Figure 62, Sheet 2 of 4

DELTA TD	SIGMA =	0.0065					SUM	= 0.2250000648200 00	LOC A	2
SEC	XBAR =	0.0173	MINIMUM =	0.0080	12-03	009	SUM OF		OPER.	1
	NUMBER =	13	MAXIMUM =	0.0270	10-48	023	SQUARES	= 0.4401002653480D-02	LOC B	0
DELTA TR	SIGMA =	0.0087					SUM	= 0.2590000815690 00	LOC A	3
SEC	XBAR =	0.0199	MINIMUM =	0.0100	12-44	008	SUM OF		OPER.	1
	NUMBER =	13	MAXIMUM =	0.0380	10-48	023	SQUARES	= 0.6059003994230-02	LOC B	0
DELTA TA	SIGMA =	0.0990					SUM	= 0.3902700996400 02	LOC A	4
SEC	XBAR =	2.7676	MINIMUM =	2.6780	12-03	009	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	3.0090	10-46	023	SQUARES	= 0.1089208326990 03	LOC B	0
DELTA TB	SIGMA =	0.0795					SUM	= 0.2977400588990 02	LOC A	5
SEC	XBAR =	2.1267	MINIMUM =	2.0270	12-07	007	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	2.2530	10-48	023	SQUARES	= 0.6340287700390 02	LOC B	0
W DOT	SIGMA =	0.1095					SUM	= 0.4031000232700 02	LOC A	6
LB/SEC	XBAR =	2.8793	MINIMUM =	2.6700	10-48	023	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	3.0200	12-03	009	SQUARES	= 0.1162199129460 03	LOC B	0
CW	SIGMA =	0.0001					SUM	= 0.8413004502650-01	LOC A	7
	XBAR =	0.0060	MINIMUM =	0.0059	10-51	028	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	0.0062	10-48	023	SQUARES	= 0.5056322418990-03	LOC B	0
PIGN MAX	SIGMA =	323.6132					SUM	= 0.2660800000000 05	LOC A	8
PSIA	XBAR =	2046.7692	MINIMUM =	1463.0000	10-48	023	SUM OF		OPER.	1
	NUMBER =	13	MAXIMUM =	2490.0000	10-51	028	SQUARES	= 0.5571714200000 08	LOC B	0
PC MAX	SIGMA =	73.7631					SUM	= 0.2529700000000 05	LOC A	9
PSIA	XBAR =	1806.9286	MINIMUM =	1670.0000	10-48	023	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	1891.0000	11-21	027	SQUARES	= 0.4578060500000 08	LOC B	0
PC AVG	SIGMA =	46.1998					SUM	= 0.1949500000000 05	LOC A	10
PSIA	XBAR =	1392.5000	MINIMUM =	1268.0000	10-48	023	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	1457.0000	11-21	027	SQUARES	= 0.2717453500000 08	LOC B	0
I ISG	SIGMA =	17.4112					SUM	= 0.2526300000000 05	LOC A	11
LB-SEC	XBAR =	1805.9286	MINIMUM =	1762.0000	10-48	023	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	1830.0000	12-41	017	SQUARES	= 0.4560632300000 08	LOC B	0
IA	SIGMA =	11.2916					SUM	= 0.2702700000000 05	LOC A	12
LB-SEC	XBAR =	1930.5000	MINIMUM =	1906.0000	10-48	023	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	1942.0000	10-44	040	SQUARES	= 0.5217726100000 08	LOC B	0
ID	SIGMA =	8.8529					SUM	= 0.2719800000000 05	LOC A	13
LB-SEC	XBAR =	1942.7143	MINIMUM =	1922.0000	11-35	026	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	1956.0000	10-44	040	SQUARES	= 0.5283896200000 08	LOC B	0
ISP	SIGMA =	1.7337					SUM	= 0.3389900695800 04	LOC A	14
	XBAR =	242.1358	MINIMUM =	239.3000	11-35	026	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	245.6001	10-16	003	SQUARES	= 0.8206552669910 06	LOC B	0
ISP(UA)	SIGMA =	0.6166					SUM	= 0.2145300399760 04	LOC A	15
	XBAR =	153.2357	MINIMUM =	151.9000	11-35	026	SUM OF		OPER.	1
	NUMBER =	14	MAXIMUM =	154.3000	10-44	040	SQUARES	= 0.3287416325720 06	LOC B	0
[illegible]	[illegible]	[illegible]					SUM	= 0.1304400000000 05	LOC A	16
	[illegible]	[illegible]	MINIMUM =	901.0000	10-46	023	SUM OF		OPER.	1
	[illegible]	[illegible]	MAXIMUM =	967.0000	12-03	009	SQUARES	= 0.1216238400000 06	LOC B	0

Ballistic Data Summary for +150°F (u)

Figure 62, Sheet 3 of 4

FIGN MAX LB	SIGMA =	110.7621					SUM	= 0.9119000000000D 04	LOC A 17
	XBAR =	651.3571	MINIMUM =	469.0000	10-48	023	SUM OF		OPER. 1
	NUMBER =	14	MAXIMUM =	791.0000	10-92	025	SQUARES	= 0.6099213000000D 07	LOC B 0
FVA AVG LB	SIGMA =	75.5115					SUM	= 0.9706000000000D 04	LOC A 16
	XBAR =	693.2857	MINIMUM =	633.0000	10-48	023	SUM OF		OPER. 1
	NUMBER =	14	MAXIMUM =	721.0000	12-05	009	SQUARES	= 0.6737492000000D 07	LOC B 0
FVB AVG LB	SIGMA =	25.1418					SUM	= 0.1066200000000D 05	LOC A 19
	XBAR =	761.5714	MINIMUM =	708.0000	10-48	023	SUM OF		OPER. 1
	NUMBER =	14	MAXIMUM =	799.0000	12-41	017	SQUARES	= 0.8128092000000D 07	LOC B 0
KB IN/SEC	SIGMA =	0.0155					SUM	= 0.5921001911160D 01	LOC A 20
	XBAR =	0.4229	MINIMUM =	0.3990	10-48	023	SUM OF		OPER. 1
	NUMBER =	14	MAXIMUM =	0.4430	12-07	007	SQUARES	= 0.2507296618660D 01	LOC B 0

Ballistic Data Summary for +150°F (u)

Figure 62, Sheet 4 of 4

2.75 FFAR — -65/+150 DEG.F

[illegible] NO.	MOTOR NO.	TEST NO. 3297-E01-OA-	DATE FIRED	DELTA TD SEC	DELTA TR SEC	DELTA TA SEC	DELTA TB SEC	W DOT LB/SEC	CW	PIGN MAX PSIA	PC MAX PSIA	PC AVG PSIA
12-30	45	020	081568	.014	.019	3.051	2.364	2.65	.00605	1770	1606	1271
12-45	14	021	081568	.014	.015	3.080	2.330	2.62	.00608	1803	1627	1286
OPERATION-LOCATIONS			1 1	1 2	1 3	1 4	1 5	1 6	1 7	1 8	1 9	1 10

Legend:

DELTA TD	Ignition delay time
DELTA TR	Ignition rise time
DELTA TA	Action time
DELTA TB	Web burn time
W DOT	Mass flow rate
CW	Mass flow coefficient
PIGN MAX	Maximum ignition pressure
PC MAX	Maximum pressure
PC AVG	Average action time pressure

Ballistic Data Summary of Gradient Firings (u)

Figure 63, Sheet 1 of 4

2.75 FFAR -65/+150 DEG.F

CHAMBER NO.	MOTOR NO.	TEST NO. 3297-E01-OA	I 150 LB-SEC	IA LB-SEC	ID LB-SEC	ISP	ISP(DA)	FY MAX LB	FIGN MAX LB	FYA AVG LB	FYB AVG LB	RB IN/SEC
12-80	45	622	1859	1926	1934	239.0	152.0	644	575	629	664	.3500
12-45	14	621	1822	1911	1920	238.4	151.5	638	566	623	679	.3505
OPERATION+LOCATIONS			1 11	1 12	1 13	1 14	1 15	1 16	1 17	1 18	1 19	1 20

Legend:

I 150	Impulse at 15 g
IA	Action time impulse
ID	Total impulse
ISP	Specific impulse
ISP(DA)	Total Impulse / Motor Weight
FY MAX	Maximum thrust
FIGN MAX	Maximum ignition thrust
FYA AVG	Average action time thrust
FYB AVG	Average burn time thrust
RB	Burning rate

Ballistic Data Summary of Gradient Firings (u)

Figure 63, Sheet 2 of 4

Parameter	Statistic	Value		Value	Firing			Sum	Location	
DELTA TO SEC	SIGMA =	0.0014					SUM	= 0.34000001302360D-01	LOC A	2
	XBAR =	0.0170	MINIMUM =	0.0160	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	0.0180	12-80	020	SQUARES	= 0.58000044345590D-03	LOC B	0
DELTA TR SEC	SIGMA =	0.0028					SUM	= 0.34000000298630D-01	LOC A	3
	XBAR =	0.0170	MINIMUM =	0.0150	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	0.0190	12-80	020	SQUARES	= 0.58800003187600D-03	LOC B	0
DELTA TB SEC	SIGMA =	0.0205					SUM	= 0.61310014724700D 01	LOC A	4
	XBAR =	3.0655	MINIMUM =	3.0510	12-80	020	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	3.0800	12-45	021	SQUARES	= 0.18795010035900D 02	LOC B	[illegible]
DELTA TA SEC	SIGMA =	0.0240					SUM	= 0.46940011978100D 01	LOC A	5
	XBAR =	2.3470	MINIMUM =	2.3300	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	2.3640	12-80	020	SQUARES	= 0.11017401603600D 02	LOC B	[illegible]
W DOT LB/SEC	SIGMA =	0.0212					SUM	= 0.52699995504090D 01	LOC A	6
	XBAR =	2.6350	MINIMUM =	2.6200	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	2.6500	12-80	020	SQUARES	= 0.13886697376500D 02	LOC B	[illegible]
[illegible]	SIGMA =	0.0000					SUM	= 0.12130003422250D-01	LOC A	7
	XBAR =	0.0061	MINIMUM =	0.0061	12-80	020	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	0.0061	12-45	021	SQUARES	= 0.73568941507800D-04	LOC B	[illegible]
PIGN MAX PSIA	SIGMA =	23.3345					SUM	= 0.35730000000000D 04	LOC A	8
	XBAR =	1786.5000	MINIMUM =	1770.0000	12-80	020	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	1803.0000	12-45	021	SQUARES	= 0.63837090000000D 07	LOC B	[illegible]
PC MAX PSIA	SIGMA =	14.8492					SUM	= 0.32330000000000D 04	LOC A	9
	XBAR =	1616.5000	MINIMUM =	1606.0000	12-80	020	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	1627.0000	12-45	021	SQUARES	= 0.52263650000000D 07	LOC B	[illegible]
PC AVG PSIA	SIGMA =	12.0208					SUM	= 0.25590000000000D 04	LOC A	10
	XBAR =	1279.5000	MINIMUM =	1271.0000	12-80	020	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	1288.0000	12-45	021	SQUARES	= 0.32743650000000D 07	LOC B	0
I TOT LB-SEC	SIGMA =	12.0208					SUM	= 0.36610000000000D 04	LOC A	11
	XBAR =	1830.5000	MINIMUM =	1822.0000	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	1839.0000	12-80	020	SQUARES	= 0.67016050000000D 07	LOC B	[illegible]
IA LB-SEC	SIGMA =	6.3640					SUM	= 0.38310000000000D 04	LOC A	12
	XBAR =	1915.5000	MINIMUM =	1911.0000	12-45	021	SUM OF		OPER.	[illegible]
	NUMBER =	2	MAXIMUM =	1920.0000	12-80	020	SQUARES	= 0.73383210000000D 07	LOC B	[illegible]
IO LB-SEC	SIGMA =	9.8995					SUM	= 0.38540000000000D 04	LOC A	13
	XBAR =	1927.0000	MINIMUM =	1920.0000	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	1934.0000	12-80	020	SQUARES	= 0.74267560000000D 07	LOC B	[illegible]
ISP	SIGMA =	0.4243					SUM	= 0.47740010076000D 03	LOC A	14
	XBAR =	238.7001	MINIMUM =	238.4001	12-45	021	SUM OF		OPER.	1
	NUMBER =	2	MAXIMUM =	239.0000	12-80	020	SQUARES	= 0.11395552050730D 06	LOC B	[illegible]
ISP[illegible]	SIGMA =	0.7778					SUM	= 0.30410005136000D 03	LOC A	15
	XBAR =	152.0500	MINIMUM =	151.5000	12-45	021	SUM OF		OPER.	[illegible]
	NUMBER =	2	MAXIMUM =	152.6000	12-80	020	SQUARES	= 0.46239325760000D 05	LOC B	[illegible]
[illegible]	[illegible]	[illegible]420					SUM	= 0.16820000000000D 04	LOC A	16
	[illegible]	[illegible]000	MINIMUM =	838.0000	12-45	021	SUM OF		OPER.	[illegible]
	[illegible]	[illegible]	MAXIMUM =	844.0000	12-80	020	SQUARES	= 0.14145600000000D 07	LOC B	[illegible]

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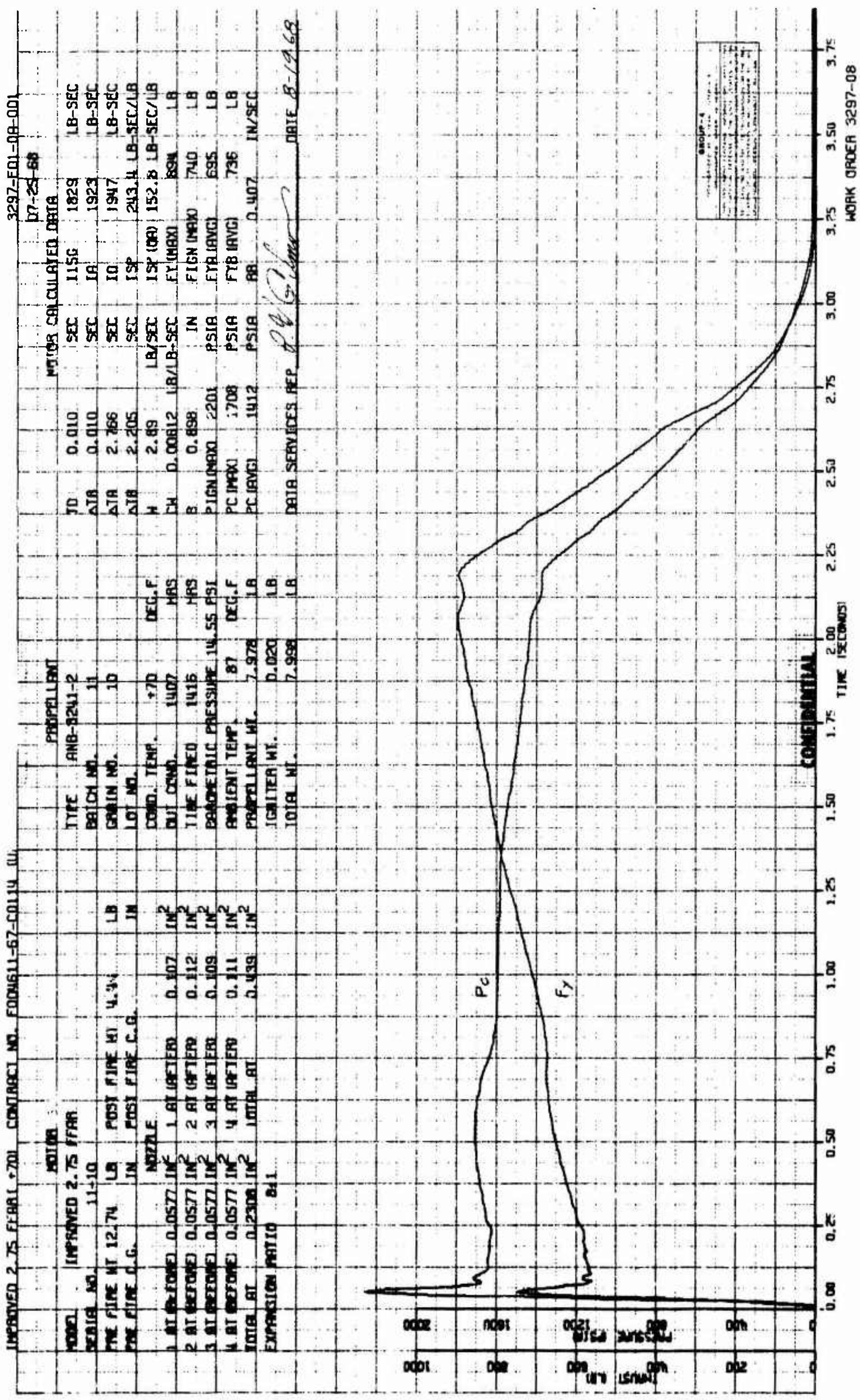
Ballistic Data Summary of Gradient Firings (u)

Figure 63, Sheet 3 of 4

FIGN MAX IN	SIGMA =	3.5355				SUM	= 0.11410000000000 04	LOC A 17
	XBAR =	570.5000	MINIMUM =	568.0000	12-45 021	SUM OF		OPER. 1
	NUMBER =	2	MAXIMUM =	573.0000	12-80 020	SQUARES	= 0.65095500000000 06	LOC B 0
FVA AVG IN	SIGMA =	4.2426				SUM	= 0.12520000000000 04	LOC A 18
	XBAR =	626.0000	MINIMUM =	623.0000	12-45 021	SUM OF		OPER. 1
	NUMBER =	2	MAXIMUM =	629.0000	12-80 020	SQUARES	= 0.78377000000000 06	LOC B 0
FVG AVG IN	SIGMA =	3.5355				SUM	= 0.13630000000000 04	LOC A 19
	XBAR =	681.5000	MINIMUM =	679.0000	12-45 021	SUM OF		OPER. 1
	NUMBER =	2	MAXIMUM =	684.0000	12-80 020	SQUARES	= 0.92889700000000 06	LOC B 0
KN IN/SEC	SIGMA =	0.0035				SUM	= 0.76500002241150 00	LOC A 20
	XBAR =	0.3825	MINIMUM =	0.3800	12-80 020	SUM OF		OPER. .
	NUMBER =	2	MAXIMUM =	0.3850	12-45 021	SQUARES	= 0.29262517142300 00	LOC B 0

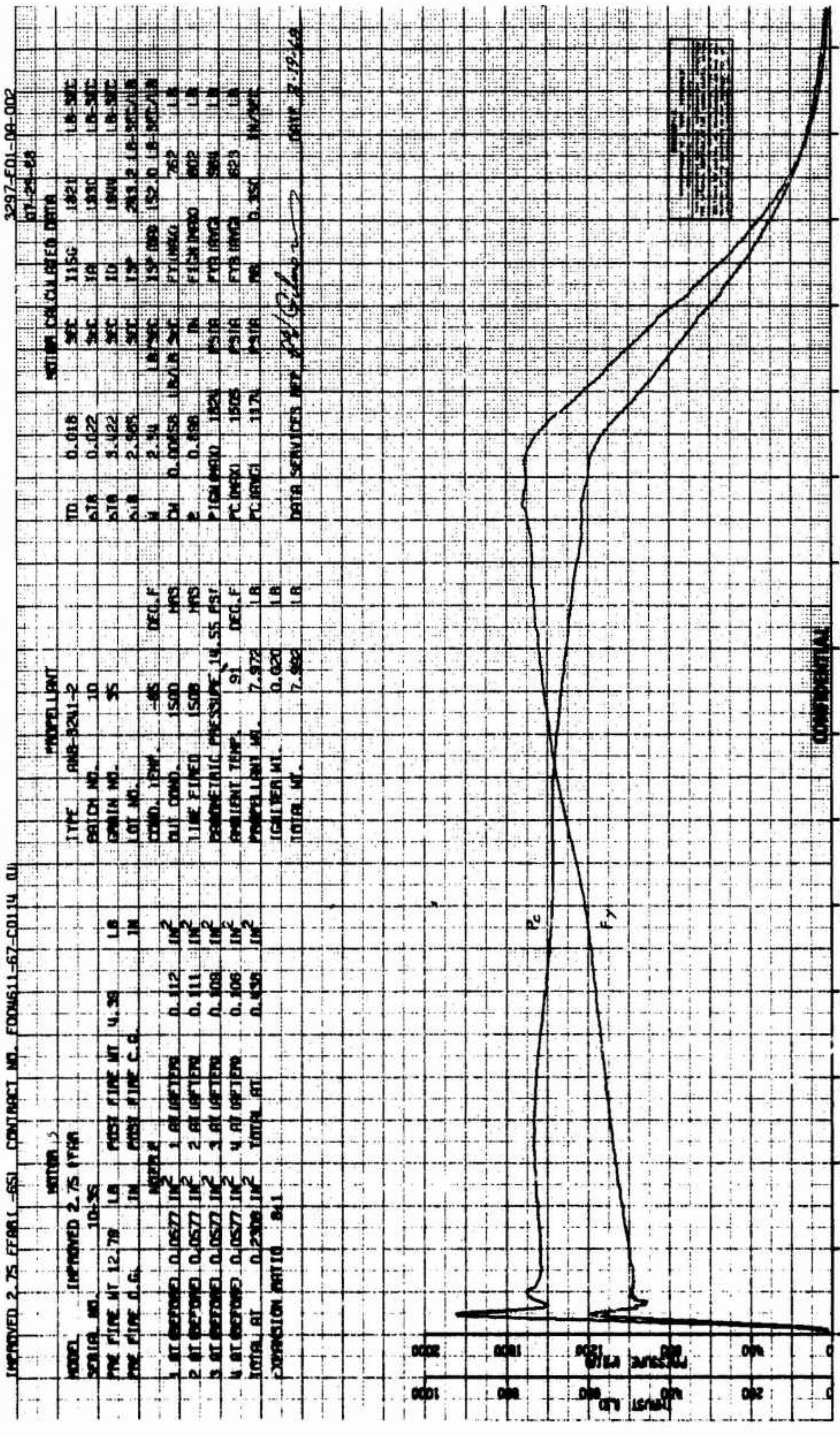
Ballistic Data Summary of Gradient Firings (u)

Figure 63, Sheet 4 of 4



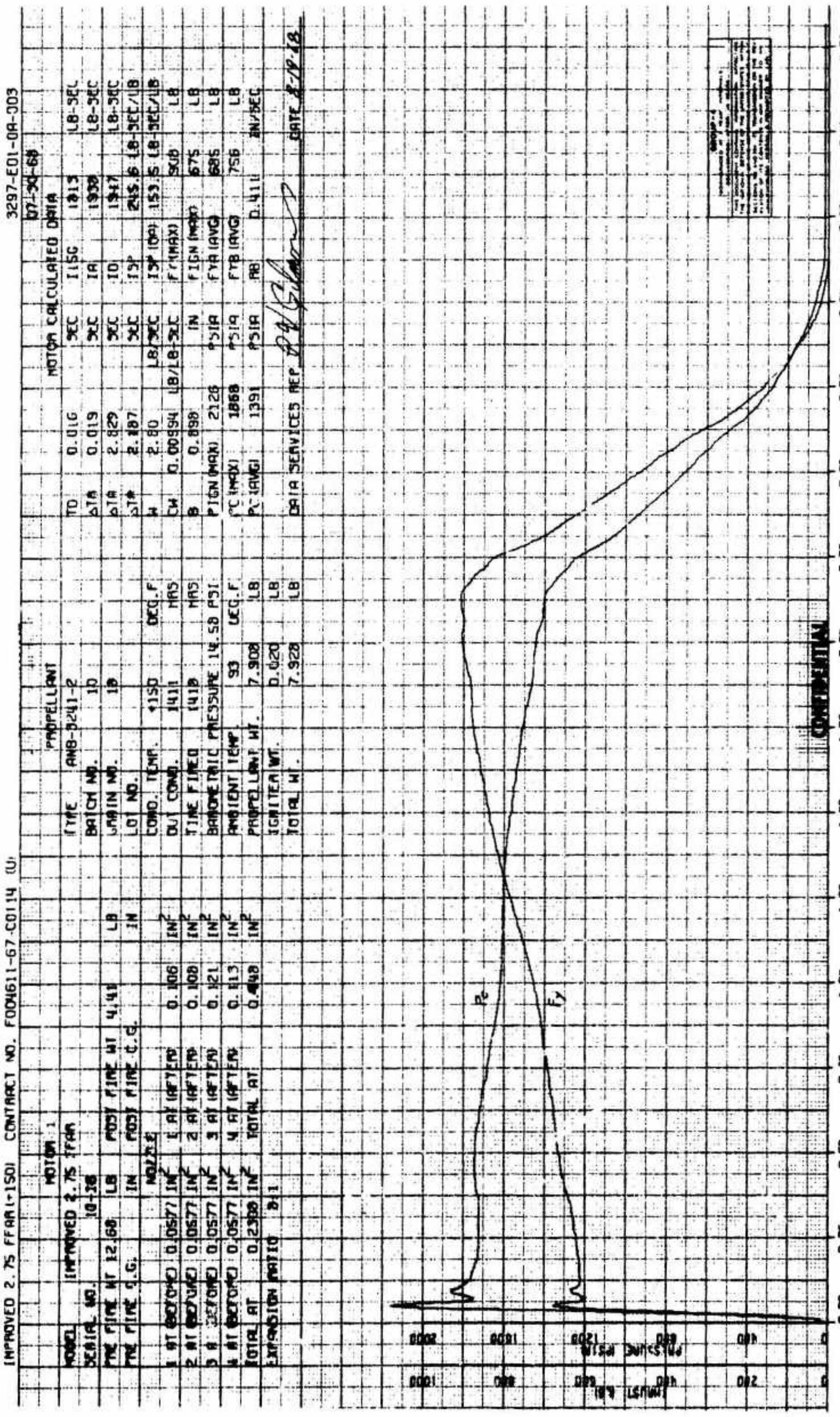
Ballistic Data and Performance Curves, Motor 3 (u)

Figure 64



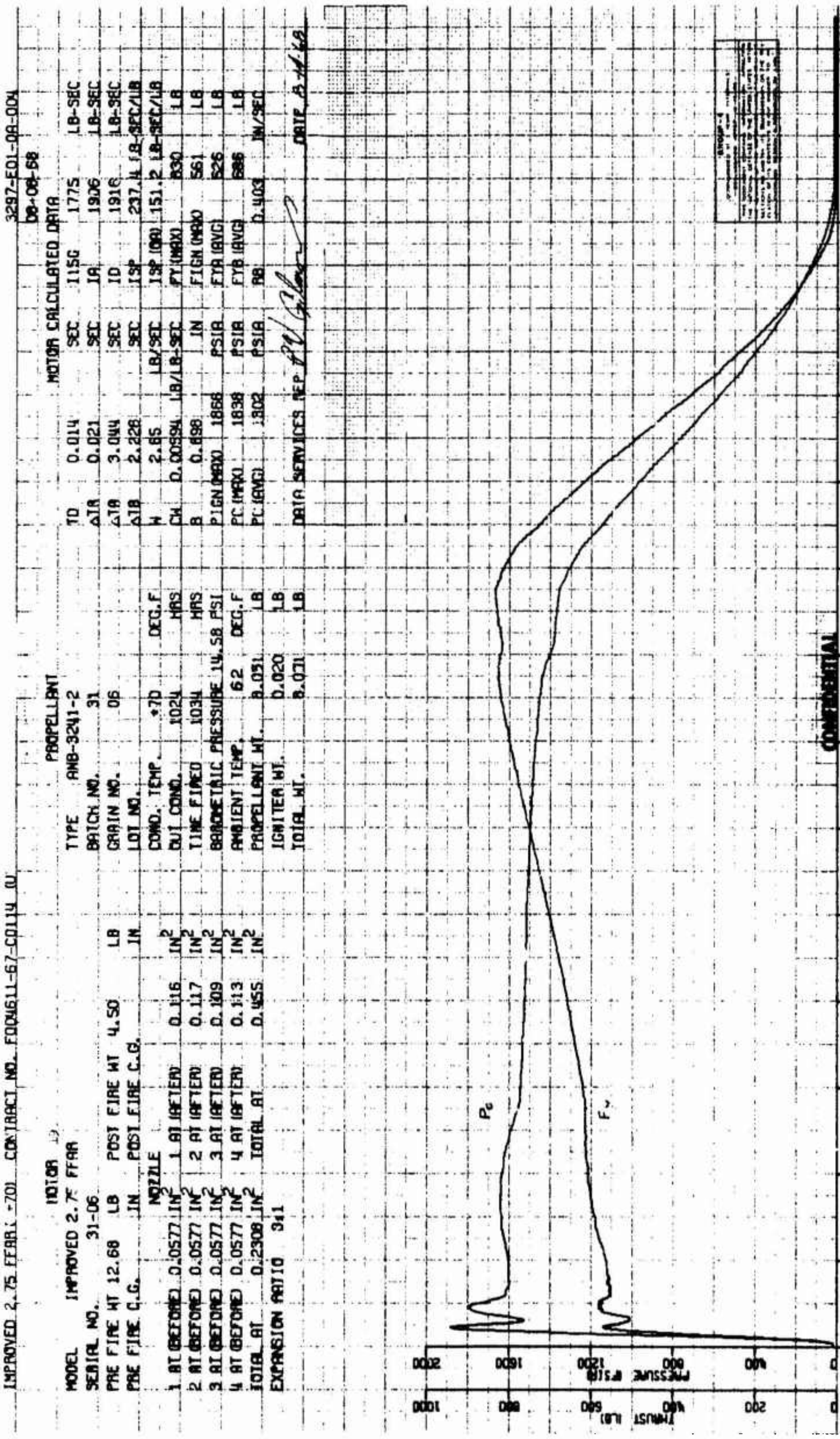
Ballistic Data and Performance Curves, Motor 5 (u)

Figure 65



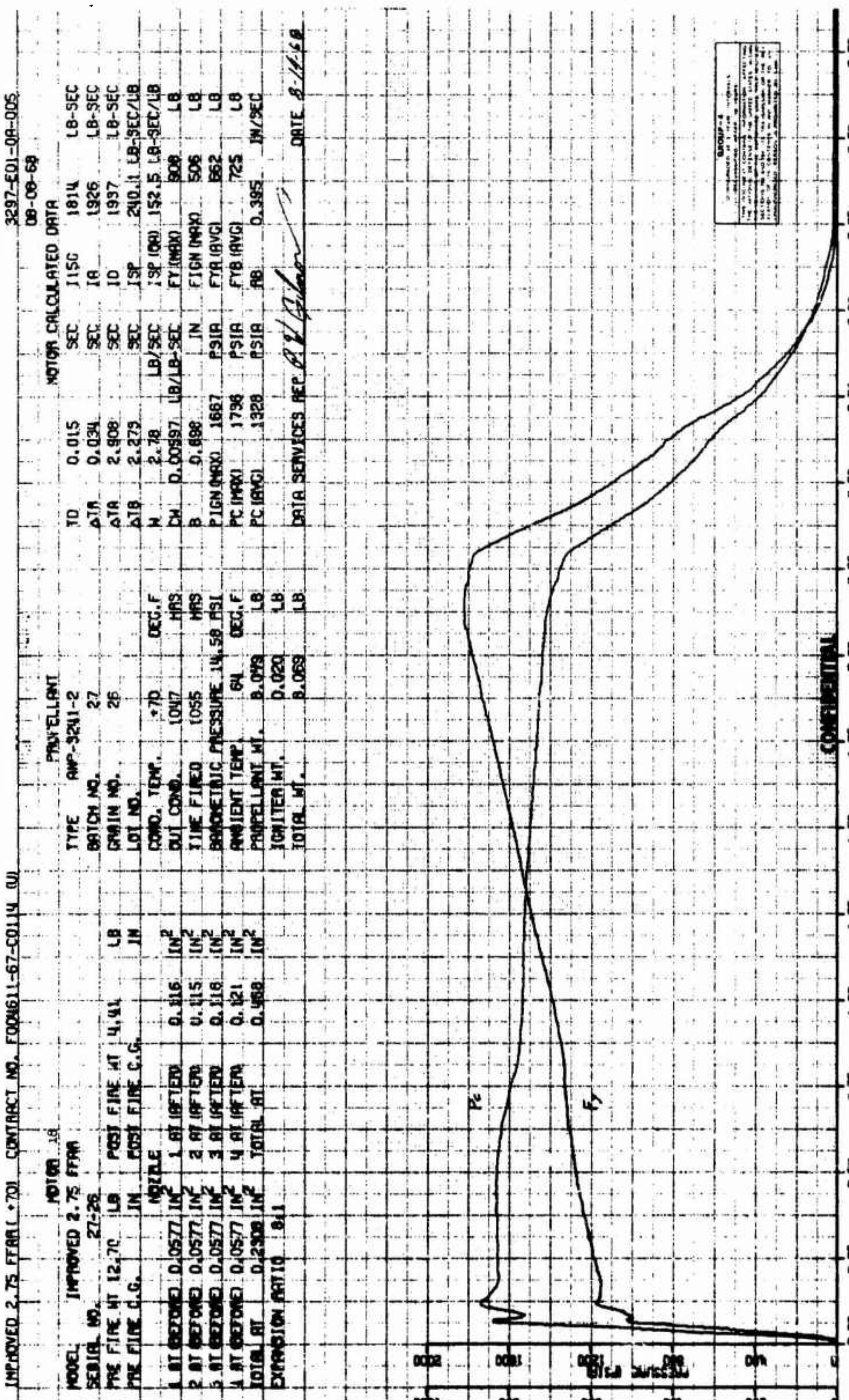
Ballistic Data and Performance Curves, Motor 1 (u)

Figure 66



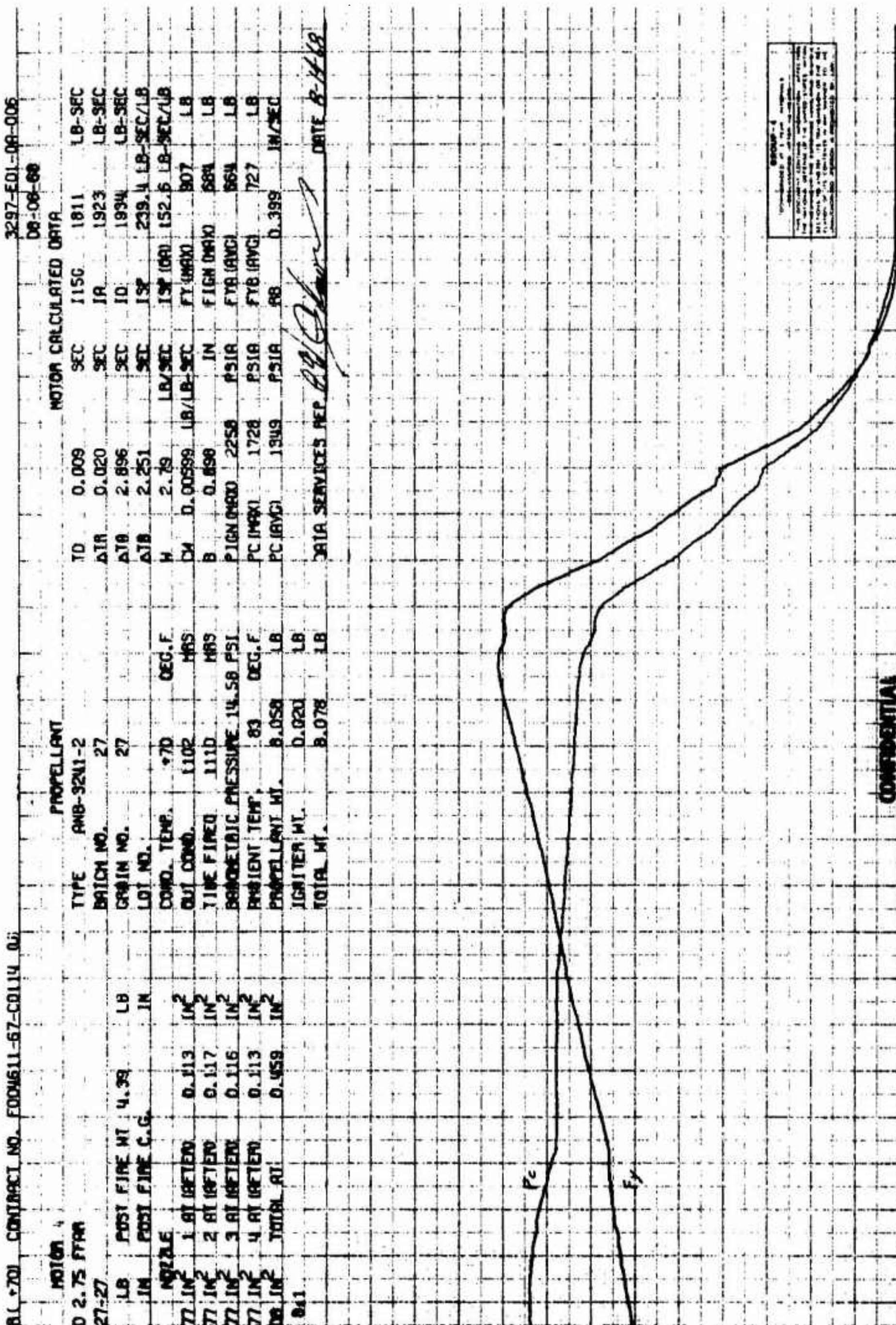
Ballistic Data and Performance Curves, Motor 19 (u)

Figure 67



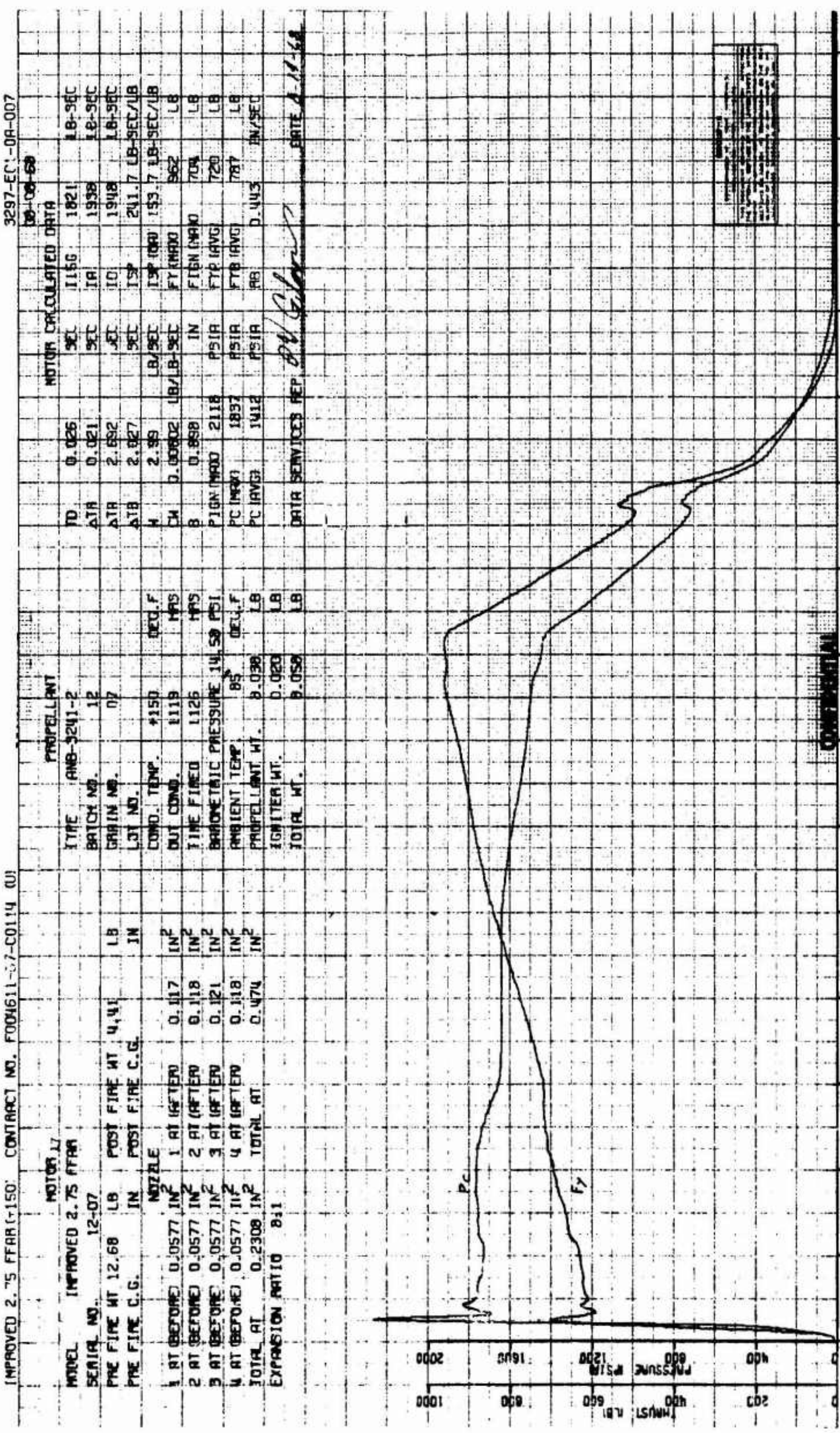
Ballistic Data and Performance Curves, Motor 18 (u)

Figure 68



Ballistic Data and Performance Curves, Motor 4 (u)

Figure 69



Ballistic Data and Performance Curves, Motor 17 (u)

Figure 70

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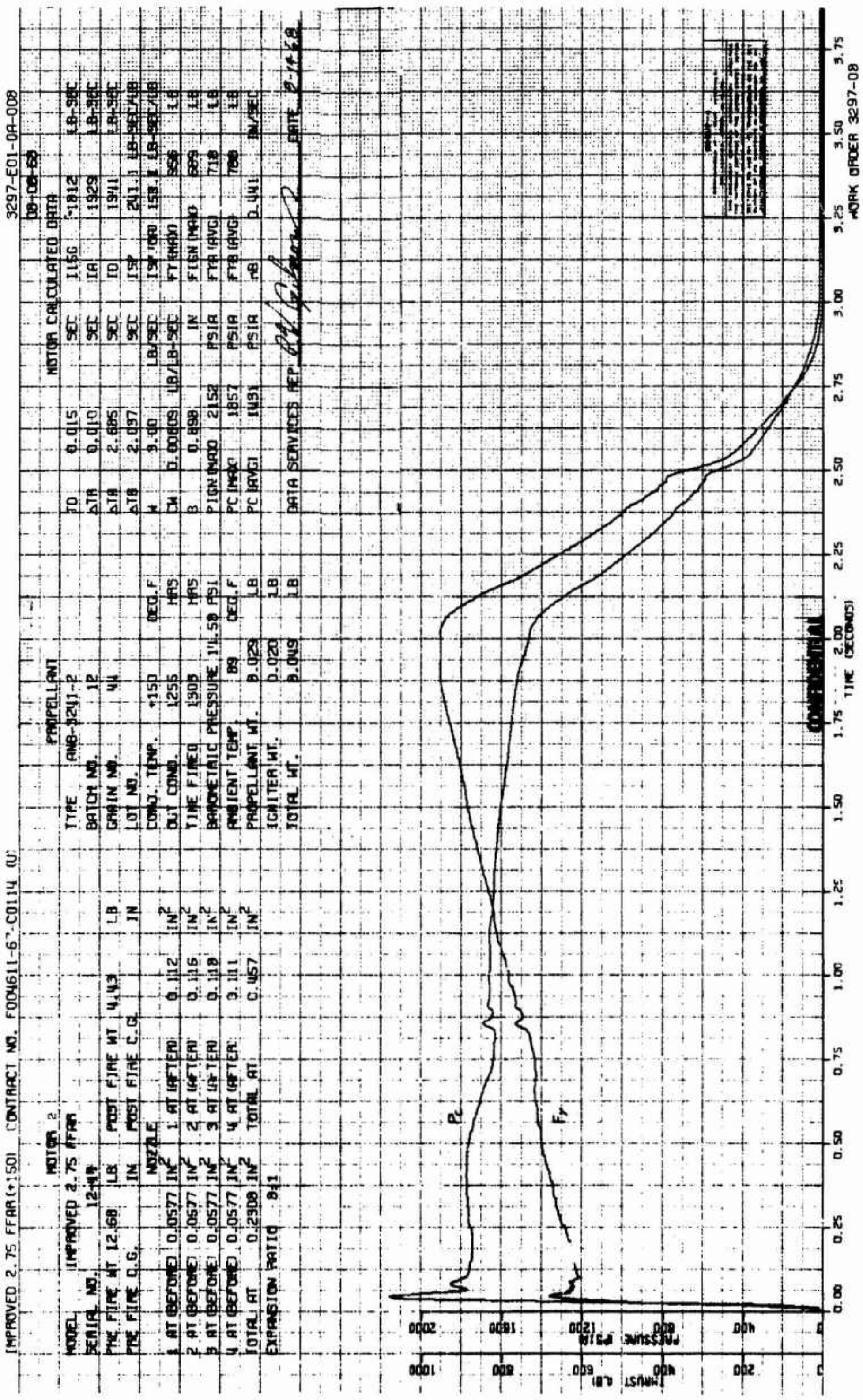

Ballistic Data and Performance Curves, Motor 2 (u)

Figure 71

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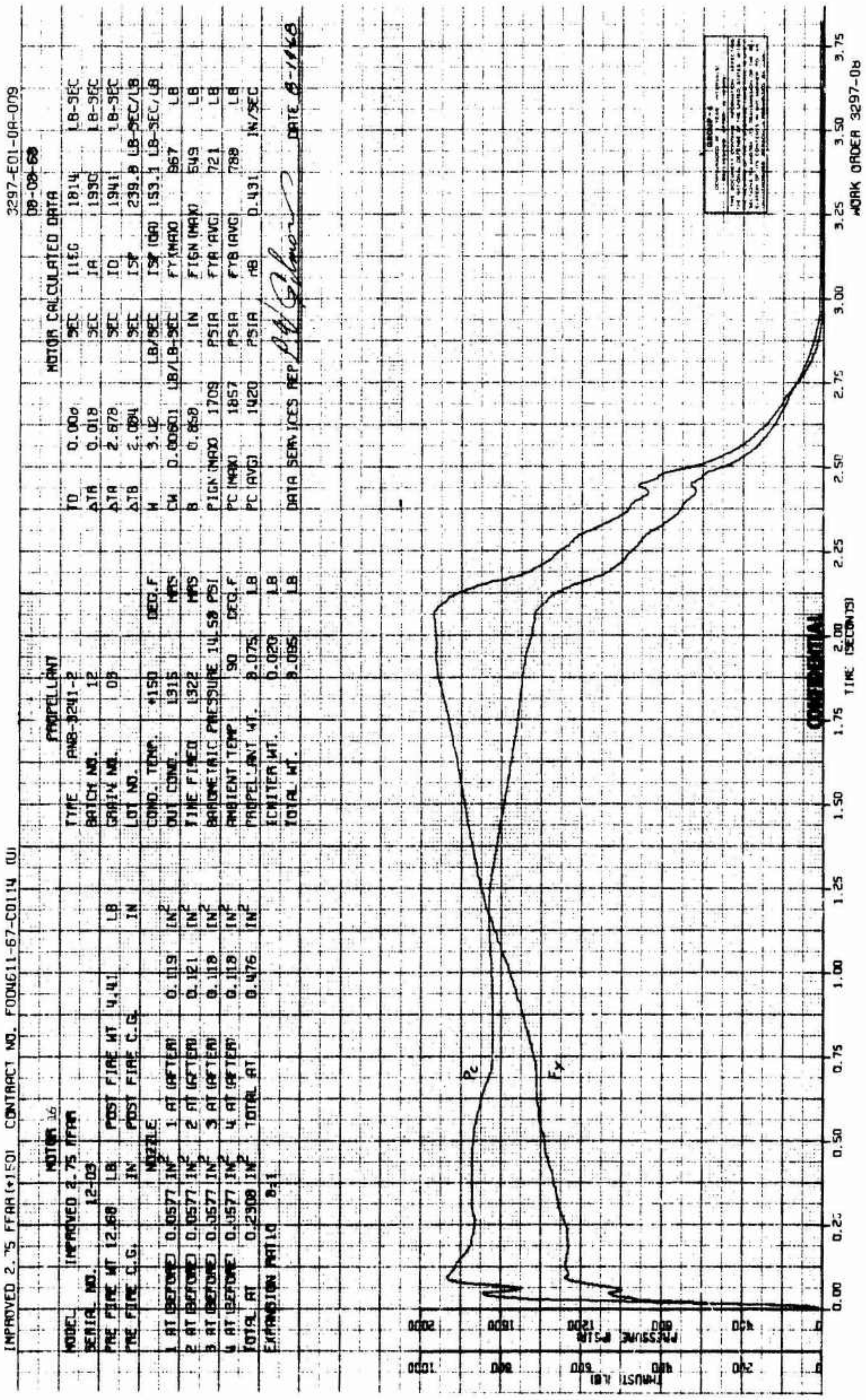
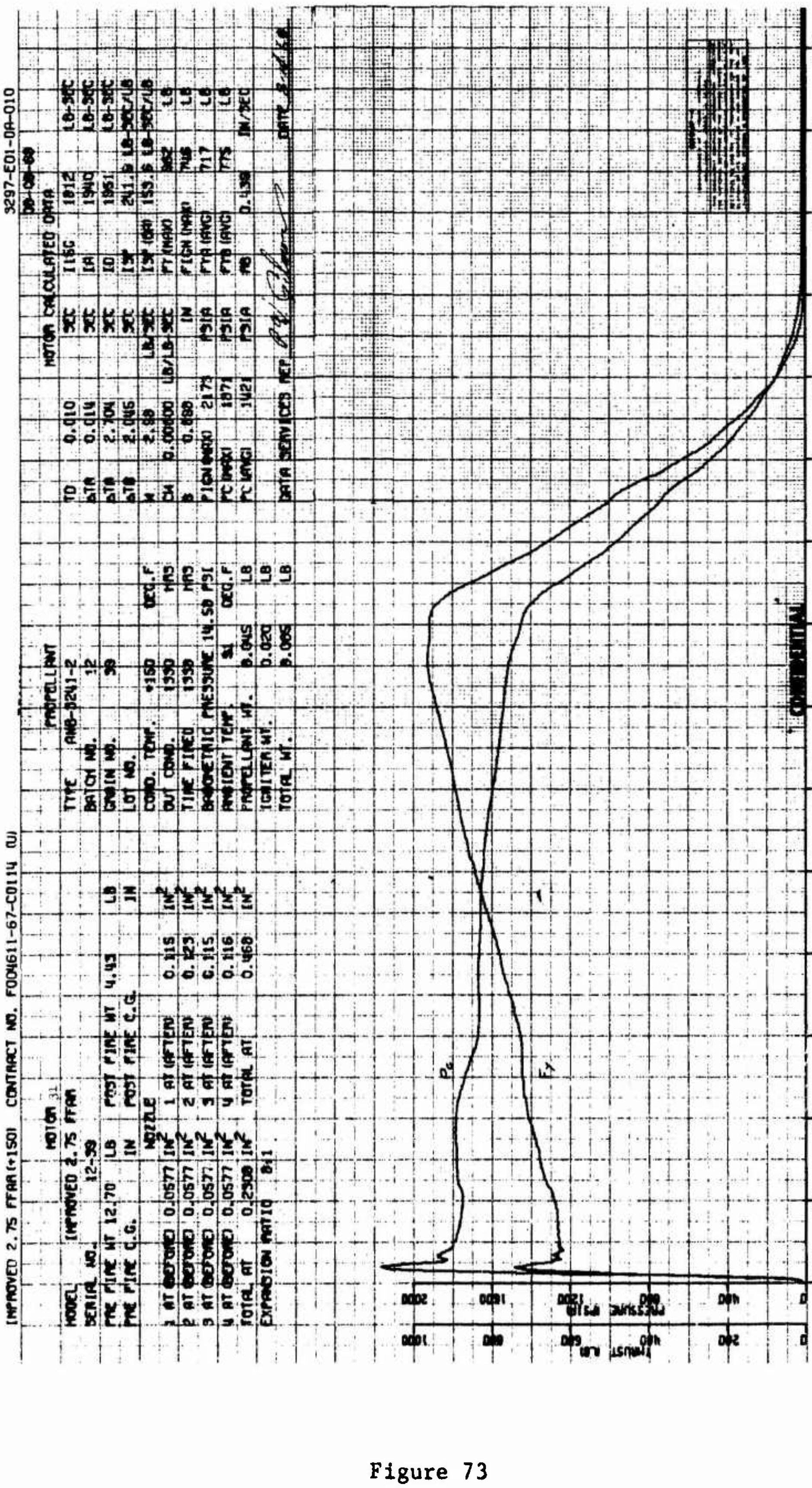


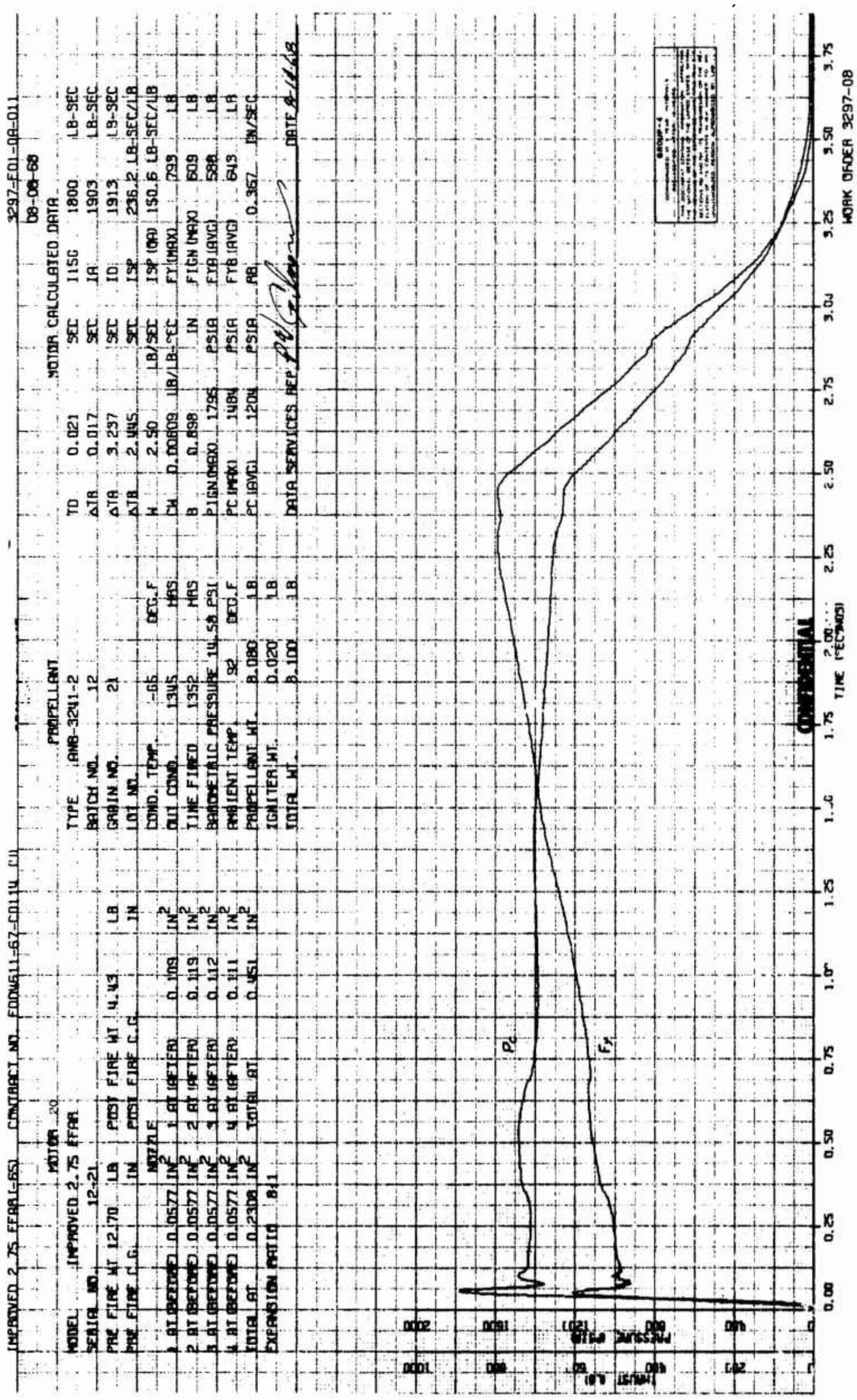
Ballistic Data and Performance Curves, Motor 16 (u)

Figure 72



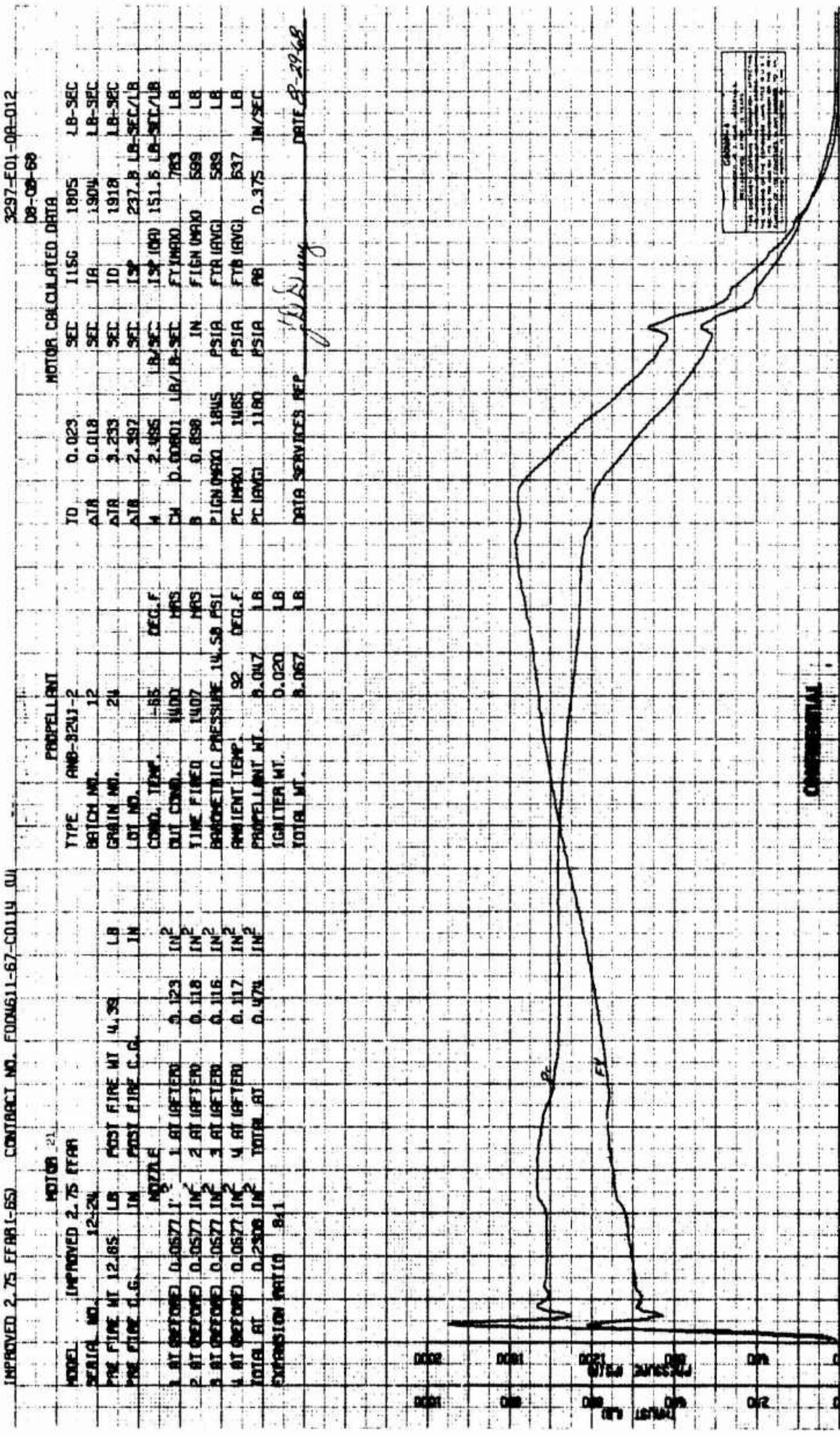
Ballistic Data and Performance Curves, Motor 31 (u)

Figure 73



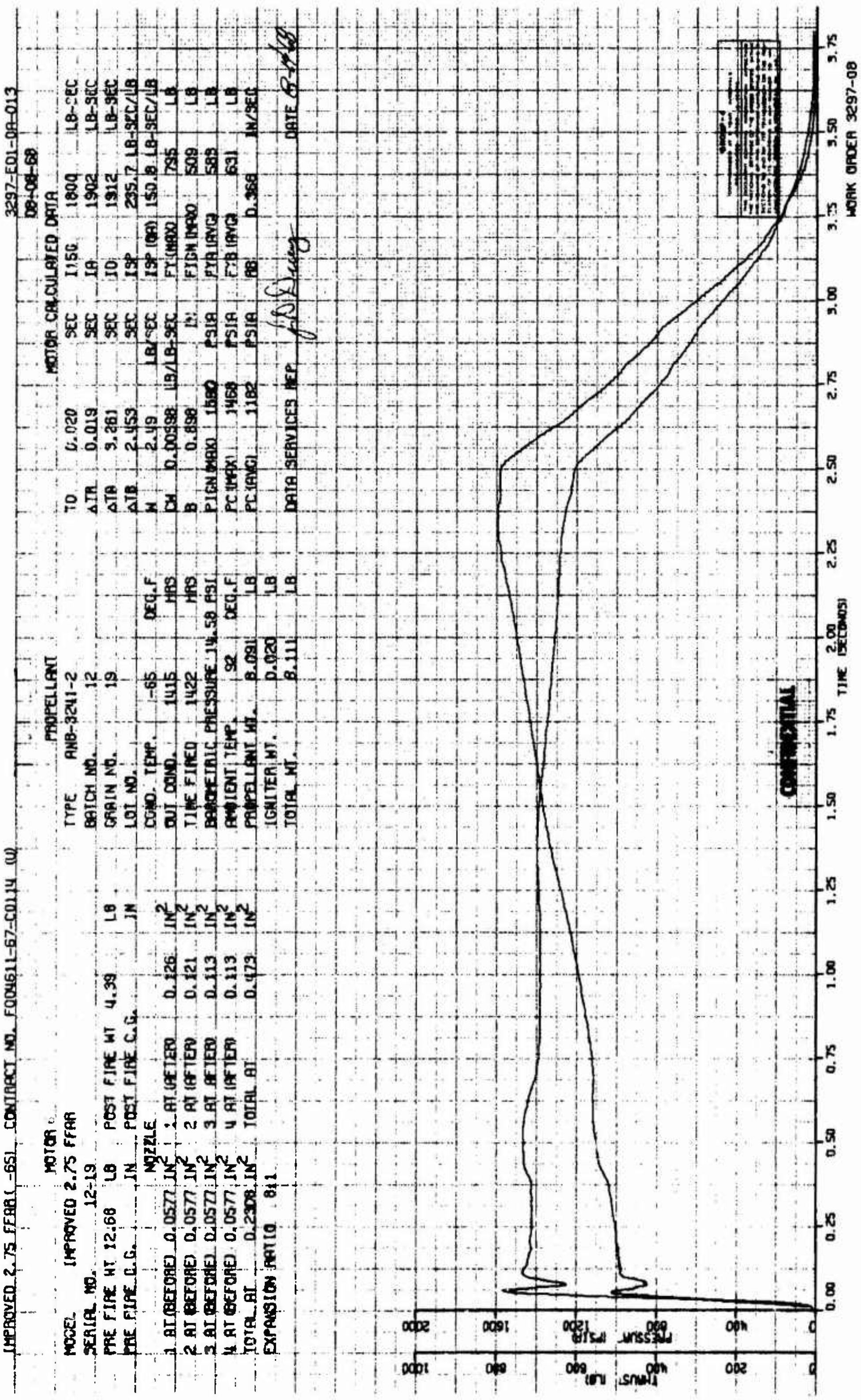
Ballistic Data and Performance Curves, Motor 20 (u)

Figure 74



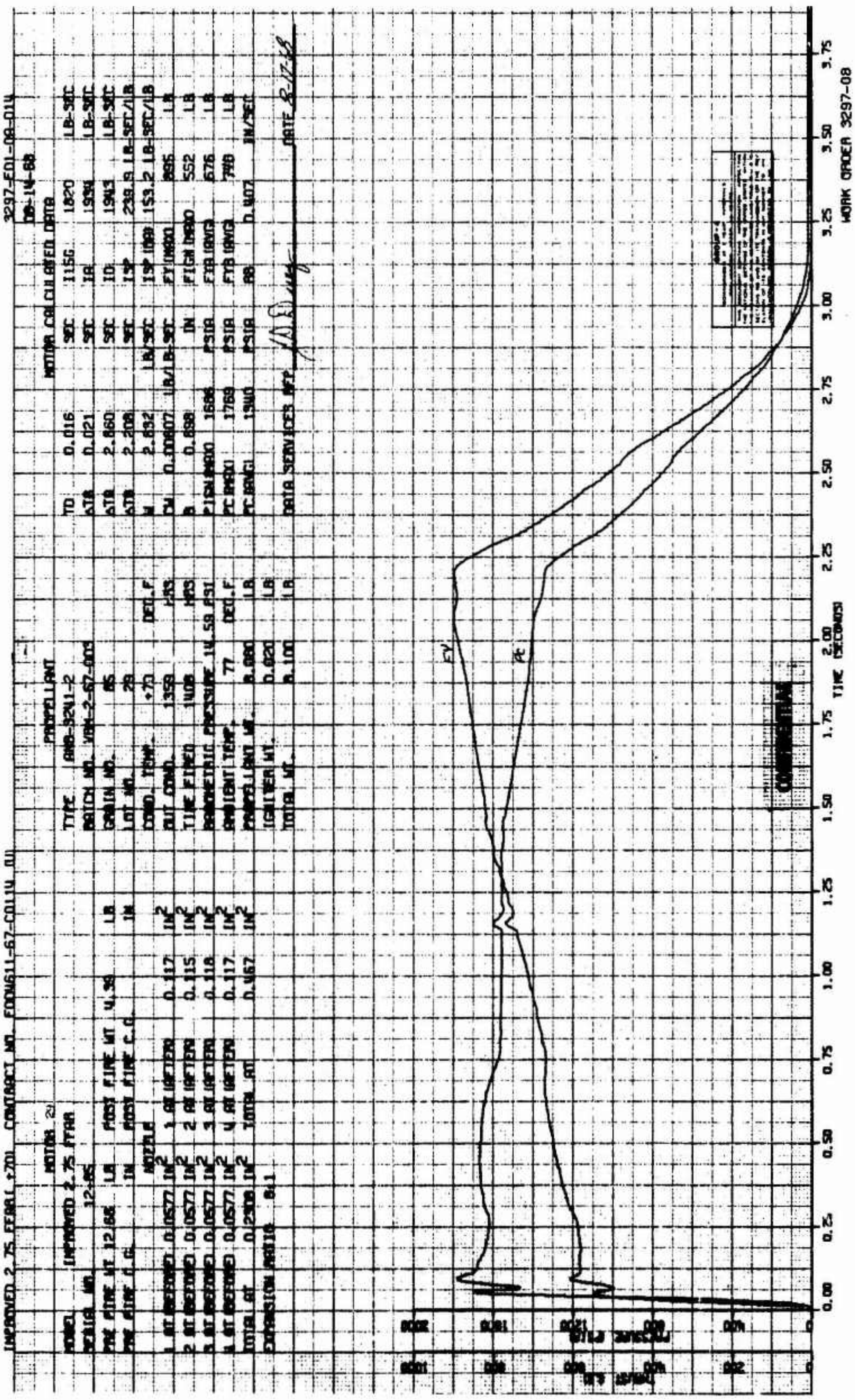
Ballistic Data and Performance Curves, Motor 21(u)

Figure 75



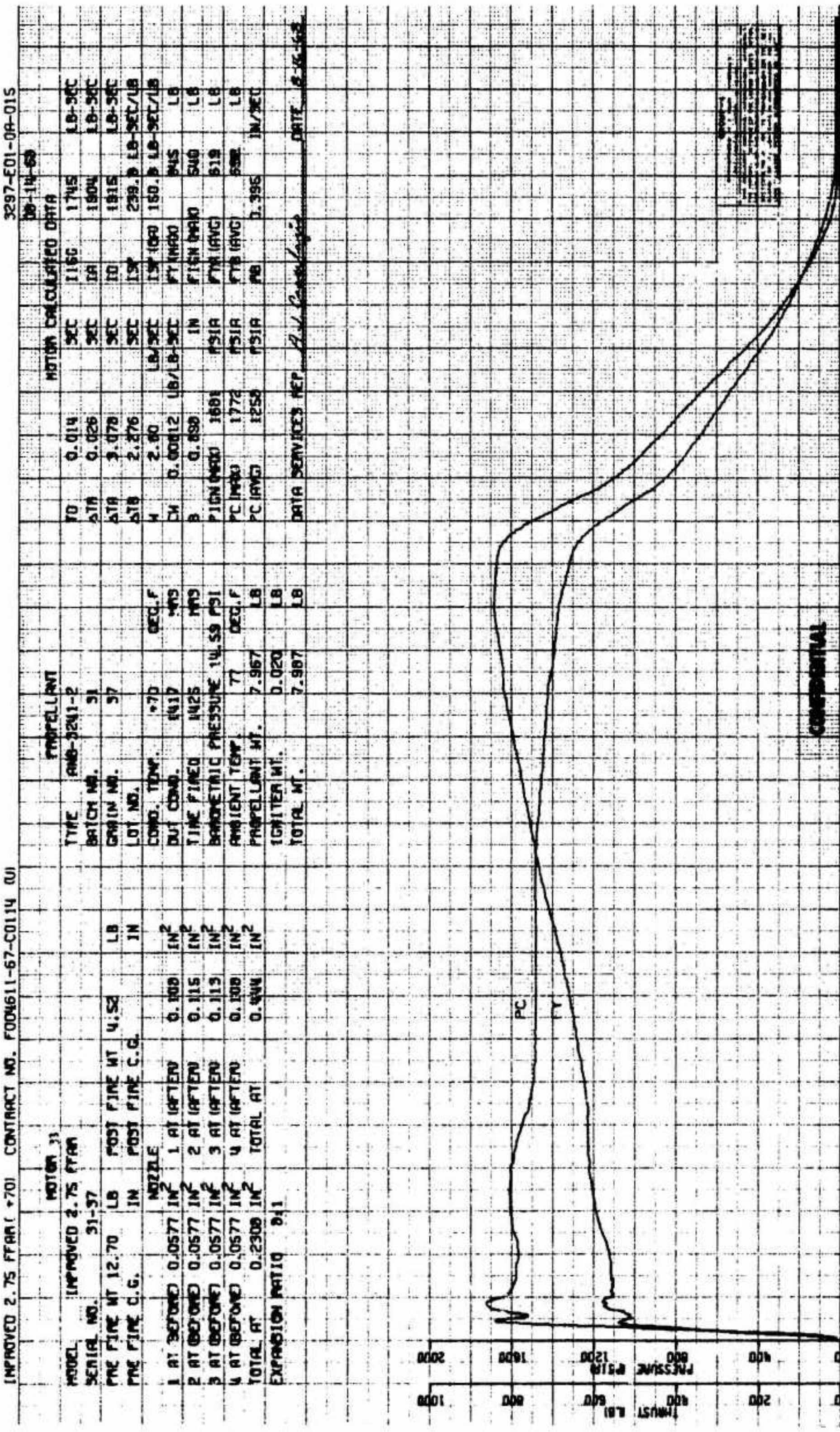
Ballistic Data and Performance Curves, Motor 6 (u)

Figure 76



Ballistic Data and Performance Curves, Motor 29 (u)

Figure 77



Ballistic Data and Performance Curves, Motor 33 (u)

Figure 78

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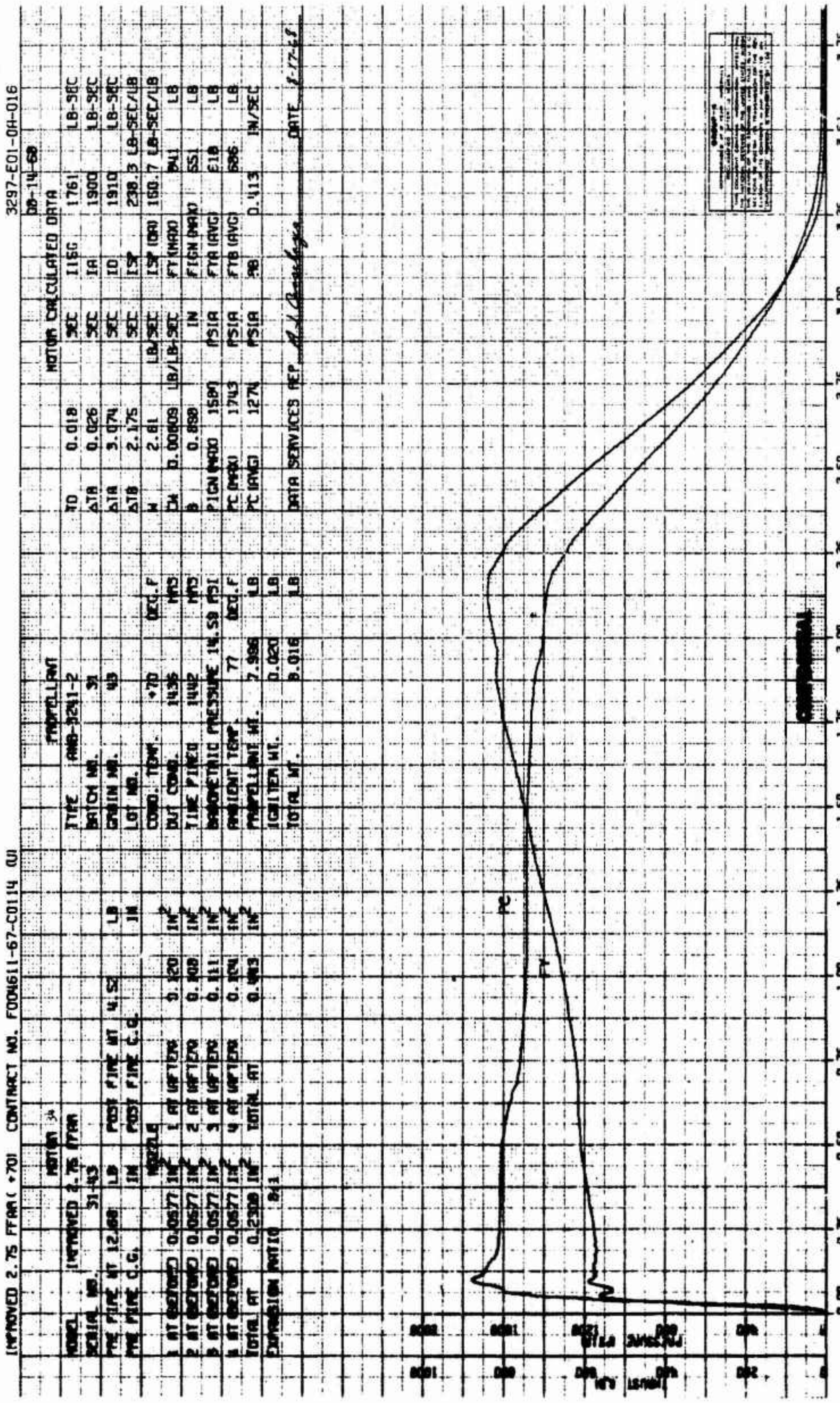

Ballistic Data and Performance Curves, Motor 34 (u)

Figure 79

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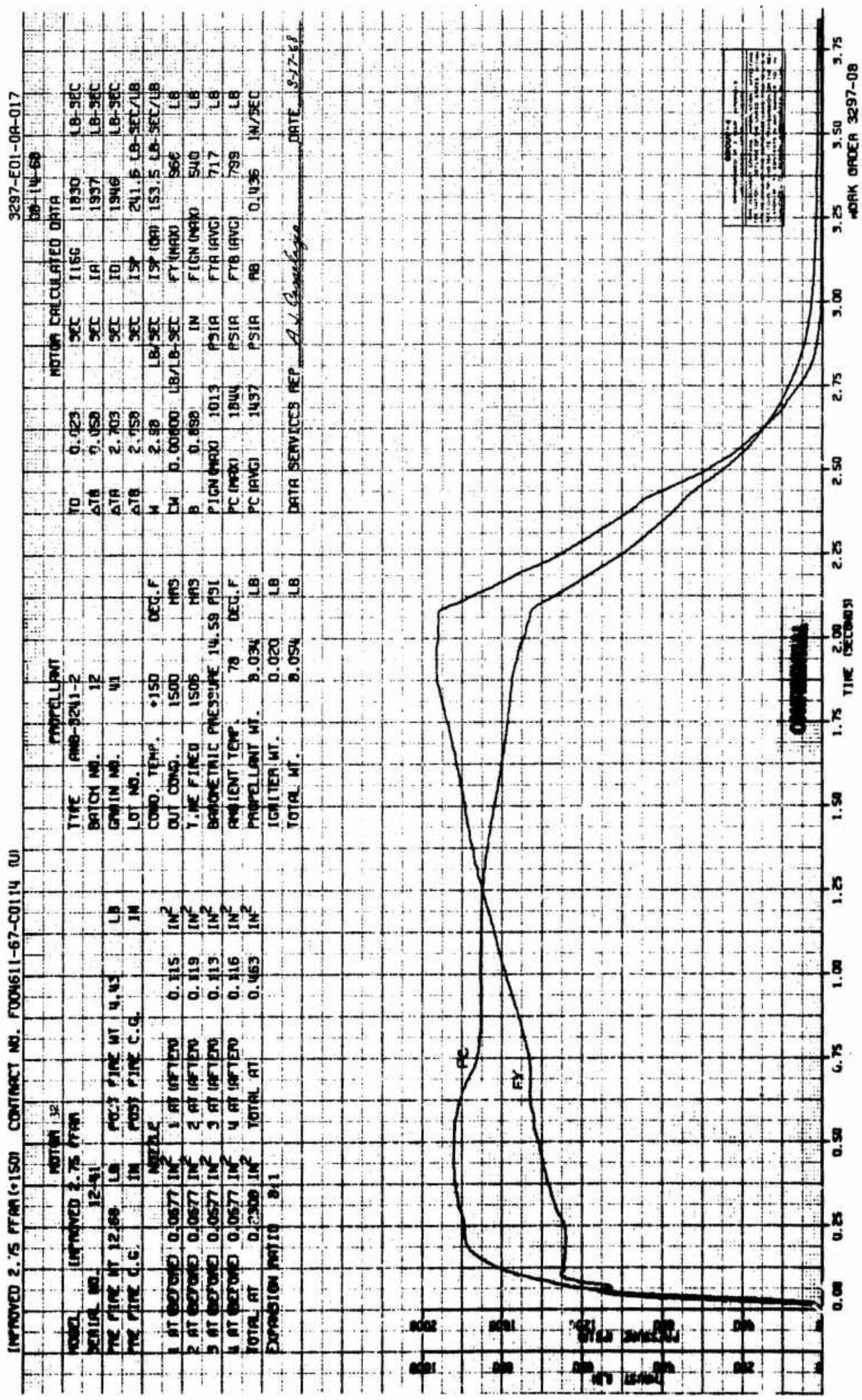
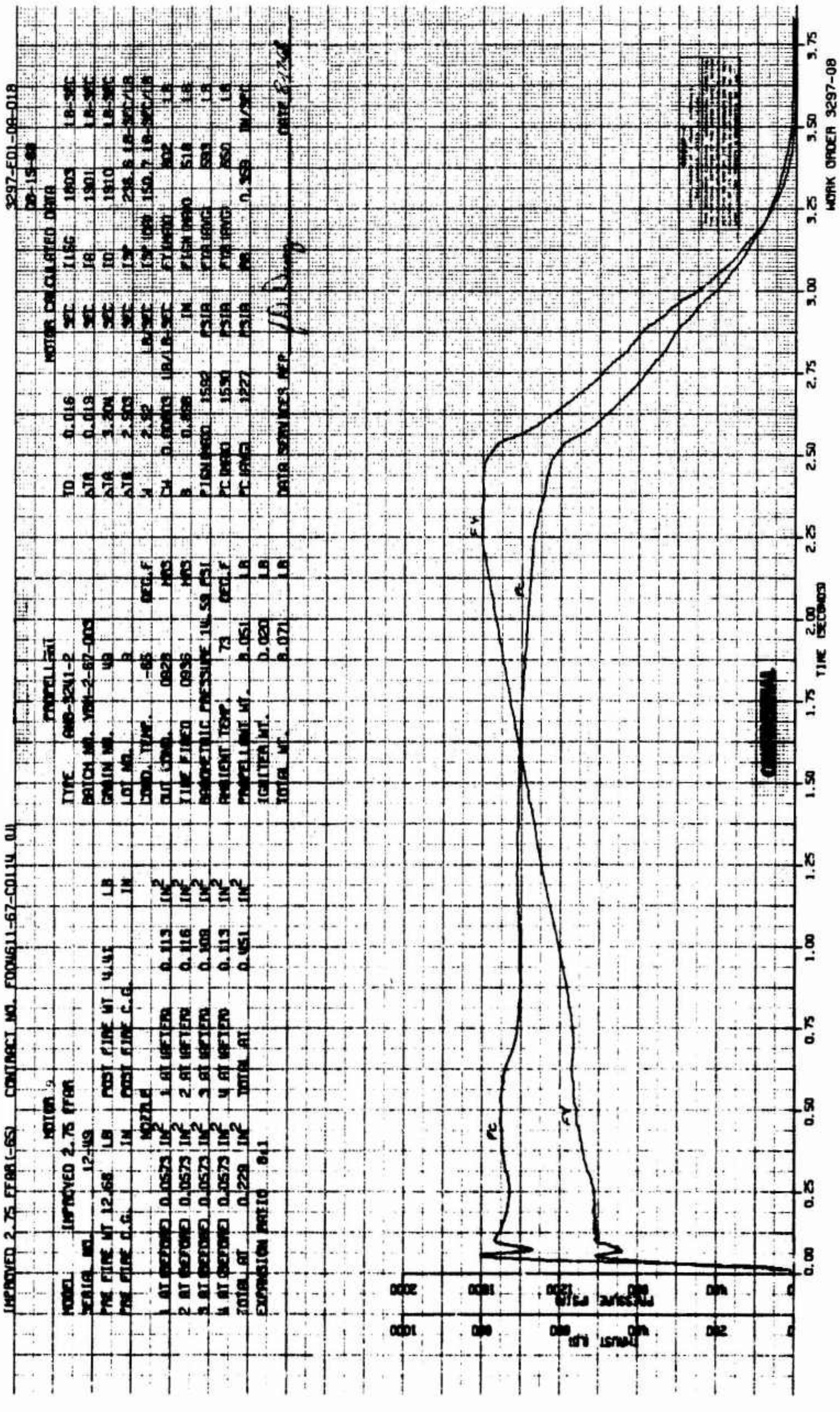


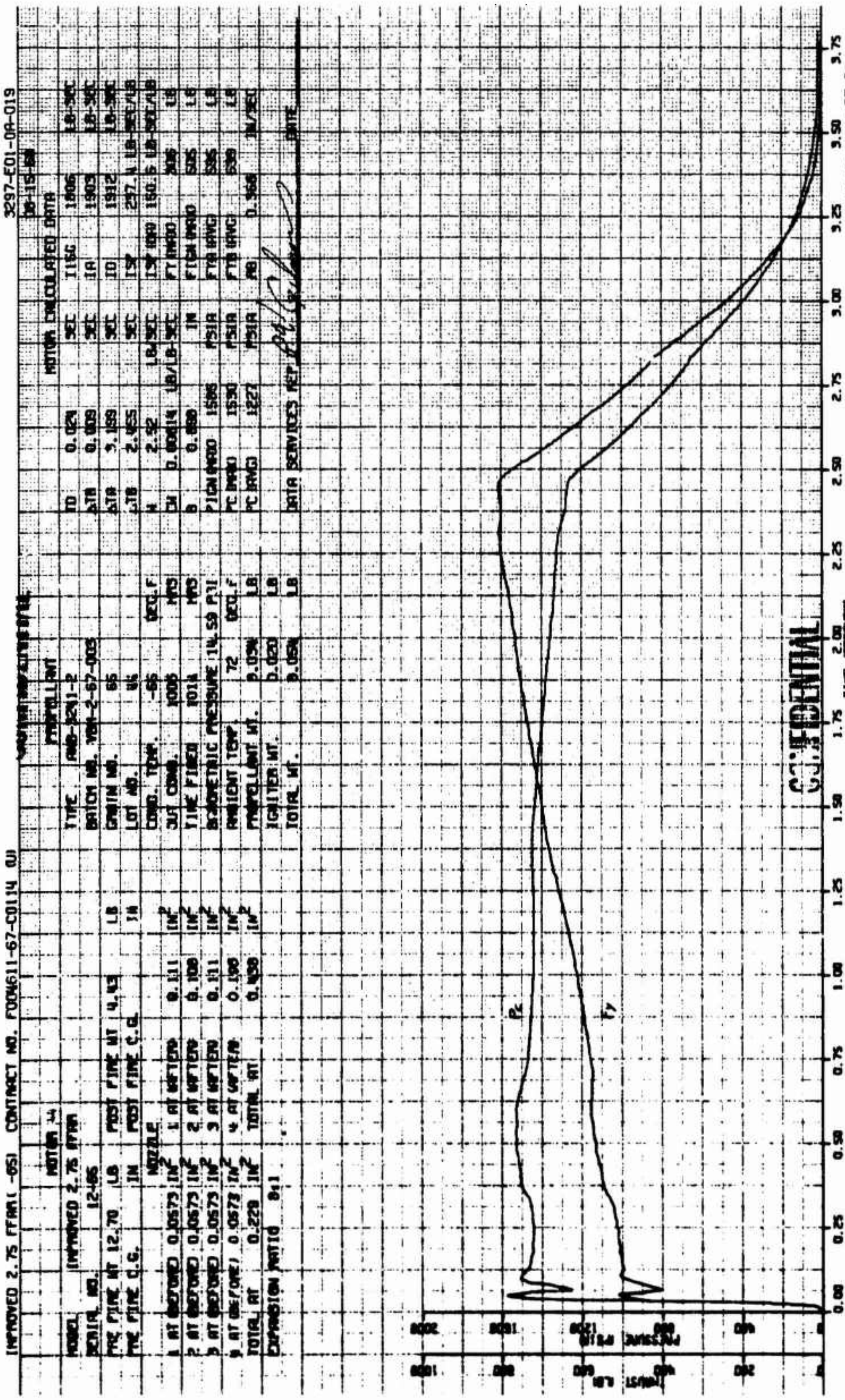
Ballistic Data and Performance Curves, Motor 32 (u)

Figure 80



Ballistic Data and Performance Curves, Motor 9 (u)

Figure 81



Ballistic Data and Performance Curves, Motor 44 (u)

Figure 82

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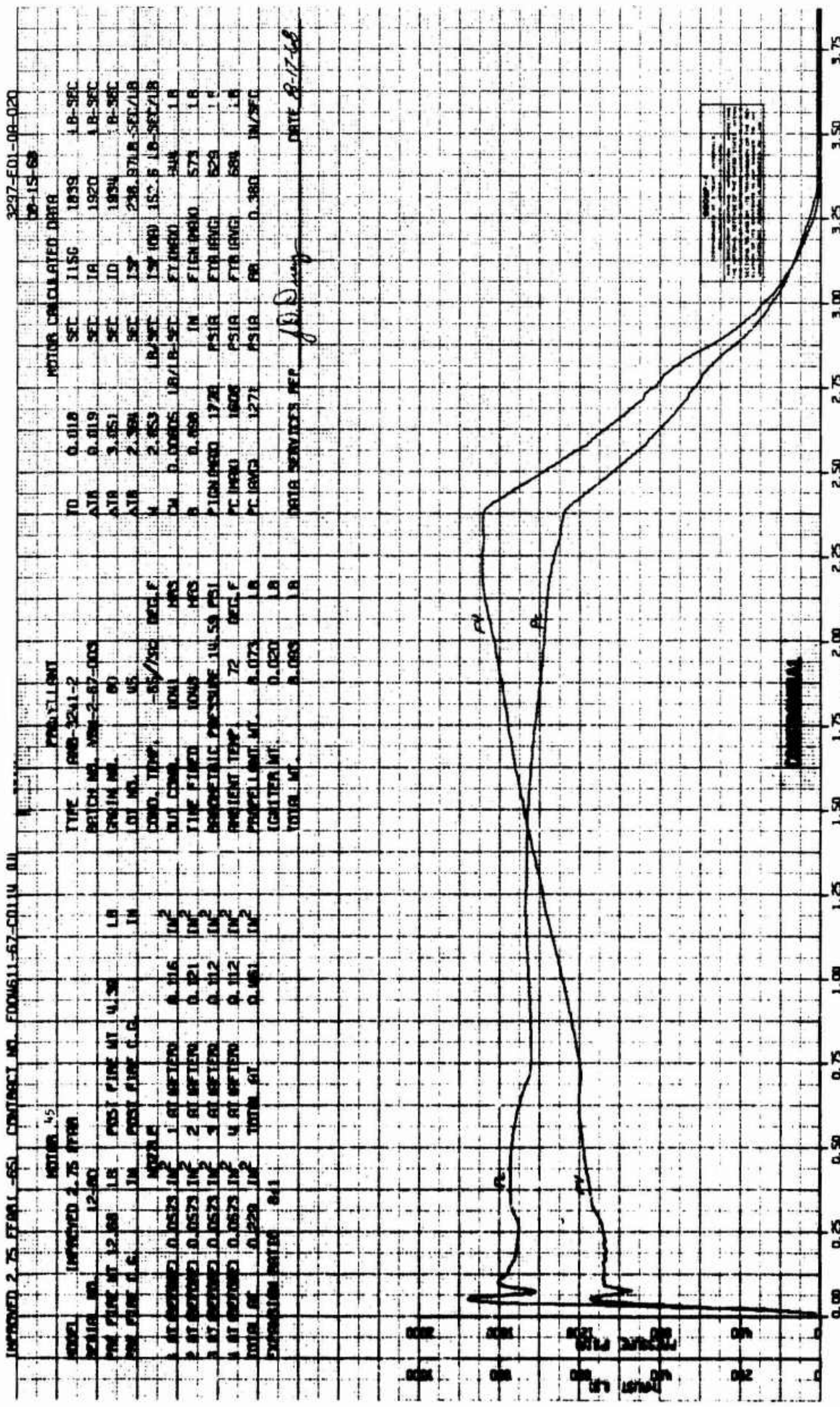

Ballistic Data and Performance Curves, Motor 45 (u)

Figure 83

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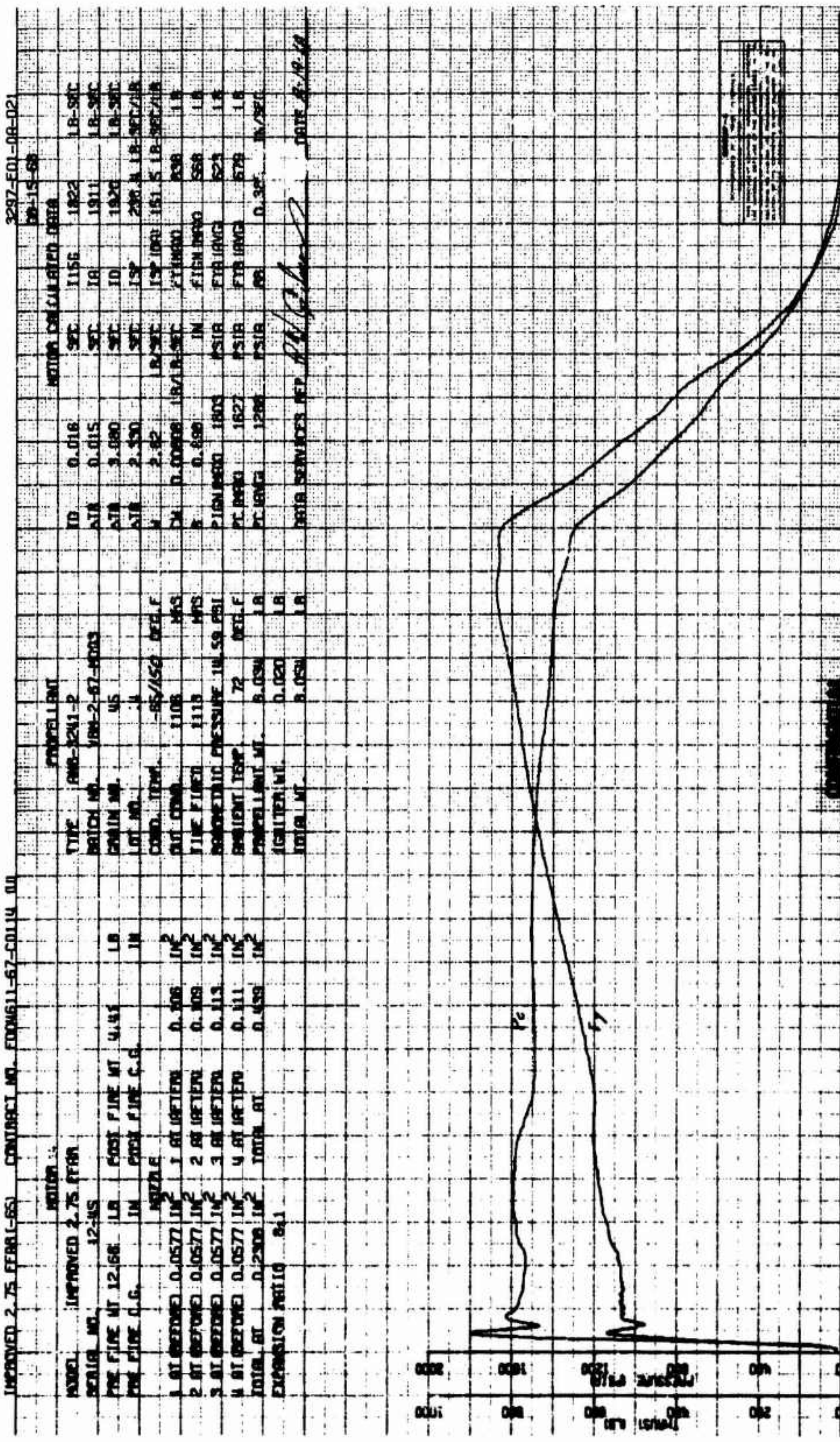
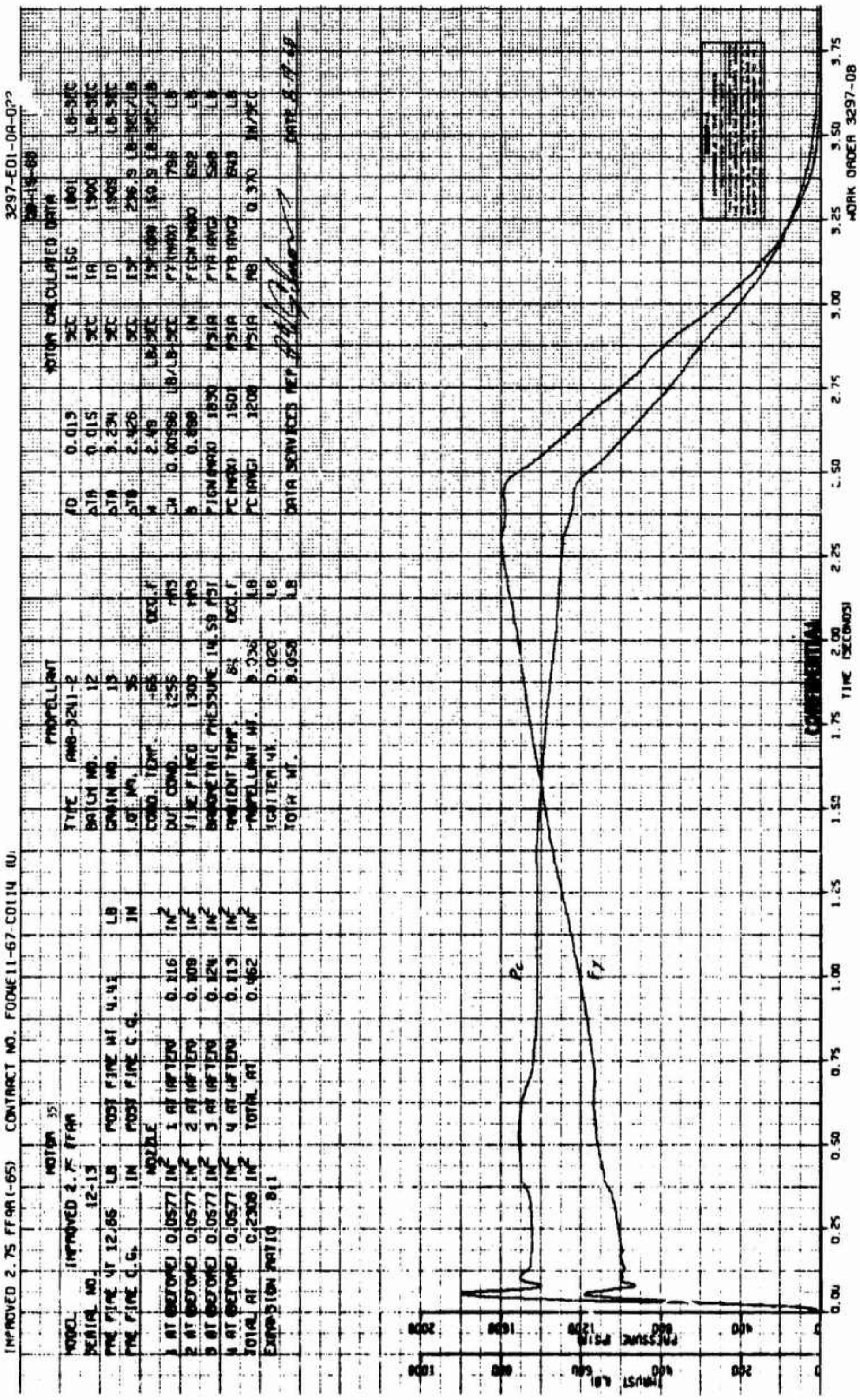


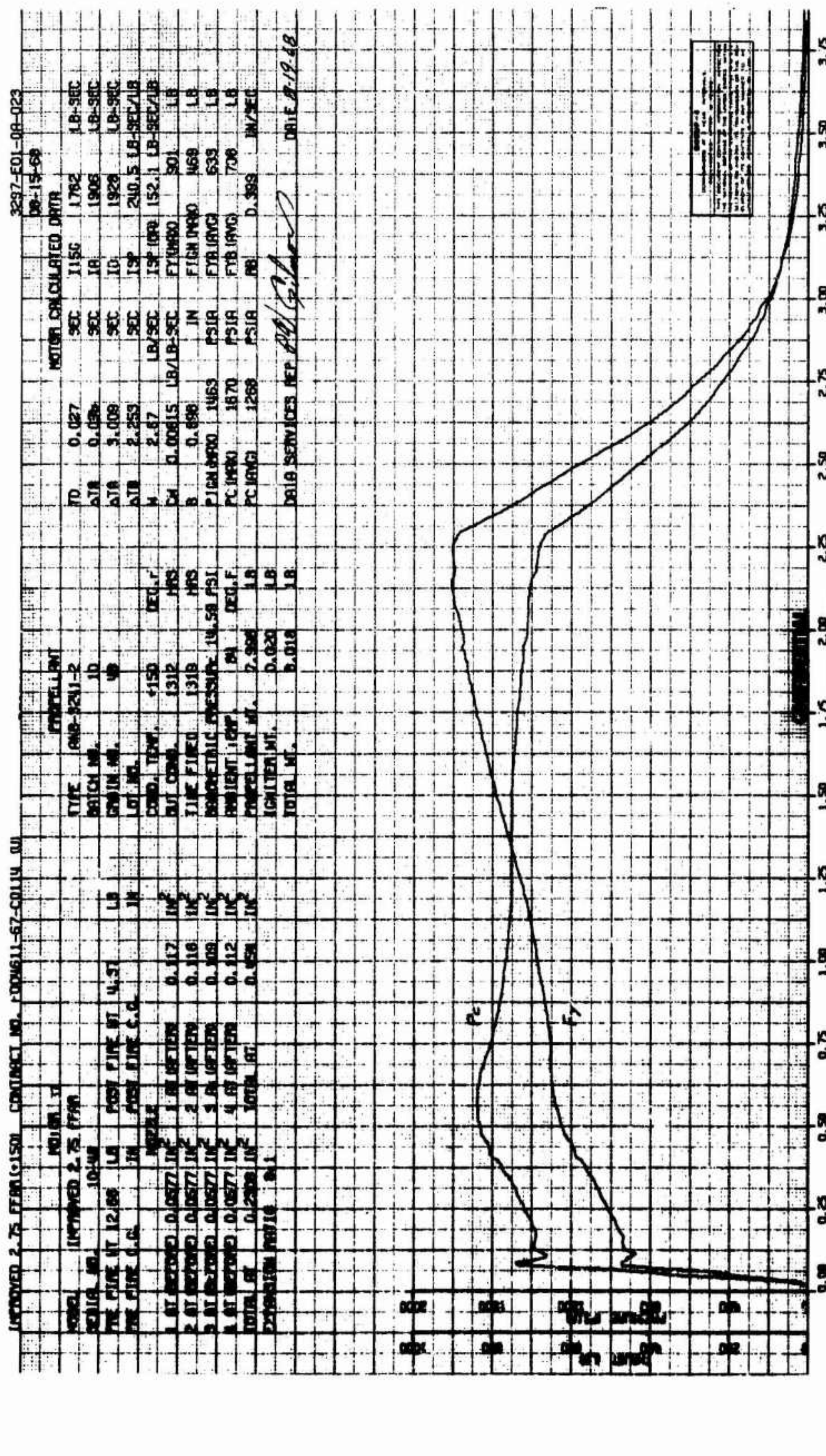
Ballistic Data and Performance Curves, Motor 14 (u)

Figure 84



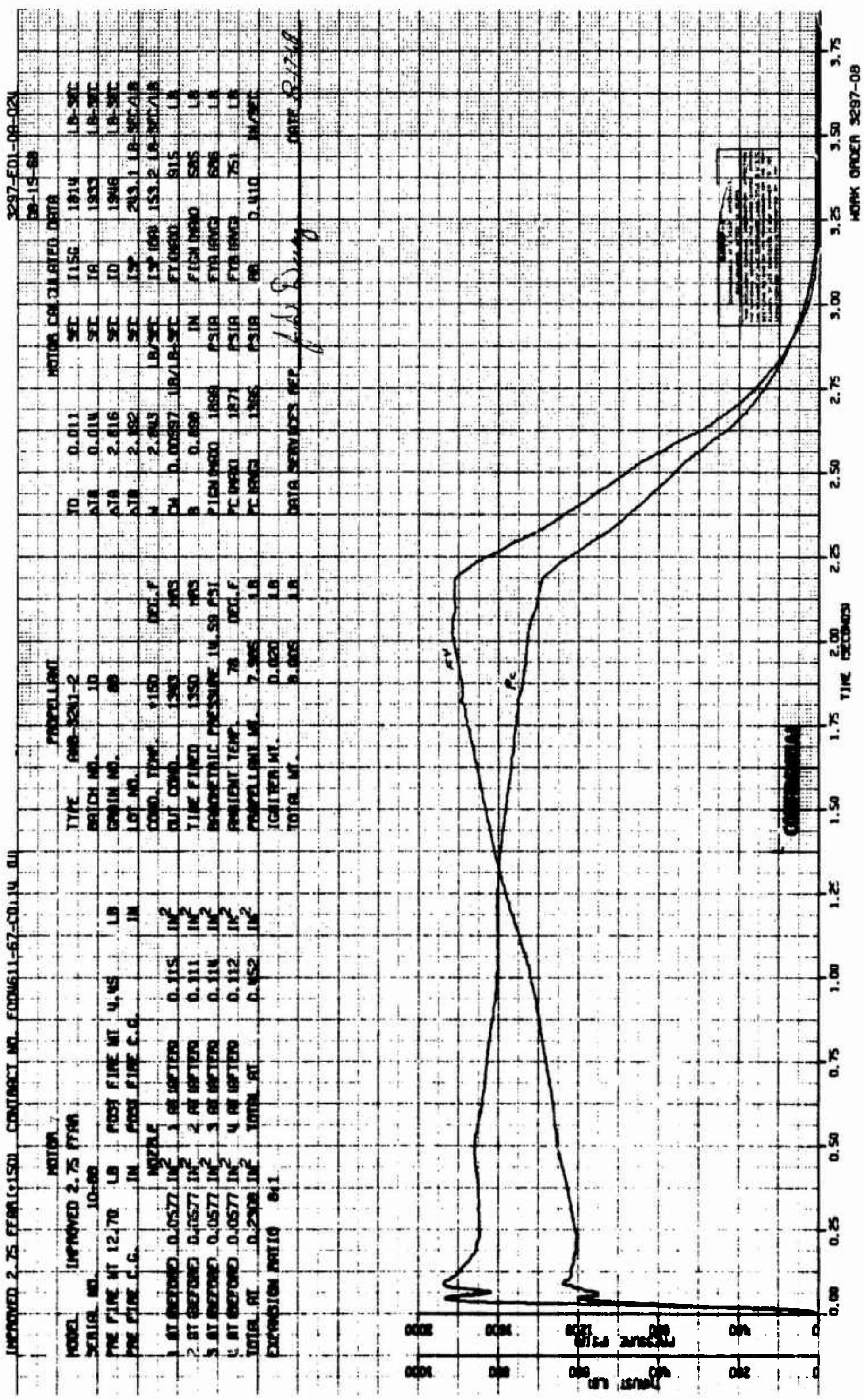
Ballistic Data and Performance Curves, Motor 35 (u)

Figure 85



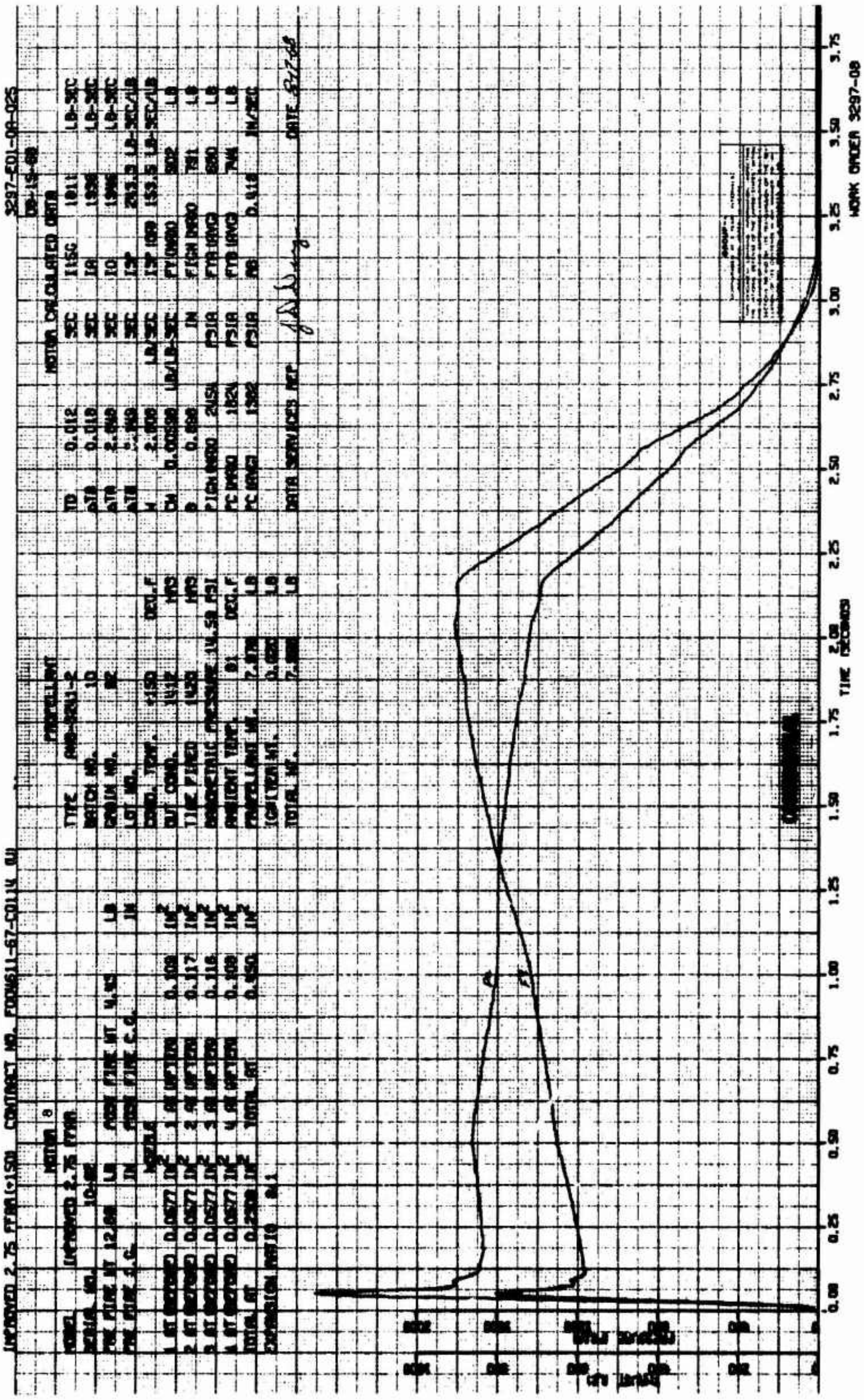
Ballistic Data and Performance Curves, Motor 37 (u)

Figure 86



Ballistic Data and Performance Curves, Motor 7 (u)

Figure 87



Ballistic Data and Performance Curves, Motor 8 (u)

Figure 88

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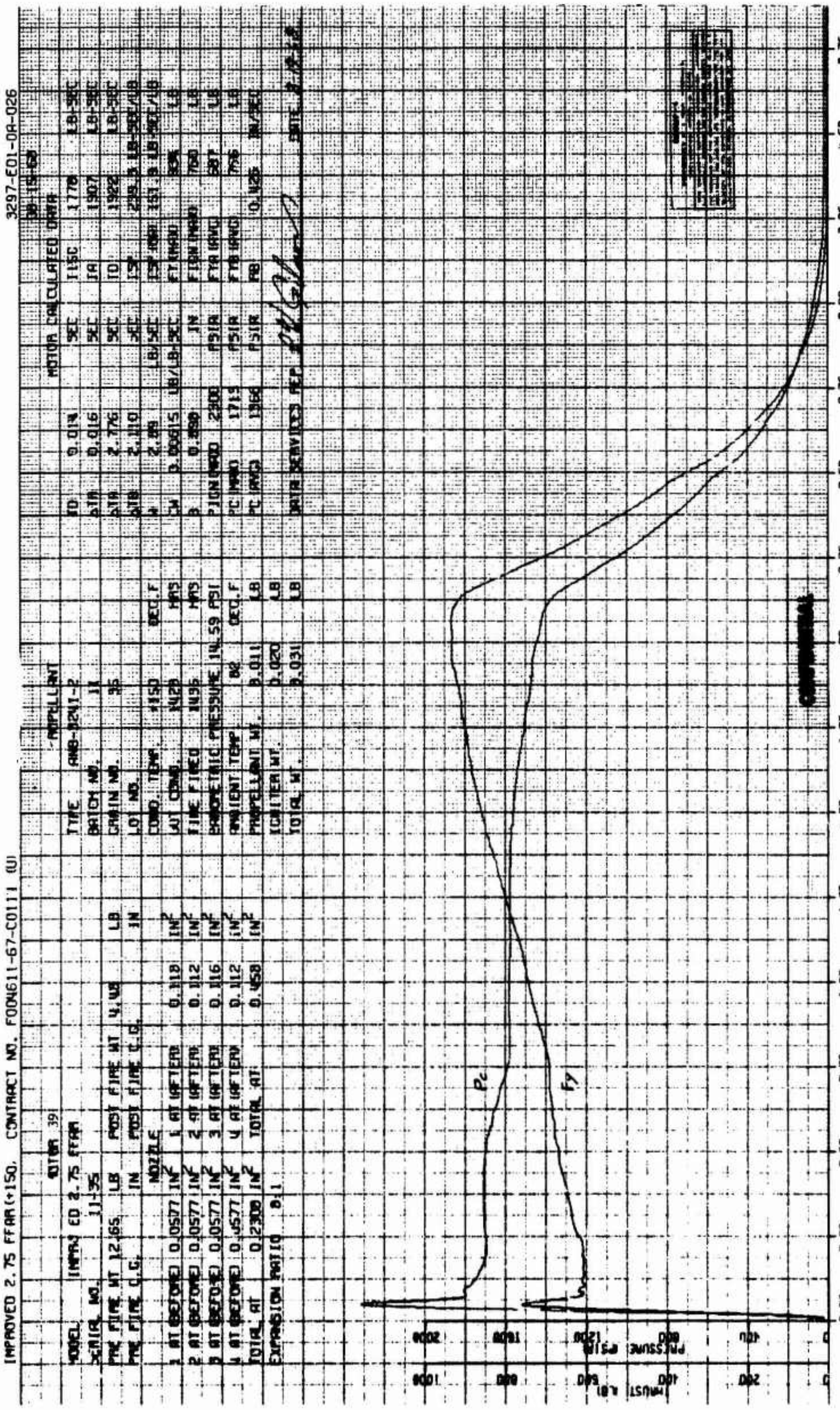

Ballistic Data and Performance Curves, Motor 39 (u)

Figure 89

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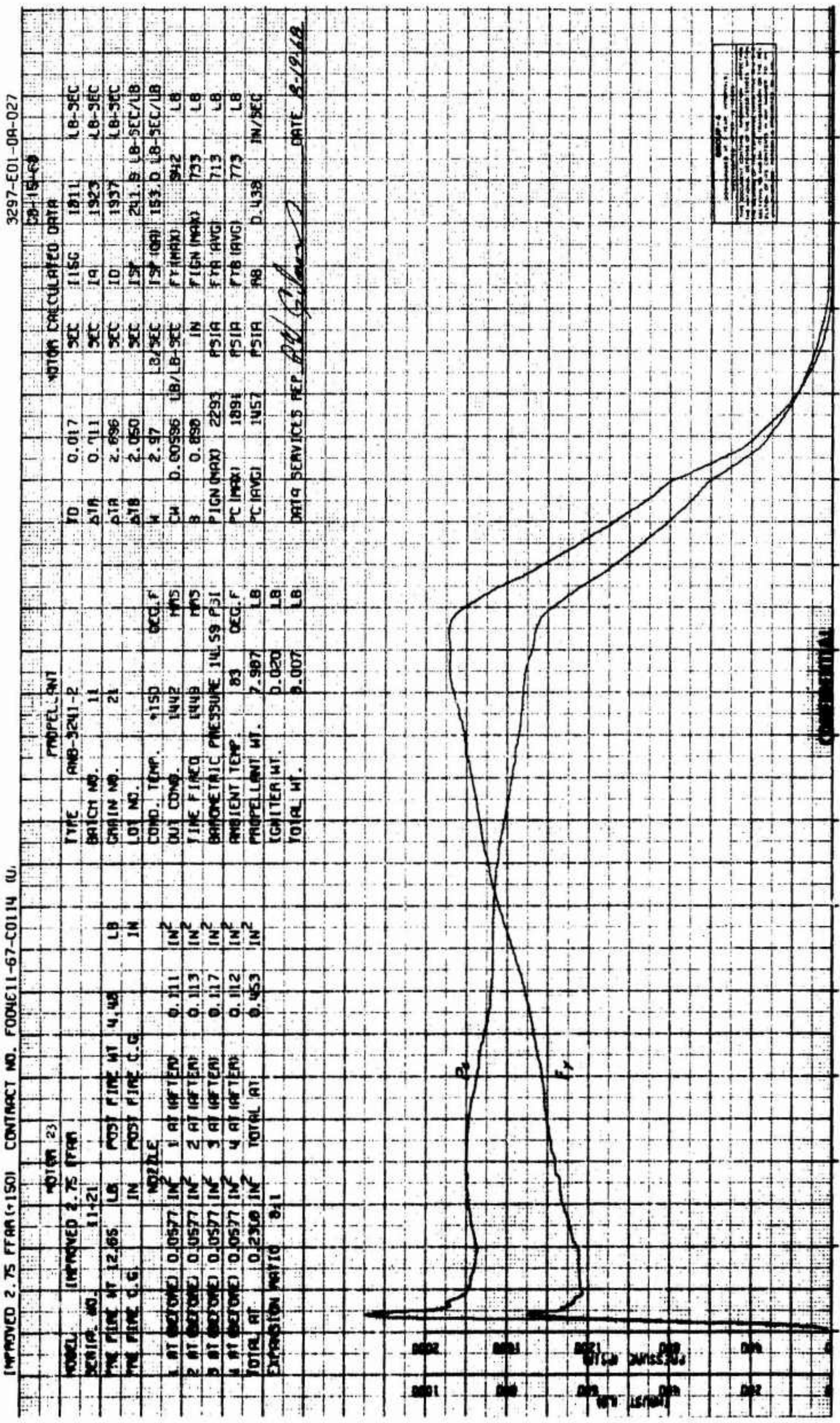

Ballistic Data and Performance Curves, Motor 23 (u)

Figure 90

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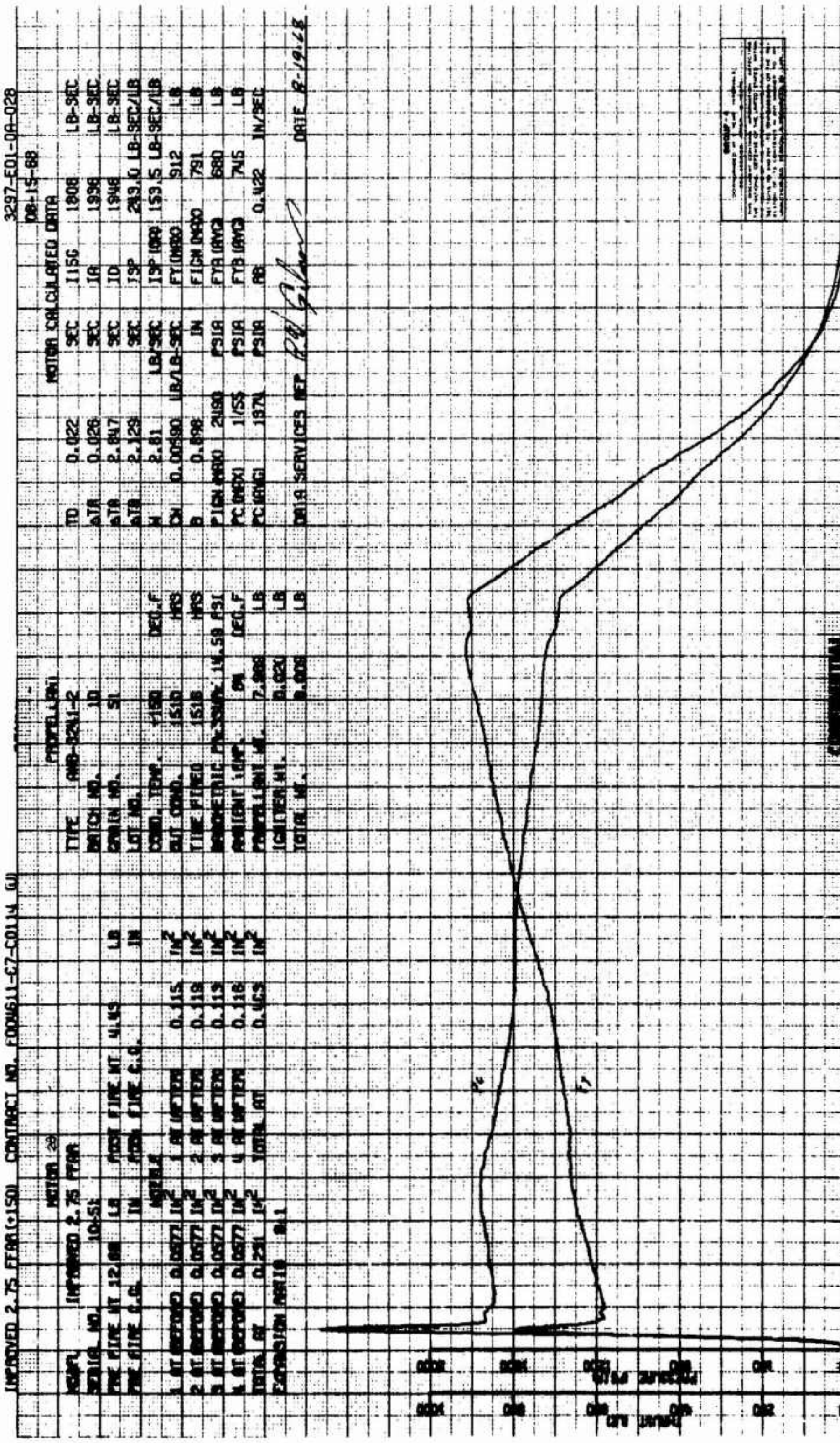

Ballistic Data and Performance Curves, Motor 28 (u)

Figure 91

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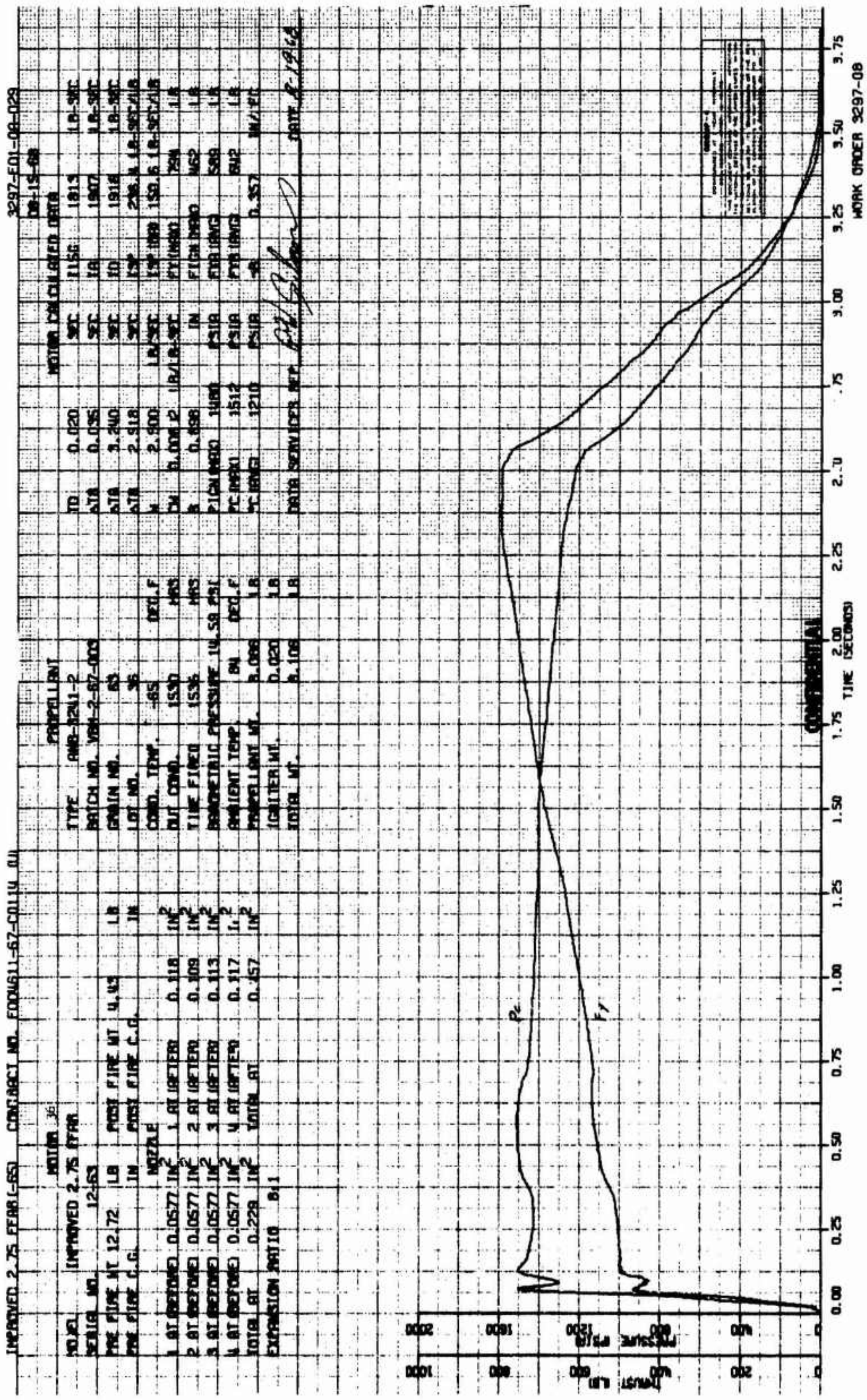
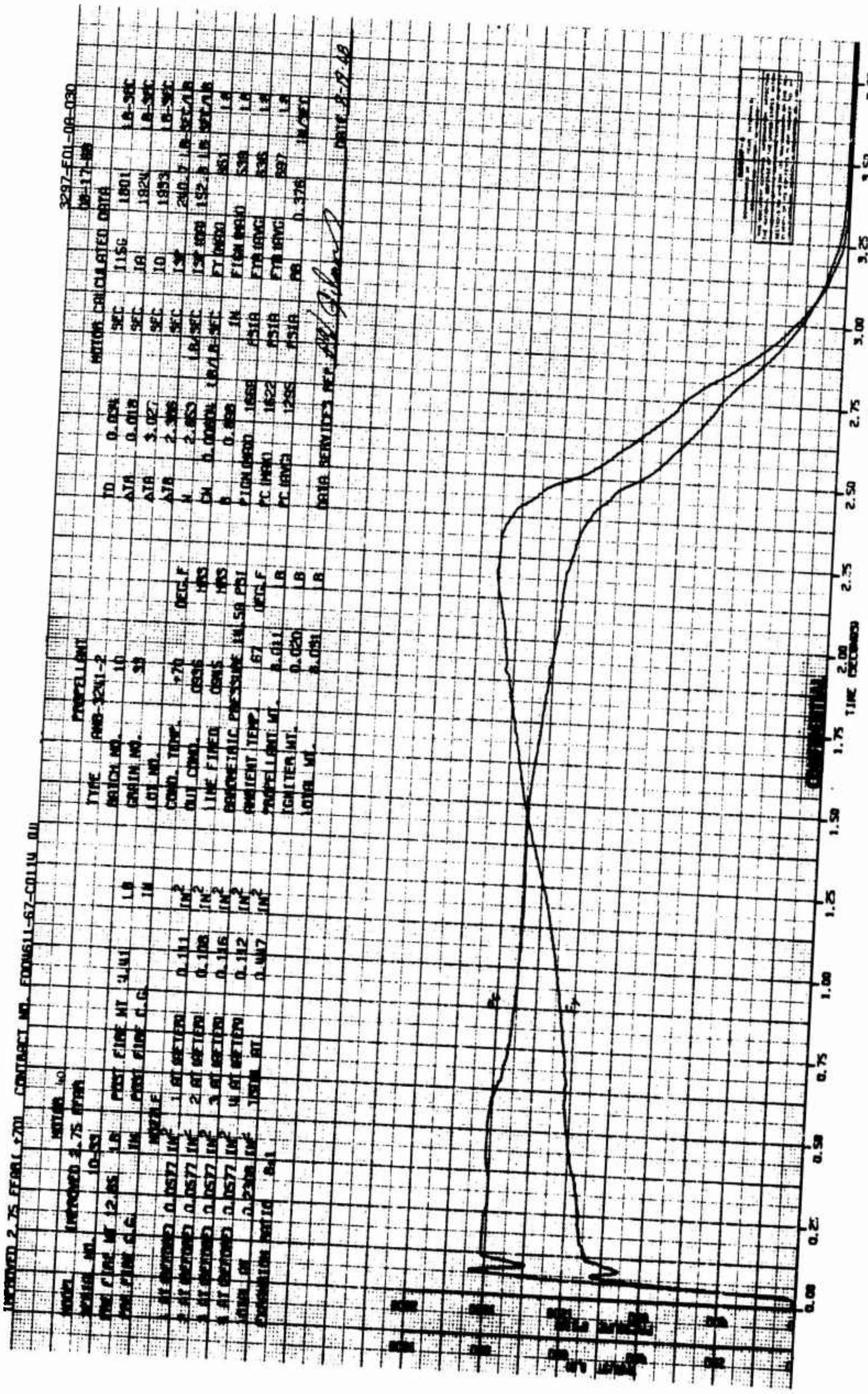


Ballistic Data and Performance Curves, Motor 36 (u)

Figure 92



Ballistic Data and Performance Curves, Motor 40 (u)

Figure 93

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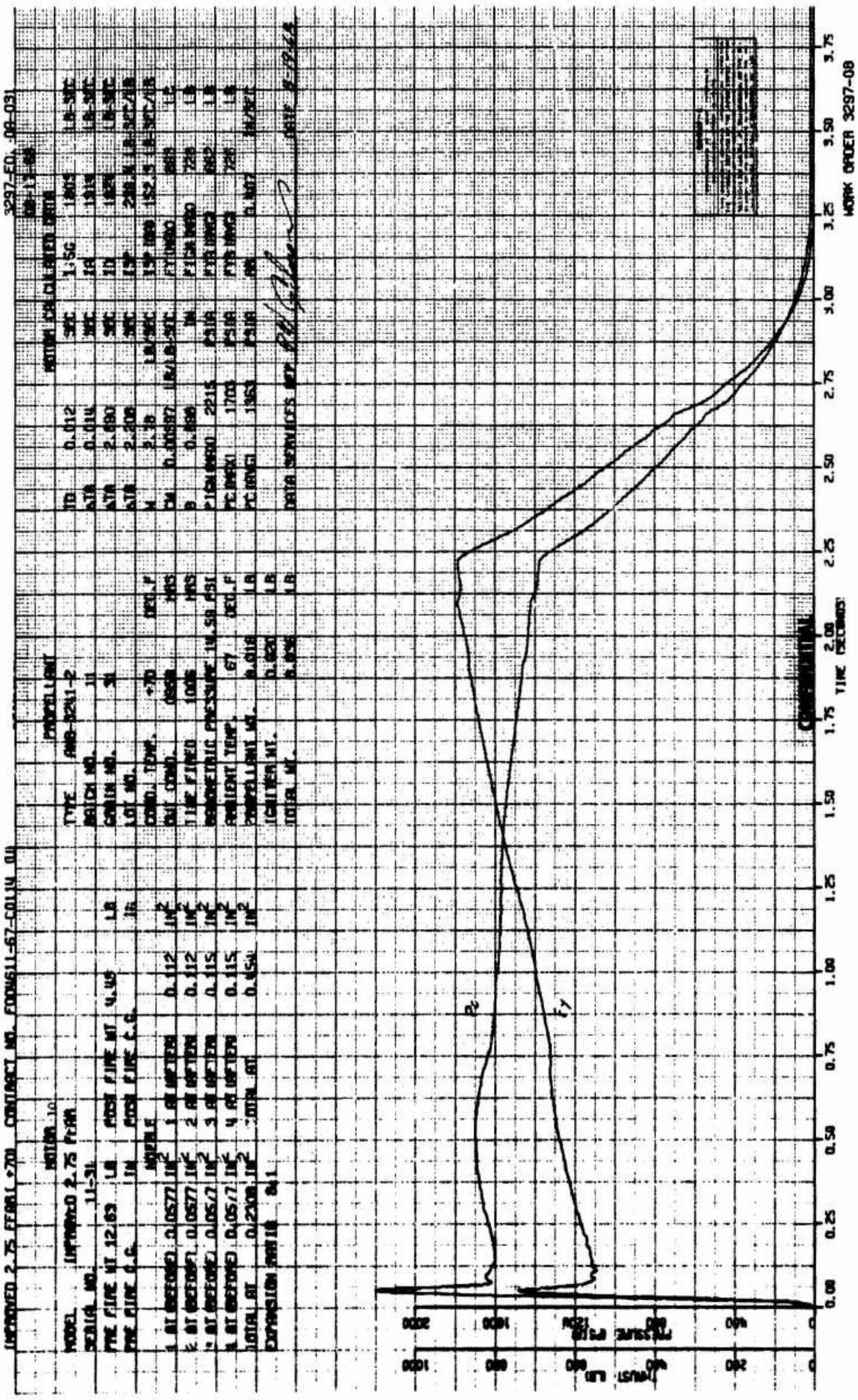

Ballistic Data and Performance Curves, Motor 10 (u)

Figure 94

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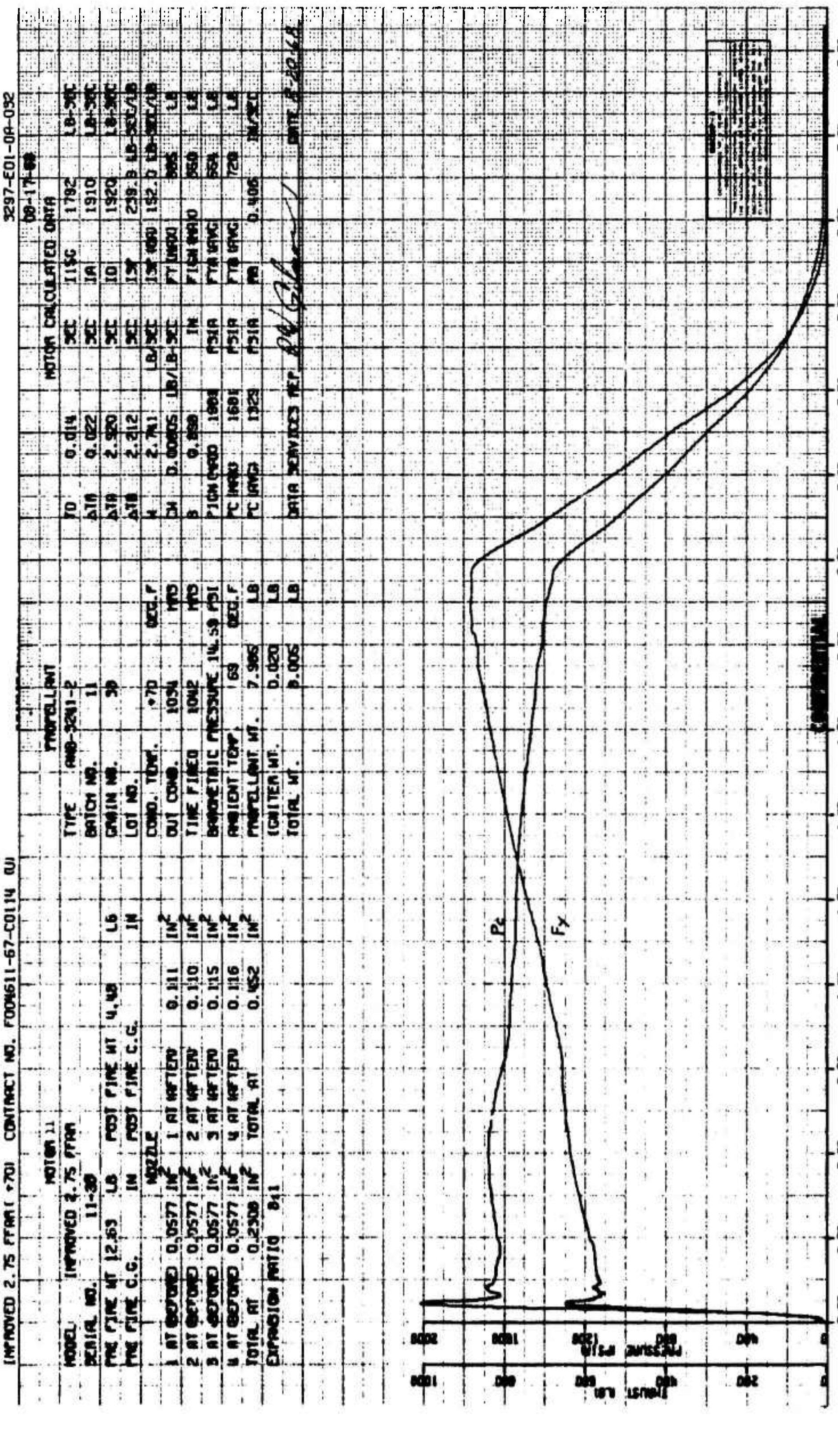
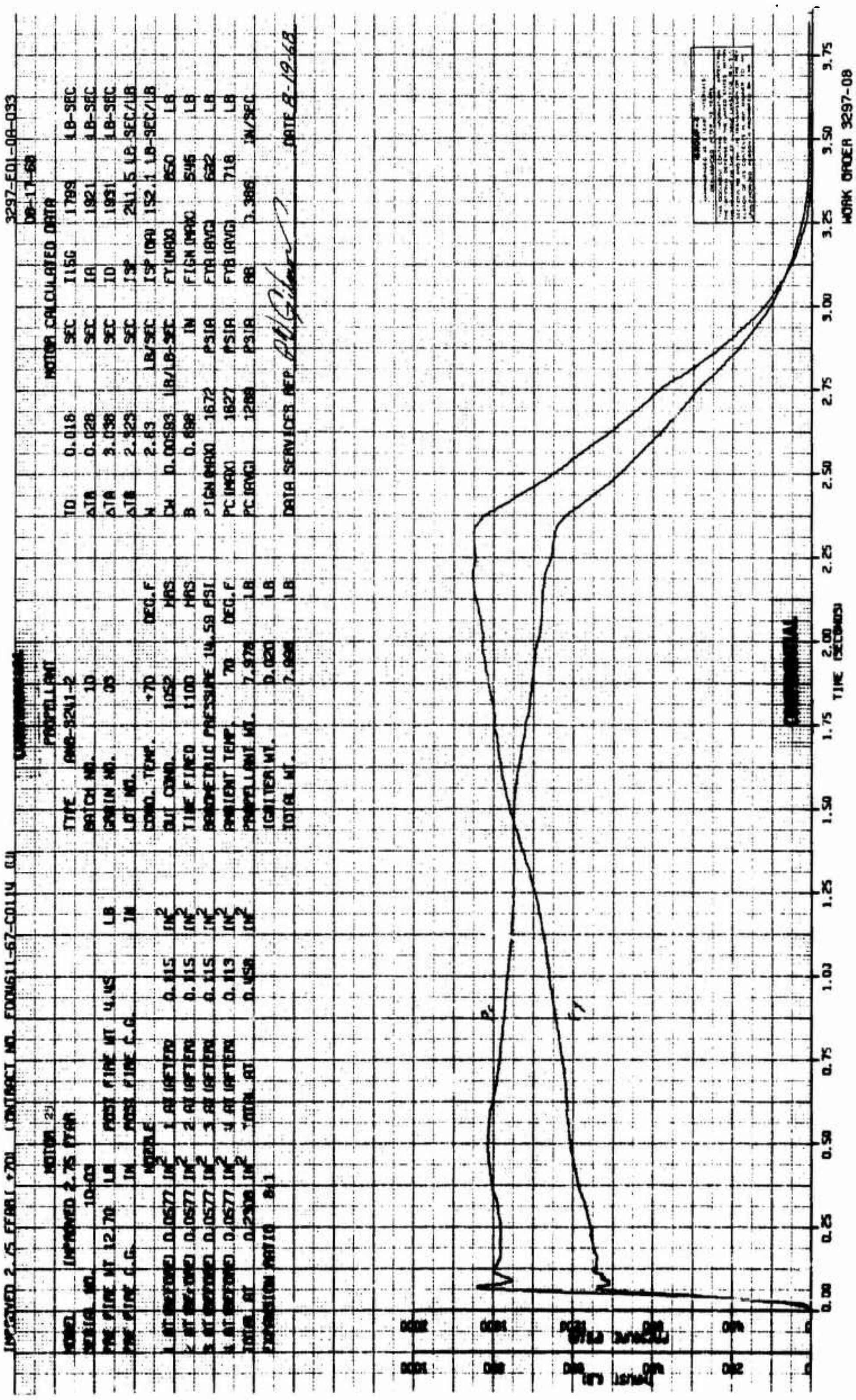


Ballistic Data and Performance Curves, Motor 11 (u)

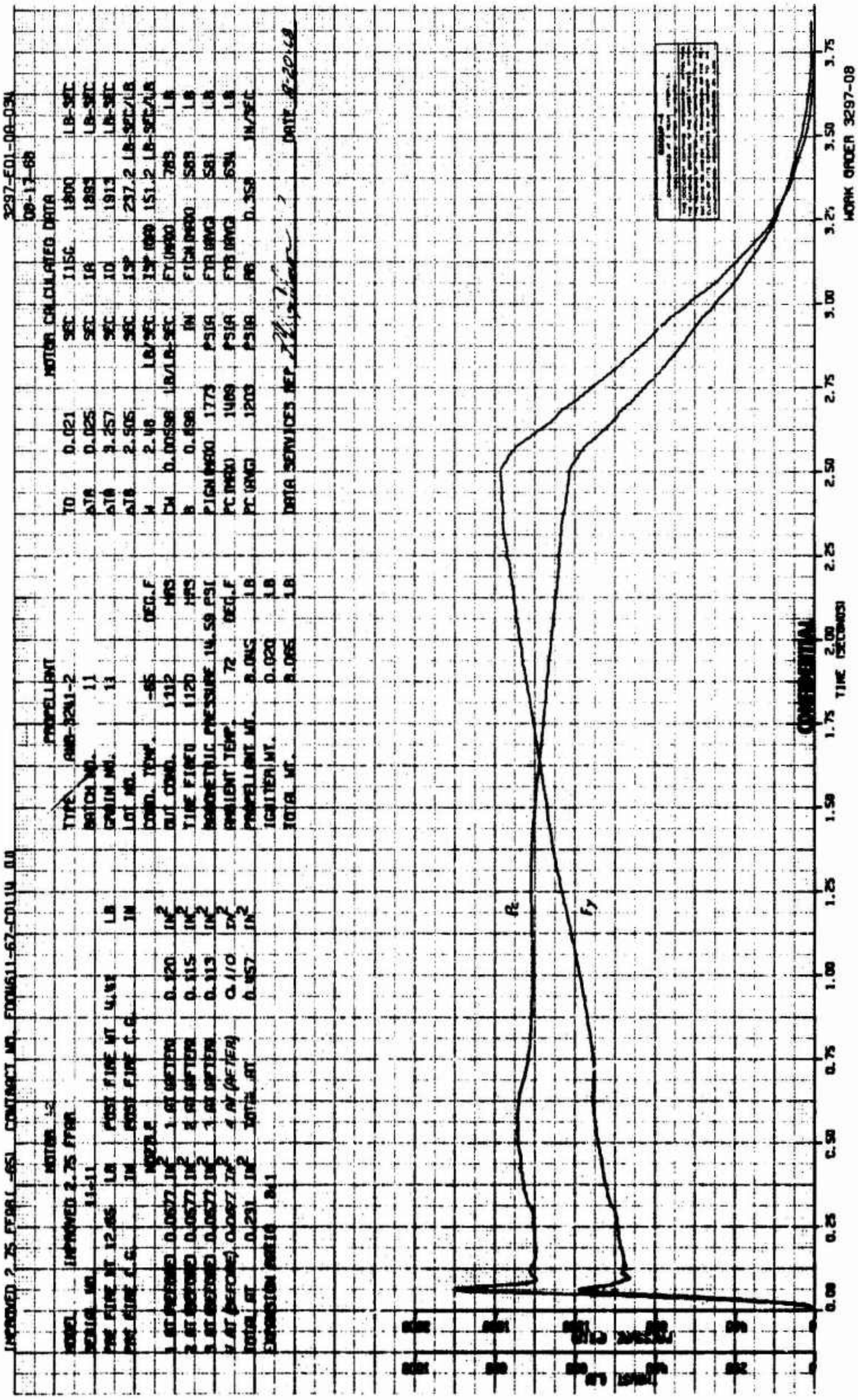
Figure 95

CONFIDENTIAL



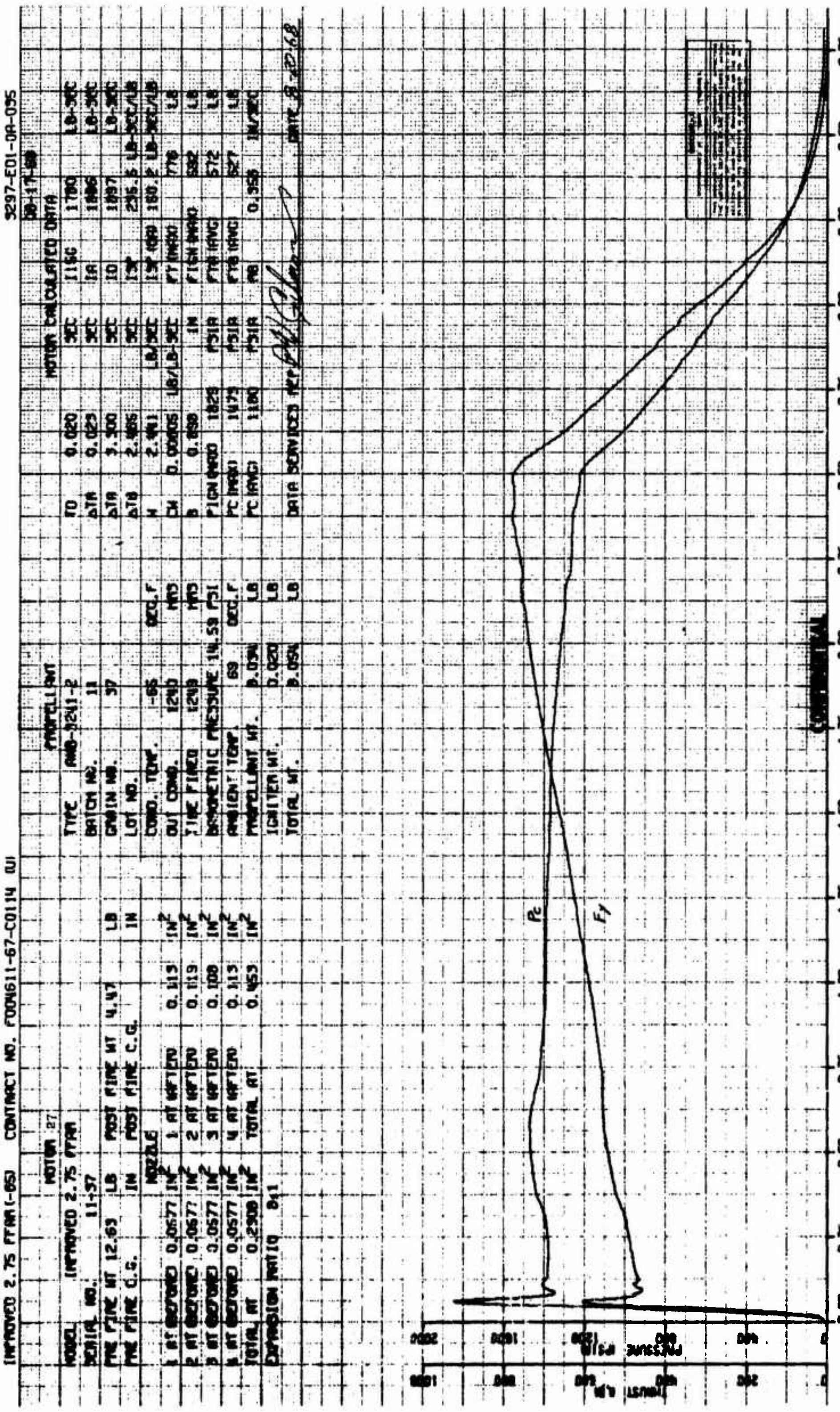
Ballistic Data and Performance Curves, Motor 25 (u)

Figure 96



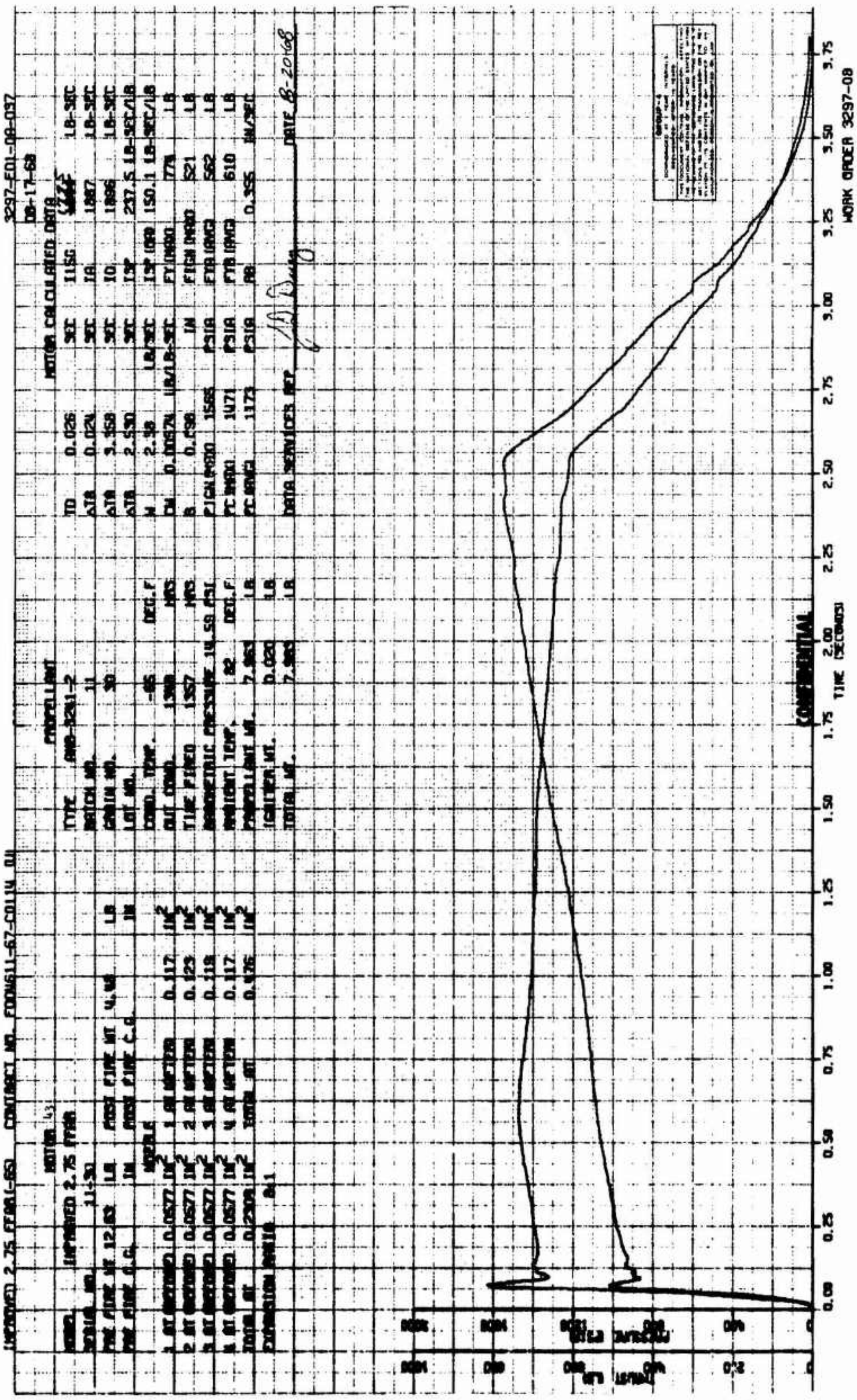
Ballistic Data and Performance Curves, Motor 42 (u)

Figure 97



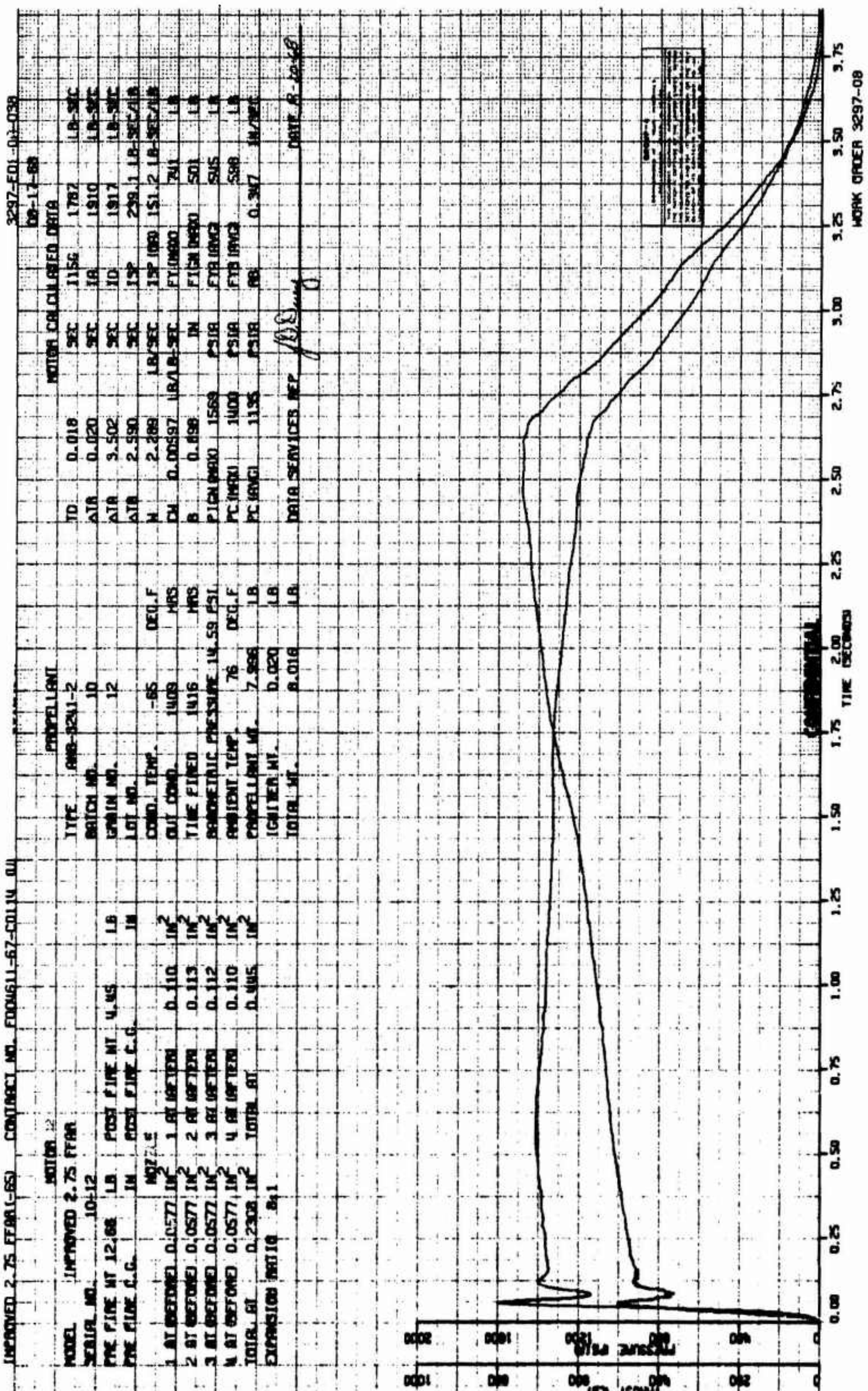
Ballistic Data and Performance Curves, Motor 27 (u)

Figure 98



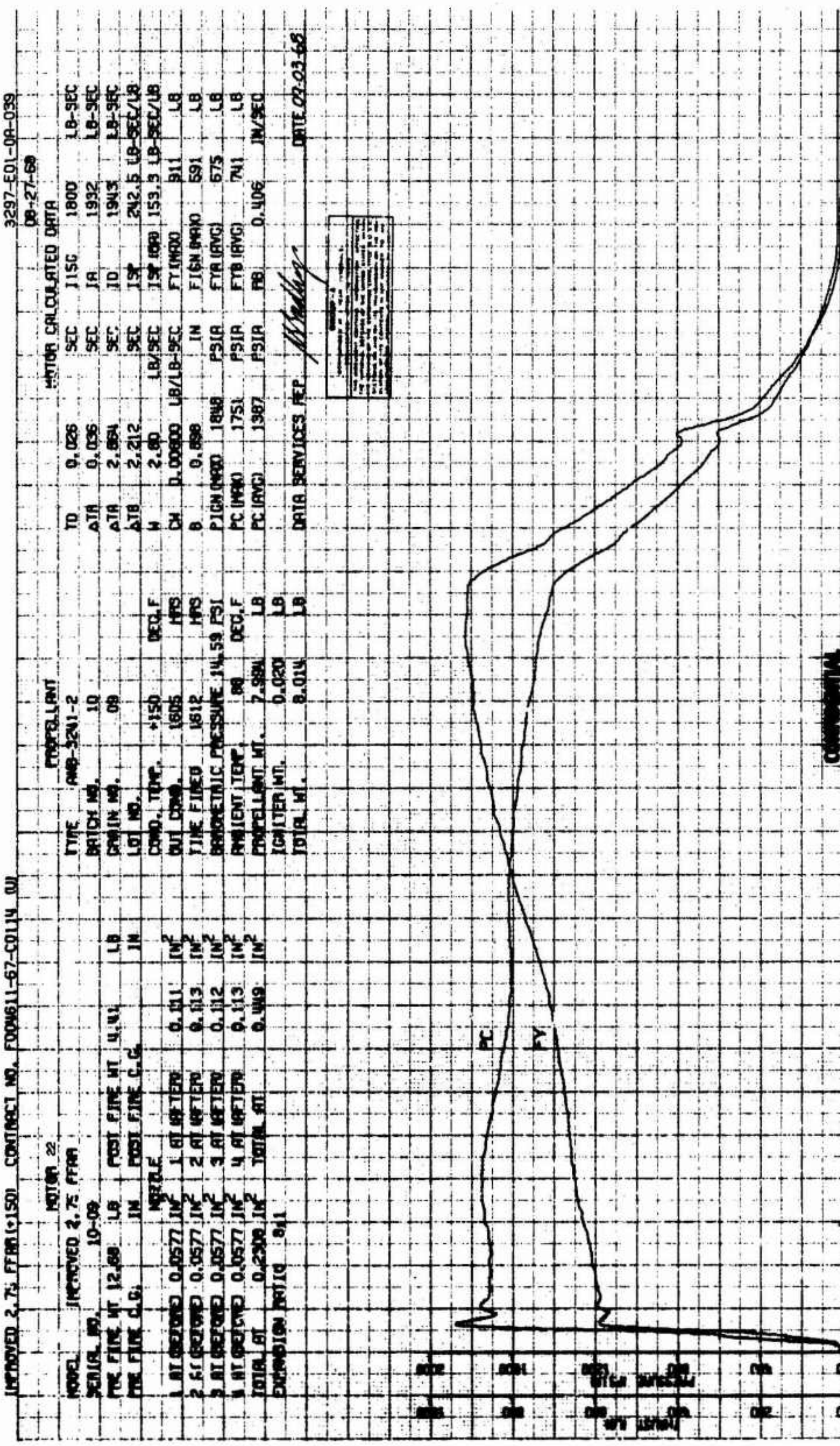
Ballistic Data and Performance Curves, Motor 43 (u)

Figure 99



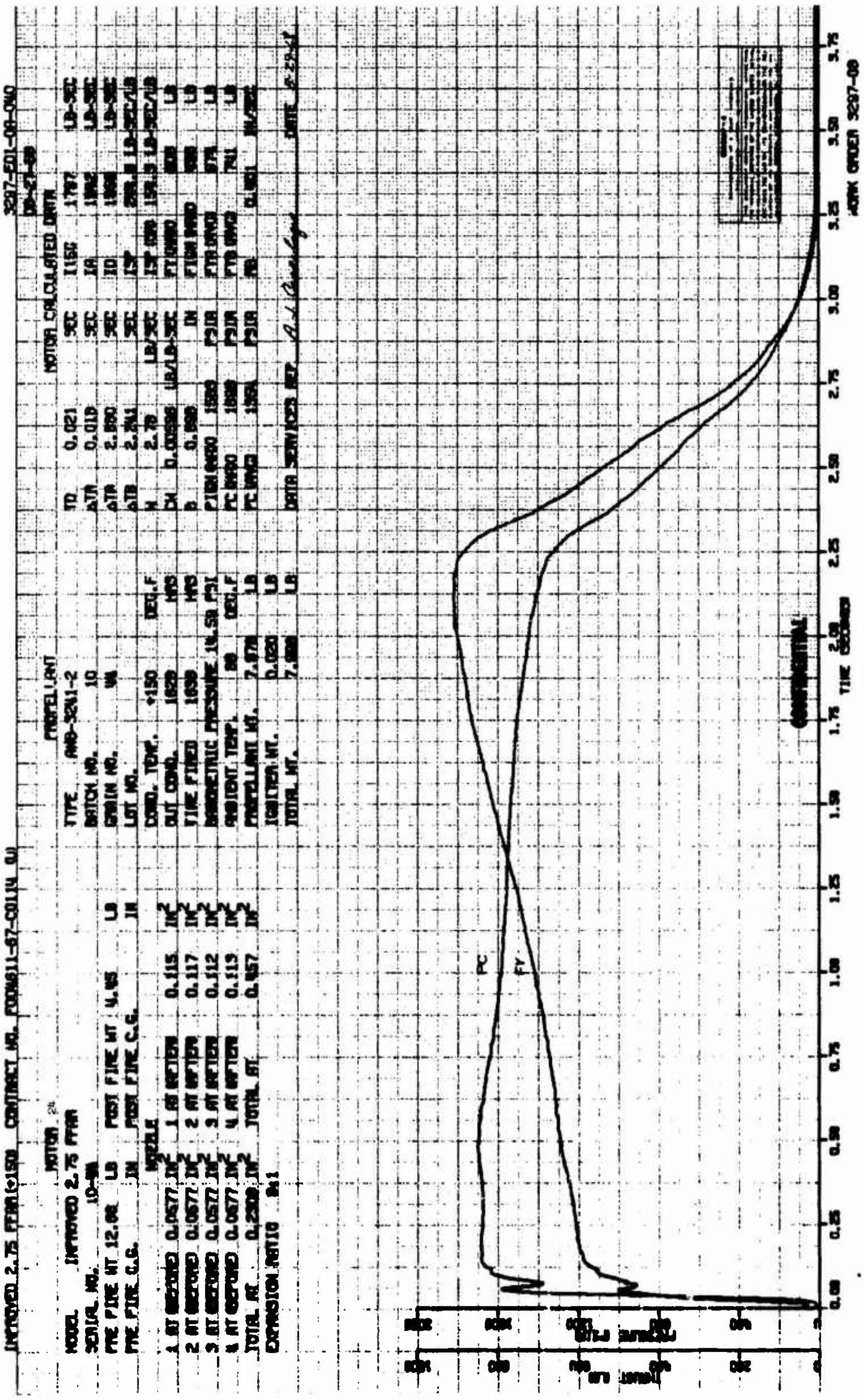
Ballistic Data and Performance Curves, Motor 12 (u)

Figure 100



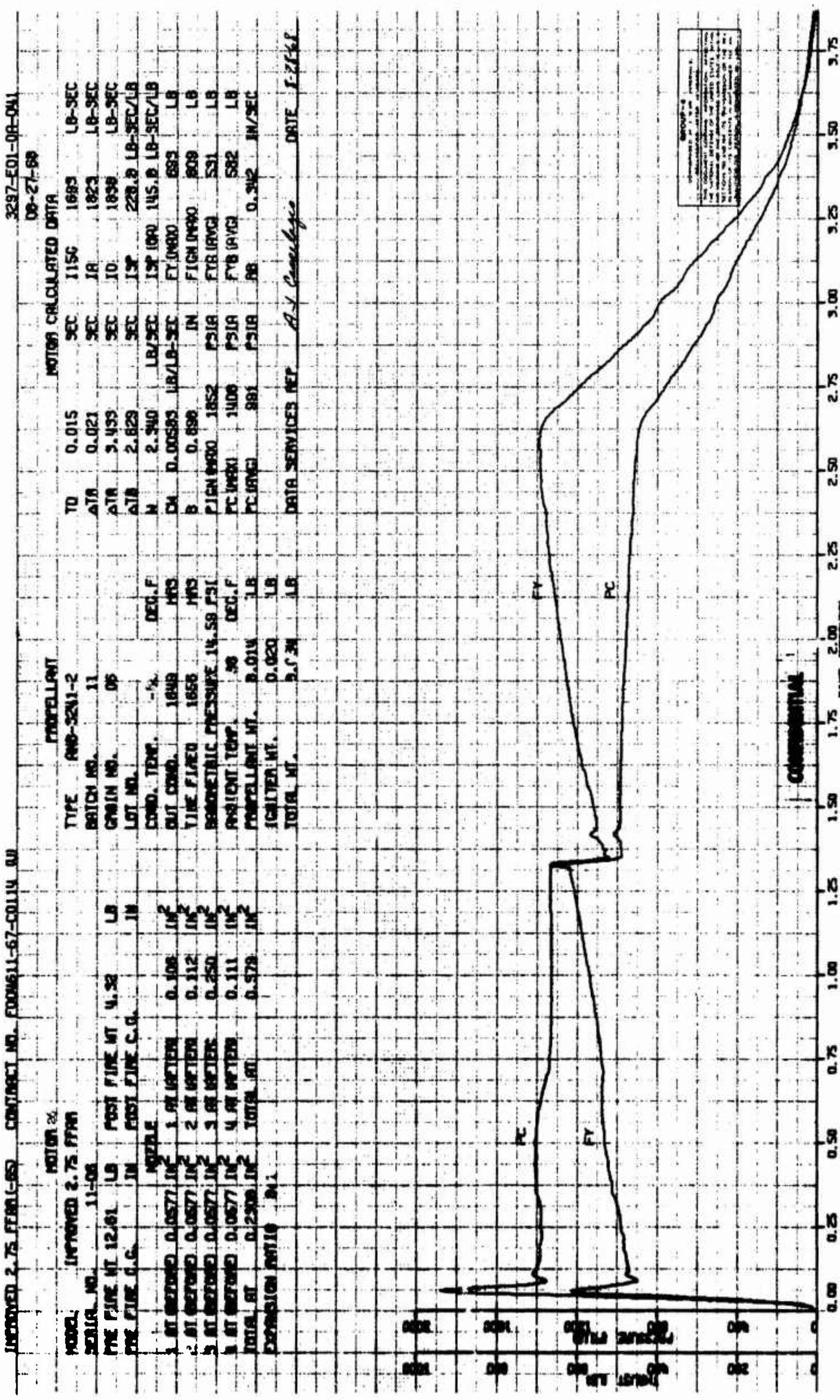
Ballistic Data and Performance Curves, Motor 22 (u)

Figure 101



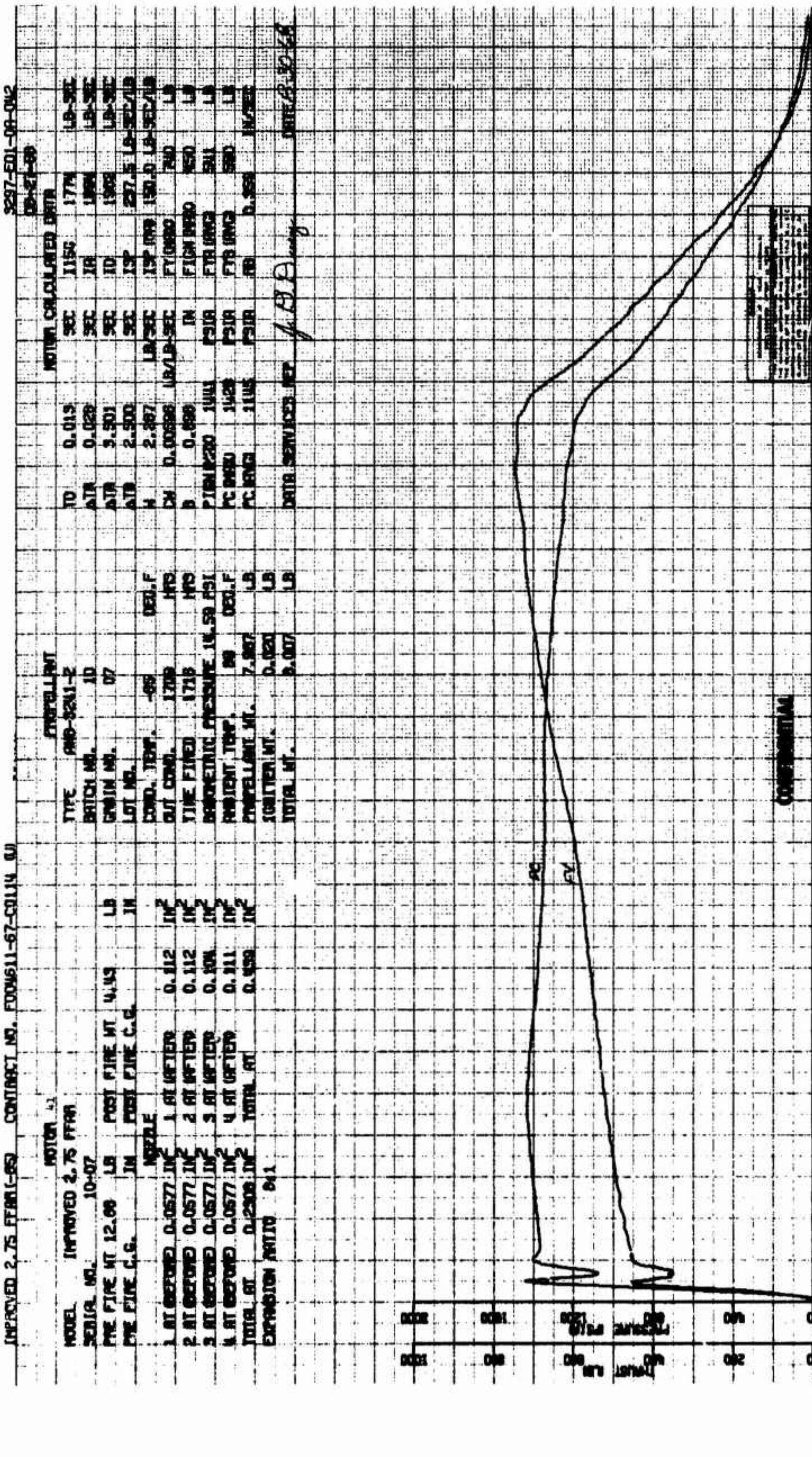
Ballistic Data and Performance Curves, Motor 24 (u)

Figure 102



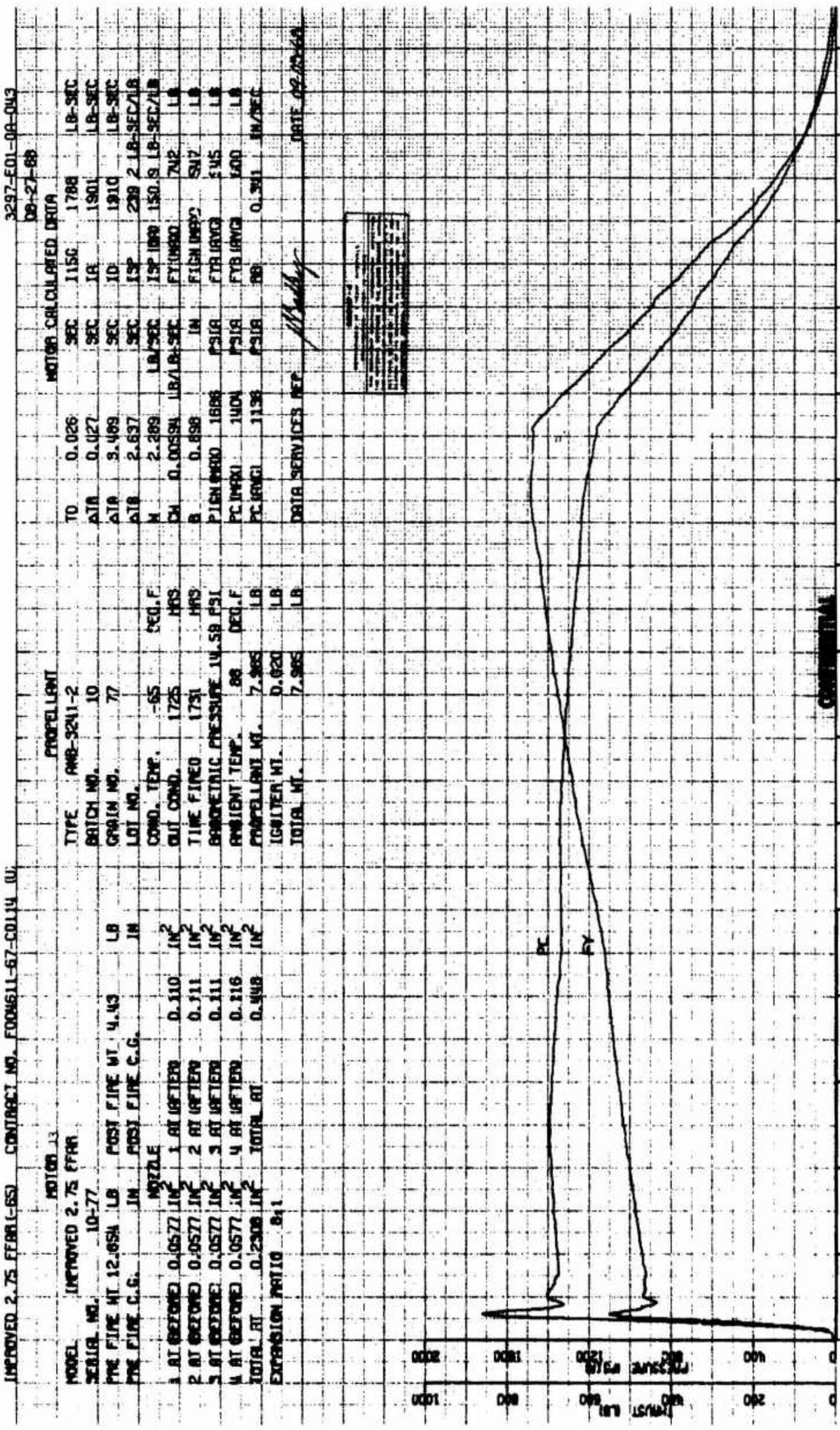
Ballistic Data and Performance Curves, Motor 26 (u)

Figure 103



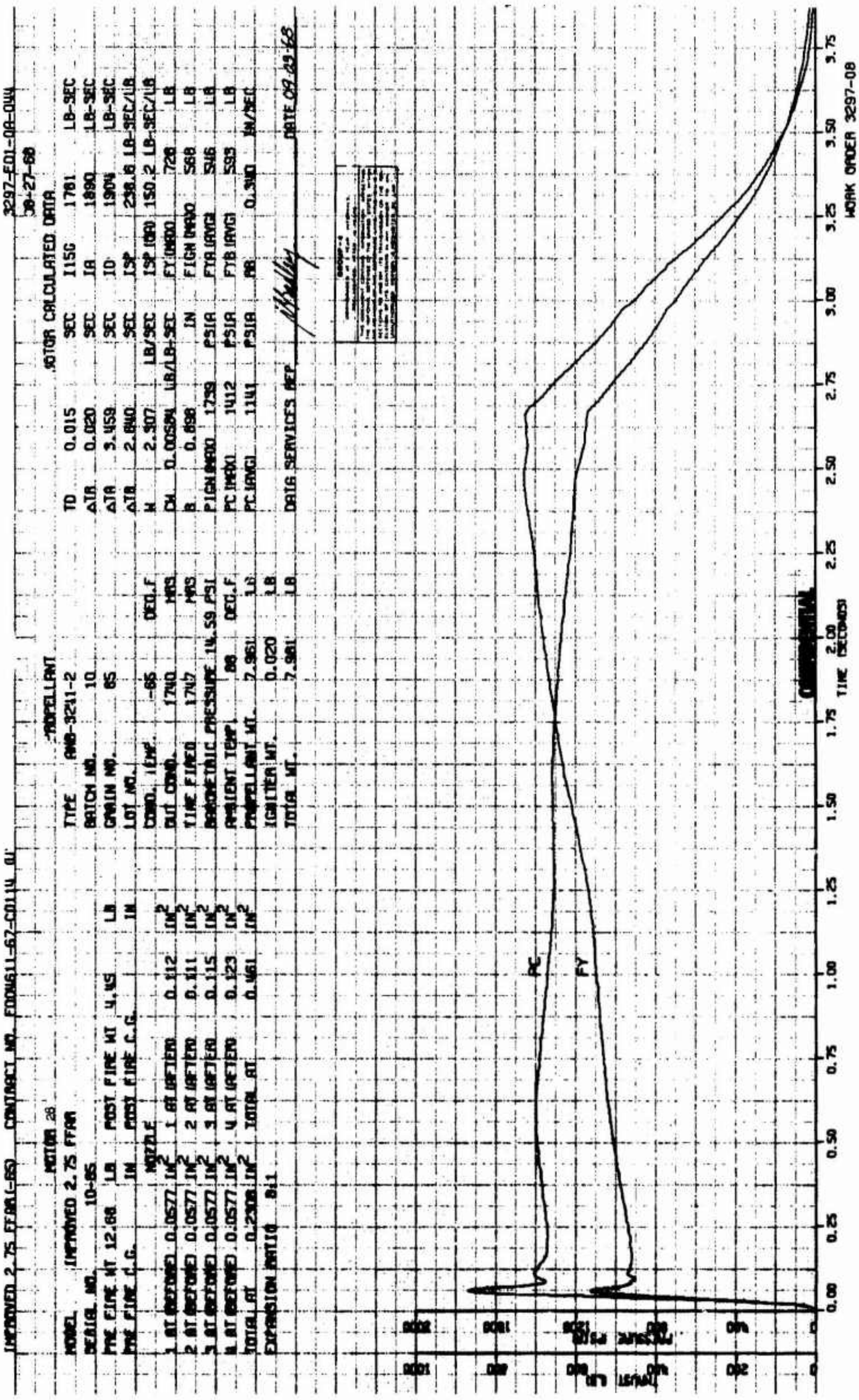
Ballistic Data and Performance Curves, Motor 41 (u)

Figure 104



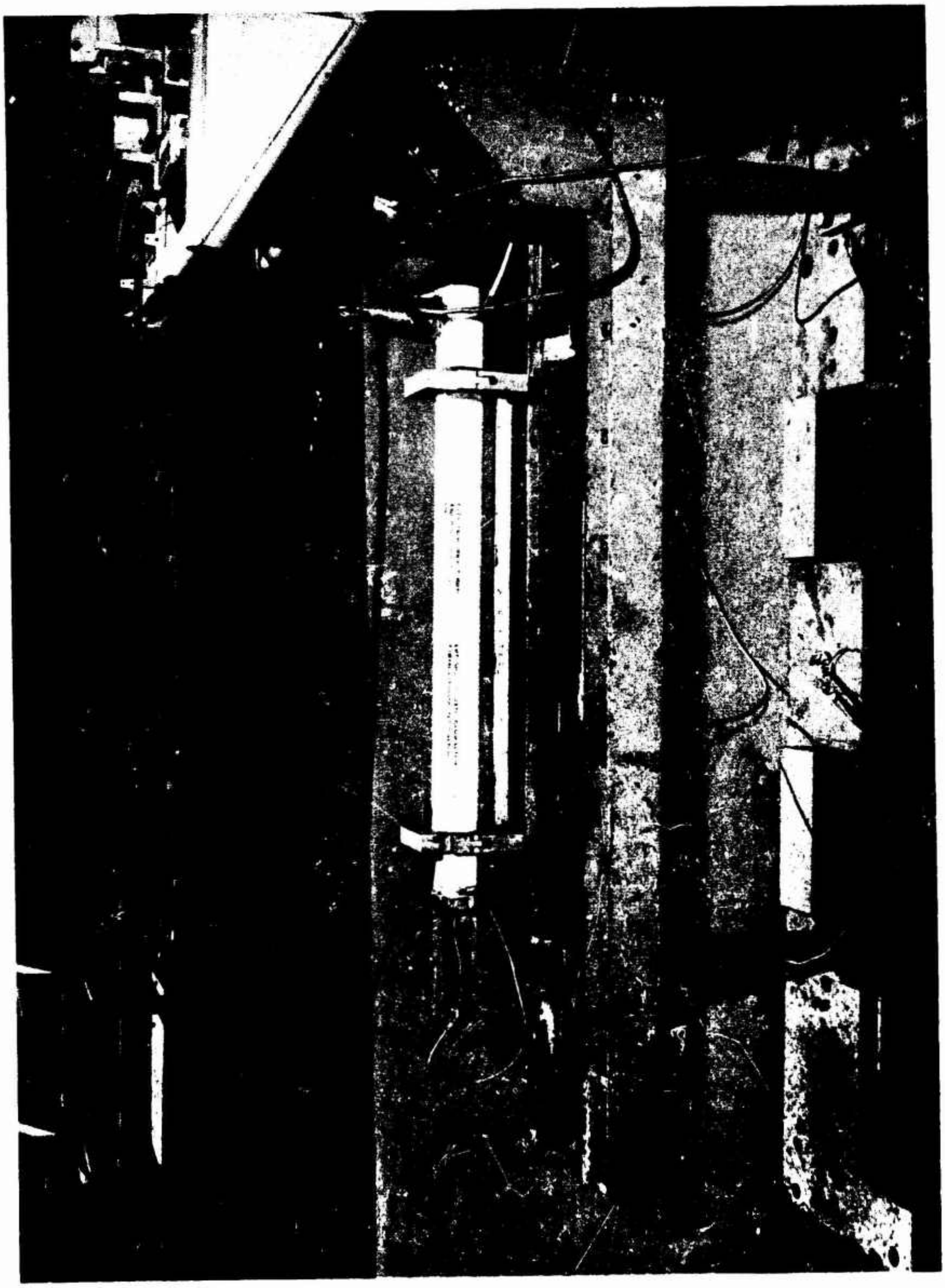
Ballistic Data and Performance Curves, Motor 13 (u)

Figure 105



Ballistic Data and Performance Curves, Motor 28 (u)

Figure 106



Typical PFRT Motor Condition and Test Setup Before Firing

Figure 107

Typical PFRT Motor Condition After Firing

Figure 108

Cross-Section of [illegible] Motor [illegible],
Showing Post-Firing Condition

Figure 109

2. Ballistic Analyses

(C) The PFRT program resulted in 40 motor firings with valid usable impulse performance (15 at -65°F, 11 at +70°F, and 14 at +150°F, as shown in Figures 60 through 62). As defined in the Improved 2.75-in. FFAR End Item Detail Specification, CP 30250, usable impulse is the thrust-time integral from the application of igniter current to the time during tailoff when the thrust drops to the values of 430 lbf at +65°F; 511 lbf at +70°F; and 555 lbf at +150°F. Since a minimum velocity is required to be met at +70°F only, these thrust cutoff levels were adjusted to include the same proportion of the thrust-time curve that would have been included had the motors been actually fired at +70°F.

(U) A comparison of the nominal and -3 sigma values of usable impulse obtained during the PFRT program and the minimum values of usable impulse allowed by the CEI specification is presented in Figure 110. Also presented for reference are the velocity and slant range at 70°F, which corresponds to the various usable impulse values. These velocities and ranges were determined on an Aerojet trajectory analysis program using the following assumptions:

1. Launch altitude, 4000 ft
2. Launch angle, -30°
3. Payload, 9.1 lb
4. Initial velocity 750 ft/sec
5. Drag - as determined from tests at Tullahoma, Tennessee

Firing Temp., °F	Cutoff Thrust, lbf	Usable Impulse, lbf-sec Nom.	Obs. (-3σ)	Req. (-3σ)	Calculated Velocity and Range at +70°F Nom.	(based on obs. min.) -3σ	(based on req.) -3σ
-65	430	1795	1753	1697	3326 ft/sec 5050 ft	3275 ft/sec 4888 ft	3206 ft/sec 4670 ft
+70	511	1795	1718	1706	3316 ft/sec 5020 ft	3221 ft/sec 4715 ft	3206 ft/sec 4670 ft
+150	555	1806	1754	1709	3226 ft/sec 5050 ft	3261 ft/sec 4845 ft	3206 ft/sec 4670 ft

Improved 2.75-in. Usable Impulse and Corresponding Velocity and Range Values (u)

Figure 110

II.D. Preliminary Flight Rating Tests - Phase III (cont)

(C) Although these calculations indicated that the minimum -3 sigma velocity and range values of the Improved 2.75 Motor would meet the required minimum velocity of 3600 ft/sec and slant range of 5000 ft, respectively, flight tests have indicated that actual performance equals or exceeds these originally required values. In the absence of flight data, it is surmised that the following may be the cause of this discrepancy:

1. Thrust velocity higher than predicted
2. Launch altitude higher than prediction
3. Payload weight lighter than specified
4. Imprecise drag values
5. Possible test inaccuracies

(C) As shown in Figure 60, the 15 firings at -65°F produced a mean value of usable impulse of 1795 lbf-sec with a lower 3-sigma limit of 1753 lbf-sec, which is considerably above the required lower limit of 1697 lbf-sec. The 11 firings at +70°F showed a mean value of usable impulse of 1795 lbf-sec (Figure 61) with a lower 3-sigma limit of 1718 lbf-sec. This is in excess of the minimum requirement of 1706 lbf-sec. The 14 firings at +150°F produced a mean value of usable impulse of 1806 lbf-sec (Figure 62) and a lower 3-sigma limit of 1754 lbf-sec, which is substantially above the required lower limit of 1709 lbf-sec.

(C) As can be seen, the +70°F firings closely approach the lower specification limit. This is due to the larger standard deviation of 25.6 lbf-sec at +70°F as compared to the deviations of 14.0 and 17.4 lbf-sec at -65 and +150°F, respectively. A possible explanation for this larger deviation is that the +70°F motors were selected from five cast lots, whereas the -65 and +150°F motors were selected from three cast lots. Thus, the +70°F motors would be subject to more variability.

3. Nozzle Failure Investigation and Analysis

All motors were successfully temperature-conditioned and static-fired, with the exception of Motor 26 (S N 11-06) at -65°F (firing 041, Figure 103). In this unit, one of the integrally molded exit cones separated from the aft-closure, thereby allowing the Carbitex throat insert to be lost at about 1.3 sec after fire switch. Motor ignition and ballistic performance up to the time of throat loss indicate normal motor operation as shown by the performance curves in Figure 103.

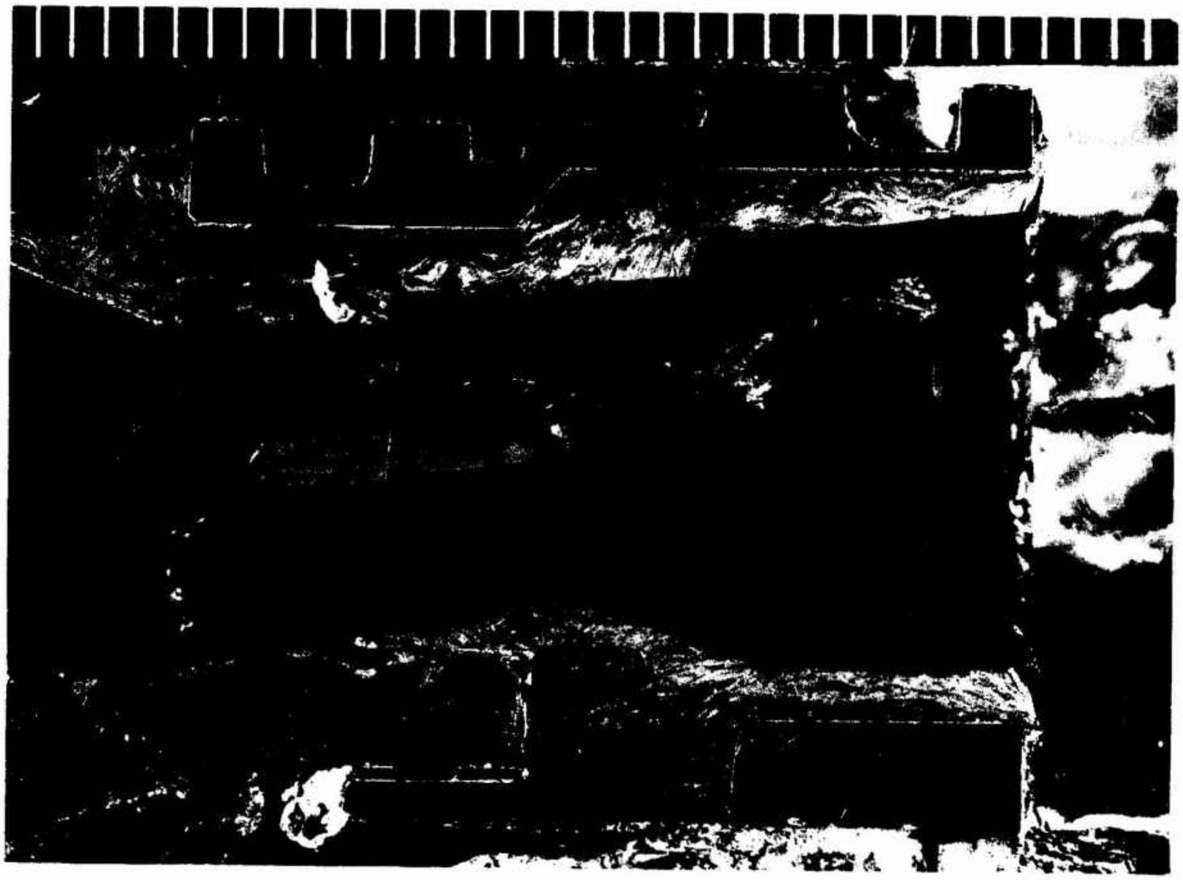
A subsequent investigation showed that the aft-closure of Motor 26 had been assembled to the chamber with a strap wrench. This tool, which was used to grasp and rotate the aft closure for inserting the lock wire, was later found to be the cause of exit-cone breakage during disassembly of another aft closure. The strap wrench was replaced by a new tool that eliminated this possible source of exit-cone damage.

Motor 26 was successfully environmentally tested. It was then conditioned to -65°F, transported by truck to the test bay, with its aft end resting on the edge of the crate, and installed on the test stand. The motor did not ignite and was returned to the manufacturing area for disassembly. The aft closure was removed from the motor with the new tool and examination of the igniter showed that the GFM Mark I squib had fired, but could not initiate the igniter pyrotechnic train because the squib did not contain the required black powder initiating charge. The fired squib was removed with a drill press that was manually operated remotely. A new squib and igniter was installed. The aft closure was returned to the manufacturing area, assembled to the chamber with the new tool, and transported to the test area. The motor was then conditioned to -65°F, transported by truck to the test bay, with its aft end again resting on the edge of the crate, and installed on the test stand. The motor successfully ignited at fire switch and operated normally until the exit cone separated and the throat insert was lost at about 1.3 sec after the fire switch.

Considering the circumstances discussed above, it was initially believed that the excessive handling of this unit before firing was the sole cause of the exit cone failure. However, investigations of a subsequent nozzle failure indicate that a closure molding problem was very possibly a contributing factor.

Subsequent to completion of the PFRT program, lot qualification motor S N 17-119 lost three exit cones and throat inserts during firing. The closure (S N 86D) was sectioned to ascertain the cause of failure and a photograph of one of the failed nozzles is presented in Figure 111. A cross section of the one remaining intact nozzle is shown in Figure 112. Examination of these photographs shows that the MXC-313 molding compound was a fiber flow pattern which is perpendicular to the nozzle center line in the area of the nozzle-sleeve/steel housing interface. This perpendicular fiber orientation is caused by leakage of the molding compound through the gap between the housing and the sleeve, as evidenced by the buildup of material on the aft face of the housing. The fibers tend to align themselves with the flow direction of the molding compound.

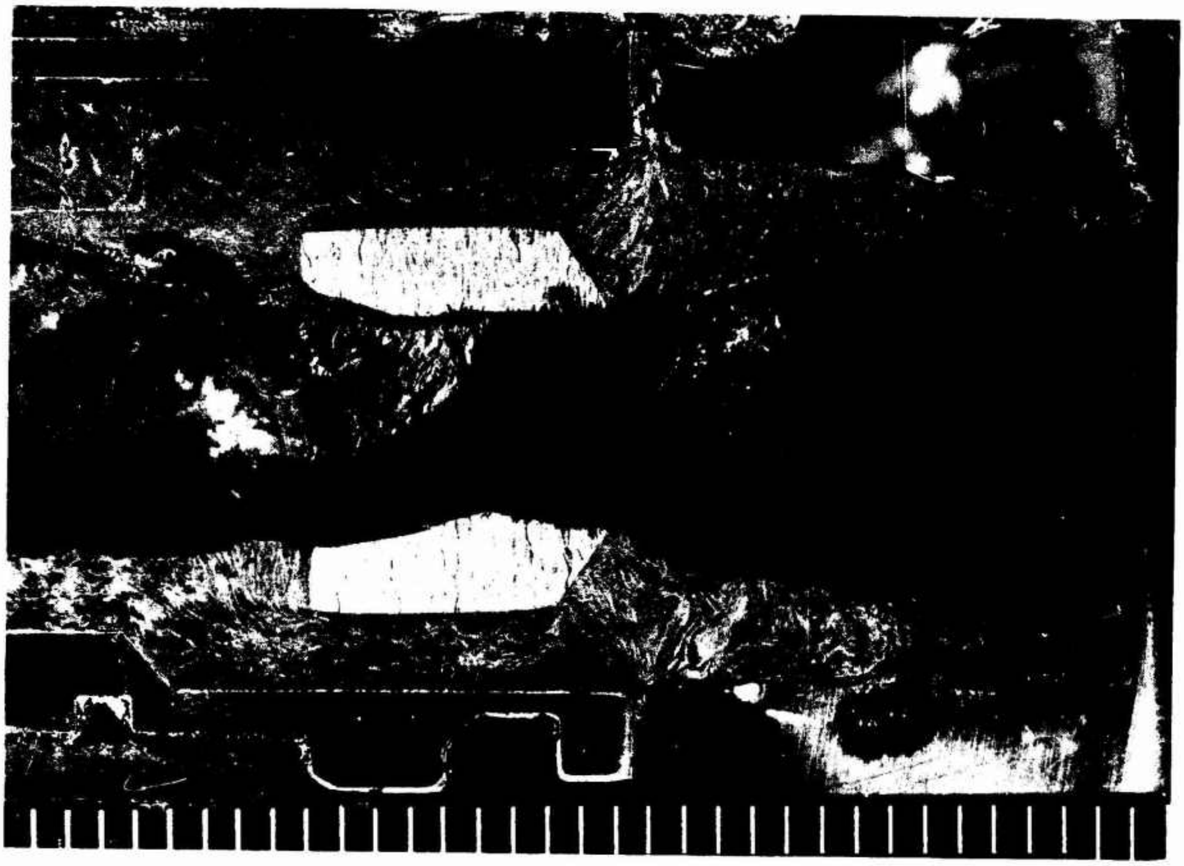
The perpendicular fiber orientation provides little strength and is an area of potential failure. As shown in Figure 111, the failure appears to be perpendicular to the nozzle centerline. The rather straight surface is representative of a failure between fibers, rather than across fibers. The potential failure mode can be seen in Figure 112 by the cracks from the throat insert to the aft end of the steel housing on both the I D and O D. The cracks follow the fiber alignment, which is approximately perpendicular to the nozzle centerline.



Mag: 3X

Cross Section of Nozzle No. 3 S/N 861 Showing the Point of Failure in the MXC 313 Molding Compound (Mag: 3X)

Figure 111



Mag: 3X

Cross Section of Nozzle No. 2 Showing the Fiber Alignment in the Region of the Taper on the Throat Insert (Mag: 3X)

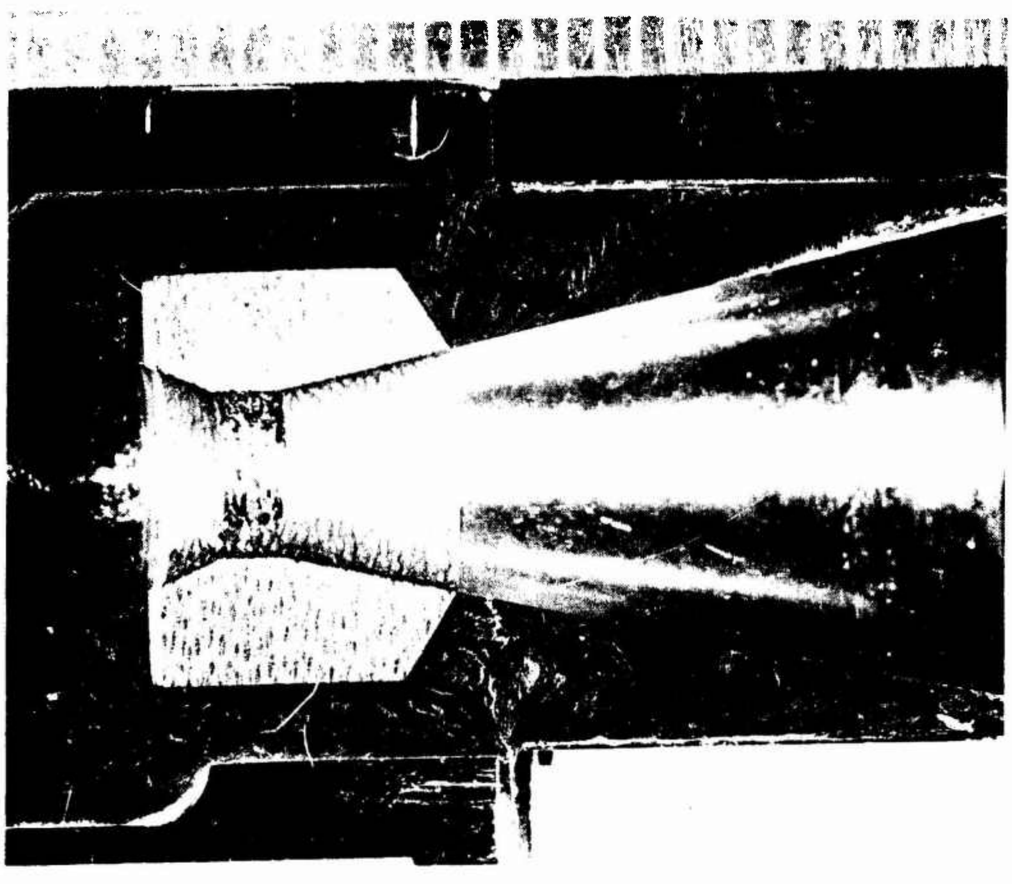
Figure 112

II.D. Preliminary Flight Rating Tests - Phase III (cont)

To further the investigation, an unfired closure assembly (S N 1203) having a thick buildup of moulding compound on the aft end of the center post was sectioned and photographed. The parts were examined to determine the major fiber alignment pattern in the moulding compound aft of the throat insert and adjacent to the steel housing. Figures 113 and 114 show the difference in fiber alignment for two of the four nozzles.

Figure 113 shows the fiber alignment adjacent to the sleeve/housing interface on the center-post side of the nozzle to be generally perpendicular to the nozzle centerline. The alignment on the O D is generally random, with less tendancy to align perpendicularly. Also noted is the fact that the buildup of molding compound on the aft face of the center post is significant (0.025 in.), while the buildup on the O D is minor. The buildup of molding compound on the center post adjacent to the second nozzle (Figure 114) is about 0.012 in. and the fiber alignment is more random. The lower flow did not produce a predominately perpendicular flow pattern. A crack starting at the I D of the nozzle would have to propagate through fibers rather than between them in this nozzle.

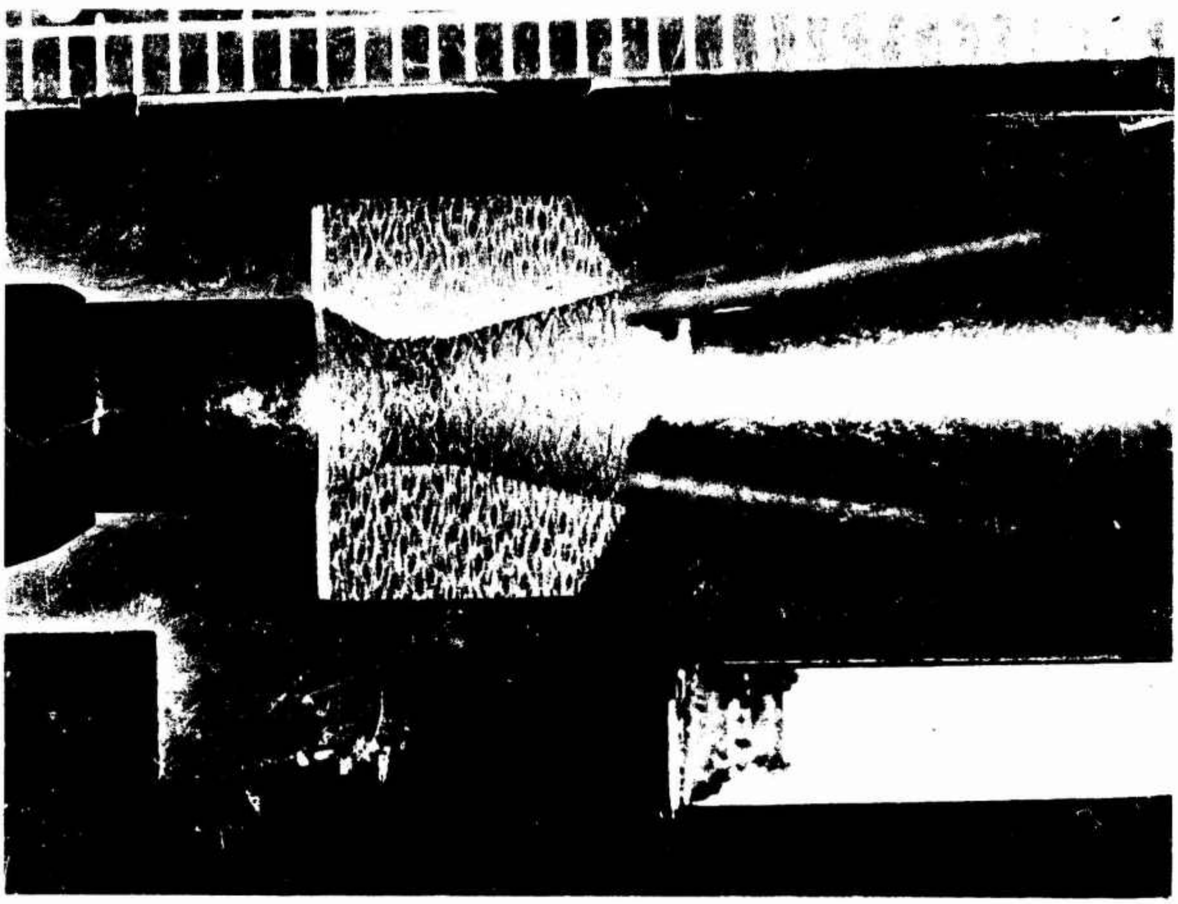
Figure 115 clearly shows the cause of the poor fiber alignment. The molding compound has moved through the opening between the steel sleeve and the steel housing. To the right of this opening, the fiber alignment, as shown by the concentration of white lines, is almost parallel to the direction of flow. Also shown in Figure 115, is a line of voids and/or a separation extending at an angle of about 30° from the perpendicular.



Mag: 3X

Nozzle No. 4 S/N 1203 Showing Carbon Fiber Alignment Patterns of the MXC 313 Molding Compound (Mag: 3X)

Figure 113



Mag: 3X

Nozzle No. 2 S/N 1203 Showing Fiber Alignment Patterns More Randomly Oriented Aft of the Throat Insert (Mag: 3X)

Figure 114

Mag: 100X

Photomicrograph of Fiber Alignment Adjacent to the Opening
Between the Sleeve and the Steel Housing, S/N 1203 (Mag: 100X)
(The white area in the top left is the steel centerpost)

Figure 115

As a result of this investigation it was concluded that improper fiber alignment aft of the throat insert was the primary cause of the failure of three nozzles of motor S N 17-119 and further, that this improper alignment was caused by extrusion of the molding compound between the steel nozzle sleeve and the steel housing during the manufacturing process. It is also possible that this problem was a contributing factor to the failure of one nozzle on PFRT motor 26 (S N 11-06).

To ensure that failures of this type do not reoccur, the aft closure design has been modified by lengthening the steel nozzle sleeve so that it extends into the I D of the hole in the steel housing, thus preventing the extrusion of molding compound between these two parts.

4. Squib Failure Investigation

In addition to the squib failure described above, ignition system difficulties were encountered in five other PFRT motors. The ignition circuits in all five motors showed no continuity when checked prior to firing. In all cases, the grounding clip provided no connection to ground. In one motor, this difficulty was compounded by lack of continuity through the squib, which was subsequently replaced. To provide a positive ground, the ground lead from the igniters in these five motors was soldered to the plate prior to firing. In future motors, the grounding clip will be soldered to the plate to provide a positive ground connection.

5. Resonant Burning Investigation

During six quality assurance firings for Cast Lot 13 delivery motors two of the motors exhibited resonant burning with D C shifts of 790 and 960 psi, respectively. The D C shifts occurred at 0.48 sec in the motor fired at -65°F and at 0.46 sec in the motor fired at +70°F. Postfiring examination showed the hardware to be intact and in normal condition, except for excessive erosion of the IBS-105-4X potting material and aft-end insulator at the grain/aft-closure interface. This ballistic anomaly led to assignment of Cast Lot 13 motors to ground-launch tests rather than air-launch tests.

Subsequently, six additional motors from Cast Lot 13 were successfully static fired. No ballistic anomalies were noted nor did post-firing examination reveal any abnormal erosion of the potting material. In these six motors, the potting material was cured for a minimum of 36 hr at +135°F as compared to the previously used minimum cure time of 12 hr. Accordingly, process instructions were changed to require a minimum cure time of 36 hr for all subsequent motors. In addition, particular care was taken to assure that no potting material is deposited in the grain bore nor overlaps the aft end of the bore in any way that might alter the gas flow characteristics. Since that time (mid September), more than 50 static tests have been performed with various lots of motors with the 36-hr potting cure time. No indication of resonant burning was observed.

E. HAZARD CLASSIFICATION TESTING

Hazard classification tests were performed with eight Improved 2.75-in. FFAR rocket motors in accordance with T.O. 11A-1-47. The results confirmed that the Improved 2.75-in. motor properly belongs to the class of explosives that will burn but not detonate.

The eight motors were tested for Aerojet by Ogden Technology Laboratories, Inc., Beaumont, California. The motors were subjected to the following tests:

II.E. Hazard Classification Testing (cont)

1. Two motors were subjected to external heat from burning lumber soaked with JP4 fuel.

2. Two motors were subjected to bullet impact from a 0.50 caliber gun located 100 ft away.

3. Two motors were subjected to Penolite booster charges initiated with engineer's blasting caps.

4. Two motors were dropped from a height of 40 ft onto a concrete pad.

All the above tests were passed satisfactorily. A detailed report of the above tests was submitted as a separate Aerojet-General report.

F. MANUFACTURING

Motor manufacturing operations for Phases I through IV of the Improved 2.75-in. FFAR program were completed in August 1968 after a 13-month program. During this time, adequate information was gained through studies, tests, and operations to prepare for mass production of the motor. All planning from the program inception was directed toward the mass production goal, and manufacturing of motors through the program was performed with equipment adaptable to mass production as much as practical. Figure 116 presents a list of direct tooling together with tooling drawing number, tool title, quantity, and pertinent comments.

This section summarizes the studies and manufacturing operations performed throughout the program.

T-Number	Tool Title or Description	Quantity	Comments
1020896	Fwd Insulator Installer	1	
1019758-B	Chamber Handling Fixture	5	(1) 60 position, (4) 70 positions.
1021247-A	Propellant Core Assy	176	36, 70, 35, 35 (176 total).
1019800-D	Core Displacement Fixture	1	
101979-A	Chamber Assy Stand	1	
1022137-A	Igniter Assy Stand	2	
1022112-A	Staking Tool - Igniter	1	
1020639	Cast Rack - Propellant	2	Used with Sophie Cast Bell.
1021114-A	Fwd Hd Liner Cutting Tool	1	
1022254	Fwd Hd Liner Cutting Tool	1	Used with T-1021114-A.
1021248-D	Mask and Core Centering Plug	176 + 36	Used with T-1021247 (106, 35, 35, = 176), (36 configuration revised; cannot use.)
1021436	Propellant Core Assy	12	7/8 dia core shaft. (Not used.)
1021524-B	Trim Tool - Mask and Liner	3	
1022223	Fwd Insulator Installer - Press	1	Used with T-1020896.
1022051-A	Core Handling Fixture-(110 Posit.)	2	
1022089-A	Trim Fixture - Grain	1	
[illegible]	Clamp Bracket	4	
1022136	O-ring Inserter	2	
1022139	Shipping Container-Igniter	5	(21) per unit.
1022257	Rotating Wrench-Closure	1	Used for installing and removing closures.
1022258	Alignment Tool - Igniter and Closure	1	
1022325	Core to Chamber Alignment Tool	1	
1022269	Support Blocks	2	Riser blocks for propellant tubes.
1022421-A	Paint Stand	4	Wood stand with (24) pegs.
1022422	View - Adapter Cast Tube	1	View flow of propellant.
1022468	Core Plug Removal Tool	1	Remove plug from chamber after casting and curing.
1022460	Masking Cap - Insulator/Lining	200	Made from caps ordered from Gilbert Plastic, Inc.
1022343	Assy Jig - Piston Torque	1	
1022377	Scraper - Closure Post	2	

GENERAL PURPOSE - TOOLING REQUIREMENTS

T-Number	Tool Title or Description	Quantity	Comments
	Propellant Cast Mach.	2	Hydraulic pump borrowed from HAWK Program.
	Liner Spray Mach.	1	

2.75 FFAR Tooling List

Figure 116

II.F. Manufacturing (cont)

1. Optimum Manufacturing Technique Trade-Off Studies

Trade-off studies to determine optimum manufacturing techniques for the Improved 2.75-in. FFAR motor commenced early in the program and were maintained current through the development and PFRT phases. As a foundation of the studies, various process and handling methods for the proposed motor were defined which appeared to have potential for adoption to mass production. These methods were than analyzed to determine the most economical production methods for various production rates and a final base method was selected. Sketches of the equipment envisioned for support of the manufacturing method were then made and were maintained current throughout the program as motor design and manufacturing method improvements were made. These sketches have been assembled into a booklet titled Improved 2.75 FFAR Motor Manufacturing Plan, 25,000 to 100,000 Units/Month , which was published in June 1968.

2. Manufacturing Method Studies

Because one of the objectives of this program was to test and prove out concepts for mass production equipment, it was necessary to develop equipment and operating techniques for most of the manufacturing operations. The major studies performed in development of the equipment and techniques are summarized as follows:

a. Release Application

Initial designs of the motor included longitudinal and circumferential band grain release patterns which were applied to the chamber sidewall to provide stress relief of the grain at low temperatures. Since no method for application of the release material in the patterns required was immediately known, studies were performed to determine possible methods and to determine the optimum method of those proven feasible. Results of the studies showed that wiping of the release onto the chamber by use of felt wicks appeared the best of several methods tested and several motors were made early in the development program by this method. Changes in the motor design were subsequently made which eliminated the release pattern requirements, and the studies were abandoned.

b. Liner and Insulation Application

Application of liner and insulation to the chamber interior proved to be one of the largest problems in the manufacturing method studies. Initially, contact was made with several commercial spray equipment companies to determine if the liner and/or insulation materials could be sprayed by commercial equipment. The tests made by these companies all indicated that the material could not be sprayed. It was then assumed that the material could be applied best by trowelling and several motors were produced by this method. However, since spraying of the liner and insulation was believed the optimum production method if equipment could be developed, studies along this line were continued. After approximately 2 months from the start of the program, a mechanism was developed which would spray the material. With this equipment, tests were performed to determine operating parameters for spray application of the liner and insulation materials. The existing production prototype spraying equipment was then designed based on the results of the tests performed. Both the liner and insulation are now sprayed into the chamber, meeting specified dimensions.

c. Propellant Casting

Volumetric discharge of propellant through a bayonet into an evacuated chamber was the proposed motor casting method and the original casting equipment was fabricated for this method. However, studies performed with this equipment, using inert propellant, showed that the bayonet was not required and that better quality motors could be produced by extruding the propellant into the evacuated chamber through a screen. Modifications were then made to the casting equipment to accommodate the results of these studies and to include hydraulic power for the machine operation. The initial motors cast with live propellant using this fixture were of satisfactory quality and were utilized in Phase II of the program. However, the second group of motors cast with the fixture were of very poor quality. Additional studies were performed on the subsequent lot for determination of optimum operating parameters when using live propellant, and the existing operating limitations were established. Motors of good quality are now consistently produced with this equipment.

3. Value Engineering Studies

A review of the motor design and manufacturing requirements for areas of maximum potential cost reduction was made early in the program. As a result of this review, the following Value Engineering studies were selected and performed:

a. Core Release System

Because of the potential for mass production of the motor, it was imperative that a low total cost core release system be found. Several candidate release materials and systems were studied and tested to determine the lowest cost system compatible with the propellant formulation. The material finally selected as a result of the studies, DC 92009 with a DC-11 dip coat, showed a savings of $127,000 on a 300,000 unit program over the next best material, fused Teflon with the DC-11 dip coat.

b. Propellant Grain Stress Relief System

This study was performed to determine the lowest cost release material and process for use as grain stress relief in the chamber. Again, several materials were tested and a final material was selected. However, prior to completion of the studies, the motor design was changed whereby the release system was not required. The Value Engineering study was therefore cancelled prior to completion.

c. Chamber Insulation Bonding

The initial 2.75 FFAR motor design required bonding of insulation into the chamber by use of epoxy based adhesives. Because of the costs associated with this adhesive system, this operation was selected as a Value Engineering study. Several alternative materials and processes were tested in this study with the chamber liner material being selected as the least expensive of the acceptable alternatives. As a result of the study, a savings of approximately $4,900 would be made on a 300,000 unit program.

d. Spraying of Aft Insulation in Chamber

The initial motor design required use of a premolded rubber insulator part in the chamber. Because of the fabrication, handling, and installation costs associated with this design, insulating of the chamber was selected for a Value Engineering study. Several materials and application methods were considered for use in the chamber to minimize the unit cost.

Of all the materials and processes evaluated, the spraying of insulation appeared the most economical, because spraying operations are readily adaptable to automated processing, and the base material was the least costly. Initially, in the study, the spraying of insulation was not feasible because of the insulation configuration. However, design changes were implemented which made the operation practical. As a result of this study, an estimated savings of $198,000 can be realized on a program of 300,000 units.

4. Miscellaneous

During this program, chambers have been received from two vendors and significant variations have been noted. Two types of chambers were received from Norris Thermador Corporation, all identified with one lot number, but with very significant variations. One type of chamber was found to be oval shaped and most of these had discrepant lockwire grooves. The other type of chamber was found to be the best of any delivered by either vendor. Alcoa manufactured chambers were found to be somewhat heavier than the Norris chambers, having a greater wall thickness. The propellant weight on motors from these chambers was therefore less, and the inert weight greater, than motors made using the Norris Thermador chambers. Chambers from either vendor were processed interchangeably with no significant problems noted. However, the oval Norris Thermador chambers were not satisfactory in test firings and after a brief period of usage were eliminated from the program.

5. Motor Manufacturing

a. Phase II Motors

Manufacture of motors on Phase II of the program commenced in September of 1967. The first group of units was insulated with SRM 81-15 rubber and utilized a four-fin core. Test firing of these units revealed an erosive burning problem such that the core fins were not required. The second lot of units was processed with a cylindrical bore. Processing of these units was completed in October of 1967, but radiographic inspection of the units revealed a bond failure problem between the propellant and liner in some of the units. Initial investigation of the problem indicated that inadequate chamber release had been applied; therefore, the application method and amount of release was changed, and motors of Lot 3 were started in November. Radiographic inspection of the Lot 3 units in December indicated all units acceptable.

Concurrent with the manufacture of the Lot 3 motors, firings of the Lot 2 motors indicated a problem with the grain stress relief design. The Lot 4 motors were, therefore, processed without the relief patterns except that three motors had the forward grain face released. After processing, radiographic inspection of the Lot 4 motors in January of 1968 revealed that the fully bonded units had propellant-liner bond failure at the forward end while the grains with the forward face released were acceptable. Two of the acceptable Lot 4 motors were then successfully fired at -65°F during January of 1968.

Based on the results of the Lot 4 motors, the Lot 5 units were manufactured in January 1968 for shipment as flight test units. Following this, processing of the Lot 6 units was started with completion occurring in February 1968.

After the propellant-liner bond failure noted in the Lot 4 motors, studies were performed to determine effects of liner cure time and temperature on the propellant-liner bond strength. These studies showed that a much stronger bond could be obtained with a lower temperature liner cure for a shorter time. The Lot 6 motors were, therefore, processed with the reduced liner cure. Additionally, the cure temperature of the propellant was reduced to reduce the stresses on the grain at -65°F. Motors from this lot successfully passed up to 34 cycles from -65 to +150°F.

Completion of the Lot 6 units in February basically completed Phase II of the program, and no motors were made during March of 1968 while the PFRT motor design was being finalized.

b. PFRT Motors

Processing of motors for PFRT commenced in April of 1968 with manufacture of the Lot 7 motors. These units were the first cast with the production prototype casting fixture. Most of the units were used as Phase II development motors. The second group of motors, Lot 8, for the PFRT Phase were processed in April and May of 1968. Radiographic inspection of the Lot 8 units revealed a severe grain void problem caused by the casting fixture operating techniques. Lots 9 and 11 were cast in June of 1968 in a vacuum bell to ensure acceptable motors for PFRT testing, while the Lot 10 motors were cast by use of the casting fixture. Tests were made during the casting operation of Lot 10 whereby the casting fixture operating limits were established for use in casting of Lot 12 and subsequent lots.

Concurrent with inert processing of the Lot 12 motors in June 1968, small grain cracks were discovered in motors of Lot 7 which were being temperature cycled. Borescope inspection of the Lot 7 motors revealed that the cause of the grain cracks was score marks made on the bore surface by defective tooling during cutting of the forward boot. Since the boot cutting operation had been performed, using this tool, on motors of Lots 9, 10, and 11, a large portion of these motors were rejected. Forward boot cutting on the Lot 12 units was performed with new tooling which could not score the grain bore.

Motors for the PFRT program were selected from Lots 7 through 12 during July 1968.

c. Delivery Units

Motors for this phase of the program were selected from Lots 10, 11, 12, 13 and 14. Lot 13 was manufactured in July of 1968 and Lot 14 in August. Each of these two lots contained 175 units which is the current maximum weekly production capacity. No significant problems were encountered in manufacture of the final three lots of motors on the program.

To ensure capability of mixing large batches of the propellant formulation as would be required on a production contract, a 6000-lb propellant batch was mixed for casting of the Lot 13 motors. Two batches of this size would be required per day in producing motors at a rate of 25,000 units/month. The Lot 10, 12, and 14 motors were cast from 2000-lb propellant batches and the Lot 11 motors, as well as most previous lots, were cast from 450-lb batches.

6. Production Motor Processing

a. Inert Chamber Processing

(1) Forward Insulator and Chamber Preparation

Forward insulators and chambers are injected into the manufacturing process in group quantities consistent with the required weekly production rate. Processing of the units will commence with solvent cleaning of the parts. After cleaning, the chambers are set aside to await insulating and the forward insulators are moved into the processing area for release application.

The release system, consisting of a primer coating and a silastic rubber, is manually applied to the forward insulators. In the first step of the operation, the insulators are masked on the aft interior surface to ensure dimensional control of the primer and release application. Following this, the primer is applied by brush to the interior surface of the insulator and allowed to air-dry. After the primer has dried, the silastic rubber release material is mixed and applied by brush or wiper methods. (Both methods have been used successfully; therefore the method is left optional to the processor.) The release material is allowed to cure at room temperature conditions after application for a minimum period of 4 hr. Following this, the masking is removed and the insulator is force-dried at approximately 180°F for a period of 6 hr. The released insulators are then moved to the chamber insulation area.

(2) Chamber Insulating

Prior to installation of the forward insulators into the chambers, the insulators are pre-lined for convenience and for better control of the liner coating quality. In this operation, IBS 105-3 liner is mixed from kitted components and applied to the interior surface of the insulators by either a brush or wiper method (again, optional to the processor). Following this, the liner is cured for approximately 1 hr and then visually inspected for continuity. Any noted discontinuities in the coating are repaired at this time. After inspection and repair as required, the liner cure cycle is completed. The insulators are then returned to the chamber insulating area for installation into the chambers. Serialization of the chambers is performed concurrent with forward insulator preparation.

IBS 105-3 liner is used for bonding the forward insulators into the chambers. After the liner is mixed, it is dispensed in a controlled quantity onto the forward face of each insulator. The insulators are then placed on an installation tool and inserted into the chambers. A hand press is utilized to seat each insulator against the forward head while, at the same time, the installation tool is used to form a feather edge of any excess liner material extruded from around the insulator.

After installation of the forward insulators, masking is applied to the aft chamber sidewall for dimensional control of the aft insulation which is sprayed in place. Upon completion of the masking operation, the chambers are moved to the liner and insulation spray fixture. Here, IBS 105-4X insulation is mixed in kitted ratios, pumped to the spray head, and centrifugally sprayed onto the aft chamber sidewall. The spray-head movement rate in the chamber is controlled to result in an insulation build-up meeting the print requirements. After a 135°F cure cycle, the insulation is manually trimmed to length and the masking is removed. Following this, the insulated chambers are inspected for conformance to print.

(3) Chamber Lining

After inspection of the insulated chambers, IBS 105-3 liner is mixed and a thin coating is manually applied by brush to the forward insulators. This operation ensures a fresh liner coat on the pre-lined insulators to ensure good bonding. Concurrently, the spray fixture is calibrated and additional liner is mixed for the sidewall liner application. Liner is then applied to the chamber sidewall by use of a spray fixture which incorporates a centrifugal type spray head. In operation, the spray head traverses the length of the chamber on a pre-determined, semi-automatic cycle.

Concurrent with application of the sidewall liner, liner is manually applied by brush to release coat the aft liner molding plugs. The plugs are installed in the chambers after the sidewall liner is applied. Upon installation in the chamber, the lined plugs complete the formation of the liner aft Y configuration required by the chamber and grain assembly drawing. The plugs also serve to center the core during propellant cure. Groups of 48 or more chambers are moved into a 135°F cure oven for approximately 18 hr cure after plug installation. Following this, the chambers are sealed in drums and shipped to the propellant casting area for storage prior to propellant casting.

II.F. Manufacturing (cont)

b. Propellant Grain Processing

(1) Propellant Preparation

Propellant processing for the Improved 2.75-in. motor is performed in three major steps: fuel preparation, oxidizer preparation, and propellant mixing. In the fuel preparation operation, a premix fuel and a final fuel are made. The premix is prepared by dispensing, weighing, and blending all of the liquid and solid ingredients in the propellant formulation, except for the oxidizer and cure chemicals. Final fuel is prepared by dispensing, weighing, and blending the cure chemicals. Oxidizer preparation operations include the dispensing, grinding, and weighing of one portion of the oxidizer required for the batch and dispensing and weighing of a second unground portion which is used "as received".

After the fuel and oxidizer have been prepared, they are transported to a vertical batch mixer. Here, the oxidizer is mixed into the premix fuel in the first mixing step. Following this, the final fuel is added to the mix. A final vacuum mixing cycle completes the mixing process, after which the mix bowl with the propellant is removed and transported to the casting area.

(2) Propellant Casting

The casting equipment, consisting of propellant transfer piping, valves, cast heads, and volumetric displacement pumps, is assembled, inspected and operated prior to receiving propellant. When the propellant in the mixing bowl is delivered to the casting building, the mix bowl is positioned on a support stand and connected to the pre-assembled piping. The chamber casting operation is then started.

The casting operation is performed in five steps: first, the lined chamber is inserted into a casting head outlet on the casting fixture; second, a vacuum is drawn in the chamber; third, a measured volume of propellant is cast into the chamber at a controlled rate; fourth, the chamber vacuum is released; and fifth, the cast chamber is removed from the cast head. During the vacuum release and chamber removal, the displacement pump re-fills for the next casting cycle.

(3) Core Displacement

After casting, the chamber is moved to the core displacement fixture. Here, release-coated cores are inserted into the cast chamber displacing the propellant to form the grain bore configuration. The forward end of the core centers in the forward insulator, the aft end centers in the aft liner molding plug which was installed during the lining operations. The chamber, grain, and core assemblies (or cored units) are placed in cure/handling crates after completion of the core displacement operations.

(4) Propellant Cure

When a cure crate has been filled with cored units, it is moved into a +110°F cure oven for a minimum period of 5 days. During this time, the propellant polymerizes (or cures). After the propellant has cured to a minimum Shore A hardness of 30, as measured on a sample cast and cured with the chambers, the chambers are moved to the core-stripping area.

(5) Core Stripping

Core stripping is performed by pulling the core from the grain. The operation is currently performed in the core displacement fixture since the stripping operation is just a reverse of the displacement operation. After the core is stripped from the grain, the aft liner plug is manually removed. The plugs and cores are then delivered to a cleaning and release application area for re-processing, and the chambers are delivered to the propellant grain trimming area.

(6) Propellant Trim

The chamber and grain assembly is secured in a holding fixture for the propellant trimming operation. The aft bore of the grain is manually trimmed to the drawing configuration by use of a shaped-blade cutter. Following this trim, the liner is cut against the forward insulator in the bore area by use of an extended tubular cutter blade. Removal of the liner from the released insulator completes the trim operation. Trimming chips and dusts are then vacuumed from the grain, a cover is placed on the chamber, and the chamber is placed in a handling crate. Filled crates are then moved to the radiographic inspection area.

(7) Radiographic Inspection

Radiographic inspection is performed on all units of total quantity of 1000 or less produced at rates of less than 600 units per month, as has been the practice. This inspection is performed with an existing 150 KV X-ray machine. Two radiographs, each obtained 90 degrees from the other, of each grain are obtained. Discrepant units are marked for culling at the assembly area.

II.F. Manufacturing (cont)

After the non-destructive inspection operations are completed, the chamber and grain assemblies are returned to the assembly area. Here, any discrepant units are removed from the group, packaged, and delivered to a disposal area. The accepted units are stored as required to await assembly operations.

c. Motor Assembly Operations

(1) Bore Restriction

Liner material, IBS 105-3, is utilized for bore restriction. After mixing the material in kitted ratios, it is manually applied by use of a special brush. The brush handle includes a stop for control of the depth of the restriction in the bore.

(2) Closure-Igniter Assembly Installation

After the bore restriction material is applied, IBS-105-4X insulation material is prepared for potting the closure-chamber joint. The mixed material is dispensed into the Y groove formed by the liner molding plug. Following this, the closure-igniter assembly is removed from its handling container, fitted with an O-ring seal, and then inserted in the chamber. A lubricated lockwire is drawn in position by rotation of the closure with a special wrench.

The motors are placed in a handling container after assembly for transportation to a cure oven. Here, the potting and bore restriction materials are cured at 135°F for approximately 40 hr. When the cure cycle is completed, the motors are delivered to the radiographic inspection area for inspection of the joint integrity. After this inspection they are returned to the assembly facility for final processing.

(3) Final Processing

Final processing operations consist of the installation of weather seals, chamber painting as required, application of ordnance marking, and application of identification stencils. After these operations are completed, the motors are inserted in shipping tubes and packaged six units to a box. The boxed units are then moved to a storage area or, as applicable, to the shipping area where they are palletized and shipped to the customer.

d. Igniter-Closure Assembly Operations

(1) Closure Hardware Installation

Igniter-closure assembly operations commence with the assembly of ground clip, piston, and fin details onto the integrally molded closure. The closure and parts are solvent cleaned as the first step in the operation. Following this, the igniter circuit ground clip is installed on the closure center post and then soldered in place. After the ground clip is installed, a lubricated O-ring is installed onto the piston, the piston is inserted into the closure post, and the cushioning O-ring, cross head, and nut details are secured on the piston aft end. Upon completion of piston installation, the fins are heated to facilitate installation of the hinge pins. The heated fins are positioned, one-at-a-time in the closure lugs and the hinge pins are pressed in place. After the fins are installed and inspected as required, the fin retainer-wire assembly is crimped to the piston wire and the crimp joint is insulated. The fins are then closed and the retainer installed. Following these assembly operations, a release primer and silastic release are manually applied by brush to the closure insulator area which contacts the aft grain area in the chamber. The completed subassemblies are then moved to the igniter fabrication and installation area.

II.F. Manufacturing (cont)

(2) Initiator Fabrication

Initiator details for the igniter assembly are fabricated concurrently with aft closure preparation. The operation consists of installing an adhesive coated Mylar disc onto a section of tubular foam material, loading of the resultant cup with a measured quantity of BPN powder, and sealing the powder in the cup by a second adhesive-coated Mylar disk. The completed parts are stored in the igniter assembly area prior to igniter assembly.

(3) Igniter-Closure

The igniter is assembled from its parts onto the closure. In the first step of the operation, adhesive is prepared for the bonding operations. Following this, the squib is installed in the cap insulator and the cap insulator is installed in the closure. The squib wires, piston lead wire, and ground wires are then cut to length, connected, and a crimp connector is installed on each lead. After the connections are completed, a continuity test is performed and the shunt wire is installed on the closure to short-circuit the squib. The igniter chamber is then installed on the insulator cap. Loading of the igniter chamber with the initiator and BPN pellet charges and installation of the foam end-plug completes the igniter fabrication, except for adhesive cure. The closures are installed in an alignment fixture for the cure operation. Cure is accomplished at approximately +160°F for a period of 4 hr. After cure, the closure-igniter assemblies are packaged in handling containers for transport to the motor assembly area.

III. CONCLUSIONS AND RECOMMENDATIONS

A. The improved 2.75-in. FFAR rocket is ready for production, as demonstrated by the successful completion of the Preliminary Flight Rating Tests.

B. Performance dispersion, and reliability requirements of the contract have been met or exceeded.

C. The propellant tailored for this application provides the requisite mechanical and ballistic characteristics, explosive hazard classification, aging stability and resistance to environmental conditions over the required temperature range of -65 to +150°F.

D. For added reliability the nozzle exit cone sleeve will be secured to the aft closure plate for improved strength and insulation fiber orientation control.

E. To accommodate automated assembly, the dimensions of the insulation joint at the aft end of the chamber should be modified. At present, potting is applied to this joint by hand as part of the assembly of the aft closure to the chamber.

F. To reduce the size of the ignition spike, while retaining the rapid ignition response of the motor, the thickness of the bore restriction should be modified.

G. To provide improved processing capability, the chamber insulation and lining should be combined into a single system.

H. The chamber forward release system should be simplified in order to reduce the handling and cure cycle processing time.