AD NUMBER
AD909985
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; APR 1973. Other requests shall be referred to Space and Missile Systems Organization, Attn: MNNPB, Norton AFB, CA 92409.**
AUTHORITY
SAMSO ltr, 1 Nov 1973

AEDC-TR-73-82

MAY 16 1973

cy 2

PRODUCTION QUALITY ASSURANCE TESTING OF A THIOKOL MINUTEMAN LGM-30G STAGE III ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE, MOTOR PQA-103

D. E. Franklin and C. H. Kunz

ARO, Inc.

April 1973

This document has been approved for public release and its distribution is unlimited. Per TAB 74-2, dtd 18 Jan, 74

Distribution limited to U. S. Government agencies only; this report contains information on test and evaluation of military hardware; April 1973; other requests for this document must be referred to Space and Missile Systems Organization (MNNPB), Norton AFB, California 92409.

ENGINE TEST FACILITY

ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

ARNOLD AIR FORCE STATION, TENNESSEE

NOTICES

PRODUCTION QUALITY ASSURANCE TESTING OF A THIOKOL MINUTEMAN LGM-30G STAGE III ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE, MOTOR PQA-103

D. E. Franklin and C. H. Kunz
ARO, Inc.

FOREWORD

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC) at the request of the Space and Missile Systems Organization (SAMSO), Air Force Systems Command (AFSC), for the Thiokol Chemical Corporation under Program Element 11213F, System 133B.

The results of the test were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted on March 5, 1973, under ARO Project No. RA159, and the manuscript was submitted for publication on March 22, 1973. The ARO Project Engineer was Mr. D. E. Franklin.

This technical report has been reviewed and is approved.

CHAUNCEY D. SMITH, JR. Lt Colonel, USAF Chief Air Force Test Director, ETF Directorate of Test	A. L. COAPMAN Colonel, USAF Director of Test

ABSTRACT

An LGM-30G Stage III solid-propellant rocket motor, PQA-103, was fired in Rocket Development Test Cell (J-5), Engine Test Facility (ETF), in support of the Minuteman Stage III Production Quality Assurance Test Program on March 5, 1973. Motor ballistic, liquid-injection thrust vector control system, roll control system, and thrust termination system performance was within model specification requirements. Ignition of the roll control gas generator and the liquid-injection thrust vector control isolation squibs was accomplished, as programmed, 2.5 sec before motor ignition at a pressure altitude of 102,000 ft. The motor was ignited at a pressure altitude of 101,000 ft. Motor ignition delay time was 89 msec. Motor thrust termination occurred at 59.93 sec at a chamber pressure of 75.3 psia. During the 59.93-sec action time the motor produced an unaugmented vacuum total impulse of 2,083,103 lbf-sec. The unaugmented vacuum specific impulse was 284.96 lbf-sec/lbm. Maximum interstage pressure at thrust termination was within specification. Postfire motor structural integrity was satisfactory.

CONTENTS

APPENDIXES

SECTION I
INTRODUCTION

The objectives of the Thiokol Chemical Corporation (TCC) Minuteman Stage III Production Quality Assurance (PQA) Program (Ref. 1), are (1) to demonstrate that production motors meet the requirements outlined in the model specification (Ref. 2) and (2) to demonstrate reliability of the Stage III operational motor. The PQA-103 motor test reported herein is the fifteenth in a series of Minuteman LGM-30G Stage III PQA motor tests to be conducted at AEDC in this program.

SECTION II
APPARATUS

2.1 TEST ARTICLE DESCRIPTION

The TCC LGM-30G Stage III Minuteman motor (Fig. 1, Appendix I) is comprised of a glass filament-wound chamber loaded with ANB-3066 solid propellant; a solid-propellant igniter with a safe-and-arm device; a single, partially submerged nozzle with a nominal expansion ratio of 22; a liquid-injection thrust vector control (LITVC) system, a hot gas roll control (RC) system; and a motor thrust termination system. Test article configuration and component serialization are presented in Table I (Appendix II). Nominal motor length and diameter are 92 and 52 in., respectively. Maximum motor mass and minimum propellant weight limits are approximately 8070 and 7280 lbm, respectively. The motor nominally produces an average thrust of 34,000 lbf at an average motor chamber pressure of 500 psia for approximately 60 sec.

The liquid-injection thrust vector control system (Fig. 2) consists of two operative and two electrically inactive electromechanical servoinjector valves, located at 90-deg intervals on the nozzle at an expansion ratio of 10.3; an injectant tank containing approximately 49.3 lbm of a 66-percent solution of strontium perchlorate injectant fluid; a squib-actuated isolation valve and pressure regulator assembly; a pressurant tank containing helium; and a launch limit pressure switch. The two electrically inactive valves, located at the 0- (target down) and 180-deg positions, are used to blank off those injection ports and provide flight configuration hydraulic simulation. Injection in the pitch plane is not required to establish system conformance to specification.

The hot gas RC system is mounted inside the forward skirt at an angular location of 22 deg. The system consists of a squib-actuated, solid-propellant gas generator and a shuttle valve with two opposed nozzles exhausting through the forward skirt.

The thrust termination system, located on the motor forward dome, consists of redundant squib initiators, redundant completely contained mild detonating fuses, linear-shaped charges, thrust termination stacks, stack bellows, and stack covers. The shaped charges, when activated, cut six circular holes in the forward dome, allowing the chamber to vent through the thrust termination stacks.

2.2 TEST CELL AND INSTALLATION

Rocket Development Test Cell (J-5)(Fig. 3 and Ref. 3) is a horizontal complex for testing rocket motors with a maximum of 100,000-lbf thrust at pressure altitudes of approximately 100,000 ft. The cell is 16 ft in diameter and 50 ft long. The cell is equipped with a temperature-conditioning system designed to maintain the test cell and motor in a prescribed temperature range from motor installation until prefire pumpdown.

The multicomponent thrust stand utilized is capable of measuring axial forces of 100,000 lbf and yaw forces of 6000 lbf. The thrust stand natural frequency for a fully loaded LGM-30G Stage III motor is approximately 27 Hz in the axial direction and 22 Hz in the yaw direction. A steam ejector-diffuser system is used in conjunction with rotating exhauster machinery to provide altitude simulation.

2.3 INSTRUMENTATION

The types of data acquisition and recording systems used during this test were a multiple-input digital data acquisition system scanning each parameter at a basic rate of 100 samples/sec (with selected parameters supercommutated to 1000 samples/sec) and recording on magnetic tape; single-input continuous recording system recording in pulse form on magnetic tape; frequency modulation (FM) systems recording on magnetic tape; and photographically recording galvanometer-type oscillographs. Motion-picture cameras operating at 200 frames/sec provided a permanent visual record of the firing. Table II presents a summary of motor instrumentation. Instrumentation calibration techniques are described in Appendix III. Estimated uncertainties of the J-5 instrument systems are presented in Appendix IV. The digital data were reduced with an IBM 370/155 computer.

SECTION III
PROCEDURE

The motor arrived at AEDC on February 26, 1973. Significant motor inspection and handling records are presented as follows:

Date	Activity or Item Performed	Remarks
February 26, 1973	Motor received at AEDC; visual inspection performed	No visible damage
February 26, 1973	Electrical check, roll control valve (STM-180)	Electrical check satisfactory
February 28, 1973	Prefire nozzle measurements taken	Results in Table III
February 28, 1973	Injection valves installed	

Date	Activity or Item Performed	Remarks
March 1, 1973	Motor transferred to test cell and installed	70 ± 5°F temperature conditioning initiated
March 1, 1973	Safe-and-arm, arm/disarm, and ignition systems check	Systems verified
March 2, 1973	LITVC system manifold leak check (STM-180)	Leak check satisfactory
March 2, 1973	Completed LITVC pintle calibrations	
March 3, 1973	Interstage volume leak check	Leak check satisfactory
March 5, 1973	Motor fired at 1645 hours	
March 5, 1973	Visual inspection performed	Motor condition satisfactory
March 6, 1973	Motor removed from test cell and transferred to Rocket Preparation Area	
March 6, 1973	LITVC system flushed and dried	
March 7, 1973	Postfire nozzle measurements	Results in Table III
March 9, 1973	Motor shipped to TCC	

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

The results reported herein were obtained from the firing of an LGM-30G Stage III motor, PQA-103, in Rocket Development Test Cell (J-5) on March 5, 1973. This was the fifteenth of a series of motors to be fired at AEDC as part of the Thiokol Minuteman LGM-30G Stage III Production Quality Assurance Program. The motor was temperature conditioned at 70 ± 5°F in excess of the required 60-hr minimum. Propellant grain temperature at the time of ignition was 71°F. A summary of storage and conditioning temperatures is presented in Table IV. Data from this test are compared with data from other tests of LGM-30G Stage III PQA motors in Table V.

4.2 BALLISTIC PERFORMANCE

Ballistic performance for this motor was within the requirements of the model specification. A summary of the performance data is presented in Table VI. Histories of axial force, chamber pressure, and test cell pressure are presented in Fig. 4.

4.2.1 Motor Ignition

The motor was successfully ignited at a pressure altitude of 101,000 ft (geometric pressure altitude, Z, Ref. 4). Motor ignition current was within the specification limits of 4.5 to 4.9 amp. Igniter performance was within the specification requirements (Ref. 5) as shown in Table VI. A history of igniter pressure during motor ignition is presented in Fig. 5.

Motor ignition delay (defined as the time from voltage application until 75 percent of the maximum chamber pressure attained during the first second of motor operation) was 89 msec. This was within the maximum specification limit of 200 msec.

4.2.2 Combustion Chamber Pressure

Average combustion chamber pressure achieved during motor action time was 520 psia. The maximum operating chamber pressure achieved during the firing was 652 psia at T + 22.65 sec. Motor chamber pressure during motor operation is compared with the manufacturer's predicted chamber pressure (Ref. 6) in Fig. 6.

4.2.3 Axial Thrust

Vacuum-corrected thrust was within model specification limits for a motor temperature conditioned at 65 to 75°F and is presented with the specification envelope in Fig. 7. Motor action time, defined as the time from the application of ignition voltage until 5000 lbf of vacuum thrust during motor tailoff, was 59.93 sec. This was within specification limits (Ref. 2) of 57.53 to 62.53 sec for a motor with a propellant grain temperature of 71°F. Average unaugmented vacuum-corrected thrust during action time was 34,759 lbf.

The average thrust coefficient during motor action time, excluding thrust augmentation, was determined from vacuum-corrected total impulse, integral of motor chamber pressure, and a throat area input table supplied by TCC. The average thrust coefficient calculated for this motor was 1.75.

4.2.4 Impulse

Measured total impulse during motor action time was 2,071,614 lbf-sec. Total impulse corrected to vacuum conditions was obtained by adding the product of the cell pressure integral and nozzle exit area to the measured total impulse. The nozzle exit area was calculated using an interpolative procedure based on a prefire measured exit area and a calculated postfire exit area (Appendix V). This vacuum correction was approximately 0.60 percent of the measured total impulse. The vacuum total impulse during action time, including thrust augmentation, was 2,084,154. The vacuum total impulse, excluding augmentation, was 2,083,103 lbf-sec. The unaugmented vacuum specific impulse for this motor, calculated using a total loaded propellant mass of 7310.1 lbm, was 284.96 lbf-sec/lbm, and was within the specification limits of 283.1 to 286.1 lbf-sec/lbm. The unaugmented vacuum specific impulse, calculated using the total propellant mass minus a TCC-supplied sliver weight of 8.0 lbm, was 285.27 lbf-sec/lbm.

4.2.5 Motor Propellant Flow Rate

Average exhaust gas mass flow rate during action time was 122.0 lbm/sec. The method of calculation for exhaust gas mass flow is presented in Appendix V.

4.3 MOTOR VIBRATION

Histories of the vibration recorded by accelerometers on the igniter boss, the nozzle aft flange, the motor forward skirt, and the arm-disarm/safe-and-arm device are presented in Fig. 8a. A schematic of the location of these accelerometers is shown in Fig. 8b. The maximum igniter boss (AIGN30Y) amplitude recorded near 32-g peak at 0.8 sec and the maximum nozzle aft flange (AN30Y) amplitude was 134-g peak at 3.6 sec. Accelerations in excess of 100-g peak (calibration limit) were recorded at motor ignition on the forward skirt (AFS-262Y). Tri-axial accelerometers were mounted on the arm-disarm/safe-and-arm device body and mounting base. The maximum amplitude recorded on the device body was 24-g peak at 0.5 sec in the radial direction (AADSA-R) and on the base was 31-g peak at 0.5 sec, also in the radial direction (AADSAB-R).

4.4 ROLL CONTROL AND LIQUID-INJECTION THRUST VECTOR CONTROL SYSTEMS PERFORMANCE

4.4.1 Roll Control System

The roll control gas generator was ignited, as programmed, 2.5 sec before motor ignition at a pressure altitude of 102,000 ft. A history of gas generator pressure during its operation is compared to the model specification limits in Fig. 9. The roll control system duty cycle is shown in Table VII. All valve response times were within the model specification limits. A summary of RC system performance is included in Table VIII.

4.4.2 Liquid-Injection Thrust Vector Control System

The LITVC isolation valve squib was ignited successfully at a simulated pressure altitude of 102,000 ft, 2.5 sec prior to motor igntiion. Thrust vector control delay time, defined as the time from application of isolation valve squib current until attainment of 655-psia pressure in the injectant manifold, was 1.368 sec. This is within the specification limits of 1.0 to 1.6 sec. Regulated helium pressure and injectant manifold pressure are presented in Fig. 10. During periods of no flow, following the establishment of steady pressure in the injectant manifold until thrust termination time, the injectant manifold pressure varied from 673 to 694 psia. This is within the specification limits of 655 to 735 psia. Manifold inlet pressure at slam suppressor pin shear was 604 psia.

The injector valves were operated per the duty cycle presented in Table IX. Histories of injector command voltage, injector feedback voltage, and injectant flow rate are presented in Fig. 11 for the two injectors which were operated during the firing. A compilation of thrust vector control performance parameters is presented in Table X.

A thrust vector angle of 2.19 deg was produced by an injectant flow rate of 10.9 lbm/sec during the time period from 3 to 4 sec. This exceeds the requirements to demonstrate a 2-deg capability. The system performance during the nominal 1- and 2-lbm/sec flow rates was within the LITVC system gain specification as shown in Fig. 12.

4.5 THRUST TERMINATION

Thrust termination was initiated 59.93 sec after motor ignition at a chamber pressure of 75.3 psia. Breakwires on the six thrust termination ports indicated the first port had been opened by 402 μsec after thrust termination signal application. The time interval from first port rupture to last port rupture was 53 μsec. This meets the specification requirements of 219 to 705 μsec.

During the first 2 sec following thrust termination, the sealed forward dome interstage volume experienced a maximum pressure rise of 0.529 psi.

4.6 STRUCTURAL INTEGRITY

Motor structural condition after firing was satisfactory. The motor postfire condition is shown in Fig. 13. Moderate leakage was noted at the bellows of thrust termination stacks 1 and 5. Leakage also occurred from one ruptured CCMDF cable to thrust termination port no. 6. There was a visual indication of a hairline crack in one of the mounting feet (nearest the explosive cord attachment) of the arm-disarm/safe-and-arm device. Postfire motor disassembly at Thiokol has revealed cracks in this vicinity on the last two PQA motors tested at AEDC. The port for the flight pressure transducer (PC-1), installed prior to delivery to AEDC, was found to be plugged postfire.

SECTION V
SUMMARY OF RESULTS

The results of testing a TCC Production Quality Assurance LGM-30G Stage III motor, PQA-103, at an average simulated altitude of 92,000 ft are summarized as follows:

1. All motor ballistic performance data from this firing conformed to model specification requirements for the LGM-30G Stage III propulsion subsystem. Propellant grain temperature at the time of motor ignition was 71°F.

2. The thrust vector and roll control systems operated as programmed throughout the firing. Thrust vector control system gain met specification requirements. Roll control gas generator performance and all roll valve response times were within model specification limits.

3. The motor was ignited at a pressure altitude of 101,000 ft and the ignition delay was 89 msec.

4. Vacuum-corrected unaugmented total impulse was 2,083,103 lbf-sec during action time. Vacuum specific impulse was 284.96 lbf-sec/lbm.

5. Thrust termination was initiated 59.93 sec after motor ignition at a chamber pressure of 75.3 psia. The first thrust termination port was opened by 402 μsec after signal application. Thrust termination interval was 53 μsec.

6. Postfire structural condition of the motor was satisfactory. Moderate leakage was noted at the bellows of thrust termination stacks 1 and 5 and also from one ruptured CCMDF cable to thrust termination port no. 6. There was a visual indication of a hairline crack in one of the mounting feet (nearest the explosive cord attachment) of the arm-disarm/safe-and-arm device.

REFERENCES

1. Thiokol Chemical Corporation, "General Test Plan, Third Stage Minuteman III, Production Quality Assurance (PQA)." April 1971.

2. "Model Specification S-133-1003-0-4, Part II, Production Configuration and Acceptance Test Requirements." January 6, 1972.

3. Test Facilities Handbook (Ninth Edition). "Engine Test Facility, Vol. 2." Arnold Engineering Development Center, July 1971.

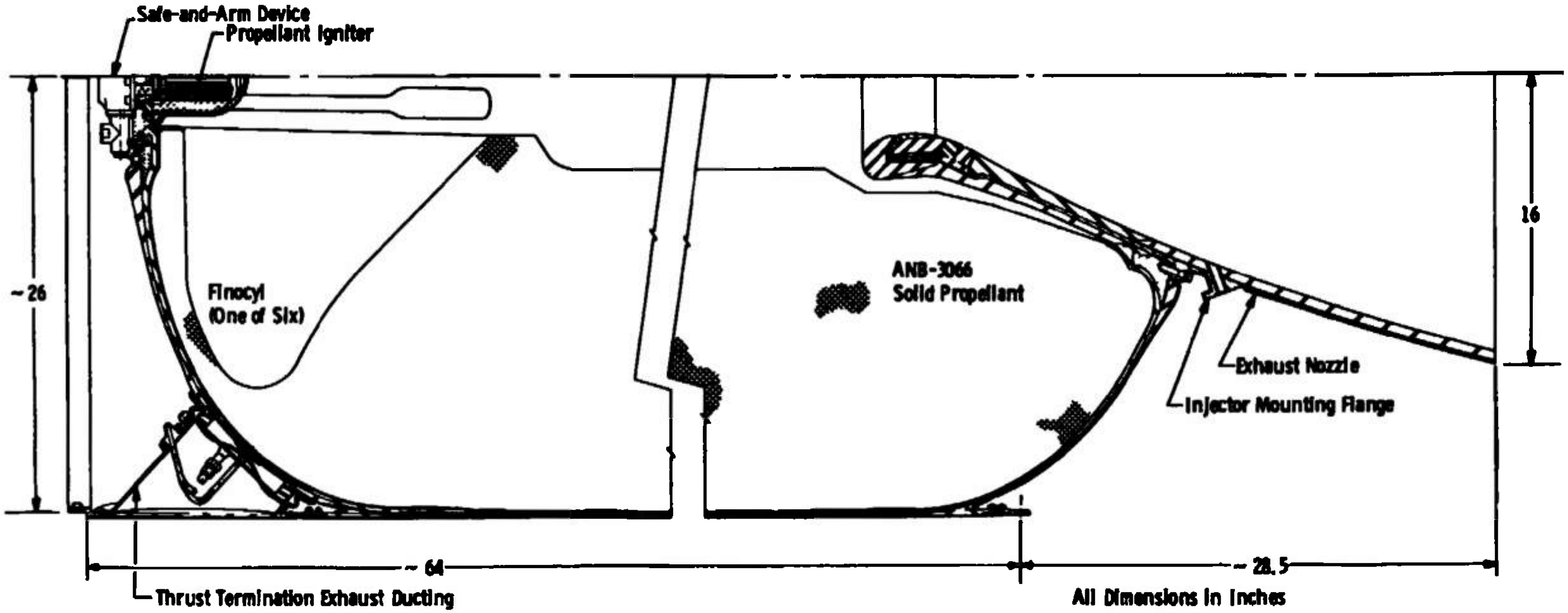
4. Dubin, M., Sissenwine, N., and Wexler, H. U.S. Standard Atmosphere, 1962. U.S. Government Printing Office, Washington, D.C., December 1962.

5. "Igniter, Propellant, Rocket Motor, Minuteman III Stage III." AGC Specification 32204, January 16, 1968.

6. "Rocket Motor Log Book, Motor PQA-103." Thiokol Chemical Corporation, November 17, 1969.

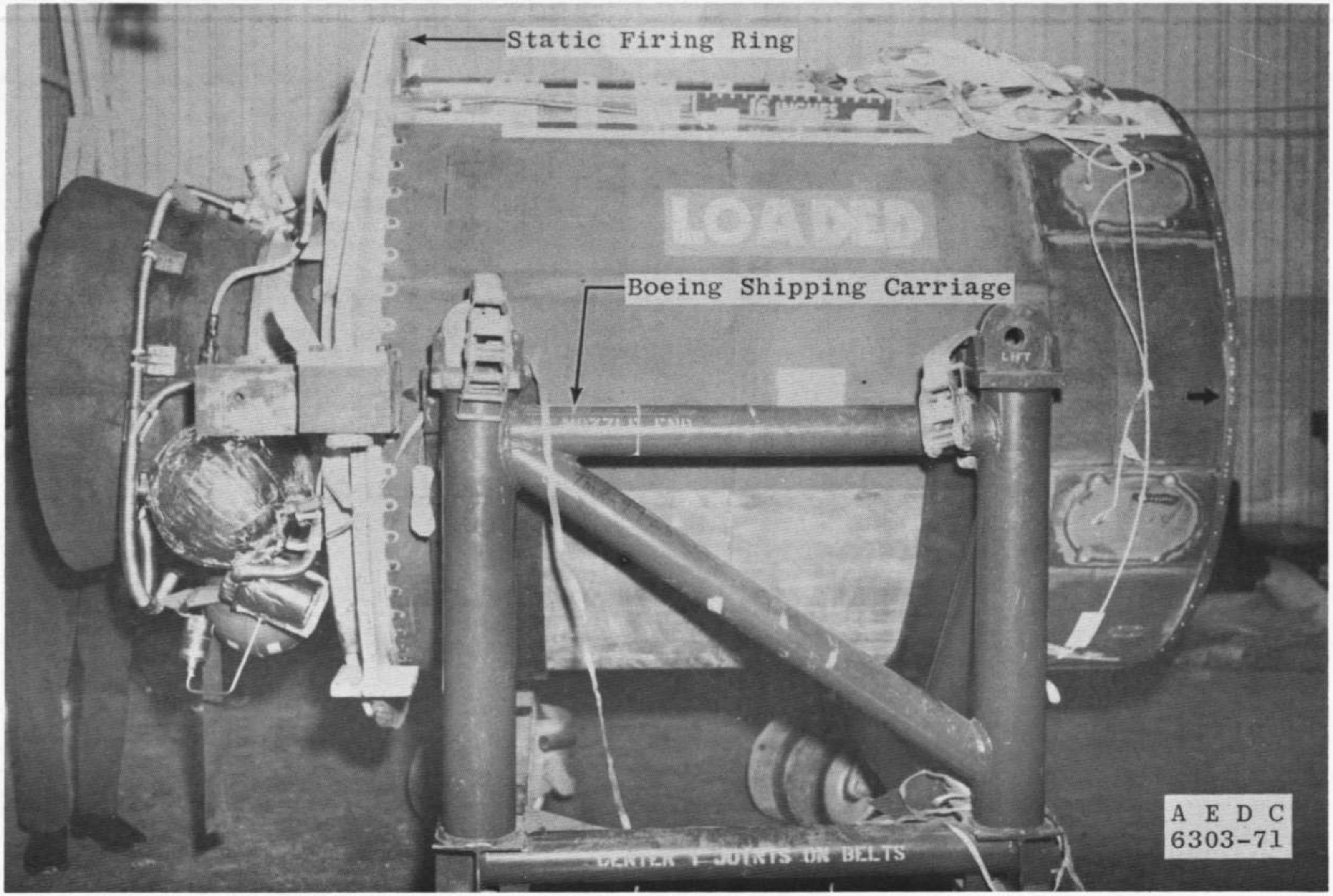
APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION CALIBRATIONS
IV. UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS
V. METHODS OF CALCULATION



a. Cutaway Schematic of Motor

Fig. 1 Minuteman LGM-30G Stage III Motor



b. Overall View, Typical
Fig. 1 Concluded

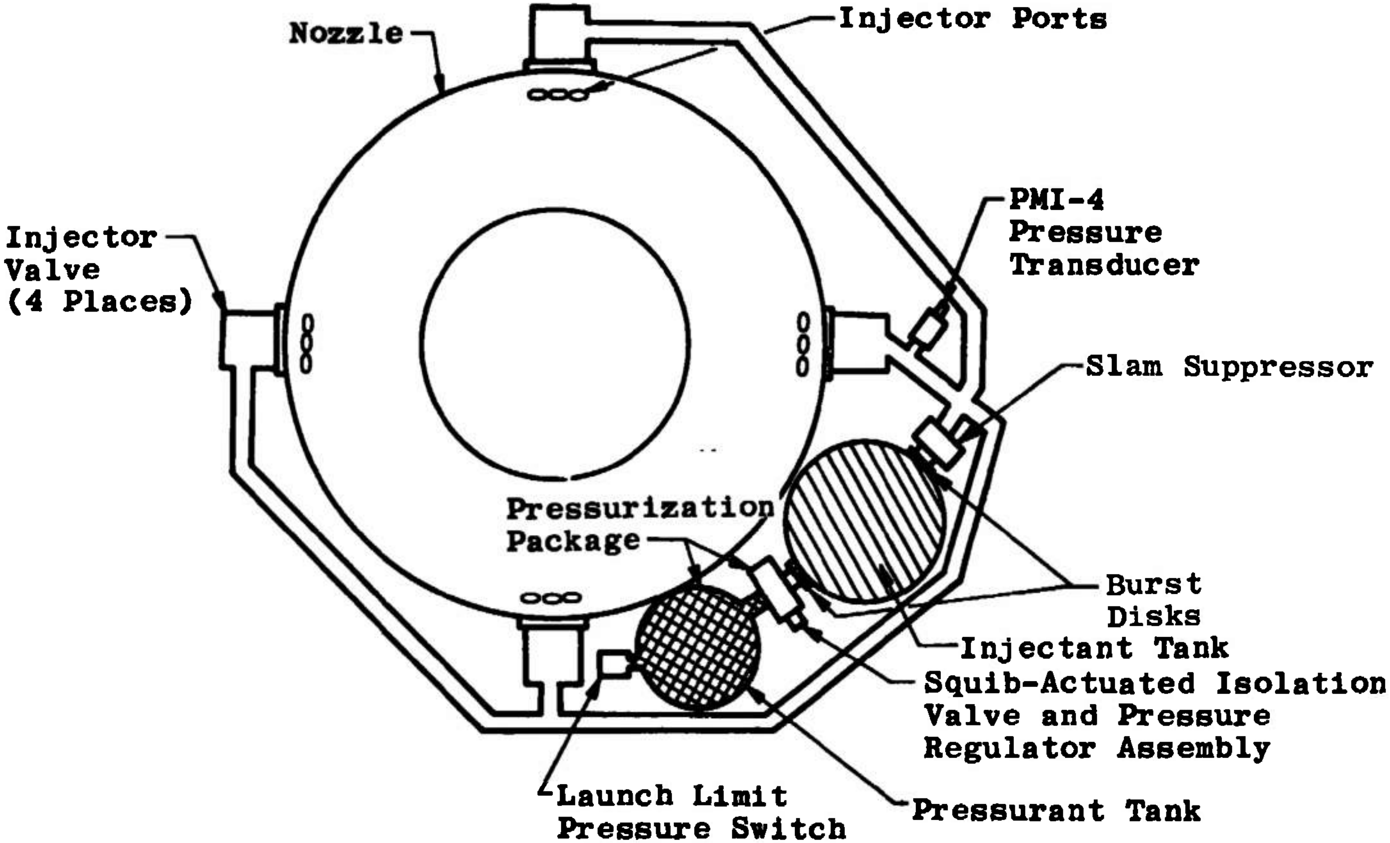


Fig. 2 Liquid-Injection Thrust Vector Control System Schematic

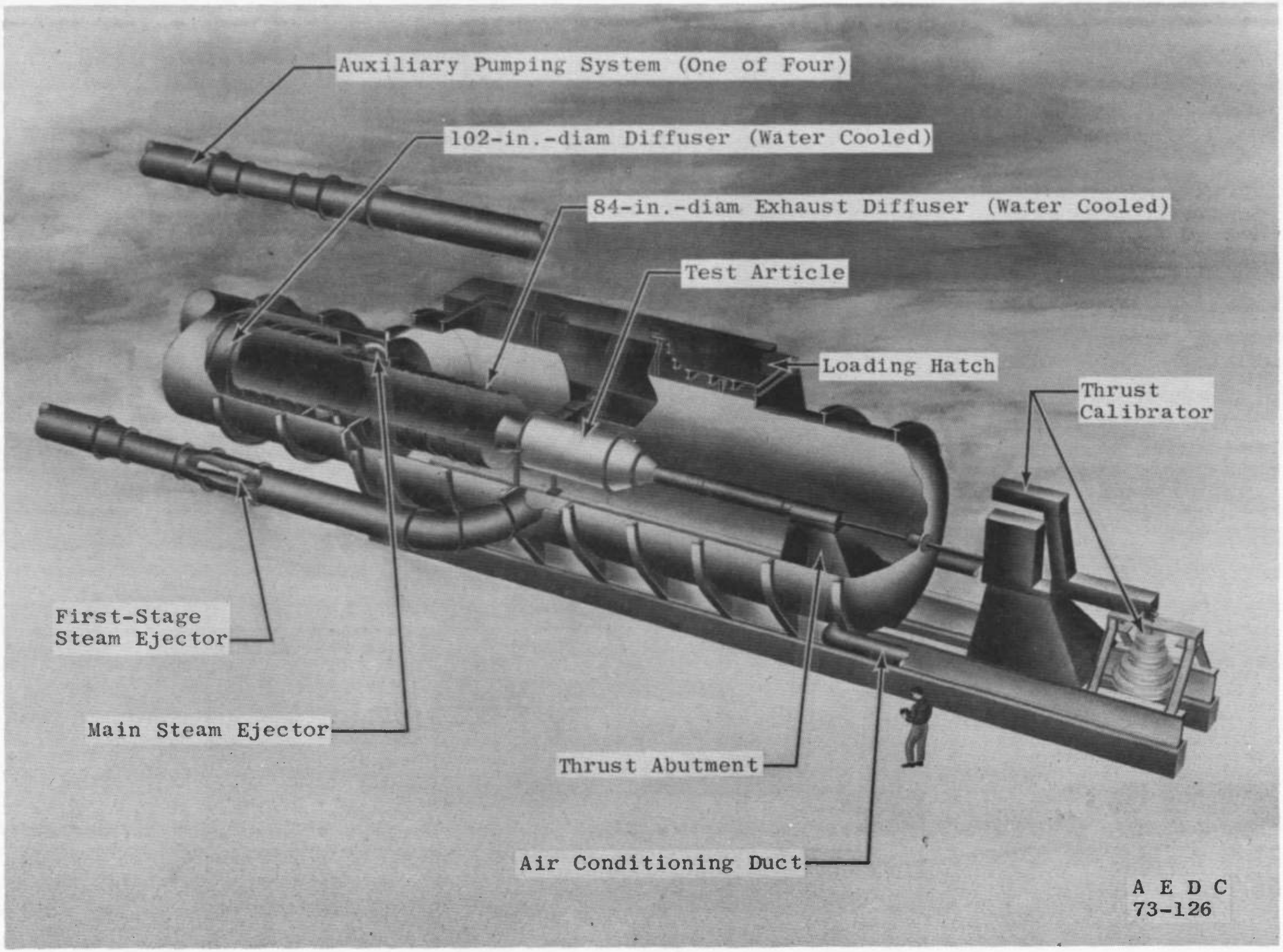


Fig. 3 Rocket Development Test Cell (J-5)

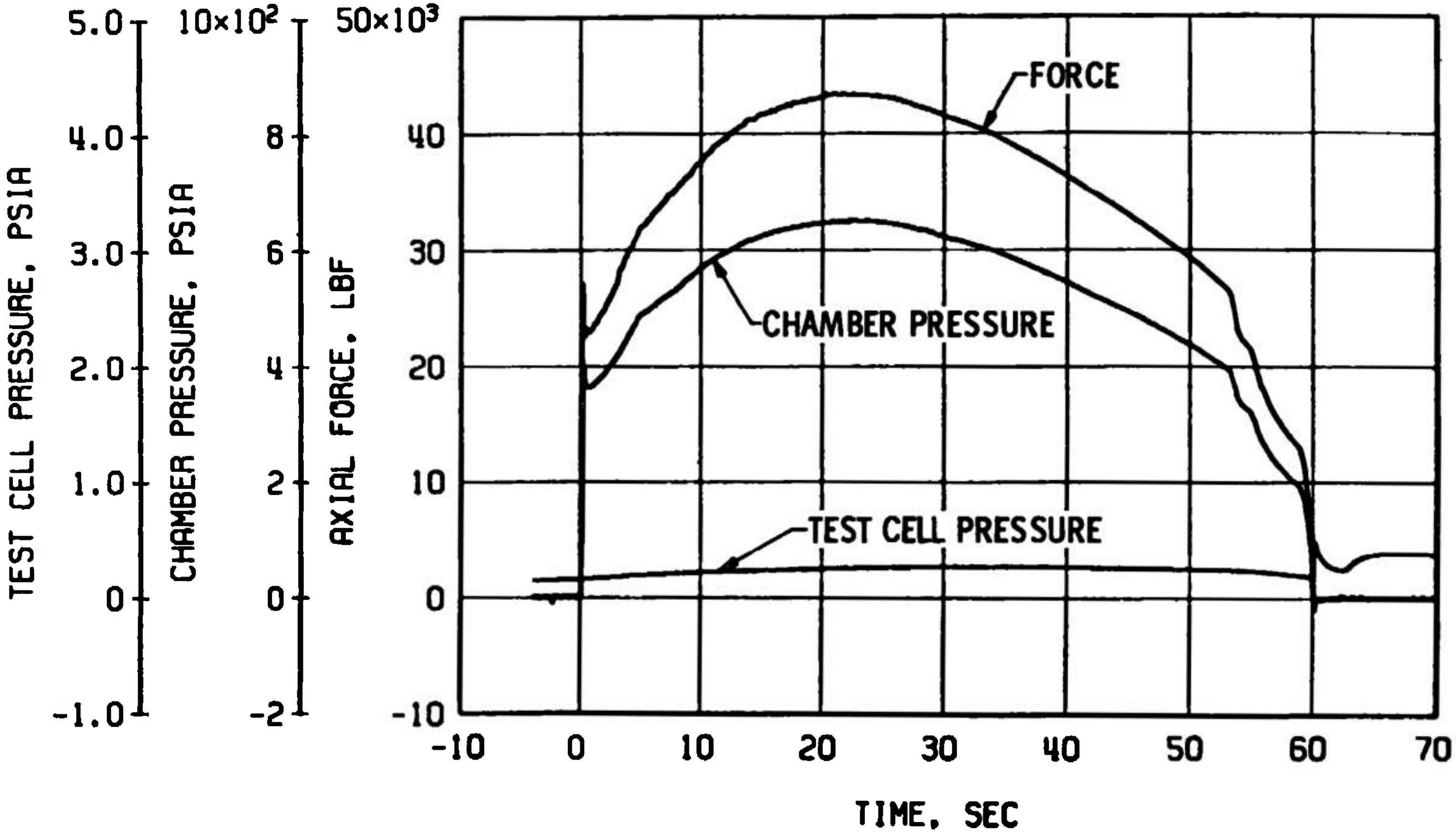


Fig. 4 Measured Axial Force, Chamber Pressure, and Test Cell Pressure during Motor Operation

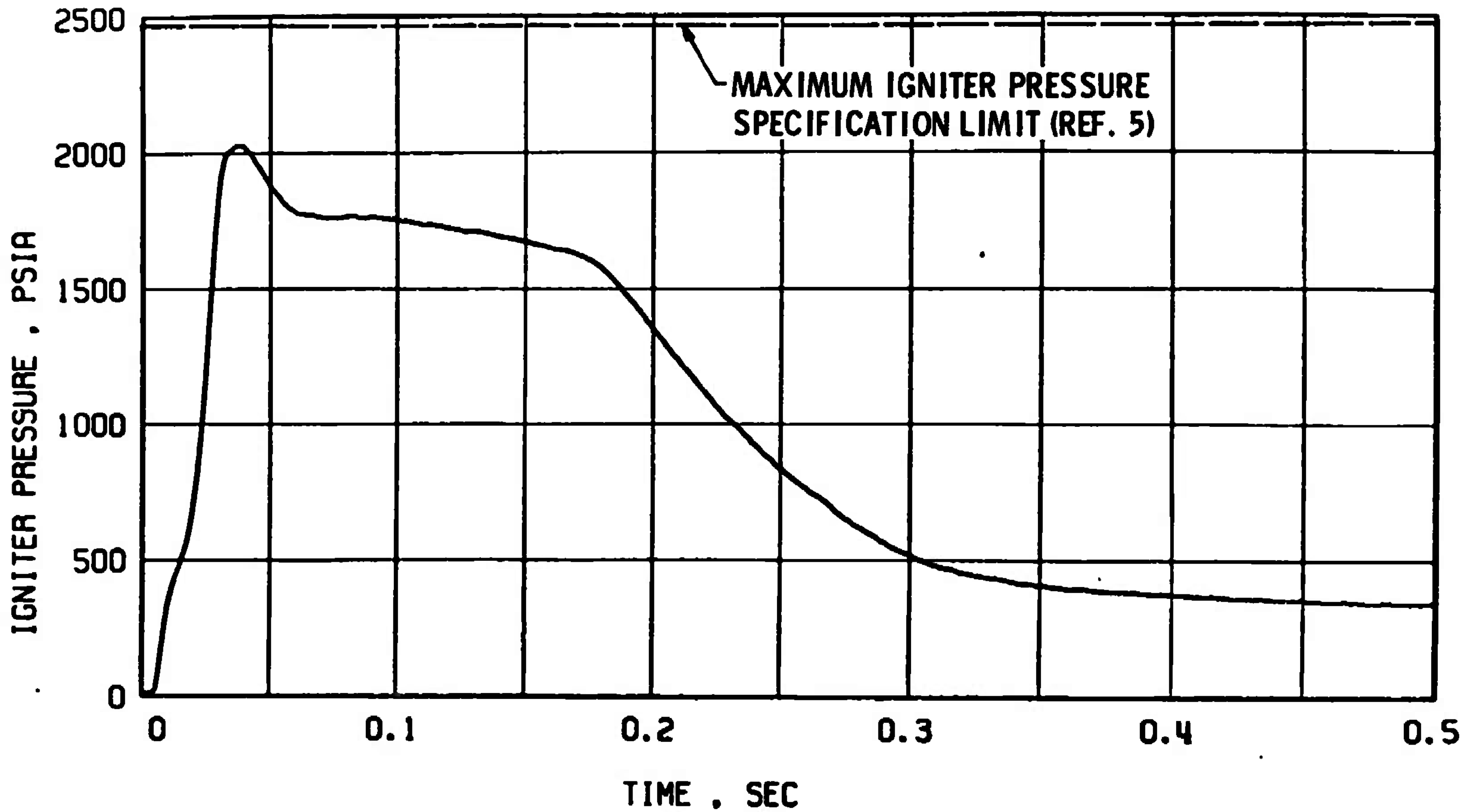


Fig. 5 Igniter Pressure Transient during Ignition

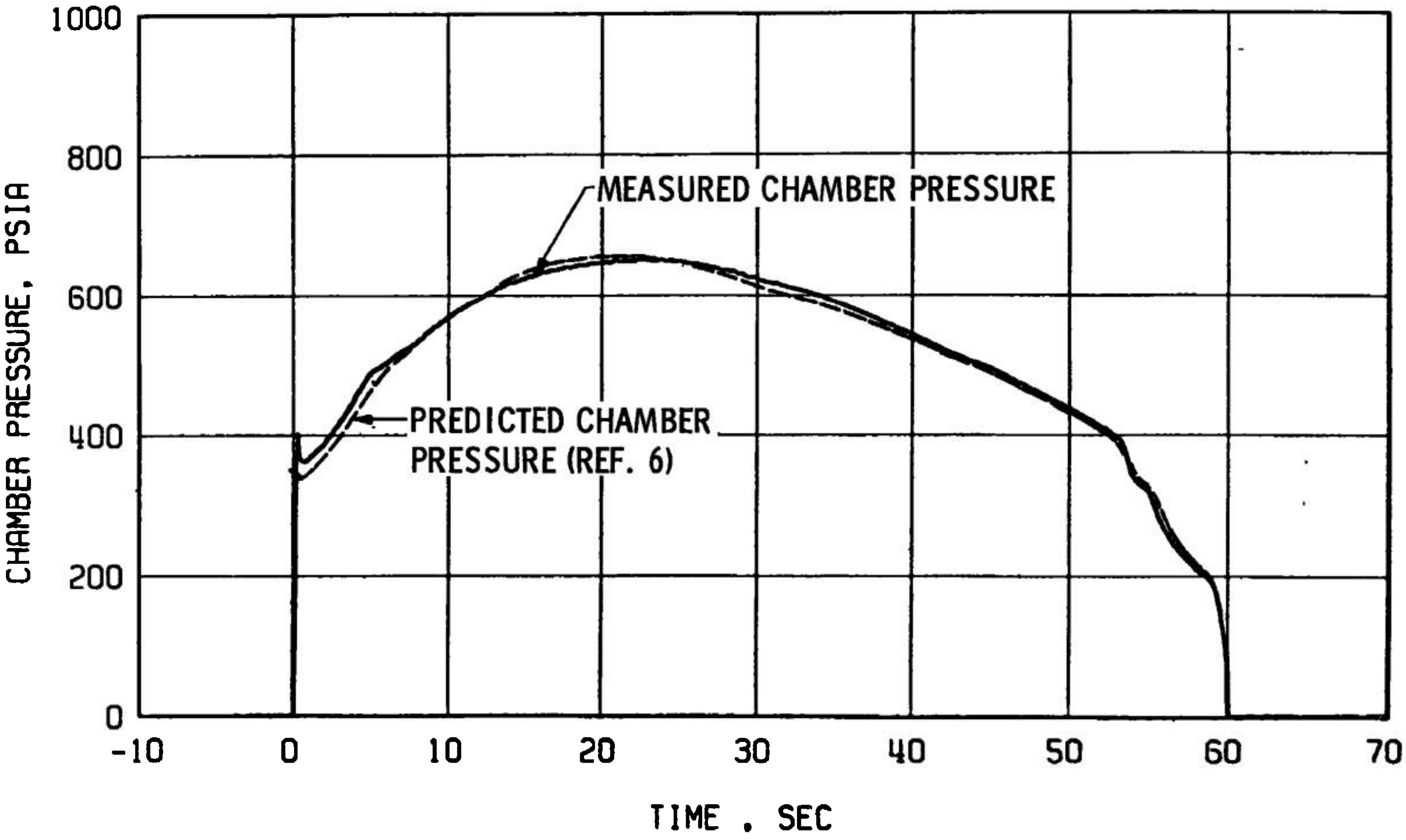


Fig. 6 Measured and Predicted Motor Chamber Pressure

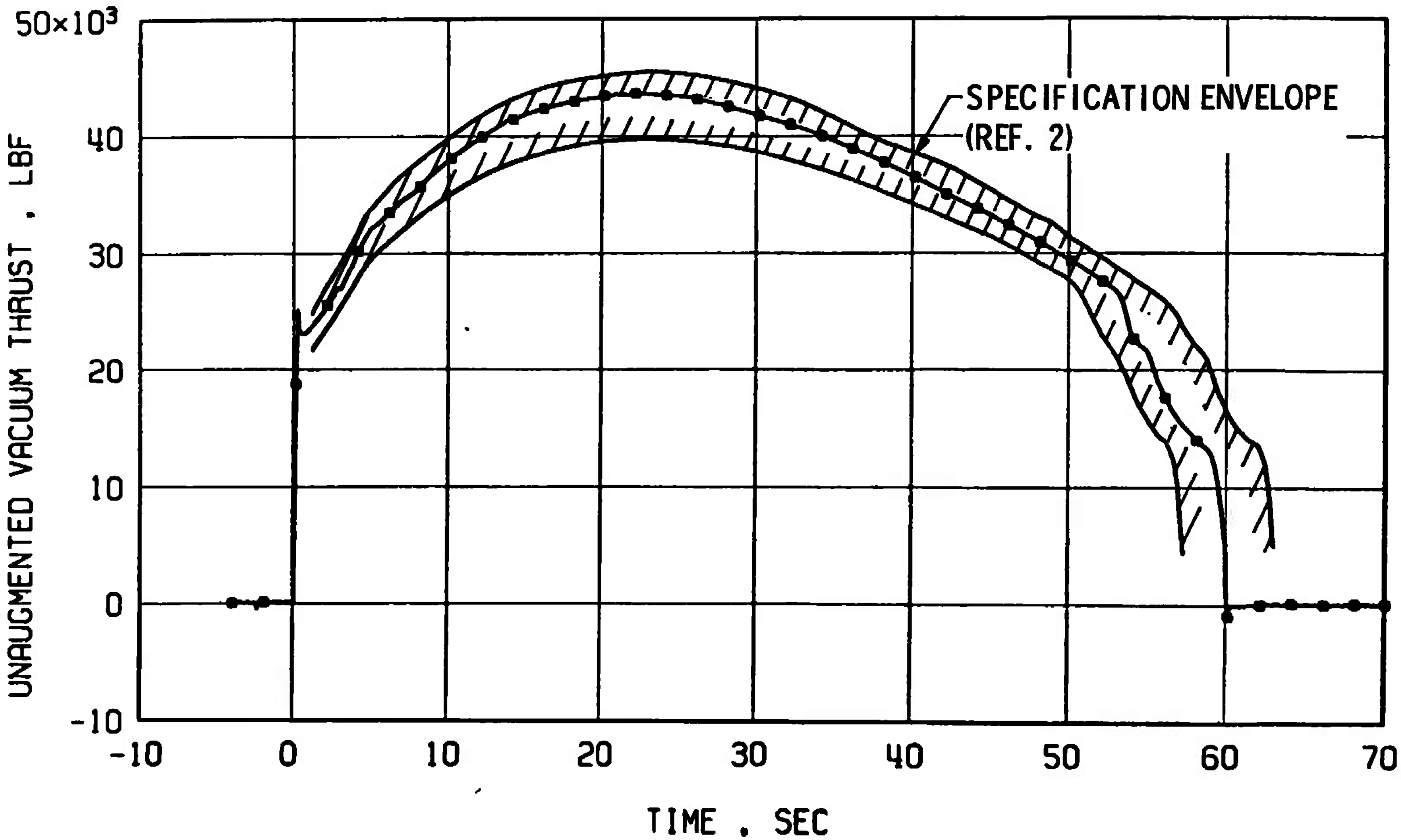
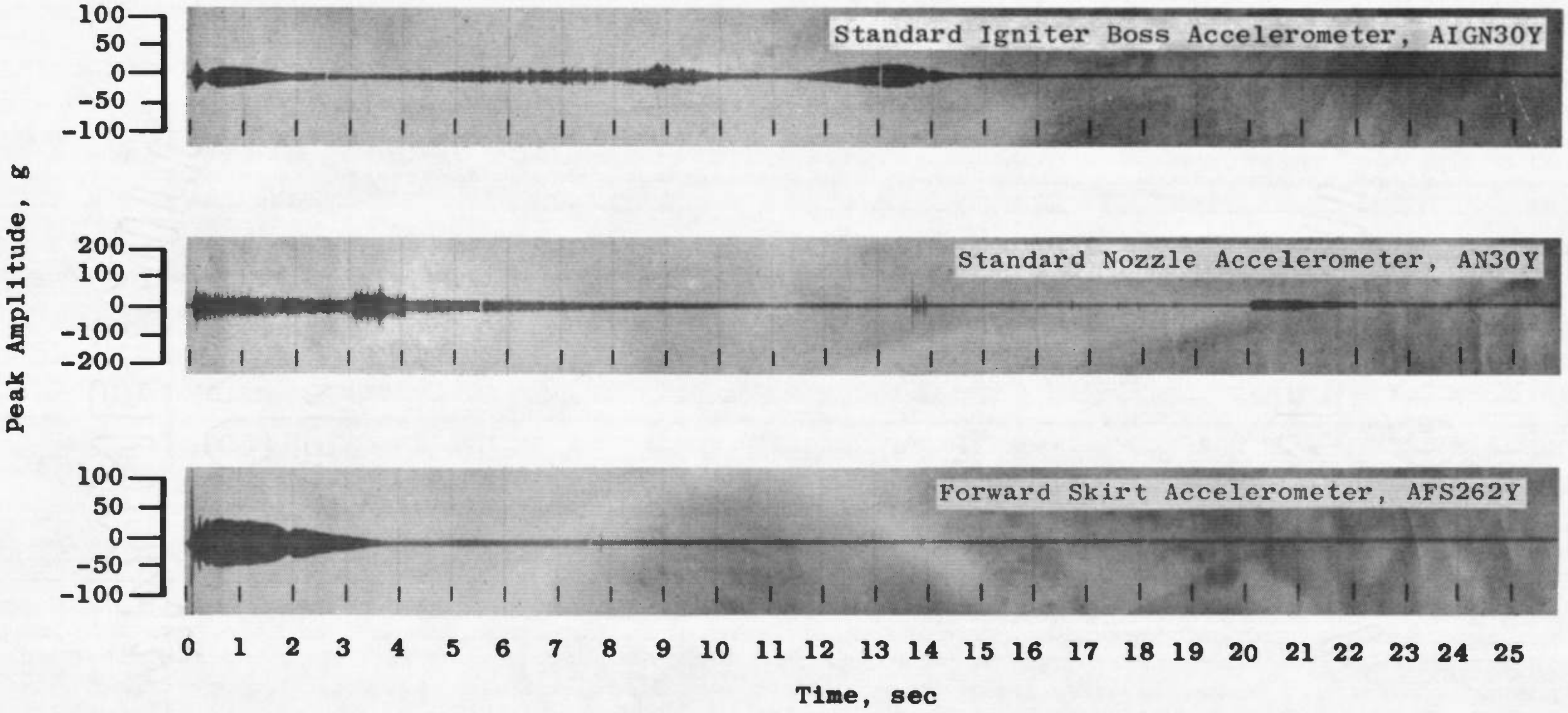
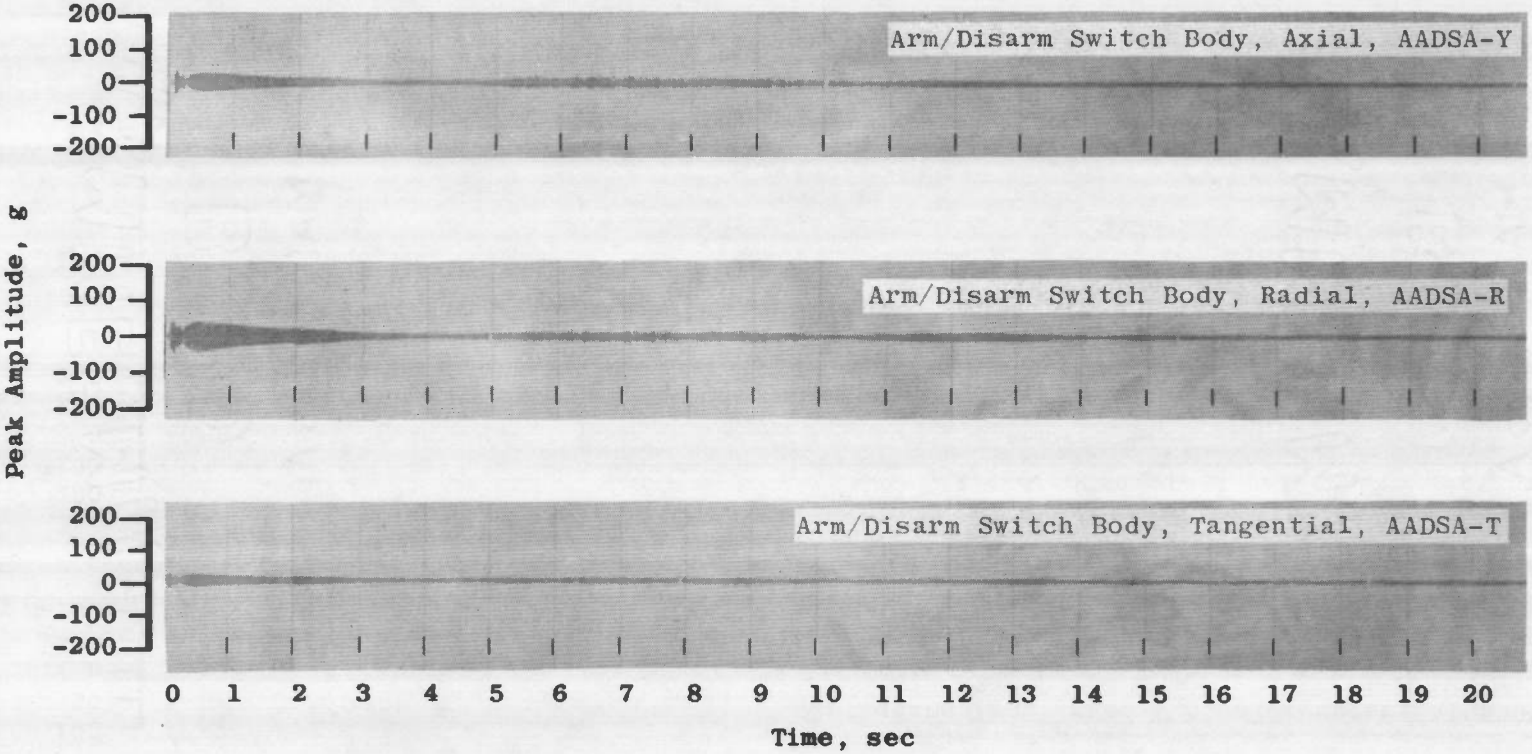


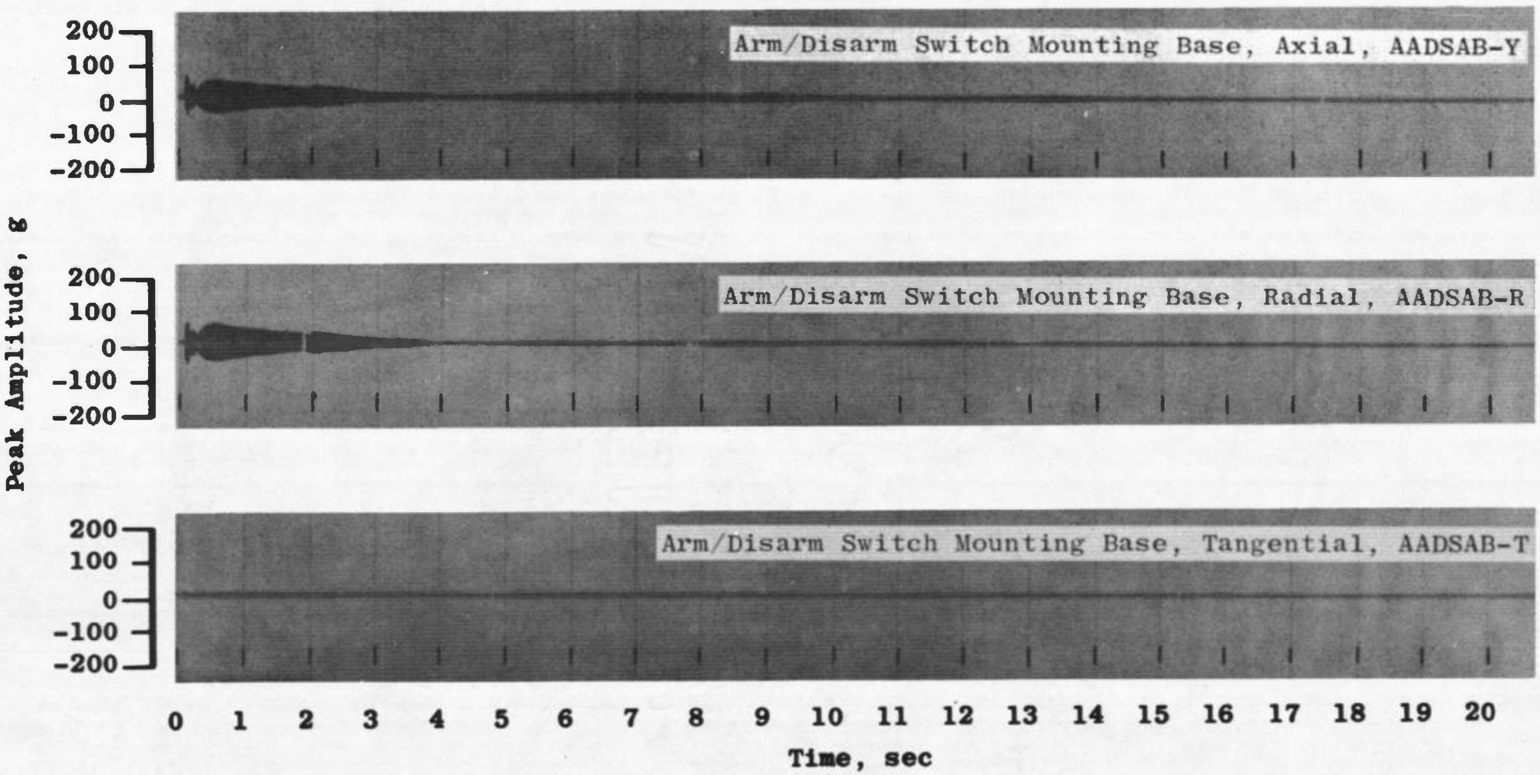
Fig. 7 Unaugmented Vacuum Thrust and Specification Envelope



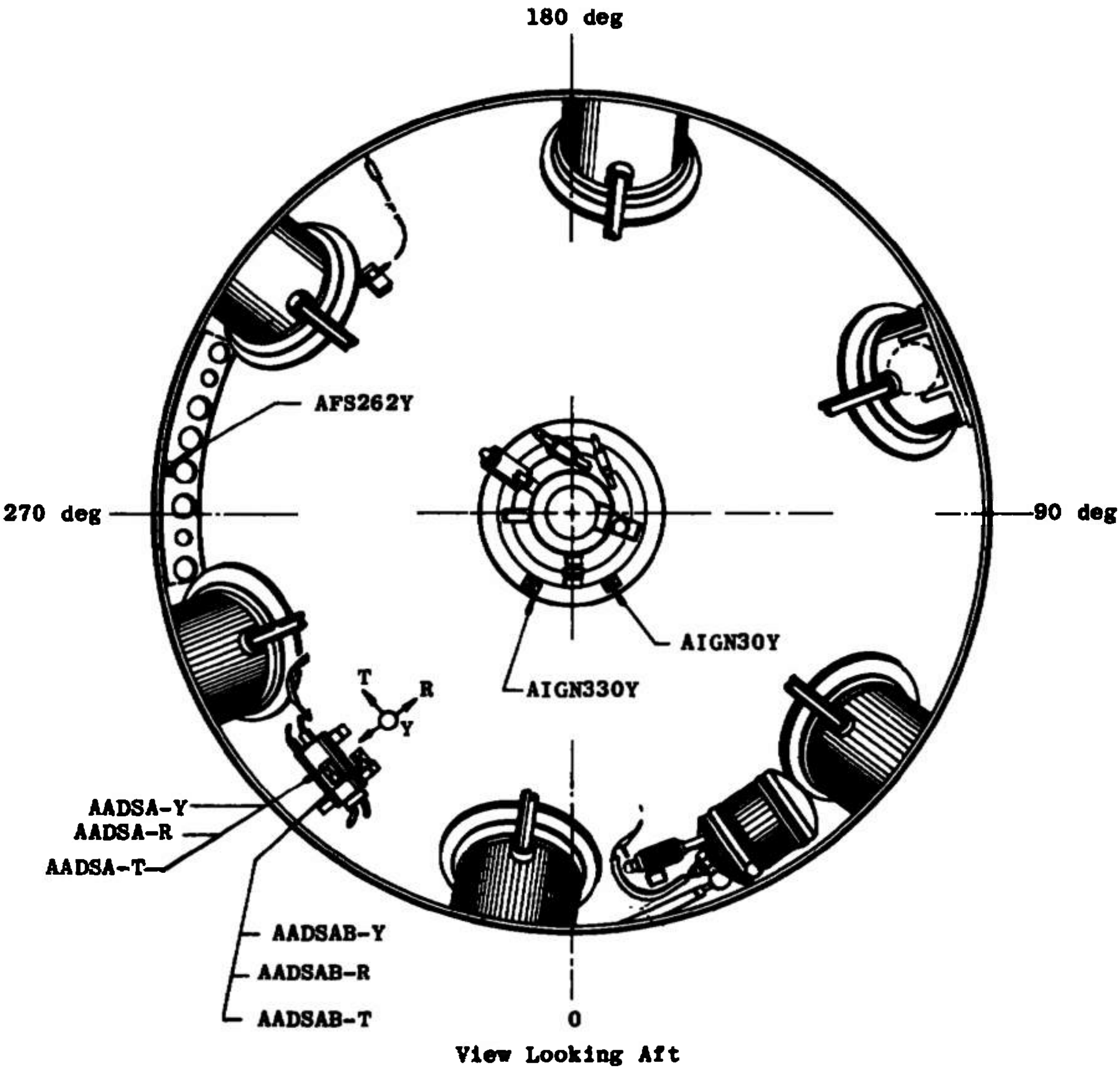
a. Motor Accelerometer Vibrations
Fig. 8 Motor Accelerometer Data



a. Continued
Fig. 8 Continued



a. Concluded
Fig. 8 Continued



b. Schematic of Accelerometer Locations
Fig. 8 Concluded

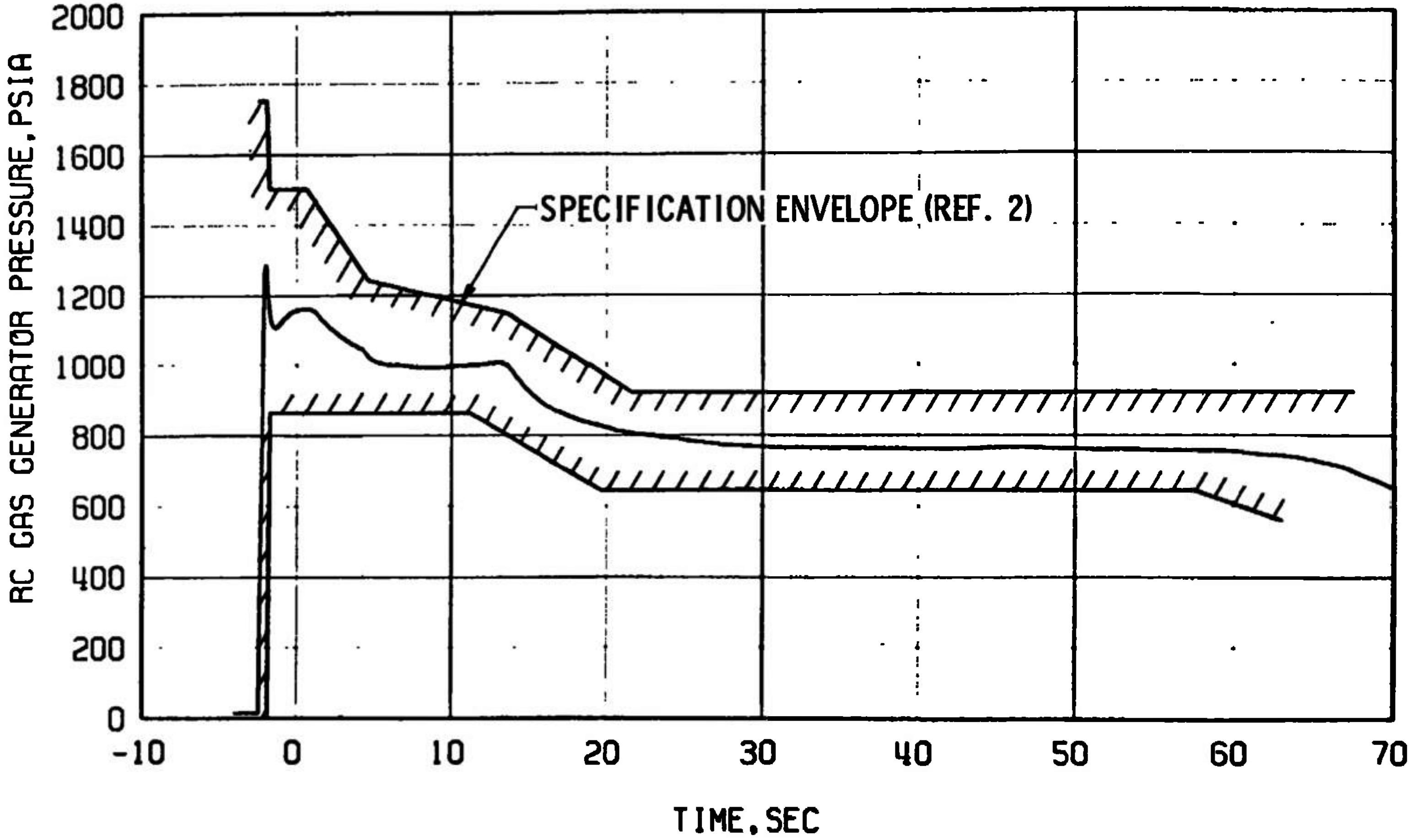
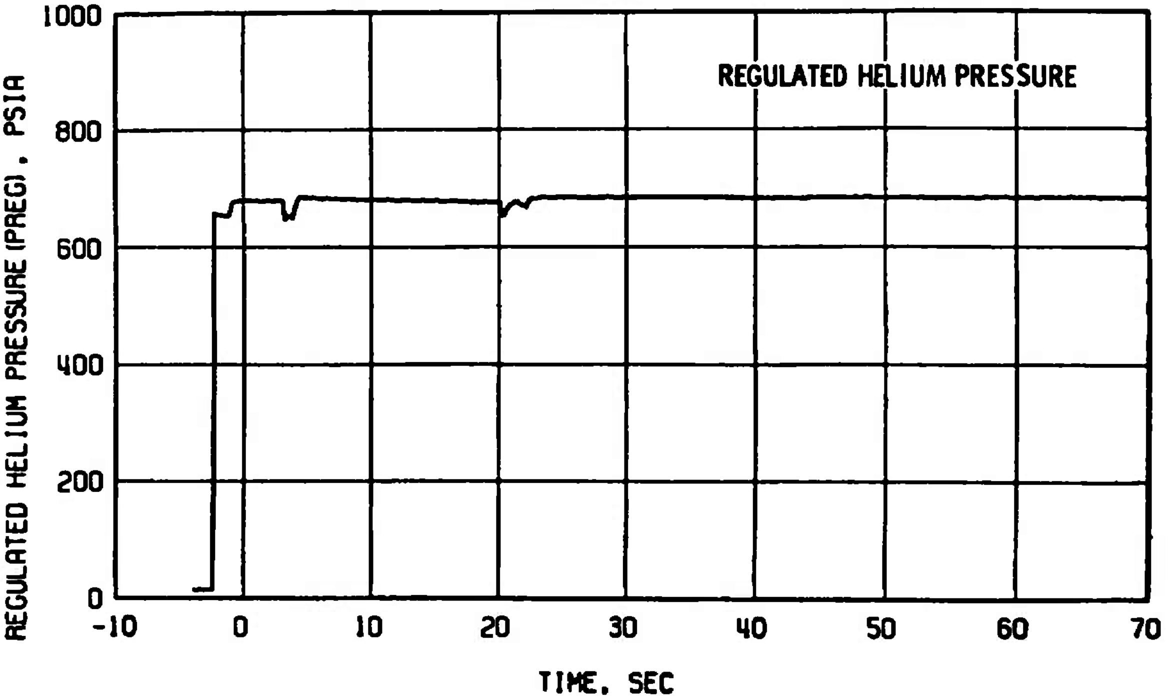


Fig. 9 Roll Control Gas Generator Pressure and Specification Envelope



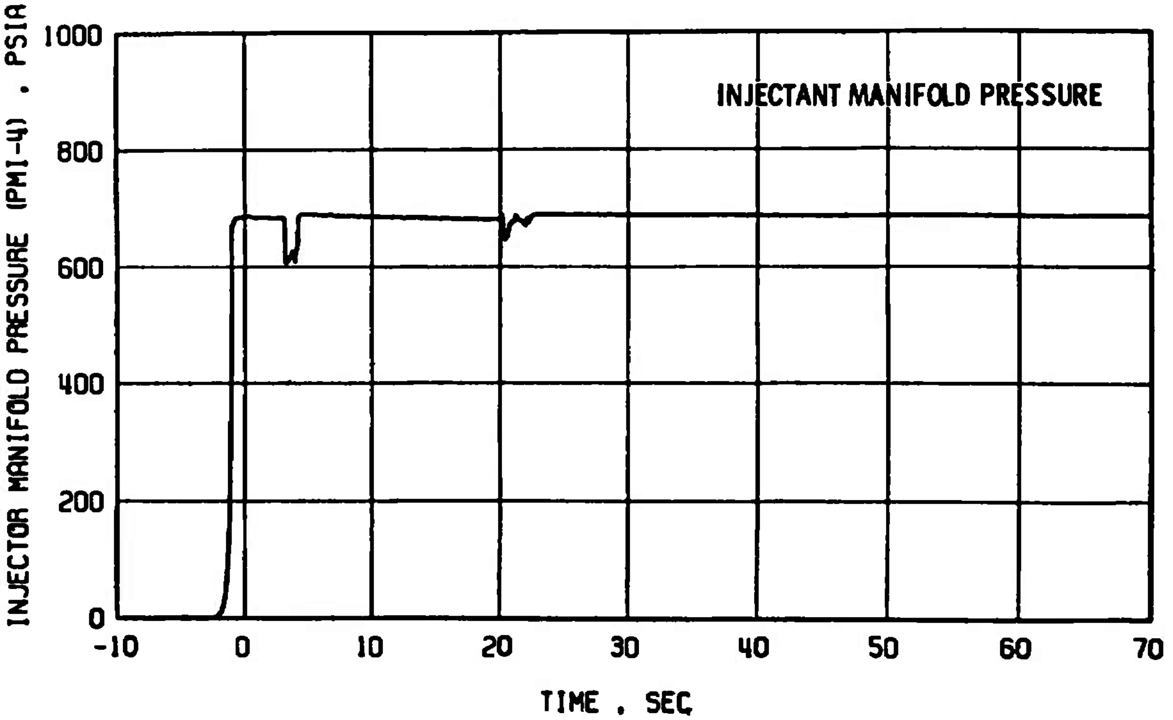
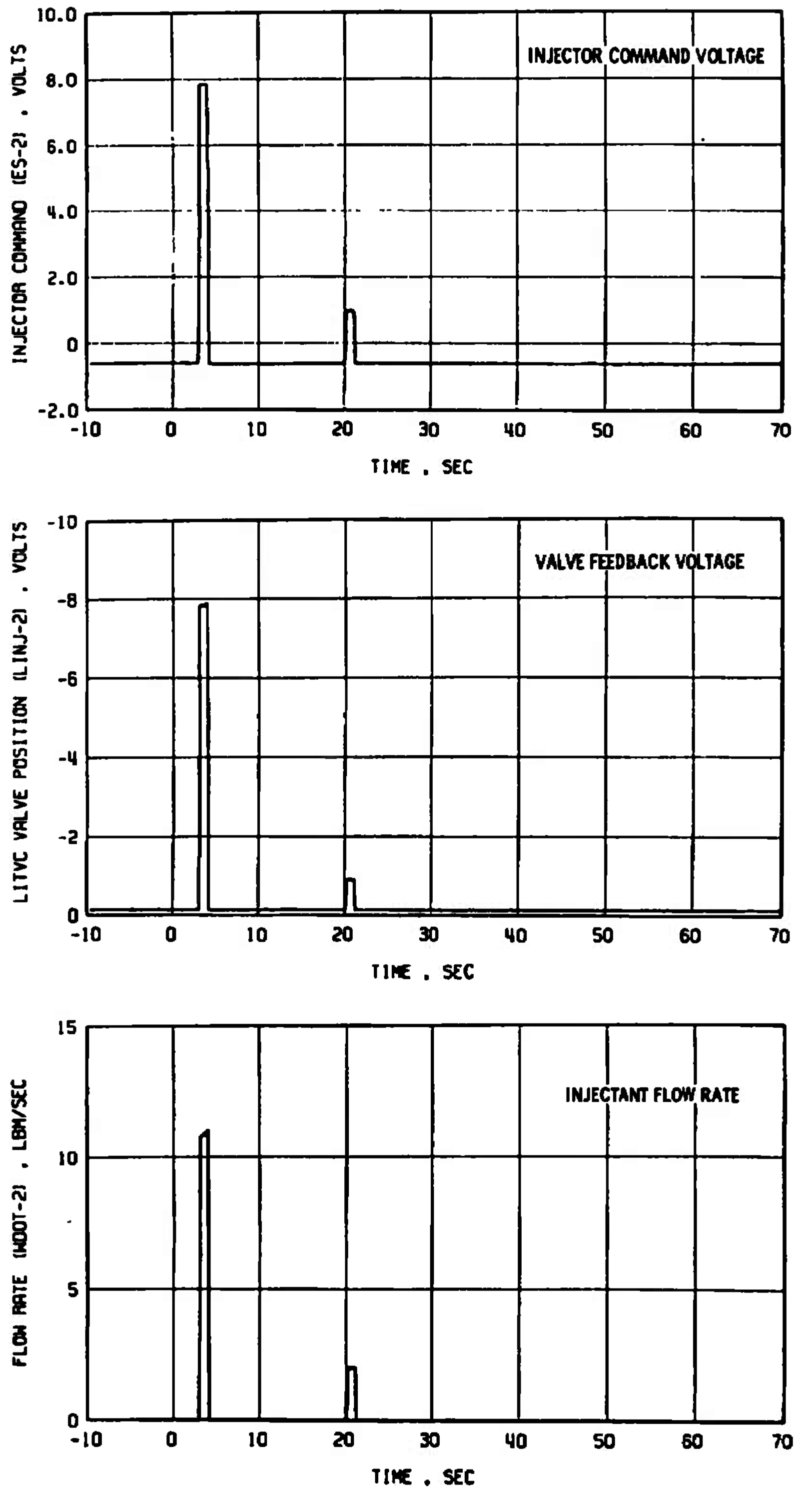
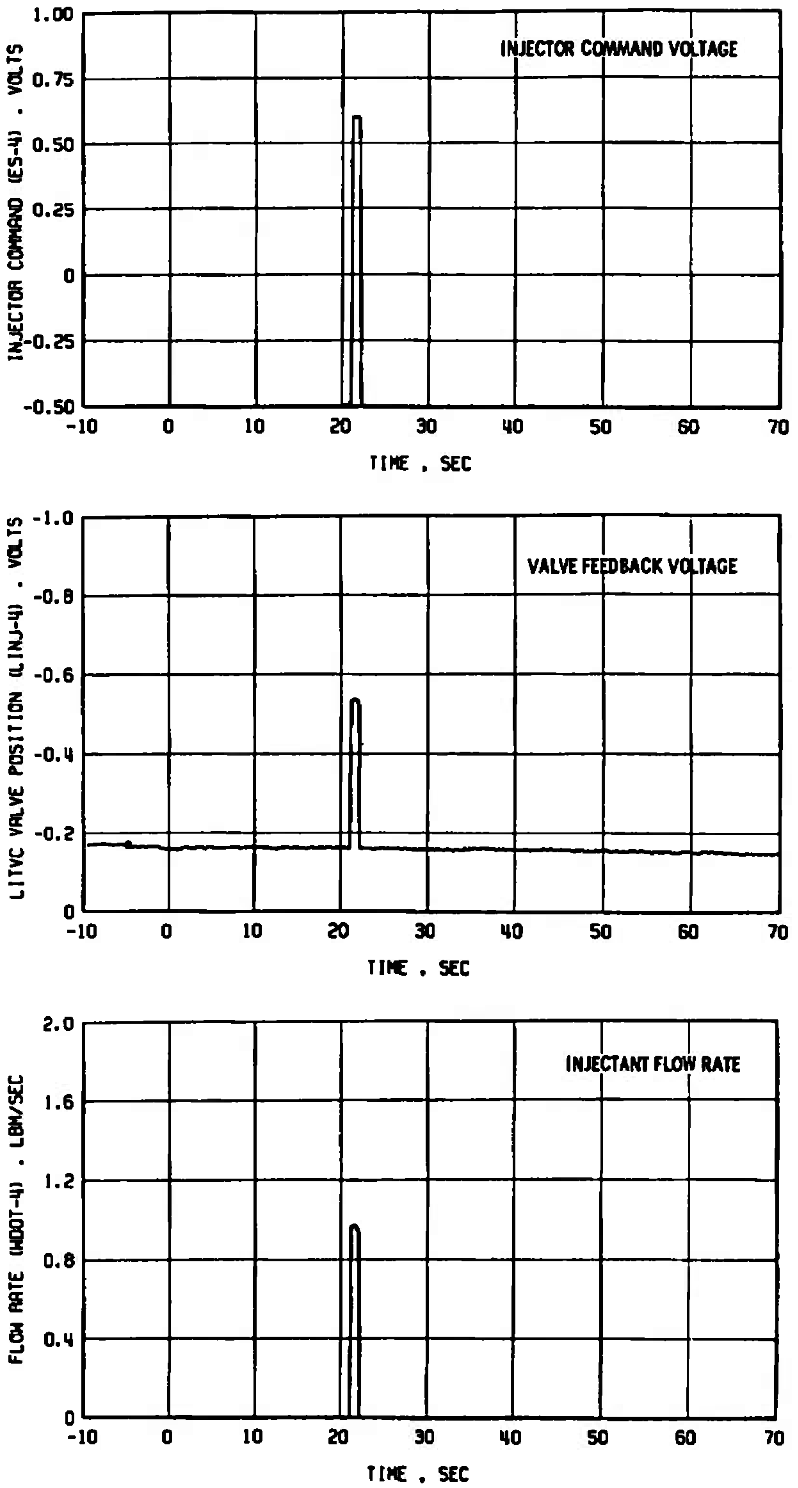


Fig. 10 Regulated Helium and Injectant Manifold Pressures during Motor Operation



a. Valve 2
Fig. 11 Thrust Vector Control Data Summary



b. Valve 4
Fig. 11 Concluded

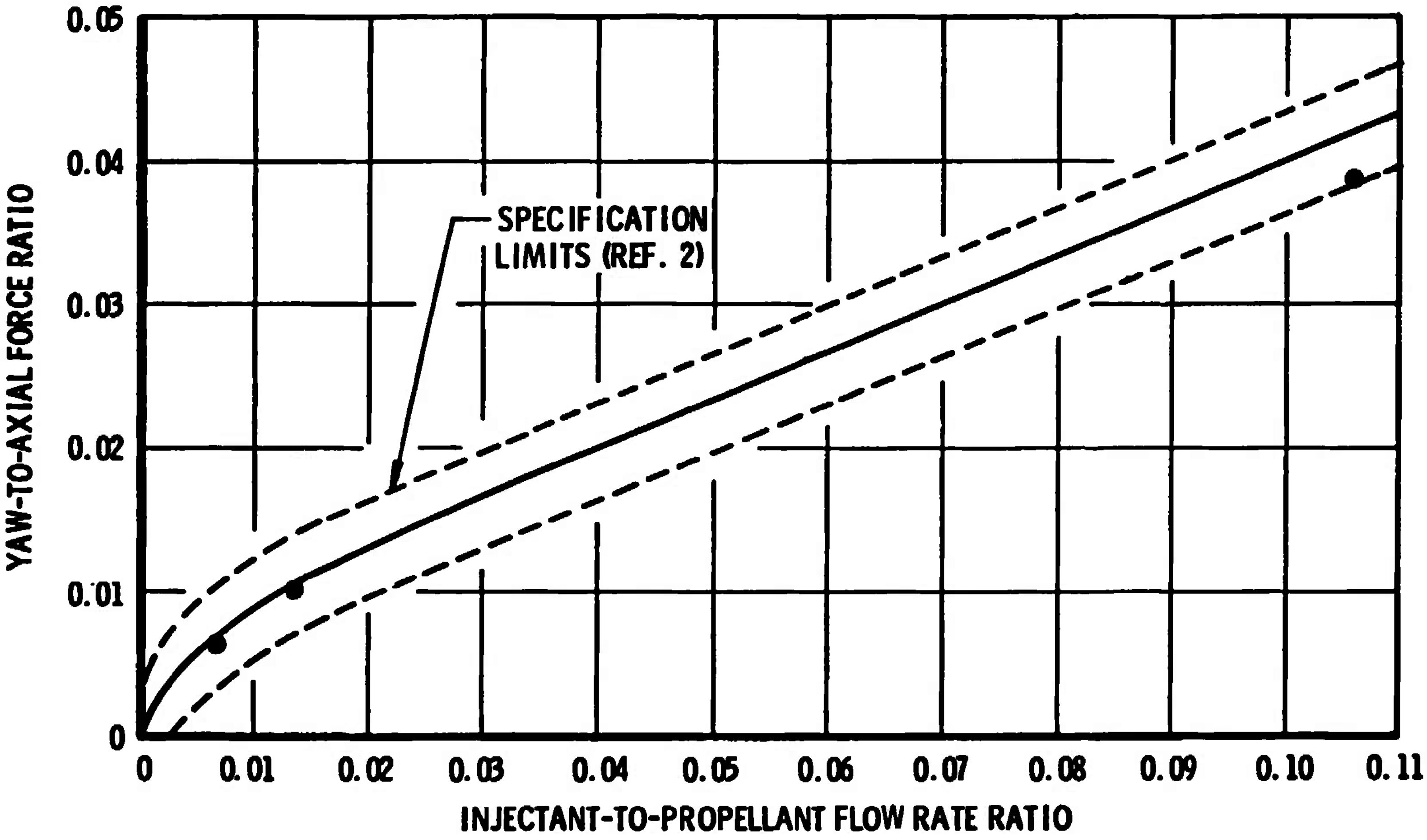
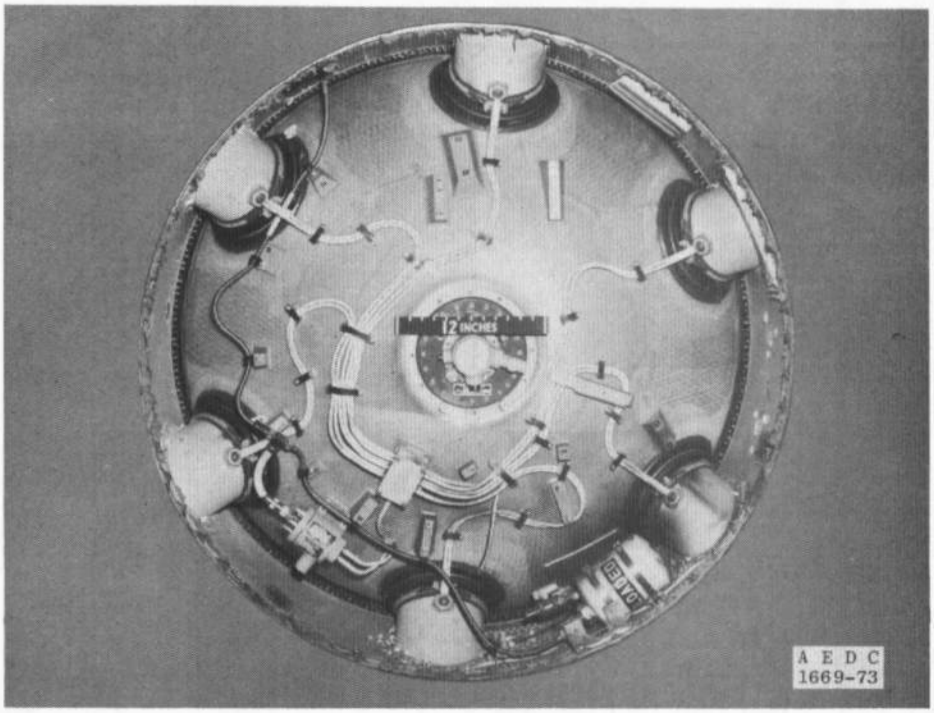
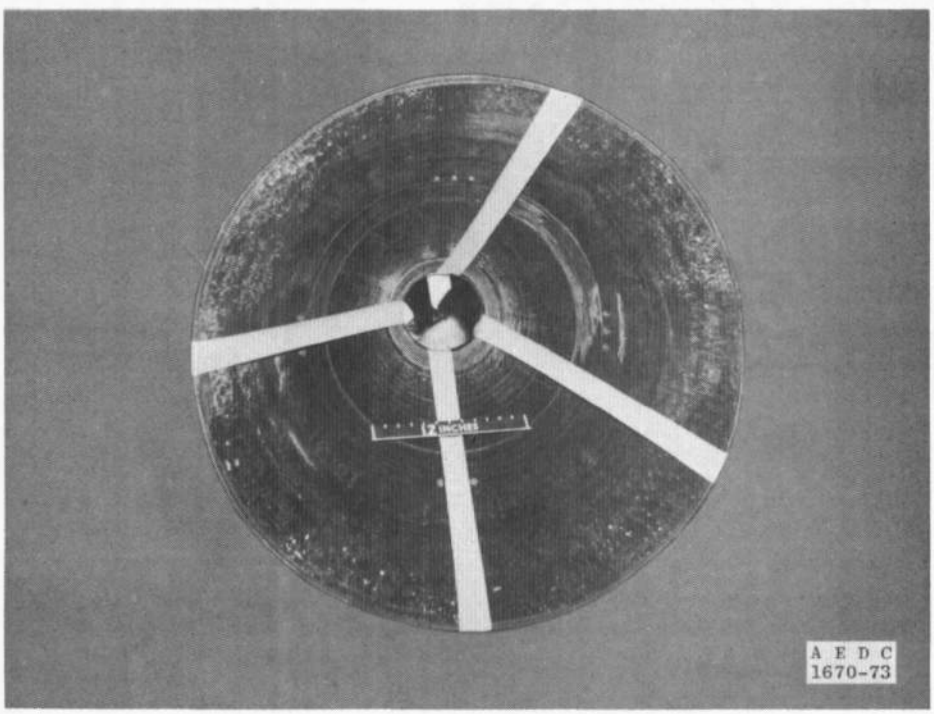


Fig. 12 Liquid-Injection Thrust Vector Control System Gain and Specification



a. Forward Dome



b. Nozzle

Fig. 13 Motor Postfire Condition

TABLE I
TEST ARTICLE CONFIGURATION

Nomenclature	Part No.	Serial No.
Motor Assembly	1147372-91	TC30207
Propellant	ANB-3066	7110038 and 7110037
Nozzle, Exhaust	1146002-39	1000214
Housing, Nozzle	1144447-19	304-2
Extension, Exit Cone	1145027-1	8238-62
Exit Cone	1127578-1	312-3
Igniter and S&A Assembly	1128361-511	1000193
Igniter Rocket Motor	1128360-505	1000193
Safe and Arm	KR80000-09	OB26865
Propellant	ANB-3066	7110011
Chamber	1127676-1	1000343
Thrust Termination System	1147368-19	N/A
Ring Assy, Retaining	1215685-17	1001826 thru 1831
Block Assy, Manifold	1214311-21	1000258
Ordnance Subsystem	1147373-19	1000192
A/D S&A Mechanism	1214110-9	1000271
Igniter Assy, (Roll Control)	1128070-13	1000496
Squib Cartridge	1128115-41	1000331
Roll Control Assy	1128070-11	1000373
Valve Assy	010-58847	531
Gas Generator Assy	20840	P-0791
LITVC System	1145433-359	N/A
Injectant Tank Assy	1145560-79	1000242
Helium Tank Assy	1128811-479	1000224
Pressurization Package	1128115-129	1000190
Pressure Switch	1128084-13	1000194
Manifold Assy	1145522-29	1000224
Servoinjector Valves*		
0°	401-09140-10M	HCC004
90°	401-09140-10	HSD0019
180°	401-09140-03M	HCC0006
270°	401-09140-10	HSD0137
Operational Pressure Transducers		
PC-1	1143914-501	1000
PMI-4	1143914-503	1000966
PRCGG	1143914-505	1001064

*Valves cleaned and checked at AEDC for use on subsequent LGM-30G Stage III motors.

TABLE II
INSTRUMENTATION SUMMARY

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLOGRAPH	STRIP CHART
	ACCELERATION	G PEAK		G PEAK				
AADSA-P	A/D-S/A SWITCH, RAD	-200 TO 200	PIEZOELECTRIC	1000 TO -1000		X		
AADSA-T	A/D-S/A SWITCH, LONG	-200 TO 200	PIEZOELECTRIC	1000 TO -1000		X		
AADSA-Y	A/D-S/A SWITCH, AX	-200 TO 200	PIEZOELECTRIC	1000 TO -1000		X		
AADSAB-R	A/D-S/A SW BASE, RAD	-200 TO 200	PIEZOELECTRIC	1000 TO -1000		X		
AADSAB-T	A/D-S/A SW BASE, LNG	-200 TO 200	PIEZOELECTRIC	1000 TO -1000		X		
AADSAB-Y	A/D-S/A SW BASE, AX	-200 TO 200	PIEZOELECTRIC	1000 TO -1000		X		
AFS-252Y	FORWARD SKIRT @ 252	-100 TO 100	PIEZOELECTRIC	1K TO 1K		X		
AIGN30Y	IGNITER BOSS @ 30	-100 TO 100	PIEZOELECTRIC	1K TO 1K		X		
AIGN330Y	IGNITER BOSS @ 330	-100 TO 100	PIEZOELECTRIC	1K TO 1K		X		
AN25Y	NOZZLE AFT FLANGE 25	-200 TO 200	PIEZOELECTRIC	1K TO 1K		X		
AN30Y	NOZZLE AFT FLANGE 30	-200 TO 200	PIEZOELECTRIC	1K TO 1K		X		
	EVENT-VOLTAGE	V DC						
EFS-1	MAIN MOTOR IGNITION	0 TO 28			X**	X	X	
EFS-2	MAIN MOTOR IGNITION	0 TO 28			X**		X	
EFS-3	LITVC IGNITION	0 TO 28			X		X	
EFS-4	LITVC IGNITION	0 TO 28			X		X	
EFS-5	ROLL CONTROL IGNIT.	0 TO 28			X	X	X	
EFS-6	ROLL CONTROL IGNIT.	0 TO 28			X		X	
EFS-9	AOTT IGNITION	0 TO 6.4			X	X	X	
EFS-10	AUTT IGNITION	0 TO 28			X		X	
	EVENT	VOLTS						
EISA	IGNITER S/A ARMING	0 TO 40			X		X	
EQA	AFT NOZZLE QUENCH	0 TO 10			X		X	
EQF	FORWARD TT QUENCH	0 TO 10			X**		X	
ERCV-1	RC COMMAND VOLTAGE	-30 TO 30			X		X	
ERDB	RUPTURE DISC BREAKWR	0 TO 1000			X			
ES-2	INJ VALVE #2 COMMAND	0 TO 10			X		X	
ES-4	INJ VALVE #4 COMMAND	0 TO 10			X		X	
ETSTT-1	TT PORT #1	0 TO 1000			X	X		
ETSTT-2	TT PORT #2	0 TO 1000			X	X		
ETSTT-3	TT PORT #3	0 TO 1000			X	X		
ETSTT-4	TT PORT #4	0 TO 1000			X	X		
ETSTT-5	TT PORT #5	0 TO 1000			X	X		
ETSTT-6	TT PORT #6	0 TO 1000			X	X		
ETTPS	LAUNCH LIMIT SWITCH	0 TO 10			X		X	

TABLE II (Continued)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL SYSTEM*	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	FORCE	LBF		LBF				
FY-1	AXIAL THRUST	-10000 TO 50000	STRAIN GAGE	100K TO 100K	X		X	X
FY-2	AXIAL THRUST	-10000 TO 50000	STRAIN GAGE	100K TO 100K	X			
FY-3F	AXIAL THRUST (FILT)	-5000 TO 5000	STRAIN GAGE	-100 TO 100	X	X		
FY-5	AXIAL THRUST	-10000 TO 50000	STRAIN GAGE	100K TO 100K		X		
FZA-1	AFT YAW	-1600 TO 1600	STRAIN GAGE	6K TO 6K	X		X	
FZA-2	AFT YAW	-1600 TO 1600	STRAIN GAGE	6K TO 6K	X			
FZA-3	AFT YAW	-1600 TO 1600	STRAIN GAGE	6K TO 6K		X		
FZF-1	FORWARD YAW	-500 TO 500	STRAIN GAGE	6K TO 6K	X		X	
FZF-2	FORWARD YAW	-500 TO 500	STRAIN GAGE	6K TO 6K	X			
FZF-3	FORWARD YAW	-500 TO 500	STRAIN GAGE	6K TO 6K		X		
	EVENT-CURRENT	AMPS						
IFS-1	MAIN MOTOR IGNITION	0 TO 5			X	X	X	
IFS-2	MAIN MOTOR IGNITION	0 TO 5			X		X	
IFS-3	LITVC IGNITION	0 TO 5			X		X	
IFS-4	LITVC IGNITION	0 TO 5			X		X	
IFS-5	ROLL CONTROL IGNIT.	0 TO 5			X		X	
IFS-6	ROLL CONTROL IGNIT.	0 TO 5			X		X	
IFS-9	AOTT IGNITION	0 TO 25			X	X	X	
IFS-10	AOTT IGNITION	0 TO 25			X		X	
IRCV-1	RC VALVE #1 COMMAND	0 TO 1.5			X**		X	
	POSITION	V DC		V DC				
LINJ-2	PINTLE VALVE #2	- 10 TO 0	LVDT	- 10 TO 0	X		X	
LINJ-4	PINTLE VALVE #4	- 10 TO 0	LVDT	- 10 TO 0	X		X	
LRCV-1	RC VALVE	-4.5 TO 4.5	LVDT	0 TO 8	X**		X	
	PRESSURE	PSIA		PSIA				
PA-1	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X		X	X
PA-2	TEST CELL	0 TO 1	STRAIN GAGE	0 TO 1	X			
PA-5	TEST CELL	0 TO 15	STRAIN GAGE	0 TO 15	X			
PC-1	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 750	X	X	X	
PC-1F	MOTOR CHAMBER (FILT)	- 25 TO 25	STRAIN GAGE	0 TO 750		X		
PC-2	MOTOR CHAMBER	0 TO 750	STRAIN GAGE	0 TO 1000	X**	X	X	X
PDF	GN2 DIF ORIFICE	-100 TO 100	STRAIN GAGE	-100 TO 100	X			
PFDA-1	FORWARD DOME AREA	0 TO 10	STRAIN GAGE	0 TO 10	X		X	X
PFDA-2	FORWARD DOME AREA	0 TO 25	STRAIN GAGE	0 TO 25	X	X		
PI-I	IGNITER	0 TO 3000	STRAIN GAGE	0 TO 3000	X**	X	X	
PMI-4	MANIFOLD INJECTANT	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	
PNS	GN2 SUPPLY	0 TO 500	STRAIN GAGE	0 TO 500	X			
POA	AFT NUZZLE QUENCH	0 TO 200	STRAIN GAGE	0 TO 200	X			

TABLE II (Concluded)

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	PRESSURE	PSIA		PSIA				
PQF	FORWARD TT QUENCH	0 TO 200	STRAIN GAGE	0 TO 200	X			
PRCGG	ROLL CONTROL GAS GEN	0 TO 1500	STRAIN GAGE	0 TO 1500	X		X	
PREG	REGULATED HELIUM	0 TO 1000	STRAIN GAGE	0 TO 1000	X		X	X
	TEMPERATURE	DEG. F		DEG. F				
TA-1	AMBIENT TEST CELL	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TA-2	AMBIENT TEST CELL	0 TO 500	C/A, TYPE K	-300 TO 2500	X			
TA-5	AMBIENT CELL	0 TO 200	C/A, TYPE K	-300 TO 2500	X			
TF-1	FORWARD GN2 FLOW LN	0 TO 200	C/A, TYPE K	-300 TO 2500	X			
TP-1	PROPELLANT GRAIN	0 TO 100	C/A, TYPE K	-300 TO 2500				X
TP-2	PROPELLANT GRAIN	0 TO 350	C/A, TYPE K	-300 TO 2500	X			
TRC-3	ROLL CONTROL GAS GEN	0 TO 200	C/A, TYPE K	-300 TO 2500	X		X	

*BASIC SAMPLING RATE 100 SAMPLES/SEC
**PARAMETER SUPERCOMMUTATED TO 1000 SAMPLES/SEC

TABLE III
NOZZLE MEASUREMENTS

Prefire Nozzle Measurements

Degrees	Throat Diameter, in.	Exit Diameter, in. (0.25 in. upstream of exit)
0	6.878	33.309
30	6.877	33.309
60	6.875	33.310
90	6.877	33.309
120	6.878	33.313
150	6.877	33.314
Average, in.	6.877	33.311
Area, sq in.	37.144	871.480
TCC-supplied area, sq in.	37.100	-

Postfire Nozzle Measurements

Degrees	Throat Diameter, in.	Exit Diameter, in. (0.25 in. upstream of exit)
0	6.815	33.435
30	6.870	33.520
60	6.902	33.425
90	6.865	33.535
120	6.835	33.000
150	6.834	33.050
Average, in.	6.854	33.328
Area, sq in.	36.896	872.385
Percent Change in Area (AEDC Measurements)	-0.7	+0.1

TABLE IV
MOTOR TEMPERATURE-CONDITIONING HISTORY

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
2/26/73	63	61	Rocket Preparation Area	46	42	Motor received at Rocket Preparation Area at 1050 hours
2/27/73	65	62		42	28	
2/28/73	74	64		28	24	
3/1/73	73	70		33	26	Motor moved to test cell at 1945 hours, exposed to ambient temperature of 52°F for 30 minutes
3/2/73	72	71	Test Cell	63	40	
3/3/73	68	75		68	53	
3/4/73	71	69		68	60	
3/5/73	70	68		70	63	Motor fired at 1647 hours, propellant temperature 71°F

TABLE V
COMPARISON OF LGM-30G STAGE III PQA MOTORS FIRED AT AEDC

Motor Number	AEDC TR Number	Date Fired	Grain Temp, °F	Ignition Delay, msec	Maximum Igniter Pressure, psia	Action Time, sec	Thrust[1] Maximum, lbf	Thrust[1] Average, lbf	Pressure Maximum, psia	Pressure Average, psia	Pressure At Thrust Termination	Total Impulse,[1] lbf-sec	Specific[1,2] Impulse, lbf-sec/lbm	Thrust Termination Delay, msec	Thrust Termination Interval, msec	LITVC Yaw Angle 3 to 4 sec, deg
PQA-1	71-240	8-14-71	70	86	2227	59.43	43,147	34,979	852	529	79.8	2,078,805	284.53	403	70	2.20
PQA-2	71-246	0-19-71	71	82	2397	59.01	43,761	35,287	652	526	74.4	2,081,204	284.52	403	52	2.13
PQA-3	71-251	8-28-71	69	04	2246	60.23	42,957	34,492	645	517	79.7	2,077,452	284.41	403	1243	2.20
PQA 4	71-253	8 9 71	69	83	2119	59.82	43,370	34,763	651	521	75.7	2,079,547	284.33	402	18	2 18
PQA-5	71-269	9-30-71	73	86	2121	59.28	43,392	35,008	648	523	76 0	2,075,281	284.18	420	35	2.21
PQA-6[3]	71-275	11-3-71	70	87	2141	---	43,346	38,605	648	580	585.4	1,386,818	284.82	420	157	2.20
PQA-7	72-49	1 25-72	71	88	2245	62.70	41,233	33,103	619	496	75.3	2,075,555	284.28	420	10	2.20
PQA-8	72-77	3-21-72	71	89	2127	60.74	42,080	34,205	831	513	75.2	2,077,596	284.43	438	17	0.32[5]
PQA-9	72-105	5-15-72	71	88	2327	58.17	43,800	35,723	636	535	74.9	2,077,980	284.31	420[4]	18	2.06
PQA-10	72-152	6-28-72	70	85	2148	58.34	44,473	35,644	666	535	73.5	2,879,457	284.41	437	18	2.12
PQA-11	72-177	8 23 72	72	84	2407	50.05	44,421	35,813	665	537	70.5	2,078,955	284.55	455	17	2.12
PQA-12	73-7	10 17 72	72	89	2353	58.40	44,245	35,542	665	533	75.0	2,075,662	284.41	480	20	2.18
PQA-101	73-43	11-17-72	71	84	2246	57 61	44,362	36,084	871	544	74.7	2,078,776	284.24	460	30	2.15
PQA-102	73-76	1-28-73	71	86	2354	60.18	42,925	34,622	643	519	75.3	2,083,334	284.94	403	80	2.12
PQA-103	73-82	3 5 73	71	80	2027	59.93	43,675	34,759	652	520	75.3	2,083,103	284.96	402	53	2.19

[1] Thrust vector control system axial augmentation removed and vacuum correction added

[2] Calculated using total propellant weight

[3] PQA-6 thrust terminated at 35.40 sec, specific impulse calculated using a calculated expended propellant weight

[4] Functioning time of two thrust termination ports not recorded because of an instrumentation anomaly

[5] Thrust vector control yaw angle below specification because the slam supressor pin failed to shear

TABLE VI
SUMMARY OF MOTOR PERFORMANCE

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
GENERAL INFORMATION			
MOTOR S/N *	PQA103 30207		
MODEL NUMBER *	SR73AJ-1		
TYPE FIRING	ALTITUDE		
DATE FIRED	03-05-73		
DATE MANUFACTURED *	11-19-72		
TOTAL MOTOR WEIGHT (PREFIRE), LBM *	8052.8		8069.1
CASE PROPELLANT WEIGHT, LBM *	7310.1		
TOTAL PROPELLANT WEIGHT (WPT), LBM *	7310.1	7291.9	
PROPELLANT SLIVER WEIGHT, LBM *	8.0		
EXPENDED PROPELLANT WEIGHT (WP), LBM	7302.1	7277.6	7314.0
PREFIRE NOZZLE THROAT AREA (TCC), SQ. IN.	37.100		
PREFIRE NOZZLE THROAT AREA (AEDC), SQ. IN.	37.144		
AVERAGE NOZZLE THROAT AREA, SQ. IN. **	38.105		
POST FIRE NOZZLE THROAT AREA (AEDC), SQ. IN.	38.896		
PREFIRE NOZZLE EXIT AREA (AEDC), SQ. IN.	878.014		
POSTFIRE NOZZLE EXIT AREA (AEDC), SQ. IN.	895.924		
PREFIRE PROPELLANT GRAIN TEMPERATURE, DEGREES F.	71	65	75
AMBIENT PRESSURE PRIOR TO FIRING, PSIA	0.150		
RELATIVE HUMIDITY PRIOR TO TEST CELL EVACUATION, PERCENT	68		
TEST CELL PERFORMANCE			
ALTITUDE			
AT PRESSURANT SQUIB IGNITION, FT.	102000		
AT MOTOR IGNITION, FT	101000	100000	
AT THRUST TERMINATION, FT	99000		
AVERAGE, FT	92000	60000	
PRESSURE			
AVERAGE, PSIA	0.236		
INTEGRAL, PSIA-SEC.	14.133		
BALLISTIC PERFORMANCE			
TIME			
IGNITER IGNITION DELAY (TO 1000 PSIA), MSEC.	22		43
IGNITER IGNITION INTERVAL, MSEC.	147		
IGNITION DELAY, MSEC	89		200
AT MAXIMUM CHAMBER PRESSURE, SEC.	22.650		
AT MAXIMUM VACUUM AXIAL THRUST, SEC.	22.200		
ACTION (75 PSIA CHAMBER PRESSURE), SEC.	59.930	57.53	62.53
THRUST TERMINATION (TT), SEC.	59.930		
THRUST TERMINATION FUNCTIONING, MICROSEC.			
STACK 1	420	219	705
STACK 2	420	219	705
STACK 3	438	219	705
STACK 4	455	219	705
STACK 5	402	219	705
STACK 6	420	219	705
THRUST TERMINATION INTERVAL, MICROSEC.	53		

TABLE VI (Concluded)

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
PRESSURE			
MAXIMUM IGNITER, PSIA	2027		2483
AVERAGE IGNITER, PSIA	1746	1560	1950
INTEGRAL OF IGNITER, PSIA-SEC.	258.4	225	314
MAXIMUM CHAMBER RISE RATE, PSIA/SEC.	7138		
MAXIMUM MOTOR CHAMBER, PSIA	652		
AVERAGE MOTOR CHAMBER, PSIA	520		
MOTOR CHAMBER INTEGRAL, PSIA-SEC.	31143		
INTEGRAL OF MOTOR CHAMBER RAISED TO 0.30 POWER, PSIA-SEC.	388		
MOTOR CHAMBER AT TT TIME, PSIA	75.3	70	80
MAXIMUM FORWARD DOME CAVITY BETWEEN TT AND TT+2 SEC., PSID	0.529		
AXIAL THRUST			
MAXIMUM MEASURED FORCE, LBF	43408		
MAXIMUM AUGMENTED VACUUM, LBF	43629		
MAXIMUM UNAUGMENTED VACUUM, LBF	43675		
AVERAGE MEASURED FORCE, LBF	34567		
AVERAGE AUGMENTED VACUUM, LBF	34776		
AVERAGE UNAUGMENTED VACUUM, LBF	34764		
IMPULSE			
MEASURED TOTAL, LBF-SEC.	2071614		
VACUUM TOTAL			
INCLUDING AUGMENTATION, LBF-SEC	2084154		
EXCLUDING AUGMENTATION, LBF-SEC.	2083430		
AUGMENTED VACUUM SPECIFIC			
OPTION 1 (USING WPC), LBF-SEC./LBM	284.45		
OPTION 2 (USING WP), LBF-SEC./LBM	285.42		
UNAUGMENTED VACUUM SPECIFIC			
OPTION 1 (USING WPC), LBF-SEC./LBM	284.35		
OPTION 2 (USING WP), LBF-SEC./LBM	285.32		
OPTION 3 (USING WPT), LBF-SEC./LBM	285.01	283.1	286.1
PROPELLANT FLOW RATE /			
AVERAGE (USING WDOTPC), LBM/SEC.	122.26		
INTEGRAL (USING WDOTPC), LBM	7327.0		
AVERAGE (USING WDOTP), LBM/SEC.	121.98		
INTEGRAL (USING WDOTP), LBM	7310.1		
MISCELLANEOUS			
RATIO OF SPECIFIC HEAT (GAMMA) *	1.20		
CHARACTERISTIC EXHAUST VELOCITY, FT./SEC.	5212.0		
LIQUID INJECTION THRUST VECTOR CONTROL PERFORMANCE			
TIME			
TVC DELAY, SEC.	1.368	1.0	1.6
PRESSURE			
DURING INJECTION SURGE, PSIA	721		1875
AVERAGE INJECTION PRESSURE FOR 130 MILLISEC AFTER TVC DELAY, PSIA	669		1500
MAXIMUM INJECTANT DURING ZERO FLOW, PSIA	694		735
MINIMUM INJECTANT DURING ZERO FLOW, PSIA	673	655	
ROLL CONTROL PERFORMANCE			
ACTION TIME, SEC.	74.900		
GAS GENERATOR PRESSURE AT 13.6 SEC., PSIA	999		
GAS GENERATOR PRESSURE AT 60. SEC., PSIA	755		
MAXIMUM GAS GENERATOR PRESSURE, PSIA	1294		

* FROM MOTOR LOG BOOK
**BASED ON TCC SUPPLIED TABLE

TABLE VII
ROLL CONTROL VALVE DUTY CYCLE

Time (sec)	Valve Position
0 to 4.0	Null
4.0 to 7.0	Cw
7.0 to 8.0	10 Hz, null to Cw to null
8.0 to 9.0	10 Hz, null to Ccw to null
9.0 to 10.0	10 Hz, Cw to Ccw to Cw
10.0 to 13.0	Ccw
13.0 to 16.0	Null
16.0 to 19.0	5 Hz, null to Cw to null
19.0 to 22.0	5 Hz, null to Ccw to null
22.0 to 25.0	5 Hz, Cw to Ccw to Cw
25.0 to 28.0	Cw
28.0 to 31.0	Ccw
31.0 to 34.0	Null
34.0 to 37.0	10 Hz, null to Cw to null
37.0 to 40.0	10 Hz, null to Ccw to null
40.0 to 43.0	10 Hz, Cw to Ccw to Cw
43.0 to 46.0	Cw
46.0 to 49.0	Ccw
49.0 to 52.0	Null
52.0 to 55.0	20 Hz, null to Cw to null
55.0 to 58.0	20 Hz, null to Ccw to null
58.0 to 61.0	20 Hz, Cw to Ccw to Cw
61.0 to 64.0	Cw
64.0 to 67.0	Ccw
67.0 to 70.0	Null
70.0 to End	Cw

TABLE VIII
ROLL CONTROL SYSTEM PERFORMANCE SUMMARY

GENERAL

TEST NO.	05
DATE FIRED	03-05-73
MOTOR S/N	PQA-103 (30207)
ROLL CONTROL ASSEMBLY S/N	1000373
TEST CONFIGURATION	ON MOTOR
ALTITUDE AT GAS GENERATOR IGNITION, FT	102,000
SYSTEM TEMP. AT GAS GENERATOR IGNITION, DEG F	71

TIMES	ACTUAL	MAXIMUM SPECIFICATION
MAXIMUM VALVE RESPONSE MSEC		
ROLL MOMENT BUILDUP		
5 HZ CW-NULL-CW	26	38
5 HZ CCW-NULL-CCW	23	38
10 HZ CW-NULL-CW	27	38
10 HZ CCW-NULL-CCW	23	38
ROLL MOMENT DECAY		
5 HZ CW-NULL-CW	19	20
5 HZ CCW-NULL-CCW	15	20
10 HZ CW-NULL-CW	19	20
10 HZ CCW-NULL-CCW	15	20
ROLL MOMENT HALF CYCLE		
5 HZ CW-NULL-CW	45	50
5 HZ CCW-NULL-CCW	38	50
10 HZ CW-NULL-CW	46	50
10 HZ CCW-NULL-CCW	38	50
ROLL MOMENT REVERSAL		
5 HZ CW-CCW-CW	32	39
10 HZ CW-CCW-CW	32	39
NULL DWELL		
5 HZ CW-NULL-CW	97	100
5 HZ CCW-NULL-CCW	97	100
10 HZ CW-NULL-CW	47	50
10 HZ CCW-NULL-CCW	47	50
COMMAND DWELL		
5 HZ CW-NULL-CW	98	100
5 HZ CCW-NULL-CCW	98	100
10 HZ CW-NULL-CW	47	50
10 HZ CCW-NULL-CCW	48	50
5 HZ CW-CCW-CW	97	100
10 HZ CW-CCW-CW	48	50

TABLE IX
THRUST VECTOR CONTROL DUTY CYCLE

Injector	Accumulated Firing Time, sec	Nominal Flow Rate, lbm/sec*
2	3 to 4	10.0
2	20 to 21	2.0
4	21 to 22	1.0
2	76 to 96	1.0

*Strontium Perchlorate

TABLE X
THRUST VECTOR CONTROL PERFORMANCE SUMMARY

NOMINAL TIME, SEC	3-4	20-21	21-22
START TIME (CALC)	3.300	20.220	21.220
STOP TIME (CALC)	3.900	20.900	21.900
INJECTOR NUMBER	2	2	4
SPECIFIED FLOW RATE, LBM/SEC	10.0	2.0	1.0
ACTUAL FLOW RATE, LBM/SEC	10.9	2.02	0.97
PINTLE POSITION, MILLIINCHES	151.36	14.44	7.02
PINTLE PRESSURE, PSIA	521.	663.	677.
PROPELLANT FLOW RATE, LBM/SEC	103	152	152
INJECTOR-TO-PROPELLANT FLOW RATE RATIO	0.106	0.013	0.006
RESULTANT YAW FORCE, LBF	1100.	433.8	259.6
UNAUGMENTED VACUUM AXIAL THRUST, LBF	28914	43419	43494
YAW-TO-AXIAL FORCE RATIO	0.0380	0.0100	0.0060
JET DEFLECTION ANGLE, DEG	2.18	0.57	0.34
RESULTANT YAW FORCE INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	101	215	267
AXIAL-THRUST AUGMENTATION, LBF	434.	169.5	109.2
PERCENT AXIAL-THRUST AUGMENTATION	1.50	0.39	0.25
AXIAL-THRUST AUGMENTATION INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	39.8	84.1	112.3

APPENDIX III
INSTRUMENTATION CALIBRATIONS

Axial-Force System

The axial-force load cell is physically calibrated in the AEDC calibration laboratory before installation in the force-measuring system. An in-place, binary-step, deadweight calibrator (permanently installed and independently grounded) is used to stimulate the force-measuring system with known physical forces. The calibrator is used before a motor firing to provide an end-to-end, in-place, multiple-step deadweight calibration of the sensing, signal conditioning, and recording systems for each of the redundant axial-force measurements. The calibrator is capable of producing forces in 1000-lbf increments from 0 to 127,000 lbf. Certification is periodically conducted to determine the magnitude of the force being produced by the calibrator at various levels within its operating range and to provide traceability to the National Bureau of Standards (NBS). The uncertainty of the certification is ±0.030 percent of full scale. Estimated uncertainty of the axial-force measuring system at discrete thrust levels has been determined to be ±0.13 percent for data obtained with the digital system.

Pressure Transducers and Yaw-Force Load Cells

These instruments were physically calibrated in the AEDC calibration laboratory before installation by direct load applications. The instrumentation recording systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions using a resistance shunting method to simulate the transducer output.

Operational Pressure Transducers (OPT)

These instruments were laboratory calibrated by TCC before installation on the motor. The calibrations were transmitted to AEDC with the motor. The operational pressure transducer incorporates a one-step internal calibration shunt which produces an electrical output signal simulating a known pressure level. This signal is used to calibrate the instrumentation recording systems both at ambient and pressure altitude conditions.

Temperatures

The thermocouples were fabricated from standard thermocouple wire, the electromotive force output of which is traceable to the NBS through the wire manufacturer. The thermocouples were connected directly to a 150°F reference temperature junction and the NBS standard temperature/voltage relationships were used for conversion to engineering units. The temperature instrumentation systems were calibrated at ambient conditions and, subsequently, at pressure altitude conditions by the voltage substitution method which simulated a known input signal.

Accelerations

The accelerometers were calibrated in the AEDC calibration laboratory using an eccentric mass vibrator before installation. The recording system was calibrated by the frequency/voltage substitution technique.

Liquid-Injection Thrust Vector Control System

Relationships between injector valve pintle position transducer feedback voltage and injectant flow rate at specific supply pressure and injectant specific gravity were provided by TCC for each valve. Calibrations at AEDC consisted of a determination of the relationship between injector valve pintle position (measured physically with a dial indicator), pintle position transducer feedback voltage, and command voltage for the particular test installation. Because the pintle position transducer feedback was measured after conditioning by the AEDC system, the magnitude obtained during the AEDC calibrations was different from those provided with the TCC-supplied injector valve calibrations which presented valve position transducer feedback voltage directly. Therefore, it was necessary to establish a relationship between AEDC feedback voltage at the fully closed and fully opened positions of the valve, and linearly interpolating to obtain intermediate points. In this manner the TCC-supplied flow rate calibration data, presented as a function of valve calibration feedback voltage, were converted to flow rate versus AEDC feedback voltage for each valve (Table III-1). The instrumentation system used to record valve feedback voltage during firing was calibrated by the voltage substitution method.

TABLE III-1
INJECTOR CALIBRATION

INJECTOR SERIAL NO. HSD0019 MOTOR NO. PQA-103

INJECTOR LOCATION 90 DEGREES

PINTLE POSITION (MILLI-INCHES)	CALIBRATION VOLTAGE (MANUF)	FEEDBACK VOLTAGE (AEDC)	FLOW RATE MIL-H-5606 (GPM)	FLOW RATE MIL-H-5606 (LB/SEC)	FLOW RATE STRONTIUM (LB/SEC)	CALIBRATION SUPPLY PRESSURE (PSIA)
0.0	0.0	-0.160	0.0	0.0	0.0	645.
2.2	0.100	-0.272	1.80	0.21	0.31	644.
4.4	0.200	-0.383	3.30	0.39	0.57	643.
6.6	0.300	-0.495	5.10	0.60	0.89	641.
7.4	0.338	-0.537	5.76	0.68	1.00	640.
8.8	0.400	-0.606	6.80	0.80	1.18	639.
11.0	0.500	-0.718	8.50	1.00	1.48	636.
13.2	0.600	-0.830	10.10	1.19	1.75	632.
14.9	0.680	-0.919	11.51	1.35	2.00	632.
15.4	0.700	-0.941	11.80	1.39	2.05	632.
17.5	0.800	-1.053	13.40	1.57	2.33	632.
19.7	0.900	-1.164	15.00	1.76	2.61	627.
21.9	1.000	-1.276	16.70	1.96	2.90	626.
32.9	1.500	-1.834	22.60	2.66	3.93	616.
43.9	2.000	-2.392	30.40	3.57	5.28	601.
54.8	2.500	-2.950	36.00	4.23	6.25	587.
65.8	3.000	-3.507	40.40	4.75	7.02	575.
76.8	3.500	-4.065	44.30	5.21	7.69	566.
87.7	4.000	-4.623	48.40	5.69	8.41	559.
98.7	4.500	-5.181	51.40	6.04	8.93	543.
109.6	5.000	-5.739	54.00	6.34	9.38	535.
120.6	5.500	-6.297	56.90	6.69	9.88	524.
124.6	5.680	-6.498	57.57	6.76	10.00	523.
131.6	6.000	-6.855	59.60	7.00	10.35	518.
153.5	7.000	-7.971	63.00	7.40	10.94	502.
175.4	8.000	-9.086	65.70	7.72	11.41	493.
197.4	9.000	-10.202	68.40	8.04	11.88	483.
219.3	10.000	-11.318	70.40	8.27	12.23	473.
241.2	11.000	-12.434	71.60	8.41	12.44	473.
250.0	11.400	-12.880	71.80	8.44	12.47	473.

CALIBRATION TEMPERATURE 100 DEG F.
CALIBRATION FLUID SPECIFIC GRAVITY 0.8450
TEST FLUID SPECIFIC GRAVITY 1.850

TABLE III-1 (Concluded)

INJECTOR SERIAL NO. HSD0137 MOTOR NO. PQA-103

INJECTOR LOCATION 270 DEGREES

PINTLE POSITION (MILLI-INCHES)	CALIBRATION VOLTAGE (MANUF)	FEEDBACK VOLTAGE (AEDC)	FLOW RATE MIL-H-5606 (GPM)	FLOW RATE MIL-H-5606 (LB/SEC)	FLOW RATE STRONTIUM (LB/SEC)	CALIBRATION SUPPLY PRESSURE (PSIA)
0.0	0.0	-0.184	0.0	0.0	0.0	646.
2.2	0.100	-0.294	1.70	0.20	0.30	646.
4.3	0.200	-0.404	3.30	0.39	0.57	643.
6.5	0.300	-0.513	5.10	0.60	0.89	643.
7.4	0.340	-0.557	5.76	0.68	1.00	641.
8.7	0.400	-0.623	6.80	0.80	1.18	639.
10.9	0.500	-0.732	8.50	1.00	1.48	638.
13.0	0.600	-0.842	10.20	1.20	1.77	635.
14.9	0.686	-0.936	11.51	1.35	2.00	634.
15.2	0.700	-0.952	11.70	1.37	2.03	633.
17.4	0.800	-1.061	13.40	1.57	2.33	633.
19.6	0.900	-1.171	15.10	1.77	2.62	632.
21.7	1.000	-1.280	16.60	1.95	2.88	629.
32.6	1.500	-1.829	24.20	2.84	4.20	612.
43.5	2.000	-2.377	31.00	3.64	5.38	601.
54.3	2.500	-2.925	36.40	4.28	6.32	591.
65.2	3.000	-3.473	41.00	4.82	7.12	578.
76.1	3.500	-4.021	45.40	5.33	7.89	567.
87.0	4.000	-4.569	49.00	5.76	8.51	555.
97.8	4.500	-5.117	52.10	6.12	9.05	545.
108.7	5.000	-5.665	55.00	6.46	9.55	535.
119.6	5.500	-6.213	57.50	6.76	9.99	530.
119.8	5.510	-6.224	57.57	6.76	10.00	529.
130.4	6.000	-6.761	59.80	7.03	10.39	518.
152.2	7.000	-7.857	63.10	7.41	10.96	506.
173.9	8.000	-8.953	65.80	7.73	11.43	496.
195.7	9.000	-10.050	68.10	8.00	11.83	489.
217.4	10.000	-11.146	70.00	8.22	12.16	482.
239.1	11.000	-12.242	71.00	8.34	12.33	477.
250.0	11.500	-12.790	71.50	8.40	12.42	477.

CALIBRATION TEMPERATURE 100 DEG F.
CALIBRATION FLUID SPECIFIC GRAVITY 0.8450
TEST FLUID SPECIFIC GRAVITY 1.850

APPENDIX IV
UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS

1.0 INTRODUCTION

The rationale for the estimated instrument system uncertainties contained in Table IV-1 is provided in this appendix. The general approach taken in the analysis, the definition of terms, and the specific evaluation of each system are presented.

2.0 METHODOLOGY

The approach taken in this analysis follows the methodology established by the ARO Standard Test Data Measurement Uncertainty (ARO-ENGR-STD-T-4, February 1972). A review of the basic concepts and terminology is given in the following paragraphs in order to provide a better understanding of individual evaluations of the J-5 instrument systems.

The uncertainty of a measurement is defined to be the maximum difference reasonably expected between a measured value and the true value. Measurement errors have two components: fixed errors and random errors. A random error results from variations between repeated measurements and is called the precision error. The statistic, s, is an estimate of the standard deviation of a population and is called the precision index. It is calculated to estimate the precision error. The precision index is

$$s = \sqrt{\frac{\sum_{i}^{N} (x_i - \bar{x})^2}{(N - 1)}} \tag{1}$$

where

N is the number of measurements

$\bar{x}$ is the average value of the measurement

x_i is the individual measurement

The second component of a measurement error is the constant or systematic error and is known as the bias. Each measurement of repeated measurements has the same bias. Large known biases are eliminated by calibrating the instrument, i.e., comparing the instrument to a standard and obtaining a correction. Small known biases may or may not be accounted for, depending upon the significance of the bias and the difficulty of correcting for the bias. Unknown biases are not correctable. Generally, the estimate of the limit for a bias is based upon judgment and experience.

In order to establish a single number for expressing a reasonable limit for the error of a measurement, some combination of bias and precision is required. It is recognized that it is impossible to define a rigorous statistic because the bias is an upper limit based upon judgment. The uncertainty U is established as that single number for stating an error. The uncertainty is centered about the measurement and is defined as

$$U = \pm(B + t_{0.95}\, S) \qquad (2)$$

where

- B is the estimated bias limit
- S is the precision index
- t is the 95th-percentile point for the two-tailed students "t" distribution

The "t" value is a function of the number of degrees of freedom (d.f.). For 30 or more degrees of freedom, a t value of 2 is assumed.

The uncertainty is an arbitrary substitute for a statistical confidence interval and can best be interpreted as the largest error to be expected. The coverage of U is greater than 95 percent under reasonable assumptions of the distribution of the bias.

In general, the errors in a measurement process originate from a multitude of different sources. The uncertainty of a total measurement can be established by two approaches:

(a) Determining the elemental error sources in the process and appropriately combining the errors and

(b) Determining the error of the complete system by comparison with a standard.

Since the error of a measurement process is the result of elemental error sources, a methodology for combining elemental errors is required in order to arrive at the total uncertainty U.

The bias limit B in equation (2) is calculated as

$$B = \sqrt{b_1^2 + b_2^2 + b_3^2 \text{----} b_n^2} \qquad (3)$$

where

- b_n is the n elemental error source

The above approach is taken because it is unreasonable to assume the unknown bias limits b_n are cumulative.

The precision error S in Equation (2) is

$$S = \sqrt{s_1^2 + S_2^2 + S_3^2 \cdots s_n^2} \tag{4}$$

where

s_n is the precision error in the n elemental source

The degress of freedom for S may be found by use of the Welch-Satterthwaite formula as follows:

$$d.f. = \frac{(s_1^2 + s_2^2 + s_3^2 \cdots s_n^2)^2}{\frac{s_1^4}{df_1} + \frac{s_2^4}{df_2} + \frac{s_3^4}{df_3} \cdots \frac{s_n^4}{df_n}} \tag{5}$$

The establishment of the d.f. for S makes it possible to define the precision error of subsequent measurement processes or analyses.

The uncertainties of the J-5 instrument systems are tabulated in Table IV-1.

TABLE IV-1
ESTIMATED TOTAL UNCERTAINTY (±2 SIGMA LIMITS) OF INSTRUMENT SYSTEMS USED IN DETERMINING MOTOR PERFORMANCE

	Uncertainty, percent, full scale
Pressure Measurements[1]	± 0.44
Temperature Measurements (Thermocouples, C/A)	± 0.47
Accelerations	±14.2
Axial-Force Measurements	± 0.13
Side-Force Measurements	± 0.45

[1]Uncertainty calculated for AEDC-supplied transducers only.

APPENDIX V
METHODS OF CALCULATION

The following recorded parameters were used for the calculations:

FY-1, FY-2	Measured axial force, lbf
FZA-1, FZA-2	Measured aft yaw force, lbf
FZF-1, FZF-2	Measured forward yaw force, lbf
LINJ-2, LINJ-4	Measured injector position feedback, vdc
PA-1, PA-2	Measured test cell pressure, psia
PC-1, PC-2	Measured motor chamber pressure, psia
PMI-4	Measured injectant manifold pressure

The following input constants were used:

ATI	Prefire nozzle throat area, sq in. = 37.100
C*	Characteristic exhaust velocity, ft/sec = 5212
DI	Prefire nozzle exit diameter, in. (see Table III)
EAC	Nozzle exit area erosion factor based on measured prefire and postfire areas from the Qualification Program = 1.204
SPG CAL	Specific gravity of calibration fluid = 0.845
SPG TEST	Specific gravity of injectant fluid = 1.850
WPT	Manufacturer's stated total propellant mass, lbm = 7310.1

A table of nozzle static pressure at the injector exit (PNE) versus injectant flow rate was provided by TCC.

Injectant Flow Rate, lbm/sec	PNE, psia
0	8.6
0.5	9.8
1.0	10.7
1.5	11.5
2.0	12.3
2.5	12.9
3.0	13.5
3.5	14.0
4.0	14.5
4.5	14.9
5.0	15.4
6.0	16.2
7.0	16.9
8.0	17.6
9.0	18.2
10.0	18.8
11.0	19.4
12.0	19.9
13.0	20.4
14.0	20.9

An input table was supplied by TCC to correct the nozzle throat area for the effects of erosion during motor operation. Nozzle throat areas versus time are as follows:

Time, sec	ATC, sq in.
0.0	37.100
0.2	37.170
0.4	37.238
0.6	37.308
0.8	37.377
1.0	37.443
1.5	37.618
2.0	37.704
3.0	37.795
4.0	37.861
5.0	37.914
6.0	37.956
7.0	37.994
8.0	38.024
9.0	38.044
10.0	38.065

Time, sec	ATC, sq in.
12.0	38.093
14.0	38.107
16.0	38.120
18.0	38.129
20.0	38.133
25.0	38.134
30.0	38.136
35.0	38.144
40.0	38.170
45.0	38.195
50.0	38.221
55.0	38.246
60.0	38.272
65.0	38.272

The following parameters were calculated from recorded data:

1. FA = Average measured axial thrust (parameters FY-1 and FY-2), lbf

2. PO = Average chamber pressure (parameters PC-1 and PC-2), psia

3. PALT = Average test cell pressure (parameters PA-1 and PA-2), psia

4. FTSM = Measured axial thrust smoothed by nine-point weighted average, lbf

$$FTSM_i = (FA_{(i-4)} + 2FA_{(i-3)} + 3FA_{(i-2)} + 4FA_{(i-1)} + 5FA_i + 4FA_{(i+1)} + 3FA_{(i+2)} + 2FA_{(i+3)} + FA_{(i+4)})/25$$

5. AEC = Calculated nozzle exit area, sq in.

$$AEC = AEI + (AEF - AEI) \cdot (t_i/TTT)$$

where

$$AEI = \left(\left(\sum_{i=1}^{6} DI_i/6\right) + 0.1247\right)^2 \cdot (0.7854)$$

where

$$AEF = (EAC)\,(AEI)$$

TTT = Thrust termination

6. FTSM VAC = Vacuum-corrected smoothed measured thrust, lbf

FTSM VAC = FTSM + (PALT · AEC)

7. FZAA = Average corrected aft yaw force (parameters FZA-1 and FZA-2), lbf

8. FZFA = Average corrected forward yaw force (parameters FZF-1 and FZF-2), lbf

9. FZR = Resultant corrected yaw force, lbf

FZR = FZAA + FZFA

FZR was then corrected for null level offsets to determine FZRC

10. FPR = Thrust-to-pressure ratio, lbf/psia

FPR = FTSMVAC/PO

11. FUPR = Unaugmented thrust-to-pressure ratio, lbf/psia

FUPR = FPR corrected by straight line interpolation during periods of injection

12. FTSMU VAC = Unaugmented smoothed axial thrust, lbf

FTSMU VAC = (FUPR) · (PO)

13. DELTA FTSM = Thrust augmentation attributable to liquid injection, lbf

DELTA FTSM = FTSM VAC - FTSMU VAC

14. CFVU = Unaugmented vacuum thrust coefficient

CFVU = (FTSMUVAC)/(PO · ATC)

15. WDPTPC = Propellant mass flow rate (Option 1), lbm/sec

WDOTPC = (G · ATC · PO)/C*

16. WDOTP = Propellant mass flow rate (Option 2), lbm/sec

$$WDOTP = (WP \cdot PO \cdot ATC) / \int_{t_o}^{t_A} (PO \cdot ATC)dt$$

where

WP = WPT - 8 (sliver weight, lbm)

t_A = Motor action time

17. WDOT-I = Injectant flow rate, lbm/sec

$$WDOT\text{-}I = WDOT\ CAL \sqrt{\frac{(\Delta P\ TEST) \cdot SPG\ (TEST)}{(\Delta P\ CAL) \cdot SPG\ (CAL)}}$$

where

WDOT CAL = Input table with injectant flow rate

(WDOT CAL) as a function of injector feedback voltage (LINJ-I) and valve calibration differential pressure (ΔP CAL) (Table III-1)

ΔP TEST = (PINJ-I) - PNE

PINJ-4 = PMI-4

PINJ-2 = Surface fit with PINJ-2 as a function of PMI-4 and LINJ-2, supplied by TCC

I = 2 or 4

18. ISPSP = Axial-thrust augmentation injectant specific impulse, lbf-sec/lbm

ISPSP = FZRC/(WDOT-I)

19. RZY = Yaw-to-axial force ratio

RZY = FZRC/FTSMU VAC

20. WDOTR = Injectant-to-propellant flow rate ratio

WDOTR = (WDOT-I)/WDOTP

21. JDA = Thrust vector angle, deg

JDA = ARCTAN (RZY)

22. AAUGISP = Axial-thrust augmentation injectant specific impulse, lbf-sec/lbm

AAUGISP = (DELTA FTSM)/(WDOT-I)

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Arnold Engineering Development Center
Arnold Air Force Station, Tennessee 37389

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
PRODUCTION QUALITY ASSURANCE TESTING OF A THIOKOL MINUTEMAN LGM-30G STAGE III ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE, MOTOR PQA-103

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report - March 5, 1973

This document has been approved for public release its distribution is unlimited. Per TAB #2 dtd 18 Jan, 74

5. AUTHOR(S) (First name, middle initial, last name)
D. E. Franklin and C. H. Kunz, ARO, Inc.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1973	60	6

8a. CONTRACT OR GRANT NO.

b. PROJECT NO

c. Program Element 11213F

d. System 133B

9a. ORIGINATOR'S REPORT NUMBER(S)
AEDC-TR-73-82

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
ARO-ETF-TR-73-35

10. DISTRIBUTION STATEMENT ~~Distribution limited to U.S. Government agencies only; this report contains information on test and evaluation of military hardware; April 1973; other requests for this document must be referred to Space and Missile Systems Organization (MNNPB), Norton AFB, California 92409.~~

11. SUPPLEMENTARY NOTES
Available in DDC

12. SPONSORING MILITARY ACTIVITY
SAMSO (MNNPB)
Norton AFB, California 92409

13. ABSTRACT
An LGM-30G Stage III solid-propellant rocket motor, PQA-103, was fired in Rocket Development Test Cell (J-5), Engine Test Facility (ETF), in support of the Minuteman Stage III Production Quality Assurance Test Program on March 5, 1973. Motor ballistic, liquid-injection thrust vector control system, roll control system, and thrust termination system performance was within model specification requirements. Ignition of the roll control gas generator and the liquid-injection thrust vector control isolation squibs was accomplished, as programmed, 2.5 sec before motor ignition at a pressure altitude of 102,000 ft. The motor was ignited at a pressure altitude of 101,000 ft. Motor ignition delay time was 89 msec. Motor thrust termination occurred at 59.93 sec at a chamber pressure of 75.3 psia. During the 59.93-sec action time the motor produced an unaugmented vacuum total impulse of 2,083,103 lbf-sec. The unaugmented vacuum specific impulse was 284.96 lbf-sec/lbm. Maximum interstage pressure at thrust termination was within specification. Postfire motor structural integrity was satisfactory.

~~Distribution limited to U.S. Government agencies only; this report contains information on test and evaluation of military hardware; April 1973; other requests for this document must be referred to Space and Missile Systems Organization (MNNPB), Norton AFB, California 92409.~~

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Minuteman						
tests (production quality assurance)						
solid-propellant rockets						
altitude simulation						
thrust vector control						
vibration						

AFSC
Arnold AFS Tenn