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PRODUCTION QUALITY ASSURANCE TESTING OF A THIOKOL MINUTEMAN LGM-30G STAGE III ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE, MOTOR PQA-102

D. E. Franklin and C. H. Kunz

ARO, Inc.

April 1973

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NOTICES

PRODUCTION QUALITY ASSURANCE TESTING OF A THIOKOL MINUTEMAN LGM-30G STAGE III ROCKET MOTOR AT SIMULATED PRESSURE ALTITUDE, MOTOR PQA-102

D. E. Franklin and C. H. Kunz
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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 January 26, 1973, under ARO Project No. RA159, and the manuscript was submitted for publication on March 2, 1973. The ARO Project Engineer for this test was Mr. D. E. Franklin.

This technical report has been reviewed and is approved.

CHAUNCEY D. SMITH, JR.
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ABSTRACT

An LGM-30G Stage III solid-propellant rocket motor, PQA-102, 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 January 26, 1973. The roll control subsystem was independently tested off-motor on January 27, 1973. Motor ballistic, roll control system, thrust vector control, and thrust termination system performance was within model specification requirements. The motor was ignited at a pressure altitude of 102,000 ft. Motor ignition delay time was 86 msec. Motor thrust termination occurred at 60.18 sec at a chamber pressure of 75.3 psia. Motor action time was 60.18 sec during which the motor produced an unaugmented vacuum total impulse of 2,083,534 lbf-sec. The unaugmented vacuum specific impulse was 284.94 lbf-sec/lbm. The roll control subsystem structural integrity was satisfactory.

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II. TABLES (Continued)

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 test of motor PQA-102 reported herein is the fourteenth in a series of Minuteman LGM-30G PQA Stage III 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 LITVC system (Fig. 2) used for the static test 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. For this test, the roll control system was removed from the motor and tested independently as a subsystem (Fig. 1c).

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 test 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 January 16, 1973. Significant motor inspection and handling records are presented as follows:

Date	Activity or Item Performed	Remarks
January 16, 1973	Motor arrived at AEDC	
January 16, 1973	Motor off-loaded and visual inspection performed	No visible damge, 70 ± 5°F temperature conditioning initiated
January 16, 1973	Prefire nozzle measurements taken	Results in Table III
January 16, 1973	Removal of RC subsystem from motor PQA-102	

Date	Activity or Item Performed	Remarks
January 17, 1973	Injector valves installed	
January 18, 1973	Interstage volume leak check	Leak check satisfactory
January 24, 1973	Motor transferred to test cell and installed	
January 24, 1973	Safe-and-arm, arm/disarm, and ignition systems check	Systems verified
January 24, 1973	Thrust vector control system leak check (STM-180)	Leak check satisfactory
January 24, 1973	Completed thrust vector control pintle calibrations	
January 26, 1973	Motor fired at 1437 hr	
January 26, 1973	Motor removed from test cell and visual inspection performed. Motor transferred to Rocket Preparation Area	Postfire motor condition satisfactory
January 26, 1973	RC subsystem transferred to test cell and installed for electrical checkout (STM-180) and instrumentation calibration	Checkouts satisfactory
January 27, 1973	RC subsystem fired at 0651 hr	
January 27, 1973	RC subsystem inspected and transferred to Rocket Preparation Area	Postfire condition of RC subsystem satisfactory
January 27, 1973	Postfire motor nozzle measurements taken	Results in Table III
January 27, 1973	RC subsystem reinstalled on motor	
January 31, 1973	Motor and RC subsystem shipped to TCC	

SECTION IV
RESULTS AND DISCUSSION

4.1 GENERAL

The results reported herein were obtained from the firings of an LGM-30G Stage III motor, PQA-102, on January 26, 1973, and off-motor RC subsystem in Rocket Development Test Cell (J-5) on January 27, 1973. This was the fourteenth in 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 for 60 hr prior to the test. The RC subsystem was temperature conditioned in excess of the required 24-hr minimum at 70 ± 5°F. Motor propellant grain temperature at the time of ignition was 71°F; prefire RC subsystem temperature was 70°F. A summary of storage and conditioning temperatures is presented in Table IV.

Data from this test are compared with data from other AEDC 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 pressures are presented in Fig. 4.

4.2.1 Motor Ignition

The motor was successfully ignited at a pressure altitude of 102,000 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 specification limits (Ref. 5) and is summarized in Table VI. A history of igniter pressure during motor ignition is presented in Fig. 5.

Motor ignition delay (defined as the time from application of ignition voltage until 75 percent of the maximum chamber pressure attained during the first second of motor operation) was 86 msec. This was within the maximum specification limit of 200 msec.

4.2.2 Combustion Chamber Pressure

Average combustion chamber pressure during motor action time was 519 psia. The maximum operating chamber pressure achieved during the firing was 643 psia at T + 22.580 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 60.18 sec. This was within the specification limits of 57.53 to 62.53 sec for a motor with a propellant grain temperature of 71°F. Average unaugmented vacuum-corrected thrust during motor action time was 34,622 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 2,071,285 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 0.6 percent of the measured total impulse. The vacuum total impulse during action time, including thrust augmentation, was 2,084,723 lbf-sec. The vacuum total impulse excluding augmentation was 2,083,534 lbf-sec. Unaugmented vacuum specific impulse for this motor, calculated using a total loaded propellant mass of 7312.3 lbm, was 284.94 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 mass of 8.0 lbm, was 285.25 lbf-sec/lbm.

4.2.5 Motor Propellant Flow Rate

Average exhaust gas mass flow rate during action time was 121.5 lbm/sec. The flow rate calculation was performed utilizing Equation 16 presented in Appendix V.

4.3 MOTOR VIBRATION

A history of the vibrations recorded by the standard accelerometer on the igniter boss (AIGN30Y) and the nozzle aft flange (AN30Y) for the first 20 sec of motor operation is presented in Fig. 8. The maximum igniter boss amplitude during this period was 35-g peak at approximately 0.1 sec, and the maximum nozzle aft flange amplitude was 100-g peak at 13.35 sec. The absolute acceleration values indicated by the standard accelerometers for this motor are comparable to those observed for previous PQA motors.

An accelerometer (AFS262) was added to the forward skirt for this test to study the transmissibility of vibrations through the skirt to upstage components. A comparison of data in Fig. 8 from the igniter boss and the forward skirt shows that the characteristic blossom of data subsequent to the ignition shock which is so evident at the igniter boss is not transmitted through the skirt. It should be recognized, however, that the mass and compliance of the J-5 thrust stand and test fixtures do not simulate the flight vehicle upstage components.

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

4.4.1 Roll Control System

The RC gas generator was ignited for the off-motor independent subsystem test at a simulated pressure altitude of 122,000 ft. Histories of gas generator pressure, roll moment, and roll moment null unbalance during gas generator operation are presented in Fig. 9 and are compared to the model specification limits. The RC 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 before motor ignition. 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 1.339 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 674 to 692 psia. This was within the specification limits of 655 to 735 psia. Manifold inlet pressure at time of slam suppressor pin shear was 585 psia.

The injector valves were operated per the duty cycle presented in Table IX. Plots 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 2.12 was produced by an injectant flow rate of 10.4 lbm/sec during the time period from 3 to 4 sec. This is within the requirement to demonstrate a 2-deg capability. The indicated system performance during the nominal 1- and 2-lbm/sec flow rates was within the system gain specification as shown in Fig. 12.

4.5 THRUST TERMINATION

Thrust termination was initiated 60.18 sec after motor ignition at a chamber pressure of 75.3 psia. Breakwires indicated that the first thrust termination port had been opened by 403 μsec after thrust termination signal application. The time from first port rupture to last port rupture was 87 μsec. This met the specification requirements of 219 to 705 μsec. (Table VI).

During the first 2 sec following thrust termination, the sealed forward dome interstage volume experienced a maximum pressure rise of 0.0764 psi. This is the highest pressure rise recorded for the PQA series.

4.6 STRUCTURAL INTEGRITY

Postfire photographs of the motor and RC subsystem are shown in Fig. 13. Postfire structural condition of the motor and RC subsystem was satisfactory. Gas leakage was noted at the bellows of thrust termination stacks 1 and 6. Leakage occurred from ruptures in the completely contained mild detonating fuses to thrust termination ports 1 and 6.

SECTION V
SUMMARY OF RESULTS

The results of testing a TCC Production Quality Assurance LGM-30G Stage III motor, PQA-102, at an average simulated altitude of 91,000 ft and its RC subsystem off-motor at an average simulated altitude of approximately 122,000 ft are summarized as follows:

1. All motor ballistic and component performance data from this firing conformed to model specification requirements for the LGM-30G Stage III propulsion subsystem.

2. The motor was ignited at a pressure altitude of 102,000 ft and the ignition delay was 86 msec.

3. Vacuum-corrected unaugmented total impulse was 2,083,534 lbf-sec during a motor action time of 60.18 sec. Vacuum specific impulse was 284.94 lbf-sec/lbm.

4. Thrust termination was initiated 60.18 sec after motor ignition at a chamber pressure of 75.3 psia. All thrust termination ports were opened by 490 μsec after signal application. Maximum thrust termination nonsimultaneity was 87 μsec.

5. The thrust vector control system operated as programmed and met specification requirements.

6. Postfire structural condition of the motor was good.

7. The RC subsystem was ignited off-motor at a simulated altitude of 122,000 ft and operated as programmed throughout the gas generator operation time. RC gas generator pressure, roll moment, and roll moment null unbalance were within specification limits throughout the subsystem test. Postfire structural condition of the RC subsystem was good.

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.

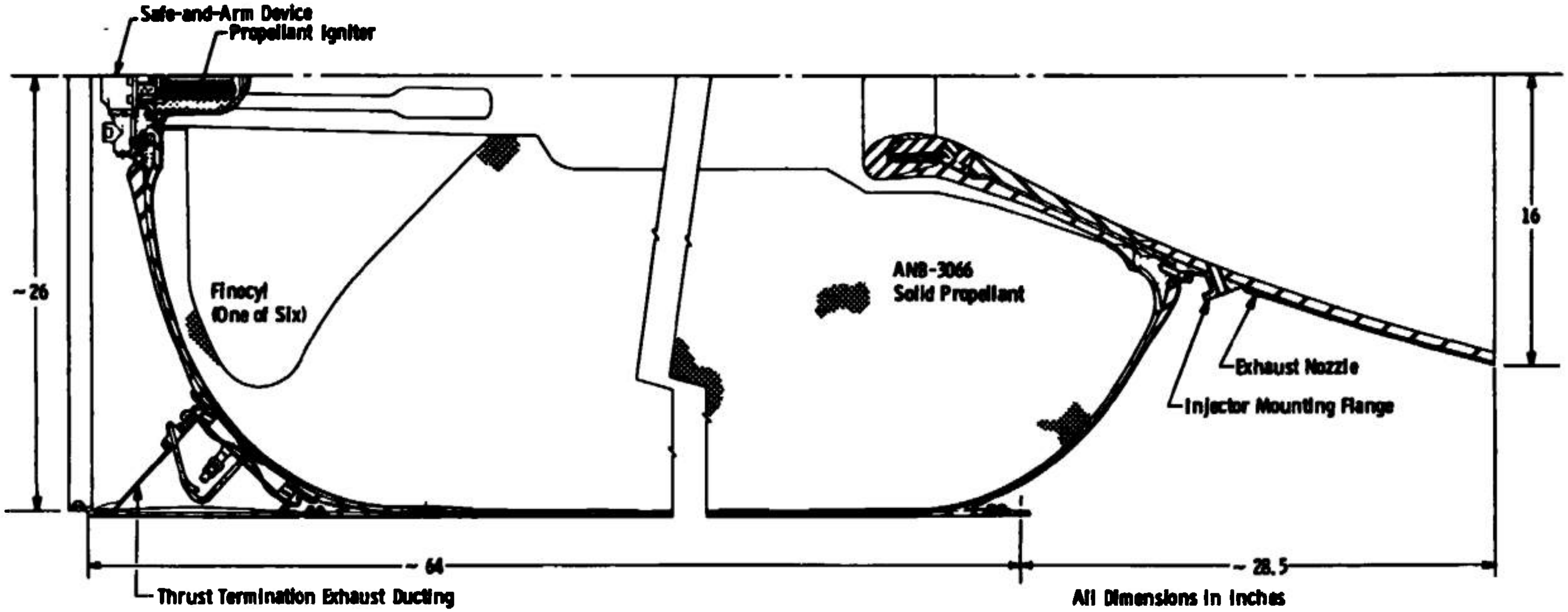
5. "Igniter, Propellant, Rocket Motor, Minuteman III Stage III." AGC Specification 32204, January 16, 1968.

6. "Rocket Motor Log Book, Motor PQA-102." Thiokol Chemical Corporation, October 1972.

7. "Forward Dome Accelerometer Maximum Response PQA-101." Thiokol Chemical Corporation Document No. TWR-6604, December 18, 1972.

APPENDIXES

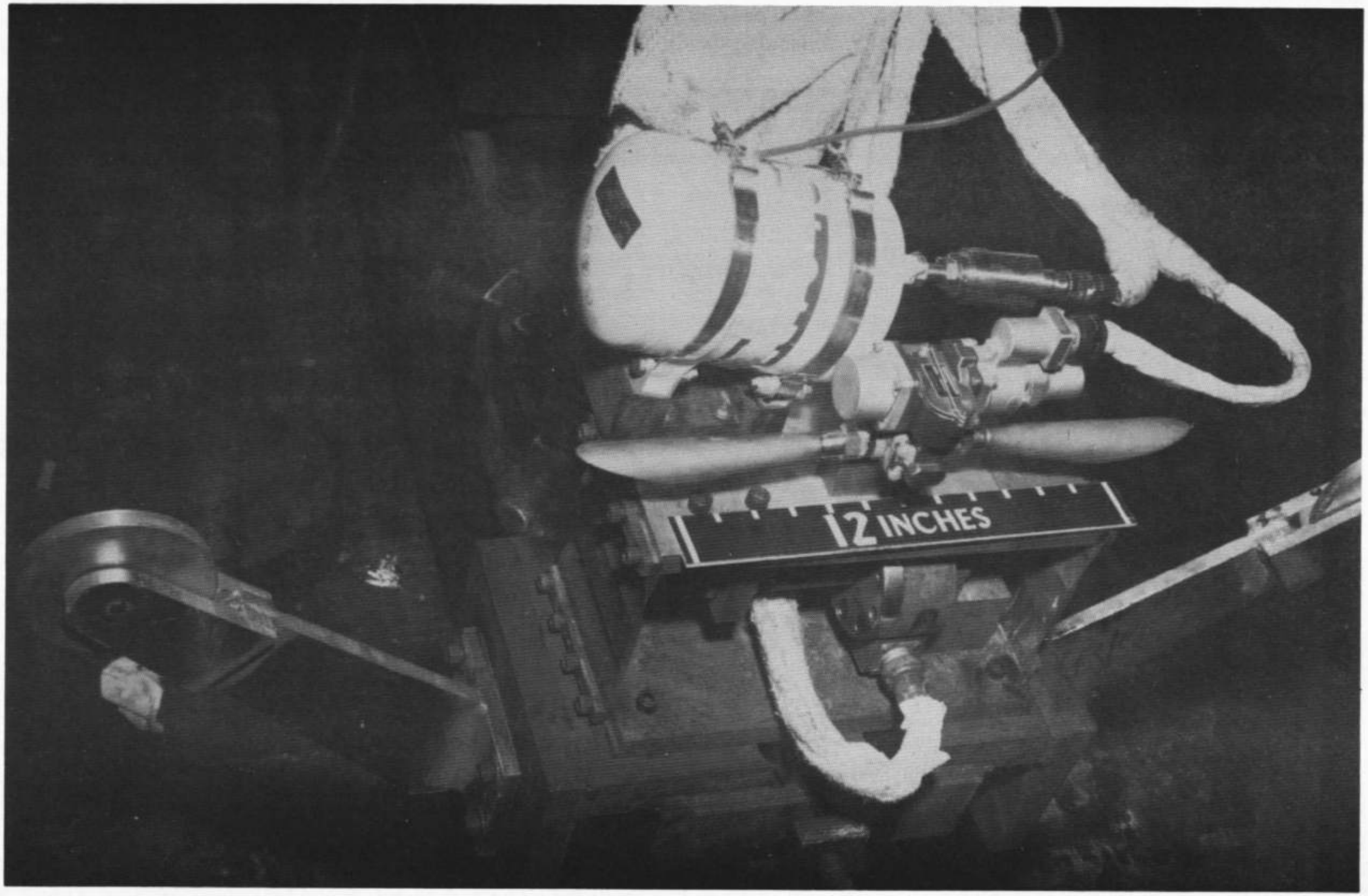
I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION CALIBRATIONS
IV. UNCERTAINTIES OF THE J-5 INSTRUMENT SYSTEMS
V. METHODS OF CALCULATION



a. Cutaway Schematic of Motor

Fig. 1 Minuteman LGM-30G Stage III Rocket Motor

b. Overall View, Typical
Fig. 1 Continued



c. Typical Roll Control Subsystem, Prefire
Fig. 1 Concluded

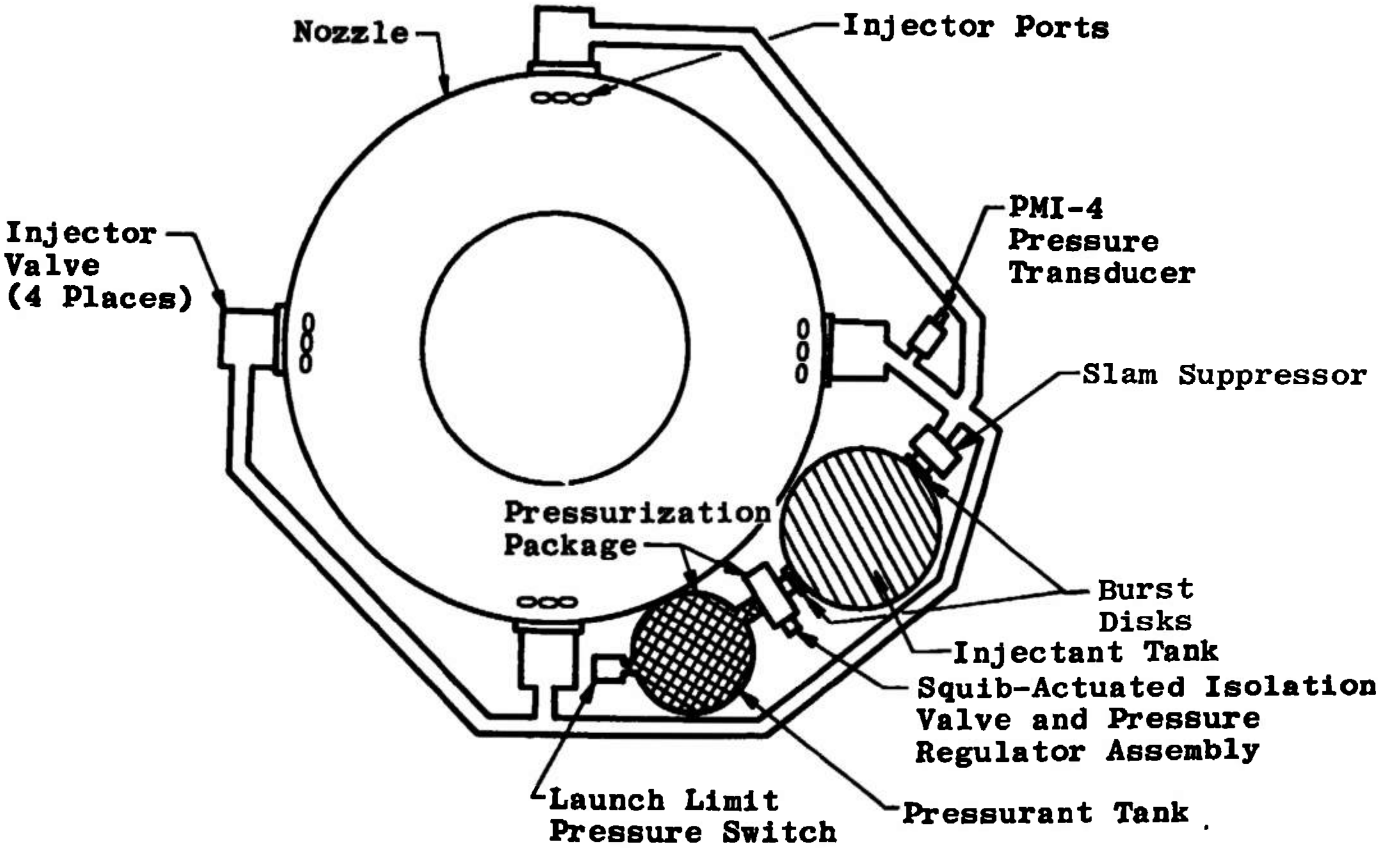


Fig. 2 Liquid-Injection Thrust Vector Control System Schematic

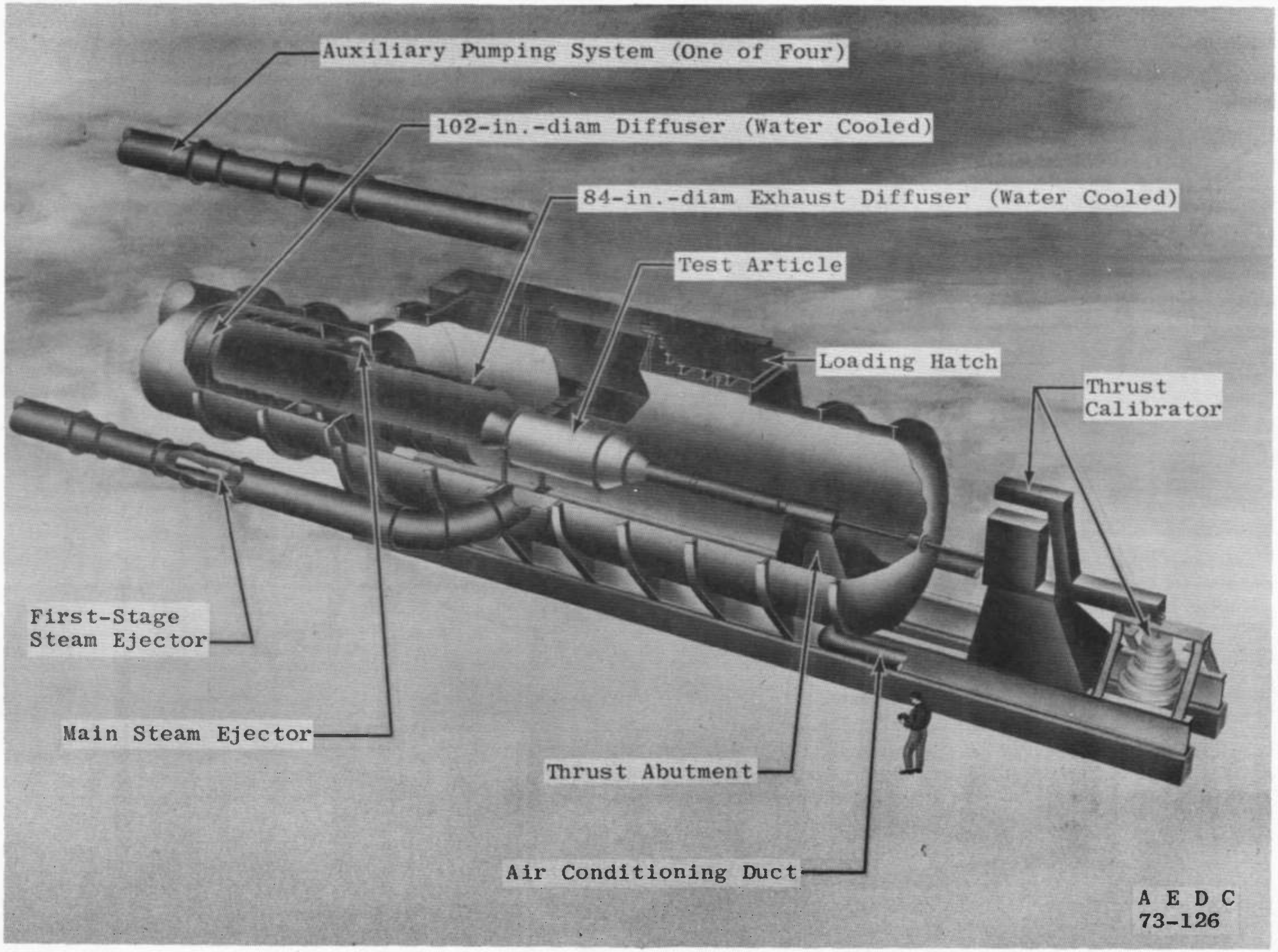


Fig. 3 Rocket Development Test Cell (J-5)

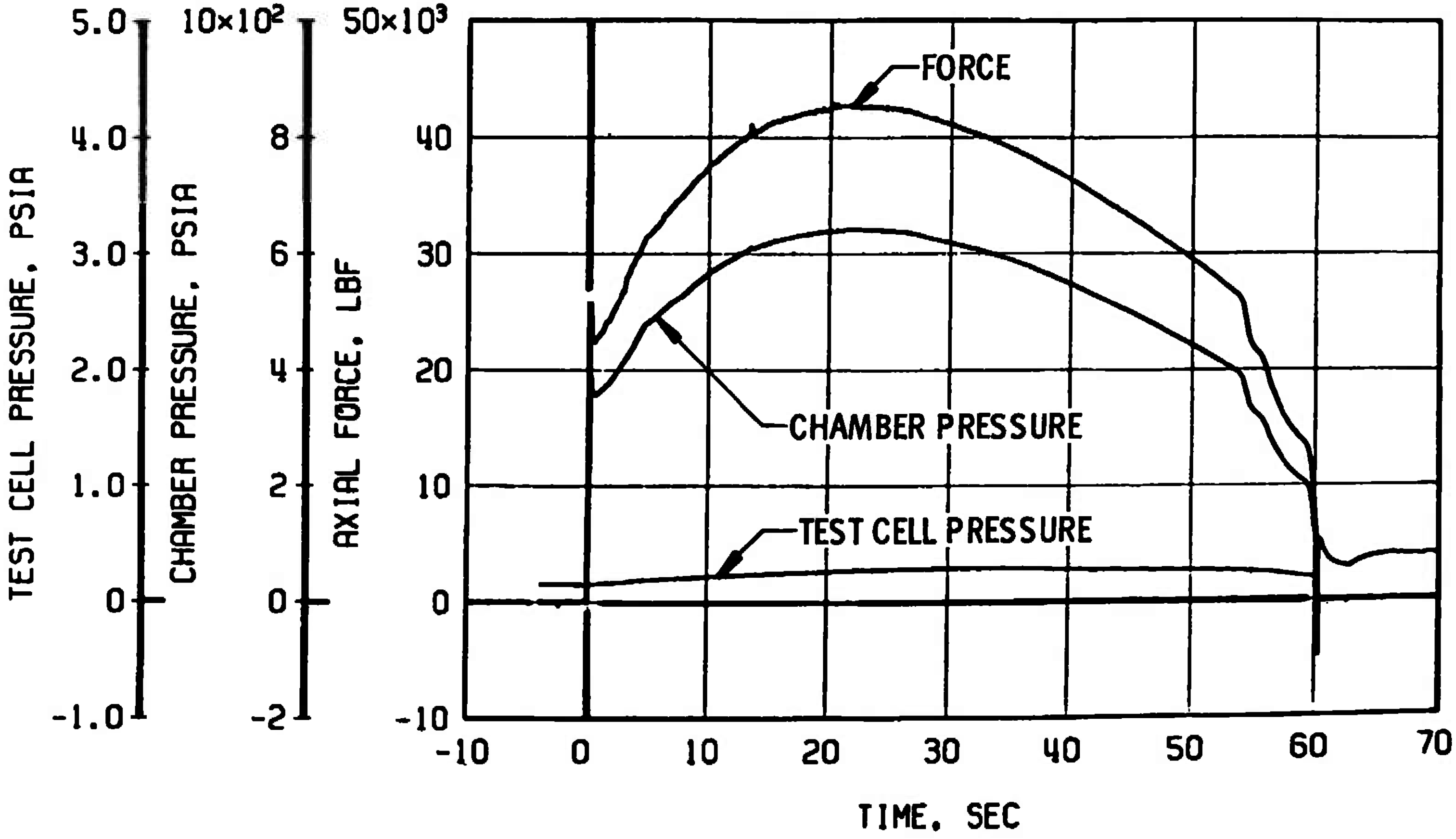


Fig. 4 Measured Axial Force, Chamber Pressure, and Test Cell Pressure during Motor Operation

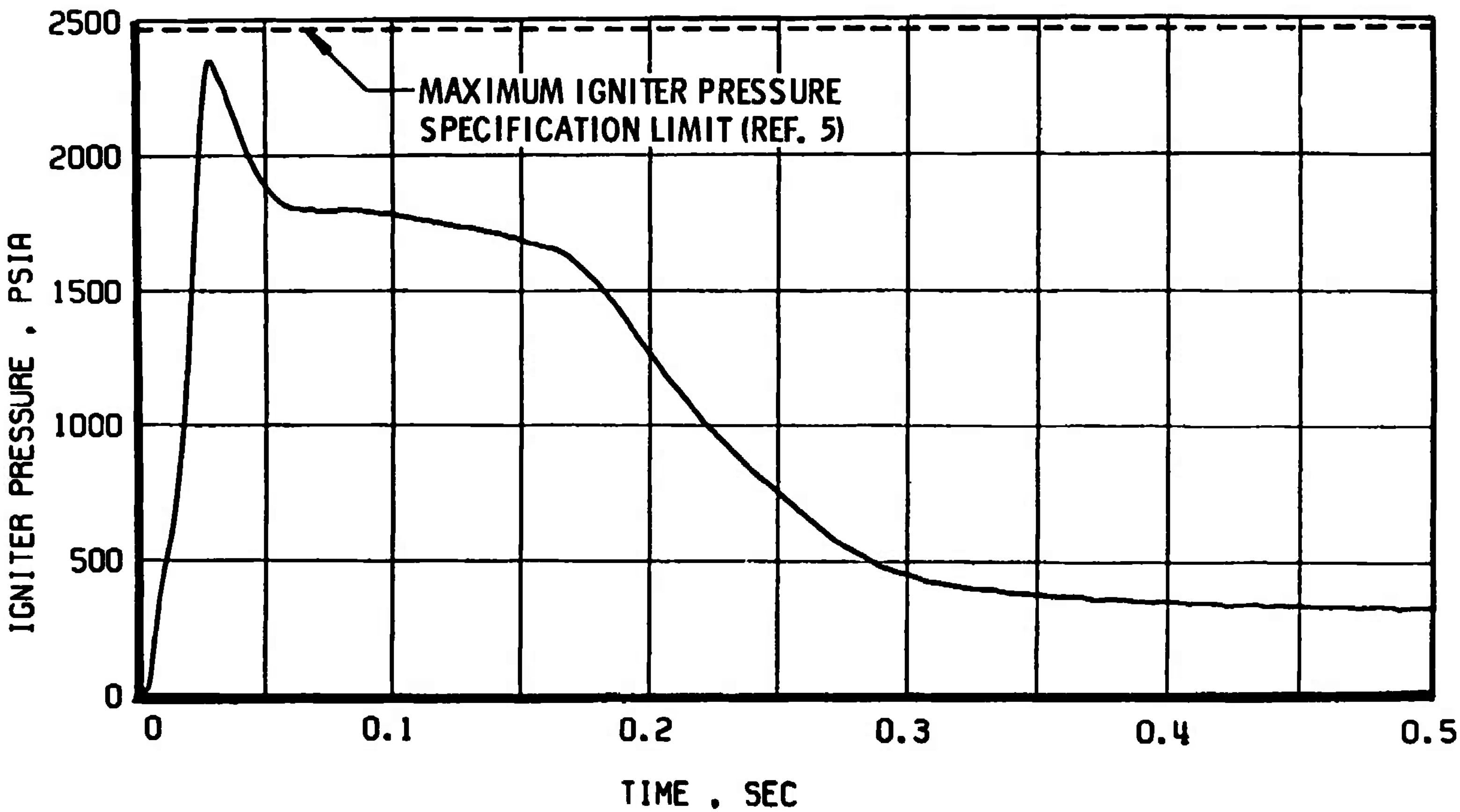


Fig. 5 Igniter Pressure Transient during Ignition

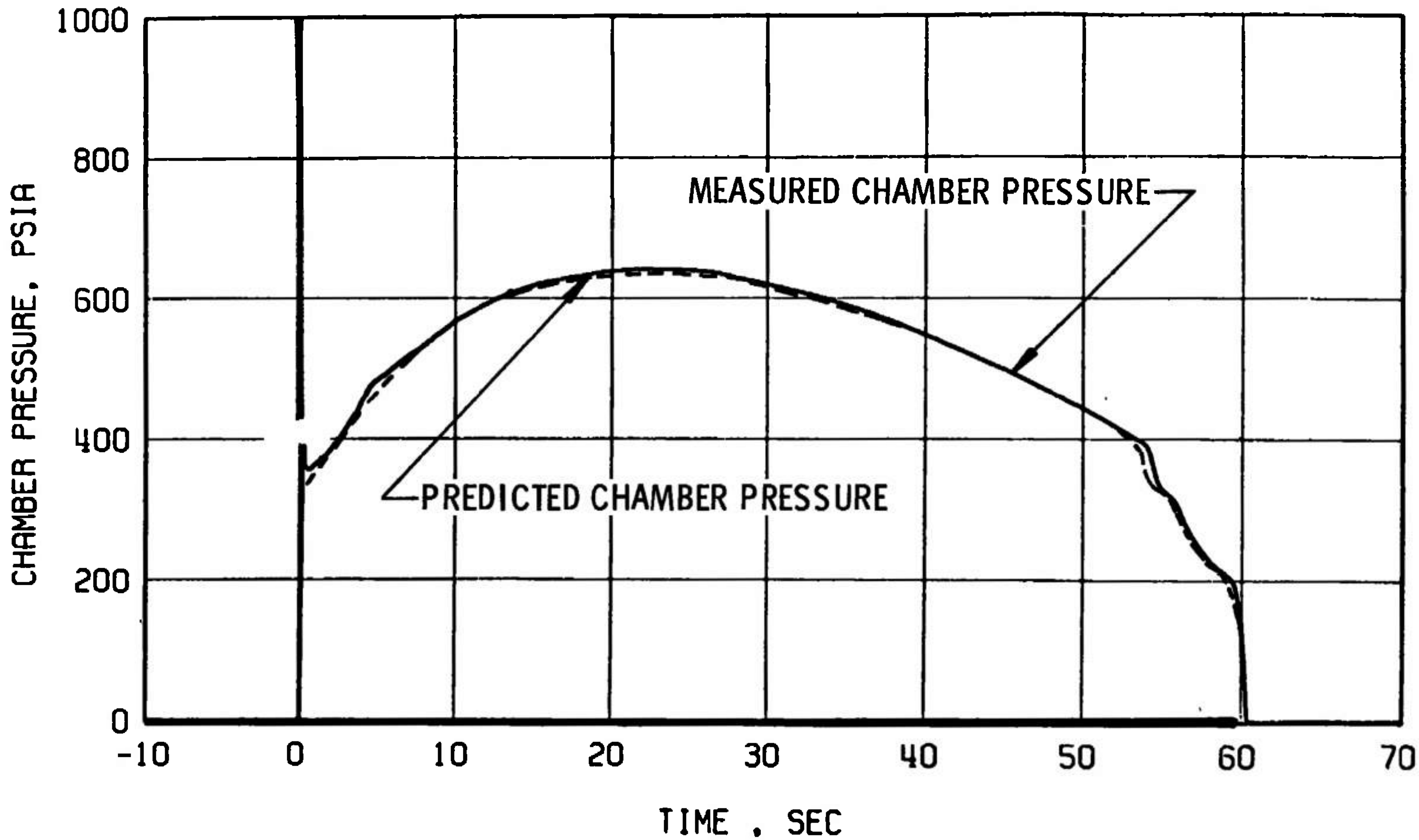


Fig. 6 Measured and Predicted Motor Chamber Pressure

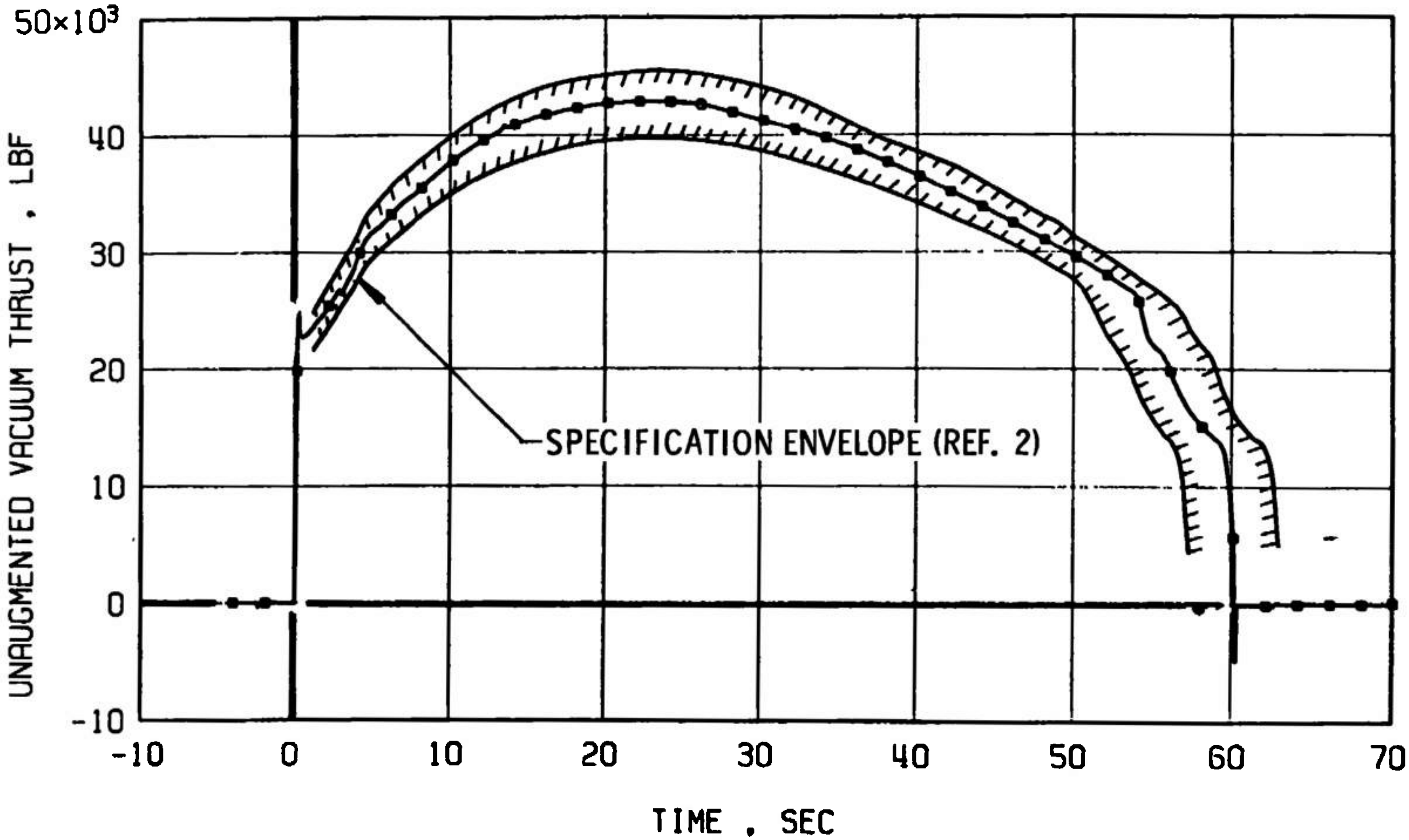


Fig. 7 Unaugmented Vacuum Thrust and Specification Envelope

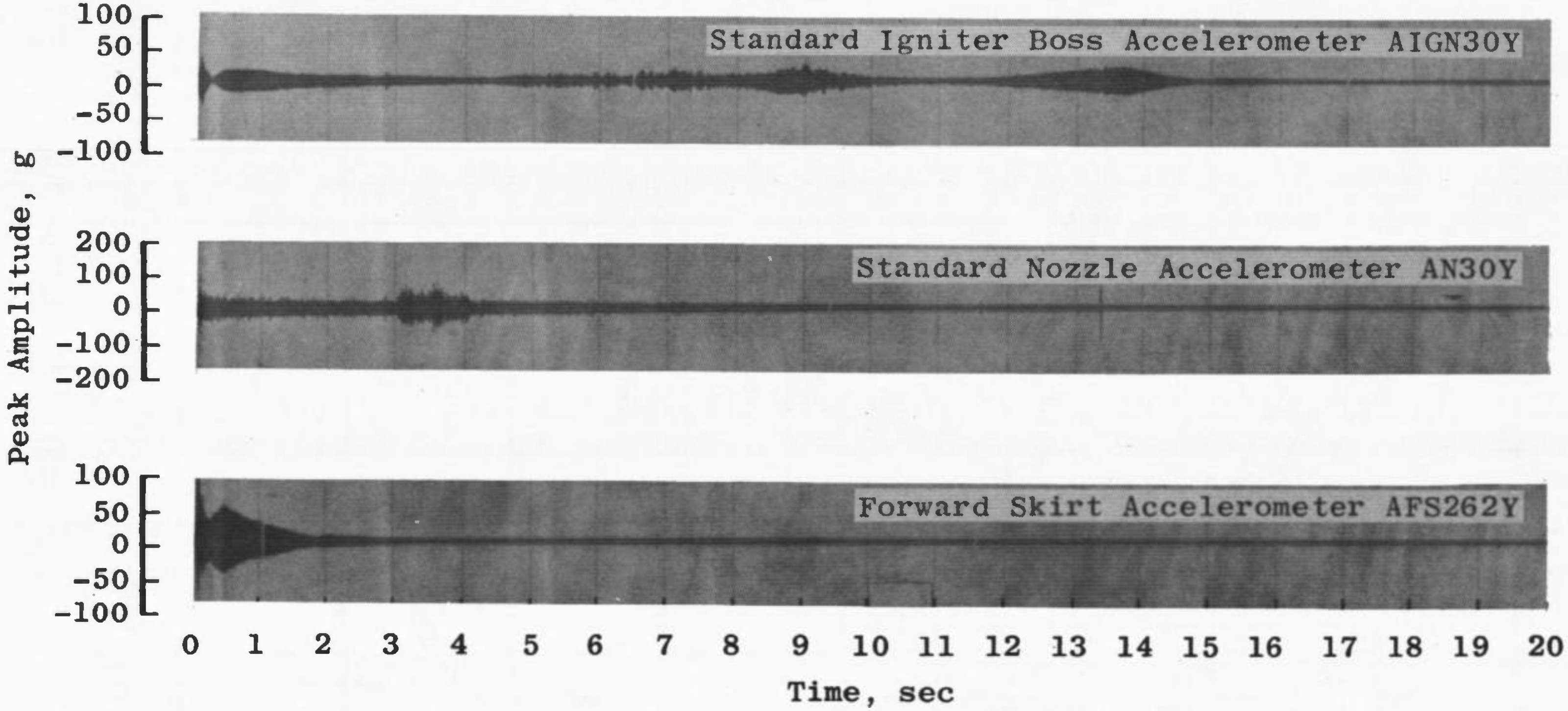
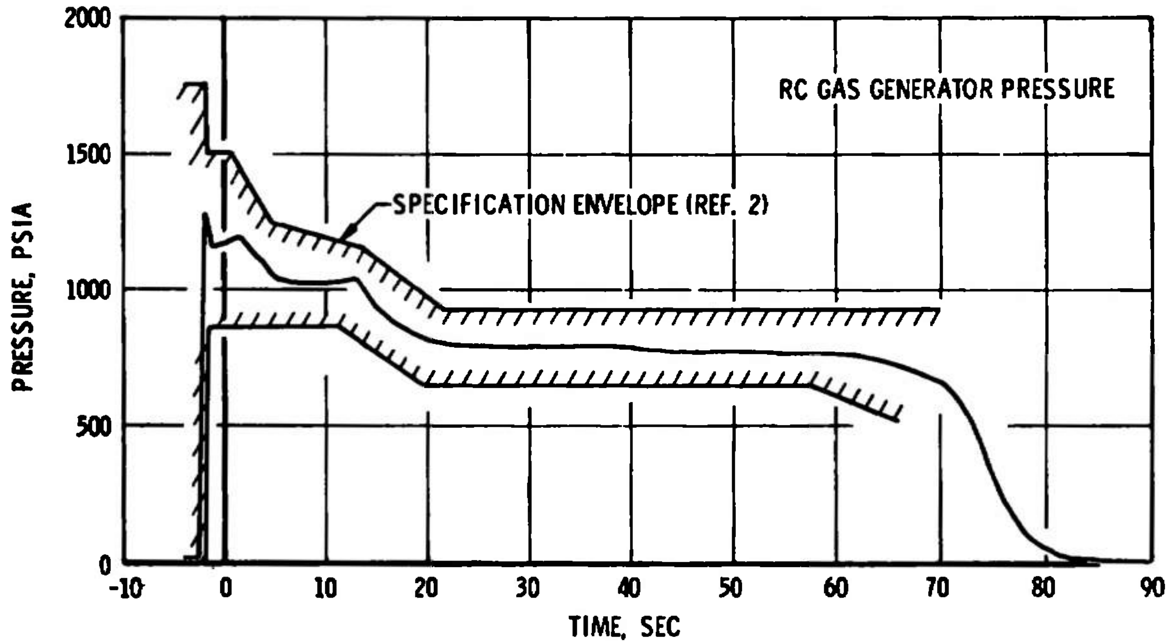


Fig. 8 Motor Accelerometer Vibrations



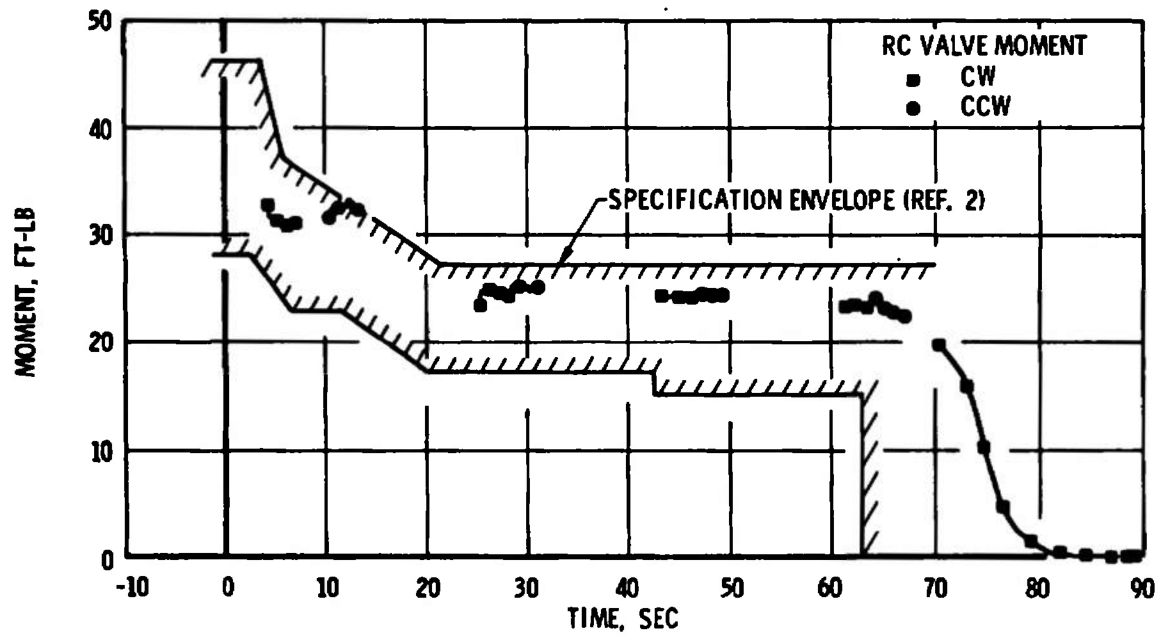


Fig. 9 Roll Control Gas Generator Pressure, Roll Moments, and Roll Moment Null Unbalance with Specification Envelopes

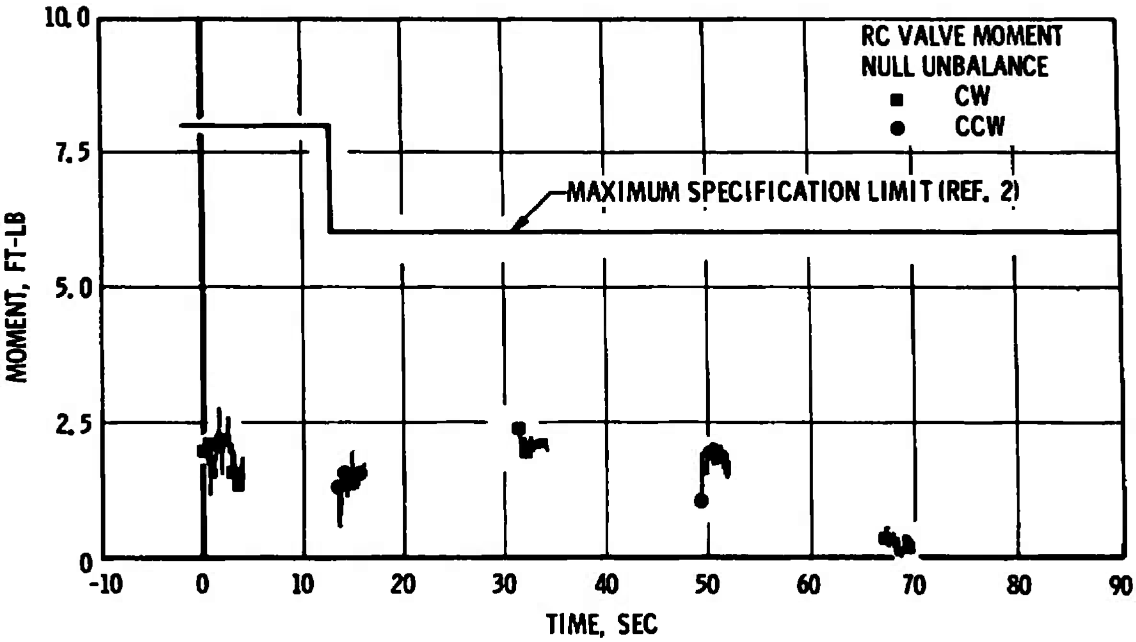


Fig. 9 Concluded

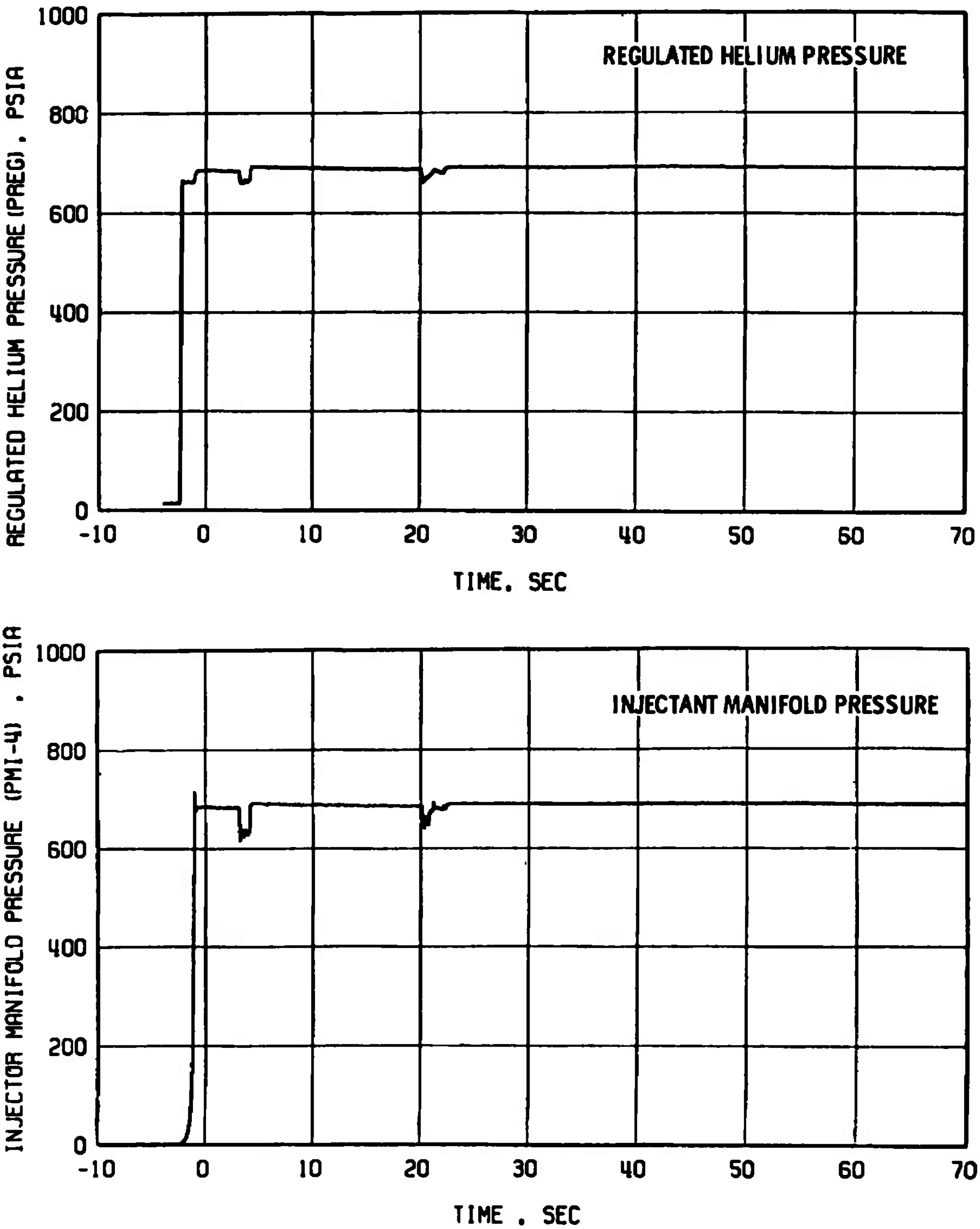
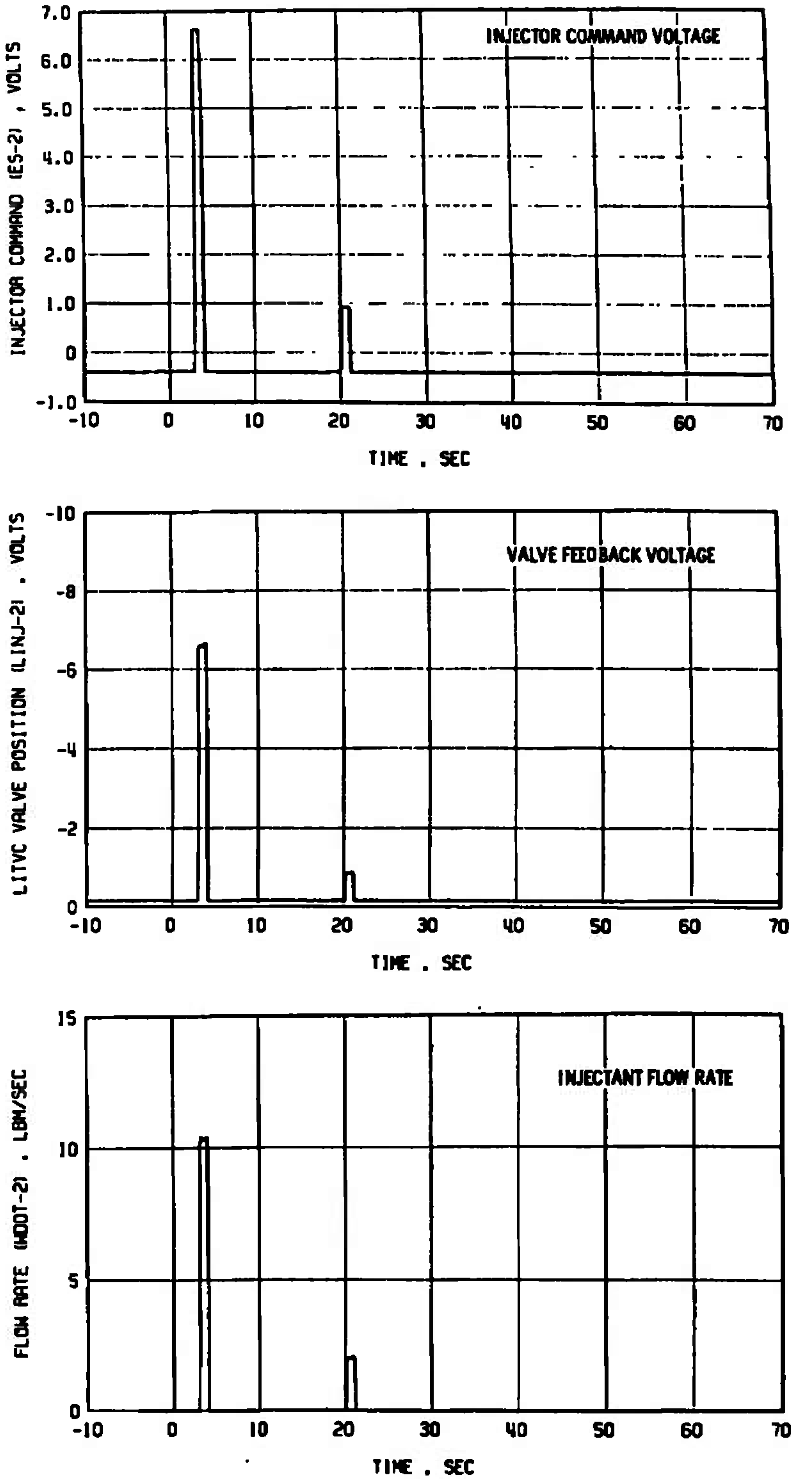
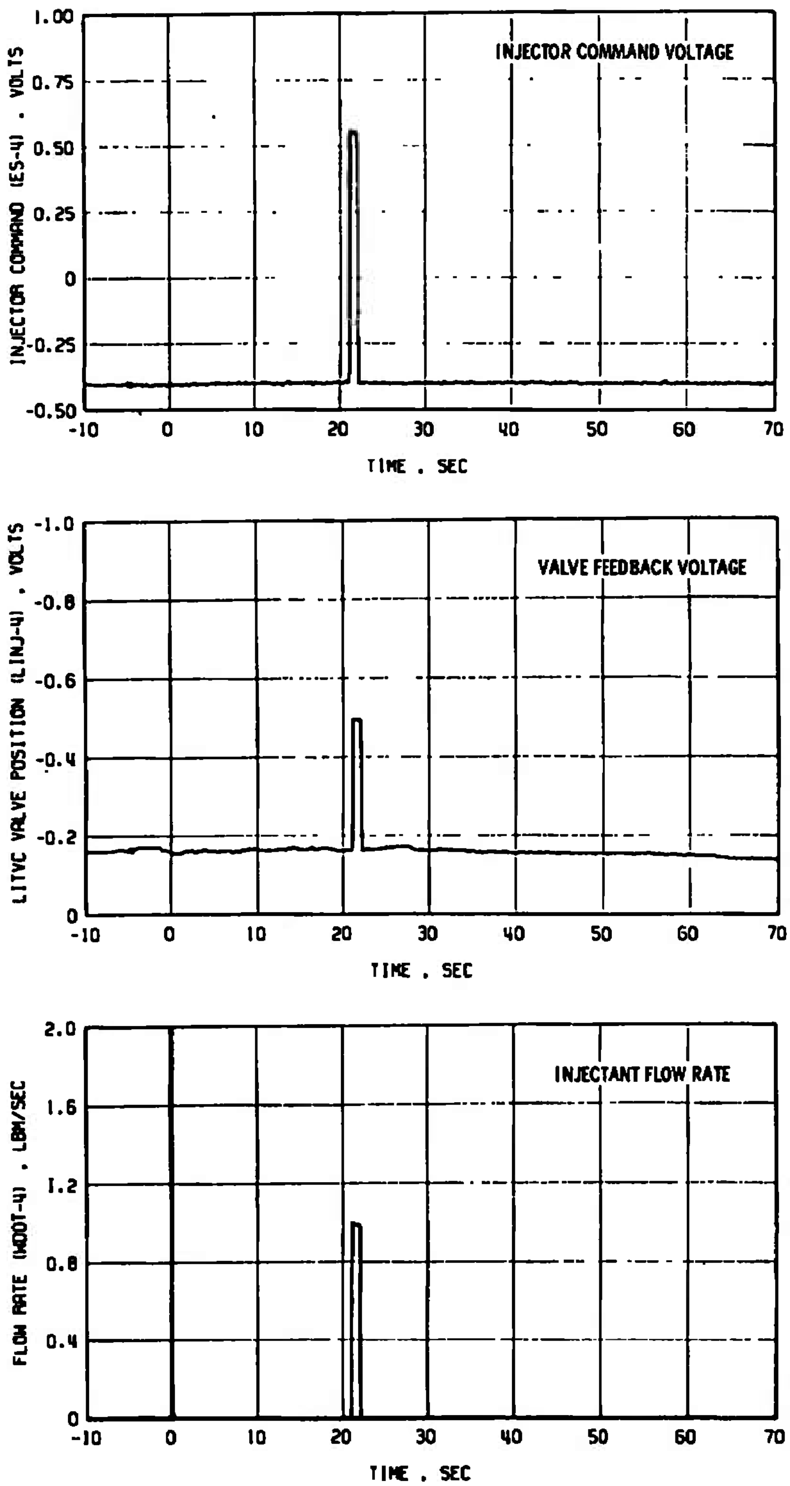


Fig. 10 Regulated Helium and Injectant Manifold Pressures during Motor Operation



a. Valve 2

Fig. 11 Thrust Vector Control Data Summary



b. Valve 4
Fig. 11 Concluded

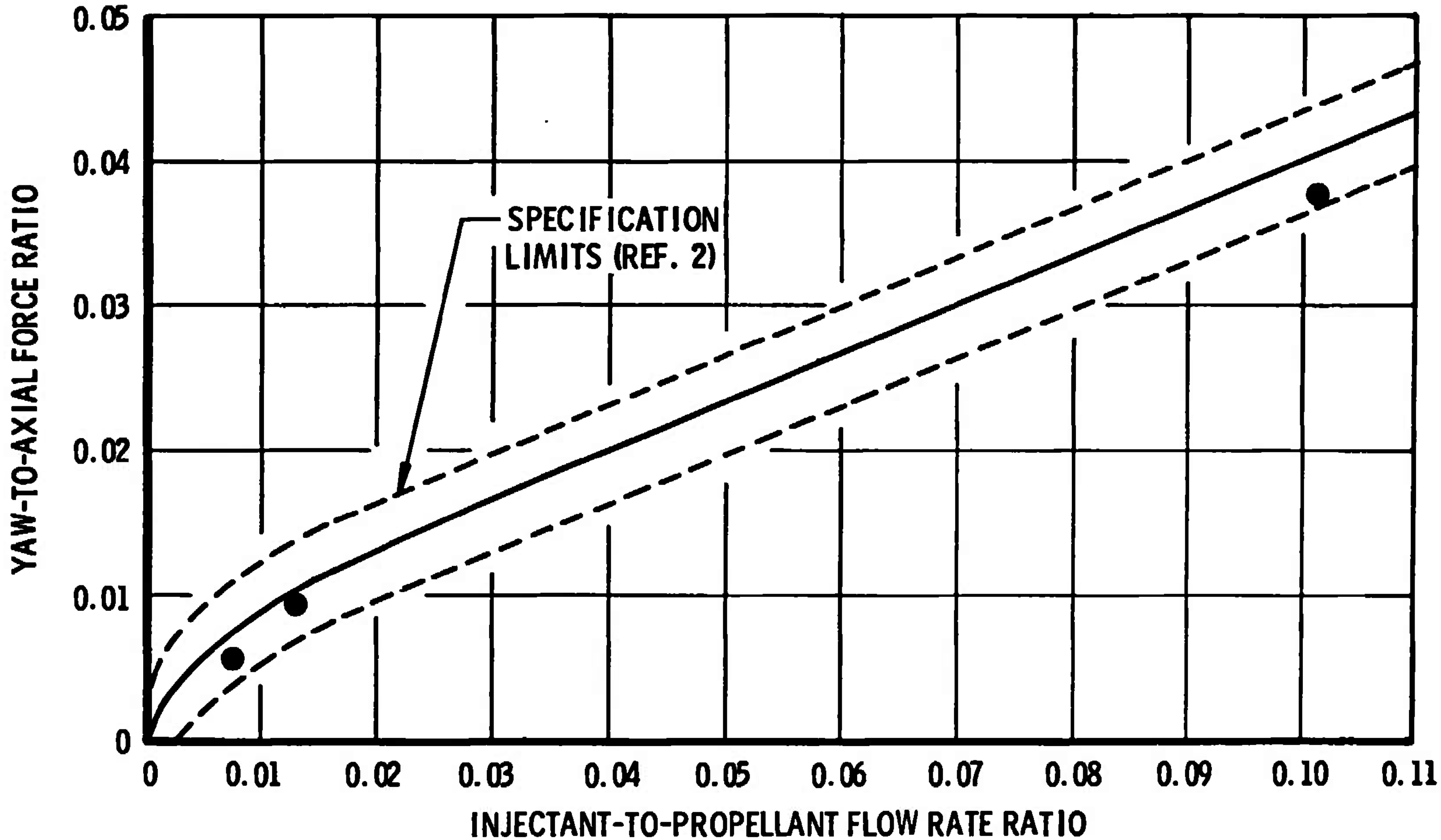
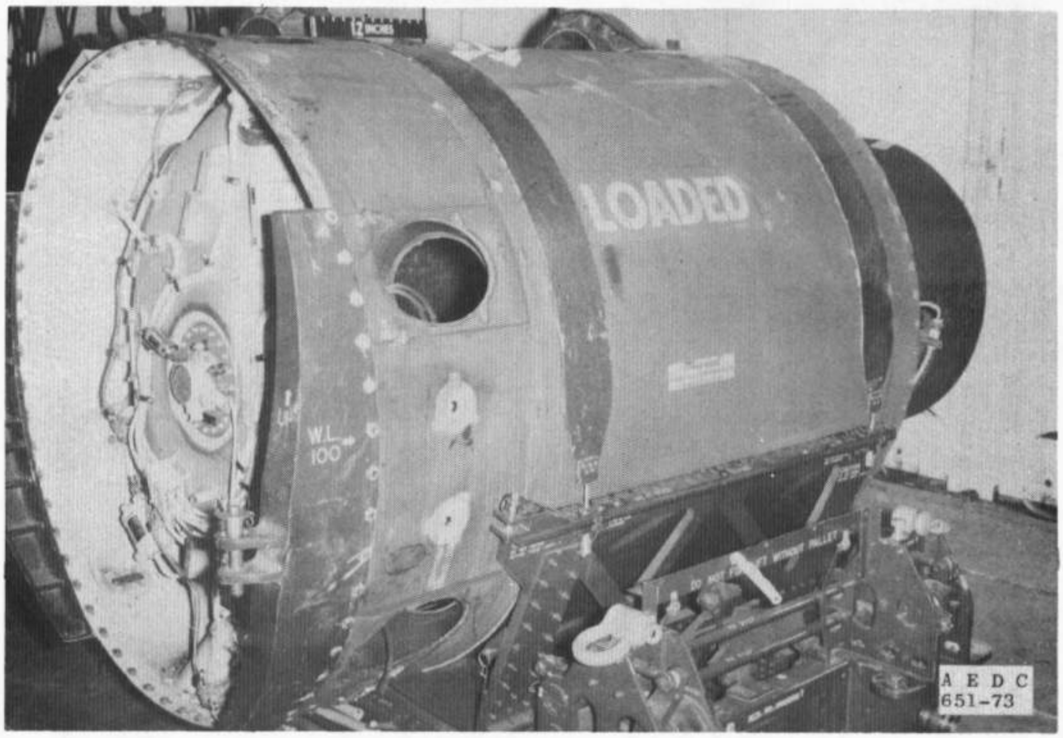
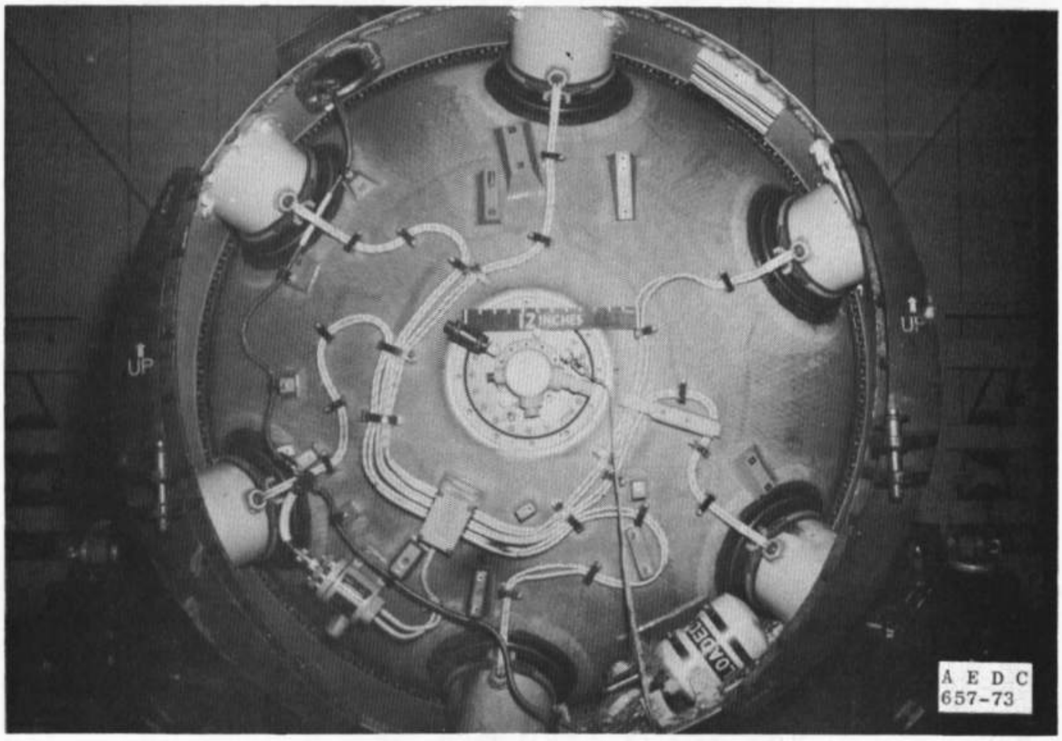


Fig. 12 Thrust Vector Control System Gain and Specification

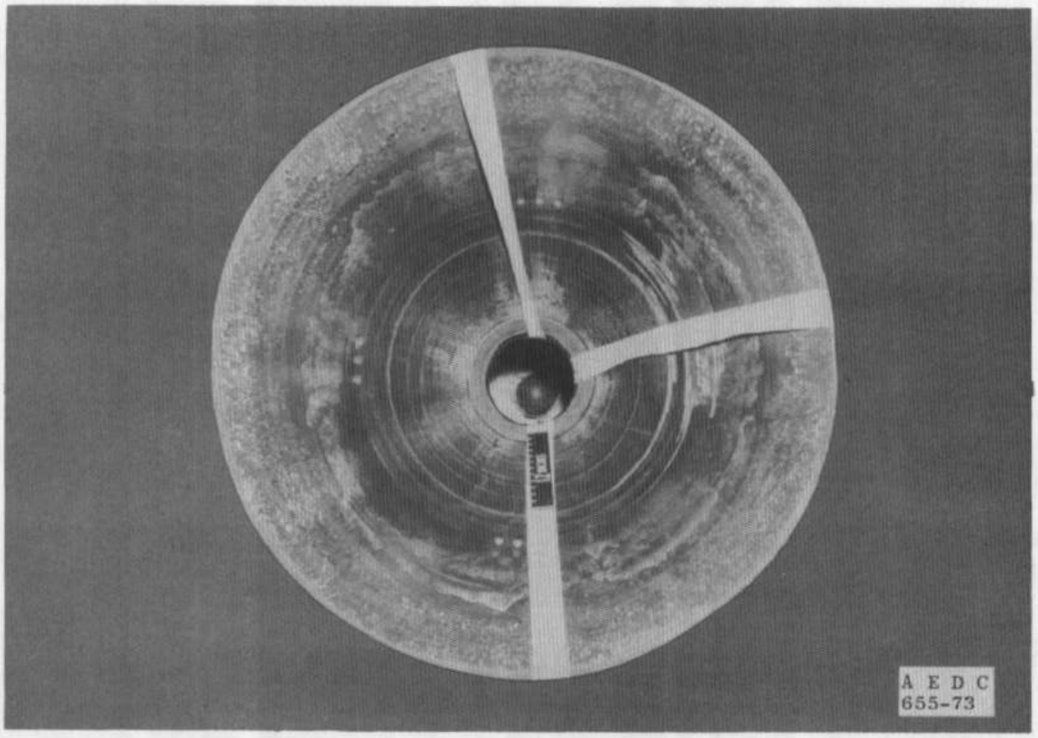


a. Overall

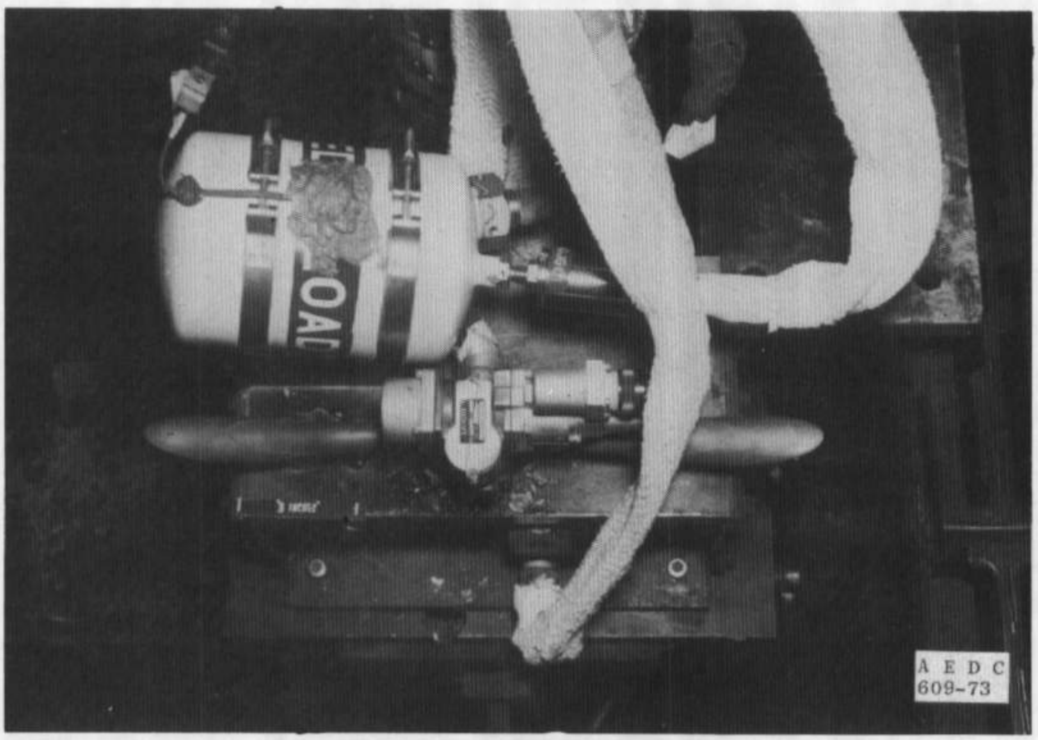


b. Forward Dome

Fig. 13 Motor and Roll Control Subsystem Postfire Condition



c. Overall Nozzle Exit



d. Roll Control Subsystem
Fig. 13 Concluded

TABLE I
TEST ARTICLE CONFIGURATION

NOMENCLATURE	PART NO.	SERIAL NO.
Motor Assy, Final	1147372-91 (1U43737-04)	TC 30195 PQA 102
Propellant	ANB-3066	7110021 7110022
Nozzle, Exhaust R. M.	1146002-39	1000202
Housing, Nozzle	1144447-19	318-3
Extension, Exit Cone	1145027-1	8238-58
Exit Cone	1127578-1	311-4
Igniter and S&A Assy	1128361-511	1000192
Igniter Rocket Motor	1128360-505	1000192
Safe and Arm	KR80000-09	0B26674
Propellant	ANB-3066	7110015
Chamber	1127676-1	1000402
Thrust Termination System	1147368-19	N/A
Ring Assy, Retaining	1215685-17	1001772-777
Block Assy, Manifold	1214311-21	1000249
Ordnance Subsystem	1147373-19	1000180
A/D S&A Mechanism	1214110-9	1000274
Igniter Assy (Roll Control)	1128070-13	1000444
Squib Cartridge	1128115-41	1000323
Roll Control Assy	1128070-11	1000364
Valve Assy	010-58847	523
Gas Generator Assy	20840	P-0772
LITVC System	1145433-359	N/A
Injectant Tank Assy	1145560-79	1000230
Helium Tank Assy	1128811-479	1000213
Pressurization Package	1128115-129	1000179
Pressure Switch	1128084-13	1000183
Manifold Assy	1145522-29	1000214

TABLE I (Concluded)

NOMENCLATURE	PART NO.	SERIAL NO.
Servoinjector Valves*		
0	401-09140-10(M)	HCC0004
90 deg	401-09140-10	HSD0131
180 deg	401-09140-03(M)	HCC0006
270 deg	401-09140-10	HSD0099
Operational Pressure Transducers		
PC-1	1143914-1	1000367
PMI-4	1143914-3	1000625
PRCGG	1143914-5	1000685

*Valves cleaned and checked at AEDC for use on subsequent LGM30G Stage III motors.

TABLE II
INSTRUMENTATION SUMMARY

PARAMETER SYMBOL	PARAMETER DESCRIPTION	MEASUREMENT RANGE	SENSOR TYPE	SENSOR RANGE	DIGITAL* SYSTEM	ANALOG TAPE	OSCILLO-GRAPH	STRIP CHART
	ACCELERATION	G PEAK		G PEAK				
AFS-262Y	FORWARD SKIRT @ 262	-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 4.4			X	X	X	
EFS-10	AOTT 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	
EROB	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	
	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		

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-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		
FRC-1	ROLL CONTROL THRUST	- 25 TO 25	STRAIN GAGE	0000 TO 0000	X		X	X
FRC-2	ROLL CONTROL THRUST	- 25 TO 25	STRAIN GAGE	0000 TO 0000		X	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-1	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			
PQA	AFT NOZZLE QUENCH	0 TO 200	STRAIN GAGE	0 TO 200	X			
PQF	FORWARD TT 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				
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

(1) SIGNALS FROM PC-1 AND FY-3 WERE FILTERED BEFORE RECORDING BY INSTALLING HIGH PASS FILTERS (3 db POINT OF 50 Hz WITH 6 db/OCTAVE ROLL OFF). NEITHER PARAMETER WAS SUCCESSFULLY RECORDED BECAUSE OF INSTRUMENTATION ANOMALIES.

TABLE III
NOZZLE MEASUREMENTS

Prefire Nozzle Measurements

Degrees	Throat Diameter, in.	Exit Diameter, in. (0.25 in. upstream of exit)
0	6.878	33.311
30	6.877	33.309
60	6.877	33.315
90	6.876	33.327
120	6.878	33.334
150	6.877	33.330
Average, in.	6.877	33.321
Area, sq in.	37.146	872.021
TCC-supplied Areas, sq in.	37.100	-

Postfire Nozzle Measurements

Degrees	Throat Diameter, in.	Exit Diameter, in. (0.25 in. upstream of exit)
0	6.858	33.520
30	6.861	33.625
60	6.858	33.512
90	6.839	33.626
120	6.821	33.617
150	6.853	33.505
Average, in.	6.848	33.568
Area, sq in.	36.835	884.971
Percent Change in Area (AEDC Measurements)	-0.8	+1.5

TABLE IV
MOTOR TEMPERATURE-CONDITIONING HISTORY

Date	Temperature, °F		Location of Motor	Relative Humidity, percent		Remarks
	High	Low		High	Low	
1/16/73	69	62	Rocket Preparation Area	31	29	Temperature below 65°F approximately 15 min
1/17/73	68	64		31	28	Temperature below 65°F approximately 10 min
1/18/73	69	67		57	32	
1/19/73	70	62		57	29	Temperature below 65°F approximately 5 min
1/20/73	70	68		29	24	
1/21/73	69	68		49	25	
1/22/73	69	68		50	46	
1/23/73	70	67		36	27	
1/24/73	72	69	Rocket Preparation Area and J-5 Test Cell (Motor)	31	26	
1/24/73	70	66	Rocket Preparation Area (Roll Control Subsystem)	26	22	Temperature below 65°F approximately 10 min
1/25/73	72	71	J-5 Test Cell (Motor)	34	26	
1/25/73	70	67	Rocket Preparation Area (Roll Control Subsystem)	30	22	
1/26/73	72	72	J-5 Test Cell (Motor)	42	28	
1/26/73	68	60	Rocket Preparation Area (Roll Control Subsystem)	52	26	Temperature below 65°F approximately 15 min
1/27/73	75	70	J-5 Test Cell (Roll Control Subsystem)	50	34	

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

Motor Number	PQA-1	PQA-2	PQA-3	PQA-4	PQA-5	PQA-6[3]	PQA-7	PQA-8	PQA-9	PQA-10	PQA-11	PQA-12	PQA-101	PQA-102
AEDC TR Number	71-240	71-248	71-251	71-233	71-269	71-275	72-49	72-77	72-105	72-152	72-177	73-7	73-43	73-76
Date Fired	6-14-71	8-10 71	8-28-71	9-8-71	9 30-71	11-3-71	1-25-72	3-21-72	5-15-72	6-29-72	8-23-72	10-17-72	11-17-72	1-26-73
Propellant Temperature, °F	70	71	68	80	73	70	71	71	71	70	72	72	71	71
Ignition Delay, msec	88	82	84	85	86	87	88	89	86	85	84	89	84	86
Maximum Igniter Pressure, psia	2227	2307	2246	2119	2121	2141	2245	2127	2327	2148	2407	2363	2246	2364
Action Time, sec	59.43	59 01	60 23	59 82	59 26	---	62 70	60 74	58.17	58.34	56.05	58.40	57.61	60.10
Thrust[1]														
Maximum, lbf	43,147	43,761	42,957	43,370	43,392	43,348	41,233	42,060	43,800	44,473	44,421	44,245	44,562	42,026
Average, lbf	34,979	35,287	34,482	34,763	35,006	36,603	33,103	34,205	35,723	35,644	35,813	33,542	36,084	34,822
Chamber Pressure														
Maximum, psia	632	652	645	651	646	648	619	631	658	666	663	665	671	643
Average, psia	529	526	517	521	623	580	496	513	535	535	537	533	544	519
At Thrust Termination, psia	79 6	74 4	79.7	75 7	78 0	585.4	73 3	75.2	74 9	73 6	70.5	75.0	74.7	75.3
Total Impulse,[1] lbf-sec	2,076,805	2,081,204	2,077,452	2,079,547	2,075,261	1,368,816	2,075,555	2,077,586	2,077,080	2,078,457	2,078,955	2,075,882	2,078,776	2,083,534
Specific Impulse,[1,2] lbf-sec/lbm	284.53	284.62	284 41	284.33	284 18	284.62	284 26	284.43	284.31	284.41	284.55	284.41	284.24	284.84
Thrust Termination Functioning Time, (First Port), μsec	403	403	403	402	420	420	420	436	420[4]	437	455	480	460	403
Thrust Termination Interval, μsec	70	52	1243	16	36	157	18	17	18	18	17	20	30	67
Liquid Injection Thrust Vector Control Yaw Angle, 3 4 sec, deg	2 20	2.13	2.20	2.18	2.21	2 20	2 20	0.32[5]	2.09	2 12	2.12	2.16	2.15	2.12

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

[2]Calculated using total loaded 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 suppressor pin failed to shear

TABLE VI
SUMMARY OF MOTOR PERFORMANCE

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
GENERAL INFORMATION			
MOTOR S/N *	PQA102 30195		
MODEL NUMBER *	SR73AJ-1		
TYPE FIRING	ALTITUDE		
DATE FIRED	01-26-73		
DATE CAST *	10-16-72		
TOTAL MOTOR WEIGHT (PREFIRE), LBM *	8052.2		8069.1
CASE PROPELLANT WEIGHT, LBM *	7312.3		
TOTAL PROPELLANT WEIGHT (WPT), LBM *	7312.3	7291.9	
PROPELLANT SLIVER WEIGHT, LBM *	8.0		
EXPENDED PROPELLANT WEIGHT (WP), LBM	7304.3	7277.6	7314.0
PREFIRE NOZZLE THROAT AREA (TCC), SQ. IN.	37.100		
PREFIRE NOZZLE THROAT AREA (AEDC), SQ. IN.	37.146		
AVERAGE NOZZLE THROAT AREA, SQ. IN. **	38.106		
POST FIRE NOZZLE THROAT AREA (AEDC), SQ. IN.	36.835		
PREFIRE NOZZLE EXIT AREA (AEDC), SQ. IN.	888.131		
POSTFIRE NOZZLE EXIT AREA (AEDC), SQ. IN.	906.248		
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	37		
TEST CELL PERFORMANCE			
ALTITUDE			
AT PRESSURANT SQUIB IGNITION, FT.	102000		
AT MOTOR IGNITION, FT	102000	100000	
AT THRUST TERMINATION, FT	97000		
AVERAGE, FT	91000	60000	
PRESSURE			
AVERAGE, PSIA	0.249		
INTEGRAL, PSIA-SEC.	14.972		
BALLISTIC PERFORMANCE			
TIME			
IGNITER IGNITION DELAY (TO 1000 PSIA), MSEC.	17		43
IGNITER IGNITION INTERVAL, MSEC.	145		
IGNITION DELAY, MSEC	86		200
AT MAXIMUM CHAMBER PRESSURE, SEC.	22.580		
AT MAXIMUM VACUUM AXIAL THRUST, SEC.	21.730		
ACTION (75 PSIA CHAMBER PRESSURE), SEC.	60.180	57.53	62.53
THRUST TERMINATION (TT), SEC.	60.180		
THRUST TERMINATION FUNCTIONING, MICROSEC.			
STACK 1	403	219	705
STACK 2	420	219	705
STACK 3	420	219	705
STACK 4	455	219	705
STACK 5	438	219	705
STACK 6	490	219	705
THRUST TERMINATION INTERVAL, MICROSEC.	87		

TABLE VI (Concluded)

	ACTUAL	SPECIFICATION MINIMUM	SPECIFICATION MAXIMUM
PRESSURE			
MAXIMUM IGNITER, PSIA	2354		2483
AVERAGE IGNITER, PSIA	1810	1560	1950
INTEGRAL OF IGNITER, PSIA-SEC.	264.3	225	314
MAXIMUM CHAMBER RISE RATE, PSIA/SEC.	6503		
MAXIMUM MOTOR CHAMBER, PSIA	643		
AVERAGE MOTOR CHAMBER, PSIA	519		
MOTOR CHAMBER INTEGRAL, PSIA-SEC.	31260		
INTEGRAL OF MOTOR CHAMBER RAISED TO 0.30 POWER, PSIA-SEC.	390		
MOTOR CHAMBER AT TT TIME, PSIA	75.3	70	80
MAXIMUM FORWARD DOME CAVITY BETWEEN TT AND TT+2 SEC., PSID	0.764		
AXIAL THRUST			
MAXIMUM MEASURED FORCE, LBF	42723		
MAXIMUM AUGMENTED VACUUM, LBF	42961		
MAXIMUM UNAUGMENTED VACUUM, LBF	42925		
AVERAGE MEASURED FORCE, LBF	34418		
AVERAGE AUGMENTED VACUUM, LBF	34641		
AVERAGE UNAUGMENTED VACUUM, LBF	34622		
IMPULSE			
MEASURED TOTAL, LBF-SEC.	2071285		
VACUUM TOTAL			
INCLUDING AUGMENTATION, LBF-SEC	2084723		
EXCLUDING AUGMENTATION, LBF-SEC.	2083534		
AUGMENTED VACUUM SPECIFIC			
OPTION 1 (USING WPC), LBF-SEC./LBM	283.45		
OPTION 2 (USING WP), LBF-SEC./LBM	285.41		
UNAUGMENTED VACUUM SPECIFIC			
OPTION 1 (USING WPC), LBF-SEC./LBM	283.29		
OPTION 2 (USING WP), LBF-SEC./LBM	285.25		
OPTION 3 (USING WPT), LBF-SEC./LBM	284.94	283.1	286.1
PROPELLANT FLOW RATE			
AVERAGE (USING WDOTPC), LBM/SEC.	122.21		
INTEGRAL (USING WDOTPC), LBM	7354.7		
AVERAGE (USING WDOTP), LBM/SEC.	121.50		
INTEGRAL (USING WDOTP), LBM	7311.6		
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.	1.339	1.0	1.6
PRESSURE			
DURING INJECTION SURGE, PSIA	697		1875
AVERAGE INJECTION PRESSURE FOR 130 MILLISEC AFTER TVC DELAY, PSIA	679		1500
MAXIMUM INJECTANT DURING ZERO FLOW, PSIA	692		735
MINIMUM INJECTANT DURING ZERO FLOW, PSIA	674	655	
ROLL CONTROL PERFORMANCE			
ACTION TIME, SEC.	74.810		
GAS GENERATOR PRESSURE AT 13.6 SEC., PSIA	1031		
GAS GENERATOR PRESSURE AT 60. SEC., PSIA	762		
MAXIMUM GAS GENERATOR PRESSURE, PSIA	1291		

* 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.	04
DATE FIRED	01-26-73
MOTOR S/N	PQA-102 (30195)
ROLL CONTROL ASSEMBLY S/N	1000364
TEST CONFIGURATION	OFF MOTOR
ALTITUDE AT GAS GENERATOR IGNITION, FT	122,000
SYSTEM TEMP. AT GAS GENERATOR IGNITION, DEG F	70

TIMES	ACTUAL	MAXIMUM SPECIFICATION
MAXIMUM VALVE RESPONSE MSEC		
ROLL MOMENT BUILDUP		
5 HZ CW-NULL-CW	22	40
5 HZ CCW-NULL-CCW	22	40
10 HZ CW-NULL-CW	25	40
10 HZ CCW-NULL-CCW	22	40
ROLL MOMENT DECAY		
5 HZ CW-NULL-CW	20	29
5 HZ CCW-NULL-CCW	16	29
10 HZ CW-NULL-CW	22	29
10 HZ CCW-NULL-CCW	17	29
ROLL MOMENT HALF CYCLE		
5 HZ CW-NULL-CW	42	65
5 HZ CCW-NULL-CCW	38	65
10 HZ CW-NULL-CW	47	65
10 HZ CCW-NULL-CCW	39	65
ROLL MOMENT REVERSAL		
5 HZ CW-CCW-CW	29	47
10 HZ CW-CCW-CW	30	47
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	48	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)	3.280	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.	10.4	2.01	0.99
PINTLE POSITION, MILLIINCHES	131.18	14.05	6.87
PINTLE PRESSURE, PSIA	543.	665.	679.
PROPELLANT FLOW RATE, LBM/SEC.	102	150	150
INJECTOR-TO-PROPELLANT FLOW RATE RATIO	0.102	0.013	0.007
RESULTANT YAW FORCE, LBF	1049.	415.7	236.8
UNAUGMENTED VACUUM AXIAL THRUST, LBF	28333	42756	42848
YAW-TO-AXIAL FORCE RATIO	0.0370	0.0097	0.0055
JET DEFLECTION ANGLE, DEG.	2.12	0.56	0.32
RESULTANT YAW FORCE INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	101	206	240
AXIAL-THRUST AUGMENTATION, LBF	759.	161.3	73.7
PERCENT AXIAL-THRUST AUGMENTATION	2.68	0.38	0.17
AXIAL-THRUST AUGMENTATION INJECTANT SPECIFIC IMPULSE, LBF-SEC./LBM	73.3	80.1	74.6

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. HS00131 MOTOR NO. PQA-102

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	-0.182	0.0	0.0	0.0	645.
2.1	0.100	-0.286	1.70	0.20	0.30	645.
4.2	0.200	-0.389	3.50	0.41	0.61	640.
6.4	0.300	-0.493	5.50	0.65	0.96	641.
6.8	0.320	-0.514	5.76	0.68	1.00	641.
8.5	0.400	-0.597	7.20	0.85	1.25	638.
10.6	0.500	-0.701	8.90	1.05	1.55	636.
12.7	0.600	-0.805	10.60	1.25	1.84	635.
13.7	0.648	-0.855	11.51	1.35	2.00	631.
14.8	0.700	-0.908	12.30	1.45	2.14	633.
16.9	0.800	-1.012	14.10	1.66	2.45	631.
19.1	0.900	-1.116	15.80	1.86	2.74	630.
21.2	1.000	-1.220	17.30	2.03	3.01	622.
31.8	1.500	-1.739	23.60	2.77	4.10	608.
42.4	2.000	-2.258	30.20	3.55	5.25	598.
53.0	2.500	-2.777	35.80	4.21	6.22	590.
63.6	3.000	-3.296	40.80	4.79	7.09	578.
74.2	3.500	-3.815	45.00	5.29	7.82	567.
84.7	4.000	-4.334	48.60	5.71	8.44	555.
95.3	4.500	-4.853	51.80	6.09	9.00	546.
105.9	5.000	-5.372	54.30	6.38	9.43	538.
116.5	5.500	-5.891	57.00	6.70	9.90	527.
120.8	5.700	-6.098	57.57	6.76	10.00	525.
127.1	6.000	-6.410	58.30	6.85	10.13	522.
148.3	7.000	-7.448	62.70	7.37	10.89	508.
169.5	8.000	-8.486	65.40	7.68	11.36	498.
190.7	9.000	-9.524	67.60	7.94	11.74	487.
211.9	10.000	-10.562	69.40	8.15	12.05	479.
233.1	11.000	-11.600	71.00	8.34	12.33	475.
250.0	11.800	-12.430	71.30	8.38	12.38	472.

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

TABLE III-1 (Concluded)

INJECTOR SERIAL NO. HSD0099 MOTOR NO. PQA-102

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 STRUNTIUM (LB/SEC)	CALIBRATION SUPPLY PRESSURE (PSIA)
0.0	0.0	-0.154	0.0	0.0	0.0	648.
2.1	0.100	-0.258	1.60	0.19	0.28	643.
4.2	0.200	-0.362	3.40	0.40	0.59	641.
6.3	0.300	-0.465	5.10	0.60	0.89	641.
7.1	0.340	-0.507	5.76	0.68	1.00	640.
8.4	0.400	-0.569	6.80	0.80	1.18	638.
10.5	0.500	-0.673	8.60	1.01	1.49	636.
12.6	0.600	-0.777	10.30	1.21	1.79	634.
14.4	0.685	-0.865	11.51	1.35	2.00	633.
14.7	0.700	-0.881	11.80	1.39	2.05	632.
16.8	0.800	-0.985	13.50	1.59	2.34	631.
18.9	0.900	-1.088	15.30	1.80	2.66	632.
21.0	1.000	-1.192	16.80	1.97	2.92	626.
31.5	1.500	-1.711	22.20	2.61	3.86	611.
42.0	2.000	-2.231	28.60	3.36	4.97	602.
52.5	2.500	-2.750	34.30	4.03	5.96	596.
63.0	3.000	-3.269	39.50	4.64	6.86	581.
73.5	3.500	-3.788	43.20	5.08	7.50	571.
84.0	4.000	-4.307	46.80	5.50	8.13	560.
94.5	4.500	-4.826	50.40	5.92	8.75	549.
105.0	5.000	-5.346	53.40	6.27	9.28	535.
115.5	5.500	-5.865	56.20	6.60	9.76	528.
121.4	5.780	-6.155	57.57	6.76	10.00	523.
126.1	6.000	-6.384	58.30	6.85	10.13	520.
147.1	7.000	-7.422	62.00	7.28	10.77	506.
168.1	8.000	-8.461	64.50	7.58	11.20	498.
189.1	9.000	-9.499	66.70	7.84	11.59	490.
210.1	10.000	-10.537	69.20	8.13	12.02	480.
231.1	11.000	-11.576	69.80	8.20	12.12	476.
250.0	11.900	-12.510	71.60	8.41	12.44	473.

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

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

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

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

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

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

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 = 7312.3

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

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

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)
23.	RT =	Roll control system torque, (or, moment), ft-lbf
	RT =	2.06 (FRC-1)

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13. ABSTRACT An LGM-30G Stage III solid-propellant rocket motor, PQA-102, 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 January 26, 1973. The roll control subsystem was independently tested off-motor on January 27, 1973. Motor ballistic, roll control system, thrust vector control, and thrust termination system performance was within model specification requirements. The motor was ignited at a pressure altitude of 102,000 ft. Motor ignition delay time was 86 msec. Motor thrust termination occurred at 60.18 sec at a chamber pressure of 75.3 psia. Motor action time was 60.18 sec during which the motor produced an unaugmented vacuum total impulse of 2,083,534 lbf-sec. The unaugmented vacuum specific impulse was 284.94 lbf-sec/lbm. The roll control subsystem structural integrity was satisfactory.

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