

UNCLASSIFIED

AD NUMBER

**AD841412**

LIMITATION CHANGES

TO:

**Approved for public release; distribution is unlimited.**

FROM:

**Distribution authorized to DoD only;  
Administrative/Operational Use; OCT 1968. Other  
requests shall be referred to NASA Marshall  
Space Flight Center, Huntsville, AL.**

AUTHORITY

**USAEDC ltr, 12 Jul 1974**

THIS PAGE IS UNCLASSIFIED

AEDC-TR-68-160

**ARCHIVE COPY  
DO NOT LOAN**

*cy1*



**ALTITUDE DEVELOPMENTAL TESTING  
OF THE J-2 ROCKET ENGINE IN  
PROPULSION ENGINE TEST CELL (J-4)  
(TESTS J4-1801-28 THROUGH J4-1801-33)**

**C. H. Kunz and H. J. Counts, Jr.**

**ARO, Inc.**

**October 1968**

This document has been approved for public release.

Its distribution is unlimited.

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Ala.

*Per AF Letter  
dated 12 July 74  
signed William  
D. Cole.*

**LARGE ROCKET FACILITY  
ARNOLD ENGINEERING DEVELOPMENT CENTER  
AIR FORCE SYSTEMS COMMAND  
ARNOLD AIR FORCE STATION, TENNESSEE**

AEDC TECHNICAL LIBRARY



5 0720 00031 7794

# ***NOTICES***

When U. S. Government drawings specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, or in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Qualified users may obtain copies of this report from the Defense Documentation Center.

References to named commercial products in this report are not to be considered in any sense as an endorsement of the product by the United States Air Force or the Government.

ALTITUDE DEVELOPMENTAL TESTING  
OF THE J-2 ROCKET ENGINE IN  
PROPULSION ENGINE TEST CELL (J-4)  
(TESTS J4-1801-28 THROUGH J4-1801-33)

C. H. Kunz and H. J. Counts, Jr.  
ARO, Inc.

Each transmittal of this document outside the Department of Defense must have prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Ala.

This document has been approved for public release  
its distribution is unlimited.

*Per AF Letter  
dtg 12 July 74  
Signed William O. Cole.*



## FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (I-E-J), under System 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. Program direction was provided by NASA/MSFC; engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2 rocket engine, and McDonnell Douglas Corporation, Missile and Space Systems Division, manufacturer of the S-IVB stage. The testing reported herein was conducted on February 15 and 22 and March 1, 8, 14, and 20, 1968, in Propulsion Engine Test Cell (J-4) of the Large Rocket Facility (LRF) under ARO Project No. KA1801. The manuscript was submitted for publication on June 21, 1968.

Information in this report is embargoed under the Department of State International Traffic in Arms Regulations. This report may be released to foreign governments by departments or agencies of the U. S. Government subject to approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama, or higher authority. Private individuals or firms require a Department of State export license.

This technical report has been reviewed and is approved.

Edgar D. Smith  
Major, USAF  
AF Representative, LRF  
Directorate of Test

Roy R. Croy, Jr.  
Colonel, USAF  
Director of Test

## ABSTRACT

Twenty-four firings and two fuel lead tests of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-28 through J4-1801-33 between February 15 and March 20, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application to the S-II stage of the Saturn V vehicle. The firings were accomplished at pressure altitudes ranging from 55,000 to 116,000 ft at engine start. The primary objective of these firings was to investigate fuel pump operation under conditions of lower than minimum engine model specification fuel pump net positive suction head and maximum thrust chamber fuel flow resistance utilizing an S-II stage center engine configuration fuel low pressure duct designed to simulate the fluid dynamic characteristics experienced during flight. Engine components were thermally conditioned to temperatures as expected during flight. Engine operation appeared to be satisfactory. The total accumulated firing duration for the six test periods was 190 sec. The total firing duration of this engine at AEDC through test period J4-1801-33 is 940 sec, resulting from 79 engine firings.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

This document has been approved for public release  
its distribution is unlimited

*Dr. A. F. Allen*  
*15 July 78*  
*signed William*  
*O. Cook*

## CONTENTS

|                                      | <u>Page</u> |
|--------------------------------------|-------------|
| ABSTRACT . . . . .                   | iii         |
| NOMENCLATURE . . . . .               | xii         |
| I. INTRODUCTION . . . . .            | 1           |
| II. APPARATUS . . . . .              | 1           |
| III. PROCEDURE . . . . .             | 7           |
| IV. RESULTS AND DISCUSSION . . . . . | 8           |
| V. SUMMARY OF RESULTS. . . . .       | 29          |
| REFERENCES. . . . .                  | 30          |

## APPENDIXES

## I. ILLUSTRATIONS

Figure

|                                                                                       |    |
|---------------------------------------------------------------------------------------|----|
| 1. Test Cell J-4 Complex . . . . .                                                    | 33 |
| 2. Test Cell J-4, Artist's Conception . . . . .                                       | 34 |
| 3. Engine Details . . . . .                                                           | 35 |
| 4. S-II Center Engine Configuration Fuel Low Pressure<br>Duct . . . . .               | 36 |
| 5. S-IVB Battleship Stage/J-2 Engine Schematic . . . . .                              | 40 |
| 6. Engine Schematic . . . . .                                                         | 41 |
| 7. Engine Start Logic Schematic . . . . .                                             | 42 |
| 8. Engine Start and Shutdown Sequence . . . . .                                       | 43 |
| 9. Engine Start Conditions for Pump Inlets and the<br>Start Tank . . . . .            | 45 |
| 10. Thrust Chamber Thermal Conditioning History,<br>Test 28A . . . . .                | 48 |
| 11. Engine Ambient Pressure, Test 28A. . . . .                                        | 49 |
| 12. Fuel Low Pressure Duct Temperature and Pressure<br>Transients, Test 28A . . . . . | 50 |
| 13. Thrust Chamber Thermal Conditioning History,<br>Test 28B . . . . .                | 51 |
| 14. Engine Ambient Pressure, Test 28B. . . . .                                        | 52 |

| <u>Figure</u> |                                                                                  | <u>Page</u> |
|---------------|----------------------------------------------------------------------------------|-------------|
| 15.           | Fuel Low Pressure Duct Temperature and Pressure Transients, Test 28B . . . . .   | 53          |
| 16.           | Thrust Chamber Thermal Conditioning History, Firing 28C . . . . .                | 54          |
| 17.           | Engine Ambient and Combustion Chamber Pressures, Firing 28C . . . . .            | 55          |
| 18.           | Engine Transient Operation, Firing 28C. . . . .                                  | 56          |
| 19.           | Fuel Low Pressure Duct Temperature and Pressure Transients, Firing 28C . . . . . | 58          |
| 20.           | Thermal Conditioning History of Engine Components, Firing 29A . . . . .          | 59          |
| 21.           | Engine Ambient and Combustion Chamber Pressures, Firing 29A . . . . .            | 61          |
| 22.           | Engine Transient Operation, Firing 29A. . . . .                                  | 62          |
| 23.           | Fuel Pump Start Transient Performance, Firing 29A . .                            | 66          |
| 24.           | Fuel Low Pressure Duct Performance, Firing 29A . .                               | 67          |
| 25.           | Thermal Conditioning History of Engine Components, Firing 29B. . . . .           | 68          |
| 26.           | Engine Ambient and Combustion Chamber Pressures, Firing 29B. . . . .             | 70          |
| 27.           | Engine Transient Operation, Firing 29B. . . . .                                  | 71          |
| 28.           | Fuel Pump Start Transient Performance, Firing 29B. .                             | 75          |
| 29.           | Fuel Low Pressure Duct Performance, Firing 29B. . .                              | 76          |
| 30.           | Thermal Conditioning History of Engine Components, Firing 29C. . . . .           | 77          |
| 31.           | Engine Ambient and Combustion Chamber Pressures, Firing 29C. . . . .             | 79          |
| 32.           | Engine Transient Operation, Firing 29C. . . . .                                  | 80          |
| 33.           | Fuel Pump Start Transient Performance, Firing 29C. .                             | 84          |
| 34.           | Fuel Low Pressure Duct Performance, Firing 29C. . .                              | 85          |
| 35.           | Thermal Conditioning History of Engine Components, Firing 29D. . . . .           | 86          |
| 36.           | Engine Ambient and Combustion Chamber Pressures, Firing 29D. . . . .             | 88          |

| <u>Figure</u>                                                                  | <u>Page</u> |
|--------------------------------------------------------------------------------|-------------|
| 37. Engine Transient Operation, Firing 29D . . . . .                           | 89          |
| 38. Fuel Pump Start Transient Performance, Firing 29D . .                      | 91          |
| 39. Fuel Low Pressure Duct Performance, Firing 29D . . .                       | 92          |
| 40. Thermal Conditioning History of Engine Components,<br>Firing 29E . . . . . | 93          |
| 41. Engine Ambient and Combustion Chamber Pressures,<br>Firing 29E . . . . .   | 95          |
| 42. Engine Transient Operation, Firing 29E . . . . .                           | 96          |
| 43. Fuel Pump Start Transient Performance, Firing 29E . .                      | 100         |
| 44. Fuel Low Pressure Duct Performance, Firing 29E . . .                       | 101         |
| 45. Thermal Conditioning History of Engine Components,<br>Firing 30A . . . . . | 102         |
| 46. Engine Ambient and Combustion Chamber Pressures,<br>Firing 30A . . . . .   | 104         |
| 47. Engine Transient Operation, Firing 30A . . . . .                           | 105         |
| 48. Fuel Pump Start Transient Performance, Firing 30A . .                      | 109         |
| 49. Fuel Low Pressure Duct Performance, Firing 30A . . .                       | 110         |
| 50. Thermal Conditioning History of Engine Components,<br>Firing 31A . . . . . | 111         |
| 51. Engine Ambient and Combustion Chamber Pressures,<br>Firing 31A . . . . .   | 113         |
| 52. Engine Transient Operation, Firing 31A . . . . .                           | 114         |
| 53. Fuel Pump Start Transient Performance, Firing 31A . .                      | 118         |
| 54. Fuel Low Pressure Duct Performance, Firing 31A . . .                       | 119         |
| 55. Thermal Conditioning History of Engine Components,<br>Firing 31B . . . . . | 120         |
| 56. Engine Ambient and Combustion Chamber Pressures,<br>Firing 31B . . . . .   | 122         |
| 57. Engine Transient Operation, Firing 31B . . . . .                           | 123         |
| 58. Fuel Pump Start Transient Performance, Firing 31B . .                      | 127         |
| 59. Fuel Low Pressure Duct Performance, Firing 31B . . .                       | 128         |
| 60. Thermal Conditioning History of Engine Components,<br>Firing 31C . . . . . | 129         |

| <u>Figure</u>                                                                  | <u>Page</u> |
|--------------------------------------------------------------------------------|-------------|
| 61. Engine Ambient and Combustion Chamber Pressures,<br>Firing 31C . . . . .   | 131         |
| 62. Engine Transient Operation, Firing 31C . . . . .                           | 132         |
| 63. Fuel Pump Start Transient Performance, Firing 31C . . .                    | 134         |
| 64. Fuel Low Pressure Duct Performance, Firing 31C . . .                       | 135         |
| 65. Thermal Conditioning History of Engine Components,<br>Firing 31D . . . . . | 136         |
| 66. Engine Ambient and Combustion Chamber Pressures,<br>Firing 31D . . . . .   | 138         |
| 67. Engine Transient Operation, Firing 31D . . . . .                           | 139         |
| 68. Fuel Pump Start Transient Performance, Firing 31D . .                      | 141         |
| 69. Fuel Low Pressure Duct Performance, Firing 31D . . .                       | 142         |
| 70. Thermal Conditioning History of Engine Components,<br>Firing 31E . . . . . | 143         |
| 71. Engine Ambient and Combustion Chamber Pressures,<br>Firing 31E . . . . .   | 145         |
| 72. Engine Transient Operation, Firing 31E . . . . .                           | 146         |
| 73. Fuel Pump Start Transient Performance, Firing 31E . .                      | 148         |
| 74. Fuel Low Pressure Duct Performance, Firing 31E . . .                       | 149         |
| 75. Thermal Conditioning History of Engine Components,<br>Firing 32A . . . . . | 150         |
| 76. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32A . . . . .   | 152         |
| 77. Engine Transient Operation, Firing 32A . . . . .                           | 153         |
| 78. Fuel Pump Start Transient Performance, Firing 32A . .                      | 157         |
| 79. Fuel Low Pressure Duct Performance, Firing 32A . . .                       | 158         |
| 80. Thermal Conditioning History of Engine Components,<br>Firing 32B . . . . . | 159         |
| 81. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32B . . . . .   | 161         |
| 82. Engine Transient Operation, Firing 32B . . . . .                           | 162         |
| 83. Fuel Pump Start Transient Performance, Firing 32B . .                      | 166         |

| <u>Figure</u>                                                                   | <u>Page</u> |
|---------------------------------------------------------------------------------|-------------|
| 84. Fuel Low Pressure Duct Performance, Firing 32B . . .                        | 167         |
| 85. Thermal Conditioning History of Engine Components,<br>Firing 32C . . . . .  | 168         |
| 86. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32C . . . . .    | 170         |
| 87. Engine Transient Operation, Firing 32C. . . . .                             | 171         |
| 88. Fuel Pump Start Transient Performance, Firing 32C . .                       | 173         |
| 89. Fuel Low Pressure Duct Performance, Firing 32C . . .                        | 174         |
| 90. Thermal Conditioning History of Engine Components,<br>Firing 32D . . . . .  | 175         |
| 91. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32D . . . . .    | 177         |
| 92. Engine Transient Operation, Firing 32D. . . . .                             | 178         |
| 93. Fuel Pump Start Transient Performance, Firing 32D . .                       | 180         |
| 94. Fuel Low Pressure Duct Performance, Firing 32D . . .                        | 181         |
| 95. Thermal Conditioning History of Engine Components,<br>Firing 32E . . . . .  | 182         |
| 96. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32E . . . . .    | 184         |
| 97. Engine Transient Operation, Firing 32E. . . . .                             | 185         |
| 98. Fuel Pump Start Transient Performance, Firing 32E . .                       | 187         |
| 99. Fuel Low Pressure Duct Performance, Firing 32E . . .                        | 188         |
| 100. Thermal Conditioning History of Engine Components,<br>Firing 32F . . . . . | 189         |
| 101. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32F . . . . .   | 191         |
| 102. Engine Transient Operation, Firing 32F. . . . .                            | 192         |
| 103. Fuel Pump Start Transient Performance, Firing 32F . .                      | 194         |
| 104. Fuel Low Pressure Duct Performance, Firing 32F . . .                       | 195         |
| 105. Thermal Conditioning History of Engine Components,<br>Firing 32G . . . . . | 196         |
| 106. Engine Ambient and Combustion Chamber Pressures,<br>Firing 32G . . . . .   | 198         |

| <u>Figure</u>                                                                   | <u>Page</u> |
|---------------------------------------------------------------------------------|-------------|
| 107. Engine Transient Operation, Firing 32G . . . . .                           | 199         |
| 108. Fuel Pump Start Transient Performance, Firing 32G . .                      | 201         |
| 109. Fuel Low Pressure Duct Performance, Firing 32G . . .                       | 202         |
| 110. Thermal Conditioning History of Engine Components,<br>Firing 33A . . . . . | 203         |
| 111. Engine Ambient and Combustion Chamber Pressures,<br>Firing 33A . . . . .   | 205         |
| 112. Engine Transient Operation, Firing 33A . . . . .                           | 206         |
| 113. Fuel Pump Start Transient Performance, Firing 33A . .                      | 210         |
| 114. Fuel Low Pressure Duct Performance, Firing 33A . . .                       | 211         |
| 115. Thermal Conditioning History of Engine Components,<br>Firing 33B . . . . . | 212         |
| 116. Engine Ambient and Combustion Chamber Pressures,<br>Firing 33B . . . . .   | 214         |
| 117. Engine Transient Operation, Firing 33B . . . . .                           | 215         |
| 118. Fuel Pump Start Transient Performance, Firing 33B . .                      | 219         |
| 119. Fuel Low Pressure Duct Performance, Firing 33B . . .                       | 220         |
| 120. Thermal Conditioning History of Engine Components,<br>Firing 33C . . . . . | 221         |
| 121. Engine Ambient and Combustion Chamber Pressures,<br>Firing 33C . . . . .   | 223         |
| 122. Engine Transient Operation, Firing 33C . . . . .                           | 224         |
| 123. Fuel Pump Start Transient Performance, Firing 33C . .                      | 228         |
| 124. Fuel Low Pressure Duct Performance, Firing 33C . . .                       | 229         |
| 125. Thermal Conditioning History of Engine Components,<br>Firing 33D . . . . . | 230         |
| 126. Engine Ambient and Combustion Chamber Pressures,<br>Firing 33D . . . . .   | 232         |
| 127. Engine Transient Operation, Firing 33D . . . . .                           | 233         |
| 128. Fuel Pump Start Transient Performance, Firing 33D . .                      | 237         |
| 129. Fuel Low Pressure Duct Performance, Firing 33D . . .                       | 238         |



| <u>Figure</u>                                                                                             | <u>Page</u> |
|-----------------------------------------------------------------------------------------------------------|-------------|
| 130. Thermal Conditioning History of Engine Components,<br>Firing 33E . . . . .                           | 239         |
| 131. Engine Ambient and Combustion Chamber Pressures,<br>Firing 33E . . . . .                             | 241         |
| 132. Engine Transient Operation, Firing 33E . . . . .                                                     | 242         |
| 133. Fuel Pump Start Transient Performance, Firing 33E . .                                                | 246         |
| 134. Fuel Low Pressure Duct Performance, Firing 33E . . .                                                 | 247         |
| 135. Thrust Chamber Temperature Effect on Fuel Pump<br>Operating Characteristics . . . . .                | 248         |
| 136. Fuel Pump NPSH Effect on Gas Generator Initial<br>Peak Temperature . . . . .                         | 249         |
| 137. Thrust Chamber Temperature Effect on Fuel Pump<br>Stall Margin during Start Tank Discharge . . . . . | 250         |
| 138. Fuel Pump Start Transient Flow Coefficient, $\phi$ . . . . .                                         | 251         |
| <br>II. TABLES                                                                                            |             |
| I. Major Engine Components . . . . .                                                                      | 252         |
| II. Summary of Engine Orifices . . . . .                                                                  | 253         |
| III. Engine Modifications (between Tests J4-1801-28<br>and J4-1801-33) . . . . .                          | 254         |
| IV. Engine Component Replacements (between<br>Tests J4-1801-28 and J4-1801-33) . . . . .                  | 255         |
| V. Engine Purge and Component Conditioning<br>Sequence . . . . .                                          | 256         |
| VI. Summary of Test Requirements and Results . . .                                                        | 257         |
| VII. Engine Valve Timings . . . . .                                                                       | 260         |
| VIII. Engine Performance Summary . . . . .                                                                | 263         |
| III. INSTRUMENTATION . . . . .                                                                            | 264         |
| IV. METHODS OF CALCULATION (PERFORMANCE<br>PROGRAM) . . . . .                                             | 280         |
| V. METHODS OF CALCULATION (HEAD RISE AND FLOW<br>COEFFICIENTS) . . . . .                                  | 289         |

## NOMENCLATURE

|       |                                                                                                                                        |
|-------|----------------------------------------------------------------------------------------------------------------------------------------|
| A     | Area, in. <sup>2</sup>                                                                                                                 |
| ASI   | Augmented spark igniter                                                                                                                |
| ES    | Engine start, designated as the time that helium control and ignition phase solenoids are energized                                    |
| GG    | Gas generator                                                                                                                          |
| MOV   | Main oxidizer valve                                                                                                                    |
| NPSH  | Net positive suction head, ft                                                                                                          |
| STDV  | Start tank discharge valve                                                                                                             |
| $t_0$ | Defined as the time at which the opening signal is applied to the start tank discharge valve solenoid                                  |
| VSC   | Vibration safety counts, defined as the time at which engine vibration was in excess of 150 g rms in a 960- to 6000-Hz frequency range |

## SUBSCRIPTS

|   |        |
|---|--------|
| f | Force  |
| m | Mass   |
| t | Throat |

## SECTION I INTRODUCTION

Testing of the Rocketdyne J-2 rocket engine using an S-IVB battleship stage has been in progress since July 1966 at AEDC in support of the J-2 engine application on the Saturn IB and Saturn V launch vehicles for the NASA Apollo Program. The 24 engine firings and two fuel lead tests reported herein were conducted during test periods J4-1801-28 through 33 on February 15 and 22 and March 1, 8, 14, and 20, 1968, respectively, in the Propulsion Engine Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Large Rocket Facility (LRF). These firings were to evaluate both the engine and fuel pump start transient performance with (1) lower than minimum engine model specification fuel pump NPSH during the start transient as required on AS-502 and subsequent flights and (2) warmer than maximum expected S-II thrust chamber temperature utilizing a 230,000-lbf-thrust configuration engine and an S-II stage center engine configured fuel low pressure duct. Test periods J4-1801-28 and 29 were conducted at pressure altitudes of approximately 55,000 ft (facility steam ejector system inoperative), whereas test period 30 and subsequent test periods were conducted at pressure altitudes of approximately 100,000 ft (geometric pressure altitude, Z, Ref. 1) (facility steam ejector system operative) at engine start. Engine components were conditioned to S-II interstage temperatures predicted for flight. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

## SECTION II APPARATUS

### 2.1 TEST ARTICLE

The test article was a J-2 rocket engine (S/N J-2047) (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and has a thrust rating of 230,000 lbf at an oxidizer-to-fuel ratio of 5.5. An S-IVB battleship stage was used to supply propellant to the engine. The fuel low pressure duct was replaced for this series of tests with a special duct (Fig. 4) designed to simulate the fluid dynamic characteristics of the center engine duct of the S-II stage. This duct was designed to decrease the fuel pump inlet total pressure during initial acceleration of fuel by the pump 4.5 psi below the level experienced at  $t_0$  and to experience 1.5-psi friction loss under main-stage flow conditions.

Heat was added to the duct with heater tape, as indicated in Fig. 4, to simulate temperature transient experienced on flight AS-501. A schematic of the battleship stage is presented in Fig. 5.

Listings of major engine components and engine orifices of this test series are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed since the previous test period are presented in Tables III and IV, respectively.

### 2.1.1 J-2 Rocket Engine

The J-2 rocket engine (Figs. 3 and 6, Ref. 3) features the following major components:

1. Thrust Chamber - The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in. -diam combustion chamber (8.0 in. long from the injector mounting to the throat inlet) with a characteristic length ( $L^*$ ) of 24.6 in., a 170.4-in.<sup>2</sup> throat area, and a divergent nozzle with an expansion ratio of 27.1. Thrust chamber length (from the injector flange to the nozzle exit) is 107 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector.
2. Thrust Chamber Injector - The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 25.0 and 16.0 in.<sup>2</sup>, respectively. The porous material, forming the injector face, allows approximately 3.5 percent of total fuel flow to transpiration cool the face of the injector.
3. Augmented Spark Igniter - The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.
4. Fuel Turbopump - The turbopump is composed of a two-stage turbine-stator assembly, an inducer, and a seven-stage axial-flow pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 38,215 ft (1248 psia) of liquid hydrogen at a flow rate of 8585 gpm for a rotor speed of 27,265 rpm.
5. Oxidizer Turbopump - The turbopump is composed of a two-stage turbine-stator assembly and a single-stage centrifugal

- pump. The pump is self lubricated and nominally produces, at rated conditions, a head rise of 2170 ft (1107 psia) of liquid oxygen at a flow rate of 2965 gpm for a rotor speed of 8688 rpm.
6. Gas Generator - The gas generator consists of a combustion chamber containing two spark plugs, a pneumatically operated control valve containing oxidizer and fuel poppets, and an injector assembly. The oxidizer and fuel poppets provide a fuel lead to the gas generator combustion chamber. The high energy gases produced by the gas generator are directed to the fuel turbine and then to the oxidizer turbine (through the turbine crossover duct) before being exhausted into the thrust chamber at an area ratio ( $A/A_t$ ) of approximately 11.
  7. Propellant Utilization Valve - The motor-driven propellant utilization valve is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.
  8. Propellant Bleed Valves - The pneumatically operated fuel and oxidizer bleed valves provide pressure relief for the boiloff of propellants trapped between the battleship stage prevalves and main propellant valves at engine shutdown.
  9. Integral Hydrogen Start Tank and Helium Tank - The integral tanks consist of a 7258-in.<sup>3</sup> sphere for hydrogen with a 1000-in.<sup>3</sup> sphere for helium located within it. Pressurized gaseous hydrogen in the start tank provides the initial energy source for spinning the propellant turbopumps during engine start. The helium tank provides a helium pressure supply to the engine pneumatic control system.
  10. Oxidizer Turbine Bypass Valve - The pneumatically actuated oxidizer turbine bypass valve provides control of the fuel turbine exhaust gases directed to the oxidizer turbine in order to control the oxidizer-to-fuel turbine spinup relationship. The fuel turbine exhaust gases which bypass the oxidizer turbine are discharged into the thrust chamber.
  11. Main Oxidizer Valve - The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high pressure duct between the turbopump and the main injector. The first-stage actuator positions the main oxidizer valve at the 14-deg position to obtain initial thrust chamber ignition; the second-stage actuator ramps the main oxidizer valve full open to accelerate the engine to main-stage operation.

12. Main Fuel Valve - The main fuel valve is a pneumatically actuated butterfly-type valve located in the fuel high pressure duct between the turbopump and the fuel manifold.
13. Pneumatic Control Package - The pneumatic control package controls all pneumatically operated engine valves and purges.
14. Electrical Control Assembly - The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation.
15. Primary and Auxiliary Flight Instrumentation Packages - The instrumentation packages contain sensors required to monitor critical engine parameters. The packages provide environmental control for the sensors.

### 2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 46,000 lb of liquid hydrogen and 199,000 lb of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant pre-valves, in the low pressure ducts (external to the tanks) interfacing the stage and the engine, retain propellant in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Propellant recirculation pumps in both fuel and oxidizer tanks are utilized to circulate propellants through the low pressure ducts and turbopumps before engine start to stabilize hardware temperatures near normal operating levels and to prevent propellant temperature stratification. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during S-II flight were routed to the respective facility venting systems.

## 2.2 TEST CELL

Test Cell J-4, Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf-thrust capacity. The cell consists of four major components (1) test capsule, 48 ft in diameter and 82 ft in height,

situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), and liquid oxygen and gaseous helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 4.

The battleship stage and the J-2 engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous nitrogen purge system for continuously inerting the normal air in-leakage of the cell; (2) a gaseous nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

An engine component conditioning system was provided for temperature conditioning engine components. The conditioning system utilized a liquid hydrogen-helium heat exchanger to provide cold helium gas for component conditioning. Components requiring temperature conditioning were the thrust chamber, turbine components, start tank discharge valve, gas generator control valve (tests 31 and 32 only), main oxidizer valve second-stage actuator, and fuel low pressure duct. Helium was routed internally through the crossover duct and tubular-walled thrust chamber and externally over the start tank discharge valve and gas generator control valve. The main oxidizer valve second-stage actuator was conditioned by admitting propellants into the engine. The

fuel low pressure duct was thermally conditioned utilizing the heater tape as shown in Fig. 4.

### 2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters and (2) facility instrumentation which was provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. The propellant recirculation flow rates were also monitored with turbine-type flowmeters. Vibrations were measured by accelerometers mounted on the oxidizer injector dome and on the turbopumps. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system (MicroSADIC®) scanning each parameter at 40 samples per second and recording on magnetic tape, (2) single-input, continuous-recording FM systems recording on magnetic tape, (3) photographically recording galvanometer oscillographs, (4) direct-inking, null-balance potentiometer-type X-Y plotters and strip charts, and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.



## 2.4 CONTROLS

Control of the J-2 engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 7. The sequence of engine events for a normal start and shutdown is presented in Figs. 8a and b. Two control logics for sequencing the stage pre-valves and recirculation systems with engine start for simulating engine flight start sequences are presented in Figs. 8c and d.

## SECTION III PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished, and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants and engine pneumatic and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer dome, gas generator oxidizer injector, and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for the engine firing. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning

system. Components which required temperature conditioning were the thrust chamber, the turbine start tank discharge valve, gas generator control valve (tests 31 and 32), main oxidizer valve second-stage actuator, and fuel low pressure duct. Table V presents the engine purges and thermal conditioning operations during the terminal count-down and immediately following the engine firing.

## SECTION IV RESULTS AND DISCUSSION

### 4.1 TEST SUMMARY

#### 4.1.1 General

Twenty-four firings and two fuel lead tests of the J-2 rocket engine (S/N J-2047) were conducted during test periods J4-1801-28 through J4-1801-33 for a total firing duration of 190 sec. The total accumulated firing duration for this engine at AEDC through test period J4-1801-33 (March 20, 1968) is 936 sec.

The principle objectives of these test periods were to evaluate both the engine and fuel pump start transient performance with (1) lower than minimum engine model specification fuel pump NPSH during the start transient as required on AS-502 and subsequent flights and with (2) warmer than maximum expected S-II stage thrust chamber temperatures. Other engine components were thermally conditioned to temperatures as expected and/or observed on flight AS-501.

A special duct designed to simulate the fluid dynamic characteristics of the S-II stage center engine low pressure fuel duct was utilized for this test series. This duct was designed to decrease the fuel pump inlet total pressure during initial acceleration of fuel by the pump 4.5 psi below the level experienced at  $t_0$  and to experience a 1.5-psi friction loss with main-stage flow conditions. Test data indicate actual pressure drop during acceleration of fuel was 4.6 psi, and friction losses resulting from main-stage flow conditions were calculated to be 1.6 psi.

Firing 29B and all subsequent firings of this series were conducted with below minimum model specification fuel pump NPSH during the starting transient (Ref. 5). Engine operation under these conditions was satisfactory except for firing 29D, which resulted in a premature engine cutoff by the engine safety cutoff system because of an excessive gas generator outlet temperature initial peak of 2460°F. For this firing,

the fuel pump inlet pressure dropped below vapor pressure for 120 msec during the starting transient. Fuel pump inlet pressure targets for test periods subsequent to test 29 were extended to provide an additional 15 ft of NPSH at engine start.

Thirteen engine firings were conducted with thrust chamber temperatures at engine start ranging from  $-114$  to  $+46^{\circ}\text{F}$ , which is warmer than expected for flight with present launch redline limits. All of these firings conducted with thrust chamber temperature warmer than  $-65^{\circ}\text{F}$  exhibited insufficient stall margin. Firing 32D conducted with an average thrust chamber temperature of  $-91^{\circ}\text{F}$  at engine start experienced a low level stall margin of 90 gpm; however, this firing was prematurely terminated at  $t_0 + 0.661$  sec by a valid cutoff signal from the stall approach monitor. This is a safety cutoff (not part of the engine safety cutoff system) which will terminate a firing if fuel flow is below 3200 gpm for any 55-msec period after  $t_0 + 0.585$  sec.

The facility steam ejector system was inoperative for test periods J4-1801-28 and J4-1801-29; therefore, these tests were conducted at pressure altitudes of approximately 55,000 ft. This system was operative on subsequent test periods which experienced pressure altitudes of approximately 100,000 ft at engine start.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are shown in Table VII. Calculated engine steady-state performance data are shown in Table VIII. Methods of calculations are shown in Appendix IV. Figure 9 shows engine start conditions for pump inlets and the hydrogen start tank for all firings. Specific test objectives and a brief summary of results obtained for each firing are presented in the following sections.

#### **4.1.2 Test J4-1801-28A**

##### **4.1.2.1 Objectives**

Conduct an 8-sec fuel lead test to be terminated at  $t_0$  to establish fuel low pressure duct (1) integrity with low fuel flow, (2) temperature transients experienced during the fuel lead, and (3) pressure transients resulting from closure of the main fuel valve.

##### **4.1.2.2 Results**

The fuel lead test was successfully accomplished, and all test objectives were obtained. The fuel low pressure duct integrity was

satisfactory under these test conditions. Thermal conditioning history of the thrust chamber is shown in Fig. 10. Engine ambient pressure experienced during the test is shown in Fig. 11. Fuel low pressure duct temperature and pressure transients experienced during the test are presented in Fig. 12.

#### **4.1.3 Test J4-1801-28B**

##### **4.1.3.1 Objectives**

Conduct an 8-sec fuel lead test (repeat of test 28A) to be terminated at  $t_0$  to further establish fuel low pressure duct (1) integrity with low fuel flow, (2) temperature transients experienced during the fuel lead, and (3) pressure transients resulting from closure of the main fuel valve.

##### **4.1.3.2 Results**

The fuel lead test was successfully accomplished, and all objectives were obtained. The fuel low pressure duct integrity was found to be satisfactory under these test conditions. Thermal conditioning history of the thrust chamber is presented in Fig. 13. Engine ambient pressure experienced during the test is presented in Fig. 14. Fuel low pressure duct pressure and temperature transients experienced during the test are shown in Fig. 15.

#### **4.1.4 Firing J4-1801-28C**

##### **4.1.4.1 Objectives**

Conduct a 0.550-sec engine firing to evaluate fuel low pressure duct integrity.

##### **4.1.4.2 Results**

The firing was successfully accomplished, and all test objectives were obtained. The fuel low pressure duct integrity was found to be satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 16 through 18, respectively. Fuel low pressure duct pressure and temperature transients experienced during the firing are shown in Fig. 19.

#### **4.1.5 Firing J4-1801-29A**

##### **4.1.5.1 Objectives**

Conduct a 7.5-sec engine firing to determine fuel low pressure duct friction losses during engine main-stage operation and magnitude of fuel pump inlet pressure drop during initial acceleration of fuel by the pump, with approximately 60 percent of maximum engine model specification fuel pump NPSH (1068 ft) at engine start.

##### **4.1.5.2 Results**

The firing was successfully accomplished, and all test objectives were obtained. Fuel low pressure duct friction losses during main stage were calculated to be approximately 1.6 psi (difference in total pressure between fuel tank ullage and fuel pump inlet). Fuel pump inlet pressure decreased 4.6 psi during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 20 through 22, respectively. Fuel pump start transient head/flow data are shown in Fig. 23. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 24.

#### **4.1.6 Firing J4-1801-29B**

##### **4.1.6.1 Objectives**

Conduct a 7.5-sec firing to evaluate the engine starting transient and fuel pump operation with -240°F and 1400-psia start tank gas conditions (high starting energy), -275°F thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

##### **4.1.6.2 Results**

The firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump operation under these test conditions were satisfactory. Fuel pump inlet pressure dropped below vapor pressure for 25 msec during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 25 through 27, respectively. Fuel pump start transient head/flow data are shown in Fig. 28. Fuel low pressure duct temperature

and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 29.

#### **4.1.7 Firing J4-1801-29C**

##### **4.1.7.1 Objectives**

Conduct a 7.5-sec firing to evaluate engine starting transients and fuel pump operation with  $-240^{\circ}\text{F}$  and 1400-psia start tank gas conditions (high starting energy),  $-150^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

##### **4.1.7.2 Results**

The firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump operation under these test conditions were satisfactory. Fuel pump inlet pressure dropped below vapor pressure for 100 msec during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 30 through 32, respectively. Fuel pump start transient head/flow data are shown in Fig. 33. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 34.

#### **4.1.8 Firing J4-1801-29D**

##### **4.1.8.1 Objectives**

Conduct a 7.5-sec firing to evaluate the engine starting transient and fuel pump operation with  $-300^{\circ}\text{F}$  and 1300-psia start tank gas conditions (high starting energy),  $-275^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

##### **4.1.8.2 Results**

All starting conditions were within starting targets; however, the firing was prematurely terminated by the engine safety cutoff system at  $t_0 + 1.1$  sec because of an excessive gas generator outlet temperature initial peak of  $2460^{\circ}\text{F}$ . Fuel pump inlet pressure dropped below vapor pressure for 120 msec during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 35 through 37,

respectively. Fuel pump start transient head/flow data are shown in Fig. 38. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 39.

#### **4.1.9 Firing J4-1801-29E**

##### **4.1.9.1 Objectives**

Conduct a 7.5-sec firing to evaluate the engine starting transient and fuel pump operation with  $-300^{\circ}\text{F}$  and 1300-psia start tank gas conditions (high starting energy),  $-150^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 110 ft at engine start.

##### **4.1.9.2 Results**

The engine firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump operation under these conditions were satisfactory. Fuel pump inlet pressure dropped below vapor pressure for 25 msec during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressure experienced during the firing, and engine start and shutdown transients are presented in Figs. 40 through 42, respectively. Fuel pump start transient head/flow data are shown in Fig. 43. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are shown in Fig. 44.

#### **4.1.10 Firing J4-1801-30A**

##### **4.1.10.1 Objectives**

Conduct a 7.5-sec firing to evaluate engine buildup time and fuel pump stall margin with  $-140^{\circ}\text{F}$  and 1250-psia start tank conditions (low starting energy),  $-275^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.10.2 Results**

The firing was successfully accomplished, and all test objectives were obtained. Main-stage operation was attained at  $t_0 + 2.192$  sec (as indicated by the time at which chamber pressure attained 550 psia). The fuel pump minimum high level stall margin was 250 gpm. This is the smallest high level stall margin noted to date at AEDC. Fuel pump NPSH dropped to 20 ft during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and

combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 45 through 47, respectively. Fuel pump start transient head/flow data are shown in Fig. 48. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 49.

#### **4.1.11 Firing J4-1801-31A**

##### **4.1.11.1 Objectives**

Conduct a 32.5-sec firing to evaluate engine buildup time and fuel pump high level stall margin with  $-300^{\circ}\text{F}$  and 1300-psia start tank gas conditions (high starting energy),  $-275^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.11.2 Results**

The engine firing was successfully accomplished, and all primary test objectives were obtained. Power was not supplied to the propellant utilization valve control panel; therefore the desired mixture ratio change could not be accomplished. The valve remained in the desired position during the start transient. Main-stage operation was attained at  $t_0 + 2.004$  sec. Fuel pump high level stall margin was 550 gpm. Fuel pump NPSH dropped to 40 ft during initial acceleration of fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 50 through 52, respectively. Fuel pump start transient head/flow data are shown in Fig. 53. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are shown in Fig. 54.

#### **4.1.12 Firing J4-1801-31B**

##### **4.1.12.1 Objectives**

Conduct a 32.5-sec firing to evaluate the engine starting transient and fuel pump operation with  $-200^{\circ}\text{F}$  and 1200-psia start tank gas conditions (low starting energy),  $-275^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.12.2 Results**

The firing was successfully accomplished, and all test objectives were obtained. The engine starting transient and fuel pump performance



under these conditions were satisfactory. Fuel pump NPSH dropped to 40 ft during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 55 through 57, respectively. Engine steady-state performance data are shown in Table VIII. Fuel pump start transient head/flow data are shown in Fig. 58. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 59.

Abnormal chillover of turbine hardware after firing 31B resulted from a leaking gas generator fuel poppet. Therefore, test requirements for subsequent firings were revised to prevent gas generator ignition by selecting a run duration of 0.600 sec. Also, because of this leak, the fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within the desired limits.

#### **4.1.13 Firing J4-1801-31C**

##### **4.1.13.1 Objectives**

Conduct a 0.600-sec partial transition firing to evaluate fuel pump low level stall margin with +50°F thrust chamber temperature, 1400-psia and -240°F start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.13.2 Results**

The partial transition firing was successfully accomplished, and the test objective was obtained. Fuel pump head/flow conditions became such that the stall region was entered at  $t_0 + 0.52$  sec. No indication of pump recovery was observed. The fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within desired target limits because of a gas generator fuel poppet leak. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 60 through 62, respectively. Fuel pump start transient head/flow data are shown in Fig. 63. Fuel low pressure duct temperature, pressure transients experienced during the firing, and fuel pump NPSH are shown in Fig. 64.

#### **4.1.14 Firings J4-1801-31D**

##### **4.1.14.1 Objectives**

Conduct a 0.600-sec partial transition firing to evaluate fuel pump low level stall margin with 0°F thrust chamber temperature, 1400-psia and -240°F start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.14.2 Results**

The partial transition firing was successfully accomplished, and the test objective was obtained. Fuel pump head/flow conditions became such that the stall region was entered at  $t_0 + 0.52$  sec. No indication of pump recovery was observed. The fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within desired target limits because of a gas generator fuel poppet leak. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are presented in Figs. 65 through 67, respectively. Fuel pump start transient head/flow data are shown in Fig. 68. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are presented in Fig. 69.

#### **4.1.15 Firing J4-1801-31E**

##### **4.1.15.1 Objectives**

Conduct a 0.600-sec partial transition firing to evaluate fuel pump low level stall margin at a -50°F thrust chamber temperature, 1400-psia and -240°F start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.15.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump start transient head/flow conditions were such that the stall region was entered by 150 gpm when cutoff occurred. Flow had increased approximately 1000 gpm before the main fuel valve began to close. The fuel turbine discharge conditioning temperature (TFTD-2) could not be maintained within desired target limits because of a gas generator fuel poppet leak. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 70 through 72, respectively. Fuel pump start transient

head/flow data are shown in Fig. 73. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 74.

#### **4.1.16 Firing J4-1801-32A**

##### **4.1.16.1 Objectives**

Conduct a 7.5-sec firing to evaluate thrust chamber pressure build-up time and fuel pump high level stall margin utilizing -300°F and 1200-psia start tank gas conditions, -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.16.2 Results**

The firing was successfully accomplished, and all objectives were obtained. Engine main-stage operation was attained at  $t_0 + 2.031$  sec. Fuel pump high level stall margin was 500 gpm. Fuel pump inlet pressure dropped below vapor pressure for 25 msec during initial acceleration of the fuel by the pump. Fuel pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 75 through 77, respectively. Fuel pump start transient head/flow data are shown in Fig. 78. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 79.

#### **4.1.17 Firing J4-1801-32B**

##### **4.1.17.1 Objectives**

Conduct a 7.5-sec firing to evaluate thrust chamber pressure build-up time and fuel pump high level stall margin utilizing -300°F and 1300-psia start tank gas conditions, -275°F thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.17.2 Results**

The firing was successfully accomplished, and all objectives were obtained. Engine main-stage operation was attained at  $t_0 + 2.058$  sec. Fuel pump high level stall margin was 750 gpm. Fuel pump inlet pressure dropped to vapor pressure during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and

shutdown transients are shown in Figs. 80 through 82, respectively. Fuel pump start transient head/flow data are shown in Fig. 83. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 84.

#### 4.1.18 Firing J4-1801-32C

##### 4.1.18.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a  $-75^{\circ}\text{F}$  thrust chamber temperature,  $-240^{\circ}\text{F}$  and 1400-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### 4.1.18.2 Results

The firing was successfully accomplished, and the objective was obtained. Fuel pump low level stall margin was 650 gpm. Fuel pump inlet pressure dropped below vapor pressure for 75 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 85 through 87, respectively. Fuel pump start transient head/flow data are shown in Fig. 88. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 89.

#### 4.1.19 Firing J4-1801-32D

##### 4.1.19.1 Objectives

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a  $-75^{\circ}\text{F}$  thrust chamber temperature,  $-200^{\circ}\text{F}$  and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### 4.1.19.2 Results

The firing was prematurely terminated at  $t_0 + 0.669$  sec by the stall approach monitor. This is a safety cutoff system which will terminate a firing if fuel flow is below 3200 gpm for any 55-msec period after  $t_0 + 0.585$  sec. All starting conditions were within the required target limits. Minimum fuel pump low level stall margin occurred at  $t_0 + 0.600$  sec and was 90 gpm. Fuel pump NPSH dropped to 5 ft during initial acceleration of the fuel by the pump. Thermal conditioning history

of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 90 through 92, respectively. Fuel pump start transient head/flow data are shown in Fig. 93. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 94.

#### **4.1.20 Firing J4-1801-32E**

##### **4.1.20.1 Objectives**

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a -100°F thrust chamber temperature, -200°F and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.20.2 Results**

The firing was successfully accomplished, and the objective was obtained. Minimum fuel pump low level stall margin was 550 gpm. Fuel pump inlet pressure dropped below vapor pressure for 100 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 95 through 97, respectively. Fuel pump start transient head/flow data are shown in Fig. 98. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 99.

#### **4.1.21 Firing J4-1801-32F**

##### **4.1.21.1 Objectives**

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing a -85°F thrust chamber temperature, -300°F and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.21.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was essentially the same during both firings 32E and 32F. Minimum fuel pump low level stall margin was 550 gpm. Fuel pump inlet pressure dropped below vapor pressure for

100 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 100 through 102, respectively. Fuel pump start transient head/flow data are shown in Fig. 103. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 104.

#### **4.1.22 Firing J4-1801-32G**

##### **4.1.22.1 Objectives**

Conduct a 1.150-sec partial transition firing to determine fuel pump start transient characteristics utilizing  $-300^{\circ}\text{F}$  and 1300-psia start tank gas conditions,  $-85^{\circ}\text{F}$  thrust chamber temperature, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.22.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump low level stall margin was 630 gpm. Fuel pump inlet pressure dropped below vapor pressure for 75 msec during initial acceleration of the fuel by the pump. Pump operation appeared satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 105 through 107, respectively. Fuel pump start transient head/flow data are shown in Fig. 108. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are presented in Fig. 109.

#### **4.1.23 Firing J4-1801-33A**

##### **4.1.23.1 Objectives**

Conduct a 32.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing a  $-100^{\circ}\text{F}$  thrust chamber temperature,  $-200^{\circ}\text{F}$  and 1200-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.23.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Low level stall

margin was 400 gpm. Fuel pump inlet pressure dropped below vapor pressure for 100 msec during initial acceleration of the fuel by the pump. Pump operation was satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 110 through 112, respectively. Fuel pump start transient head/flow data are shown in Fig. 113. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 114. Engine steady-state performance data are shown in Table VIII.

#### **4.1.24 Firing J4-1801-33B**

##### **4.1.24.1 Objectives**

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing a  $-100^{\circ}\text{F}$  thrust chamber temperature,  $-300^{\circ}\text{F}$  and 1300-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.24.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level stall margin was 650 gpm. Fuel pump NPSH dropped to 15 ft during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 115 through 117, respectively. Fuel pump start transient head/flow data are shown in Fig. 118. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 119.

#### **4.1.25 Firing J4-1801-33C**

##### **4.1.25.1 Objectives**

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing  $-100^{\circ}\text{F}$  thrust chamber temperature,  $-240^{\circ}\text{F}$  and 1400-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.25.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level

stall margin was 725 gpm. Fuel pump inlet pressure dropped below vapor pressure for 75 msec during initial acceleration of the fuel by the pump. Pump operation was satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 120 through 122, respectively. Fuel pump start transient head/flow data are shown in Fig. 123. Fuel low pressure duct pressure and temperature transients experienced during the firing and fuel pump NPSH are presented in Fig. 124.

#### **4.1.26 Firing J4-1801-33D**

##### **4.1.26.1 Objectives**

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing -100°F thrust chamber temperature, -140°F and 1250-psia start tank gas conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.26.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level stall margin was 550 gpm. Fuel pump NPSH dropped to 15 ft during initial acceleration of the fuel by the pump. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 125 through 127, respectively. Fuel pump start transient head/flow data are shown in Fig. 128. Fuel low pressure duct temperature and pressure transients experienced during the firing and fuel pump NPSH are shown in Fig. 129.

#### **4.1.27 Firing J4-1801-33E**

##### **4.1.27.1 Objectives**

Conduct a 7.5-sec firing to evaluate the effect of thrust chamber temperature on fuel pump start transient performance utilizing -100°F thrust chamber temperature, -300°F and 1200-psia start tank conditions, and fuel pump NPSH of 125 ft at engine start.

##### **4.1.27.2 Results**

The firing was successfully accomplished, and the objective was obtained. Fuel pump operation was satisfactory. Fuel pump low level



stall margin was 400 gpm. Fuel pump inlet pressure dropped below vapor pressure for 50 msec during initial acceleration of the fuel by the pump. Pump operation was satisfactory. Thermal conditioning history of engine components, engine ambient and combustion chamber pressures experienced during the firing, and engine start and shutdown transients are shown in Figs. 130 through 132, respectively. Fuel pump start transient head/flow data are shown in Fig. 133. Fuel low pressure temperatures and pressure transients experienced during the firing and fuel pump NPSH are presented in Fig. 134.

#### 4.2 START TRANSIENT INVESTIGATION OF THE EFFECTS OF FUEL PUMP NPSH

The need to reduce fuel pump inlet pressure limits from 28 psia (present minimum model specification) to 27 psia at engine start, as a result of structural problems determined to affect the S-II stage fuel tank on vehicles AS-502, AS-503, and AS-504, justified testing of the J-2 engine with reduced fuel pump inlet pressures at AEDC. Firings of this test series subsequent to firing 29A were conducted at inlet pressures of approximately 26.0 psia.

Data from flight AS-501 indicated the maximum differential temperature between the S-II stage fuel tank bulk and any J-2 engine fuel pump inlet at engine start was 1.2°F. Each degree of temperature differential results in an effective loss of 3.3 psi (110 ft of NPSH). Since data indicated only 0.7°F temperature differential was realized during the integrity check of the low pressure fuel duct during test period J4-1801-28, heat was added to the duct (reference Section 2.1) on subsequent test periods, and temperature differentials as high as 1.8°F at engine start were obtained.

Firings of this test series were successfully accomplished with (1) NPSH as low as 70 ft at engine start (80 ft below minimum model specifications) as a result of reducing fuel pump inlet pressure to approximately 26.0 psia (2 psi lower than minimum model specifications and 1 psi lower than minimum expected on flights AS-502, AS-503, and AS-504) and (2) differential temperatures between the fuel tank bulk and fuel pump inlet as high as 1.8°F (0.6°F higher than maximum observed on any engine during flight AS-501).

##### 4.2.1 Fuel Pump Inlet Pressure Oscillations

The fuel pump inlet pressure experienced abnormal oscillations on firings with reduced NPSH as compared with firing 29A which had approximately 600 ft NPSH (Fig. 24). Firing 29A experienced fuel pump

inlet pressure oscillations with amplitudes of 0.5 psia at a frequency of 3 Hz. Firing 29B, which was typical of all firings with reduced NPSH, exhibited oscillations with amplitudes of 2.5 psia at 4 Hz (Fig. 29).

#### 4.2.2 Fuel Pump Head Rise and Flow Coefficients

Head rise and flow coefficients used in this section are defined by the following relationships:

$$\text{Head rise coefficient } \psi = 32,150 \frac{H}{N^2}$$

where  $H$  = Total pump head rise, ft

$N$  = Pump speed, rpm

$$\text{Flow coefficient } \phi = 0.2291 \frac{Q}{N}$$

where  $Q$  = Volumetric flow rate, gpm

$N$  = Pump speed, rpm

Derivation of these equations is shown in Appendix V.

Flow coefficient relates tip speed of the inducer to the absolute fluid velocity and is proportional to the fluid velocity relative to the rotating surfaces. Head rise coefficient relates pump developed head and pump speed and is proportional to the energy imparted to the fluid by the pump. These coefficients define a unique operating characteristic of a pump under noncavitating, steady-state conditions.

Fuel pump head rise coefficient is presented as a function of thrust chamber temperature and NPSH in Fig. 135a. These data were reduced at  $t_0 + 0.58$  sec to alleviate the effect of the main oxidizer valve opening. These data indicate that an approximate 35-percent increase in head rise coefficient was experienced as NPSH was reduced by approximately 600 ft and with thrust chamber temperatures ranging from  $-300$  to  $-175^\circ\text{F}$ . Since only one firing of this series was conducted with high NPSH, it was necessary to supplement this figure with data from previous test periods (J4-1801-21 through 23) utilizing the 230,000-lbf-thrust configured engine. Test data were not available for comparison with thrust chamber temperatures warmer than  $-175^\circ\text{F}$  and at the higher NPSH values in the aforementioned test series.

A similar comparison for fuel pump flow coefficient is presented in Fig. 135b. These data show a 10-percent decrease in flow coefficient was experienced with the reduced NPSH and over the same temperature range.

#### 4.2.3 Gas Generator Outlet Initial Transient Temperature Peaks

The effect of reduced NPSH on gas generator outlet initial transient temperature peaks is shown in Fig. 136 for a specific set of starting conditions (-300°F thrust chamber temperature and high starting energy). Sufficient data were not available to generate a family of these curves for various starting conditions. These data show that a significant increase in gas generator outlet temperature occurred as NPSH was reduced from 180 to 80 ft at engine start. Firing 29D was prematurely terminated by the engine safety cutoff system because of the excessive gas generator outlet temperature peak of 2460°F. The gas generator control valve was inadvertently chilled on this firing (Table VI). This resulted in delayed gas generator control valve poppet movement (Table VII) and delayed gas generator ignition (40 msec). Sufficient data are not available at this time to determine the effect of this valve temperature on gas generator outlet transient temperatures.

#### 4.3 START TRANSIENT INVESTIGATION OF THE EFFECTS OF THRUST CHAMBER TEMPERATURE

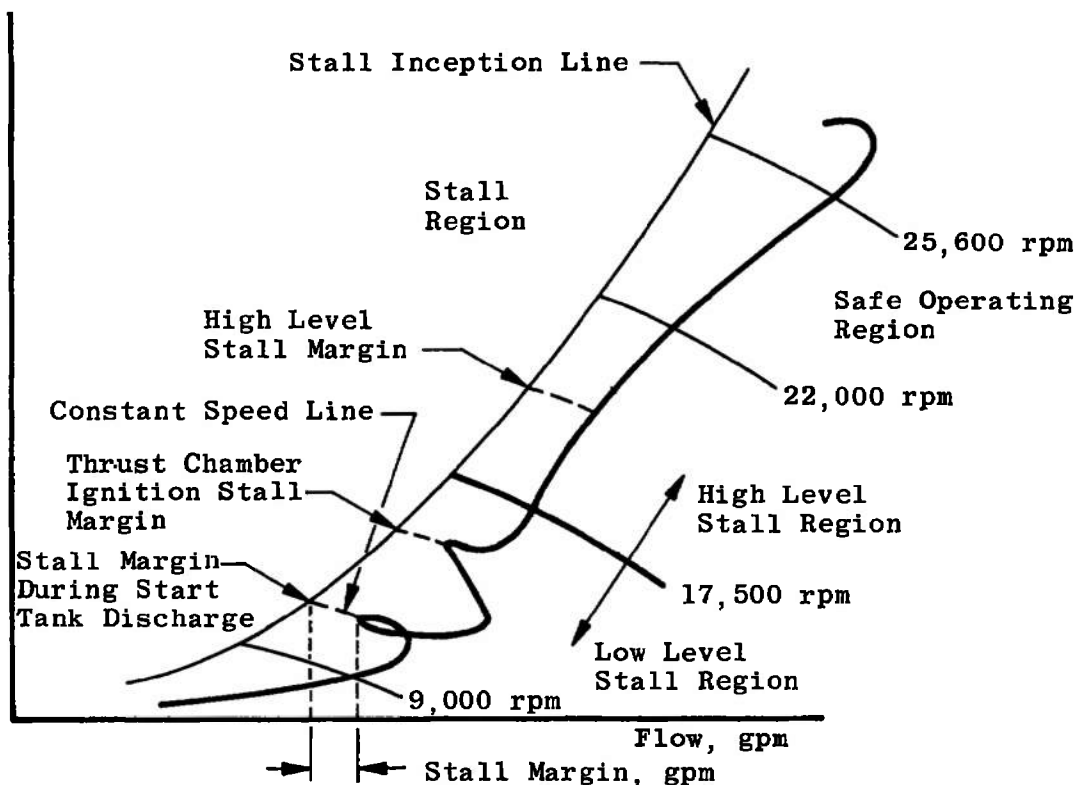
During AS-500 flight series prelaunch activities, the S-II stage J-2 rocket engine thrust chambers are conditioned to obtain temperature in the range of from -200 to -275°F at liftoff (Ref. 6). Since certain S-1C/S-II interstage components must be maintained at a temperature warmer than approximately -100°F, any recycle in the countdown, occurring after the thrust chambers have been conditioned, imposes a hold to allow the interstage area to return to ambient temperature. If this hold were not imposed, rechilling of the thrust chambers would cause these interstage component temperatures to decrease below the minimum.

If the S-II stage engine thrust chambers could be conditioned to temperatures in the range of approximately -100°F, then holds initiated during the conditioning period could be tolerated and holds incurred as a result of recycles would be eliminated. Based on AS-501 flight data, thrust chamber temperatures at engine start would be approximately -60°F. Therefore, testing in the later part of this test series was directed toward these warmer thrust chamber temperatures utilizing the lower than minimum engine model specification fuel pump NPSH. The resulting effect on fuel pump operation during start tank discharge is presented in the following sections.

##### 4.3.1 Fuel Pump Stall Margin

Fuel pump stall margin before thrust chamber ignition was affected primarily by thrust chamber temperature in a given range of fuel pump

NPSH. This effect is shown in Fig. 137. The warmer thrust chamber, having the higher fuel flow resistance, reduced stall margin, whereas thrust chamber temperatures of approximately  $-300^{\circ}\text{F}$  had essentially no resistance to fuel flow and therefore, produced the highest stall margin. Stall margins were read along a constant speed line between the stall inception line and the closest approach of the actual head/flow data in the region of interest as shown below.



Three partial transition firings (J4-1801-31C, D, and E) were conducted to determine the thrust chamber temperature at which the fuel pump will stall. For these firings, engine cutoff was programmed to occur at  $t_0 + 0.600$  sec. to avoid possible excessive gas generator outlet temperature peaks and resulting turbine damage. Average throat-to-exit thrust chamber temperatures for the three firings were  $+46$ ,  $+7$ , and  $-64^{\circ}\text{F}$ . During firings 31C and 31D, the fuel pump stalled and exhibited no tendency to recover before engine cutoff. During firing 31E fuel pump head/flow data entered low level stall region by approximately 150 gpm. Flow had not increased significantly before engine cutoff signal but did increase approximately 1000 gpm before the main fuel valve started to close. Flow coefficient  $\phi'$  (based on fuel pump discharge conditions) where

$$\phi' = \frac{\omega}{ArN}$$

$\omega$  = Mass flow

$\rho$  = Fluid density

A = Pump discharge area

r = Impeller radius

N = Pump speed

is shown in Fig. 138. It will be noted that at the time of initial main fuel valve closure, flow coefficient on firing 31E is above 0.23, which is the point at which Rocketdyne-supplied steady-state test data show the March 15 turbopump to be in a condition of stall. Since gas generator ignition did not occur on this firing (31E), no conclusion could be drawn concerning the success of a main-stage firing with these thrust chamber temperatures.

On the basis of pump performance exhibited during firings 31C, D, and E, thrust chamber temperatures of approximately -110°F at engine start were utilized during test periods J4-1801-32 and 33. All firings during these test periods were successfully accomplished with stall margins during start tank discharge ranging from 400 to 750 gpm as start tank pressure at engine start was increased from 1200 to 1400 psia utilizing fuel pump NPSH of approximately 125 ft at engine start. No engine component damage was incurred as a result of these firings.

#### 4.3.2 Fuel Pump Head Rise and Flow Coefficients

Thrust chamber temperature effect on fuel pump flow coefficient ( $\phi$ ) and head coefficient ( $\psi$ ) as defined in Section 4.2.3 is shown in Fig. 135. Flow coefficient shows a tendency to decrease as thrust chamber temperature at engine start becomes warmer. In other words, for a given pump speed, fluid velocity tends to decrease for the warmer thrust chamber temperature. Thus, the impeller blades are operating at a higher angle of attack and, therefore, closer to a condition of stall.

Head rise coefficient shows a tendency to increase as thrust chamber temperature at engine start increases. This is because of the higher back pressure produced by the higher fuel flow resistance.

#### 4.4 POST-TEST INSPECTION

##### 4.4.1 Test J4-1801-28

Post-test inspection of the engine and fuel low pressure duct showed each to be in satisfactory condition. However, the battleship stage oxidizer sump seal failed and caused excessive fires in the engine/stage area resulting in damage to seven instrumentation cables. The seal and damaged cables were subsequently replaced.

##### 4.4.2 Test J4-1801-29

Post-test inspection showed the engine and fuel inlet duct to be in satisfactory condition. Because of the excessive gas generator outlet temperature during firing 29D, the fuel turbine blades were inspected for erosion. No significant erosion was noted. The gas generator temperature probe was not damaged, but a redundant probe was installed.

##### 4.4.3 Test J4-1801-30

During firing 30A, the main fuel valve exhibited abnormal delay and opening times. Immediately after the firing, the thrust chamber experienced an abnormal chilldown when propellants were permitted into the engine. Post-test inspection of the main fuel valve, installed before this test period, showed the valve gate to be partially open. Otherwise, the engine was in satisfactory condition.

##### 4.4.4 Test J4-1801-31

Post-test inspection showed the engine to be in satisfactory condition, except for the gas generator control valve. The fuel poppet was found to be leaking, which was observed in the control room after firing 31B. Hence, the valve was replaced.

##### 4.4.5 Test J4-1801-32

Post-test inspection showed the engine to be in satisfactory condition. No hardware damage was noted.

##### 4.4.6 Test J4-1801-33

Post-test inspection showed the engine to be in satisfactory condition. No hardware damage was noted.

## SECTION V

### SUMMARY OF RESULTS

The results of the 24 firings and two fuel lead tests of the Rocket-dyne J-2 rocket engine conducted between February 15, 1968, and March 20, 1968, in Test Cell J-4 are summarized as follows:

1. S-II stage center engine low pressure fuel duct fluid dynamic characteristics (with the exception of flight-imposed acceleration) were successfully simulated utilizing a specially configured duct during this test series. Heat added to this duct produced differential temperatures between the fuel tank bulk and fuel pump inlet as high as 1.8°F (0.6°F higher than maximum observed on any engine during flight AS-501).
2. Firings of this test series were successfully accomplished with NPSH as low as 70 ft at engine start (80 ft below minimum model specifications). These conditions were obtained by reducing fuel pump inlet pressure to approximately 26.0 psia (2 psi lower than minimum model specifications and 1 psi lower than minimum expected on flights AS-502, AS-503, and AS-504).

Testing with this reduced NPSH was observed to have the following effects on the fuel pump and engine start transient operation:

- a. A significant increase in gas generator outlet initial transient temperature peaks (for firings with low resistance to fuel flow, -300°F thrust chamber, and high starting energy).
  - b. Fuel pump head rise coefficient was observed to increase, and fuel pump flow coefficient was observed to decrease.
  - c. Fuel pump inlet pressure oscillations with five times the amplitude and 33 percent higher frequency were observed as compared with firing 29A, which had 60 percent of maximum engine model specification NPSH.
3. Firings of this test series were successfully accomplished with thrust chamber average temperatures of approximately -110°F at engine start. These increased temperatures were observed to have the following effects on the fuel pump start transient.
    - a. Low level stall margins ranging from 400 to 750 gpm were observed as start tank pressure at engine start was increased from 1200 to 1400 psia.

- b. Fuel pump head coefficient was observed to increase, and flow coefficient was observed to decrease with respect to colder thrust chamber temperatures.
4. Fuel pump stall was observed to occur at thrust chamber temperatures at engine start of +46 and +7°F. Data on fuel pump operation conducted with a thrust chamber of -64°F were inconclusive but appeared to be marginal.

## REFERENCES

1. Dubin, M., Sissenwine, N., and Wexler, H. U. S. Standard Atmosphere, 1962. December 1962.
2. Franklin, D. E. and Counts, H. J. "Altitude Testing of the J-2 Rocket Engine in Propulsion Engine Test Cell (J-4) (Tests J4-1801-24 through 27)." AEDC-TR-68-91, June 1968.
3. "J-2 Rocket Engine, Technical Manual Engine Data." R-3825-1, August 1965.
4. Test Facilities Handbook (7th Edition). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, July 1968.
5. "Engine Model Specification Liquid Propellant Rocket Engine - Rocketdyne Model J-2." R-2158C3, January 1966.
6. "Saturn Launch Vehicle Flight Evaluation Report - AS-501 Apollo 4 Mission." George C. Marshall Space Flight Center, MPR-SAT-FE-68-1, January 1968.



**APPENDIXES**

- I. ILLUSTRATIONS**
- II. TABLES**
- III. INSTRUMENTATION**
- IV. METHODS OF CALCULATION (PERFORMANCE PROGRAM)**
- V. METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)**

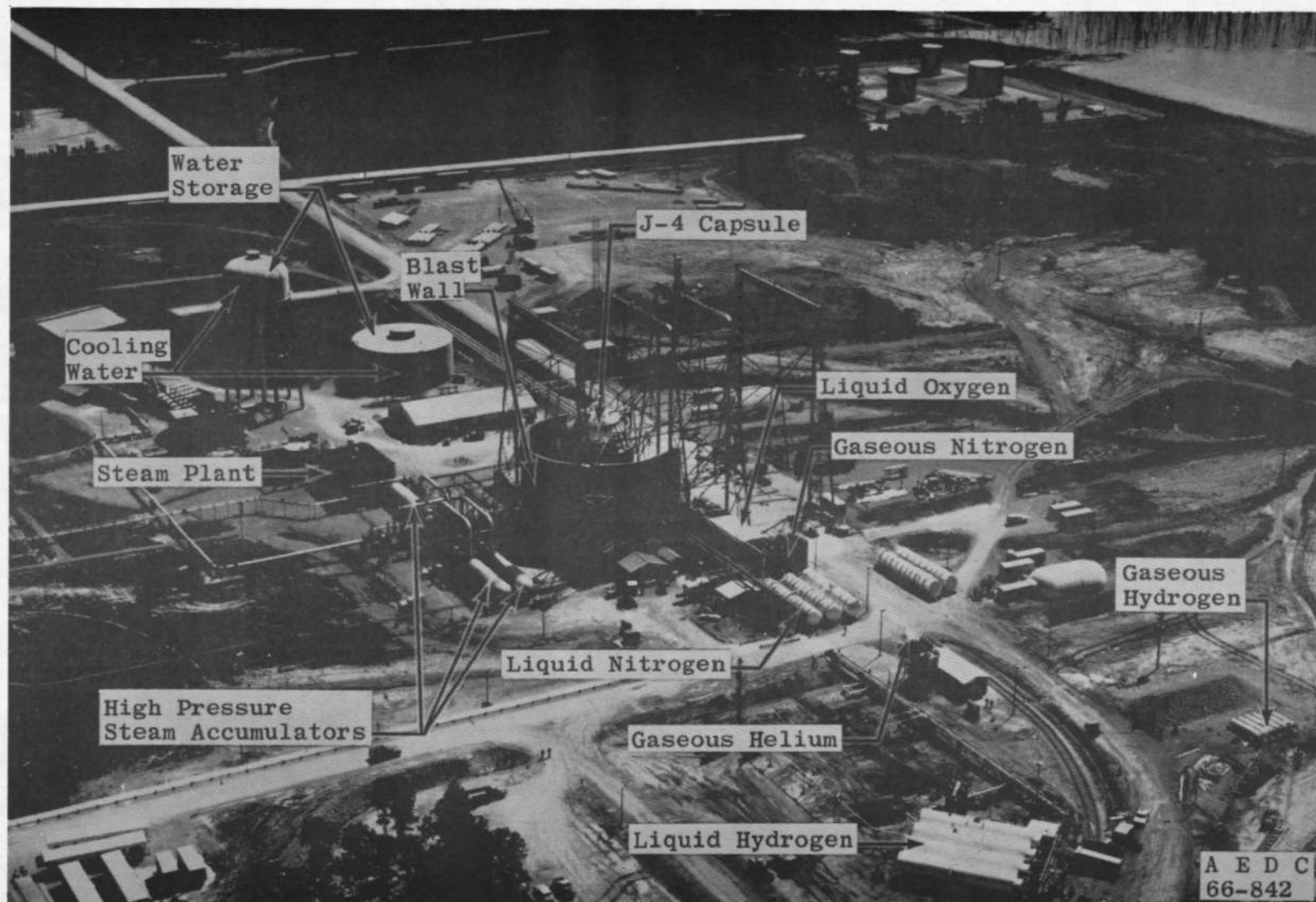


Fig. 1 Test Cell J-4 Complex

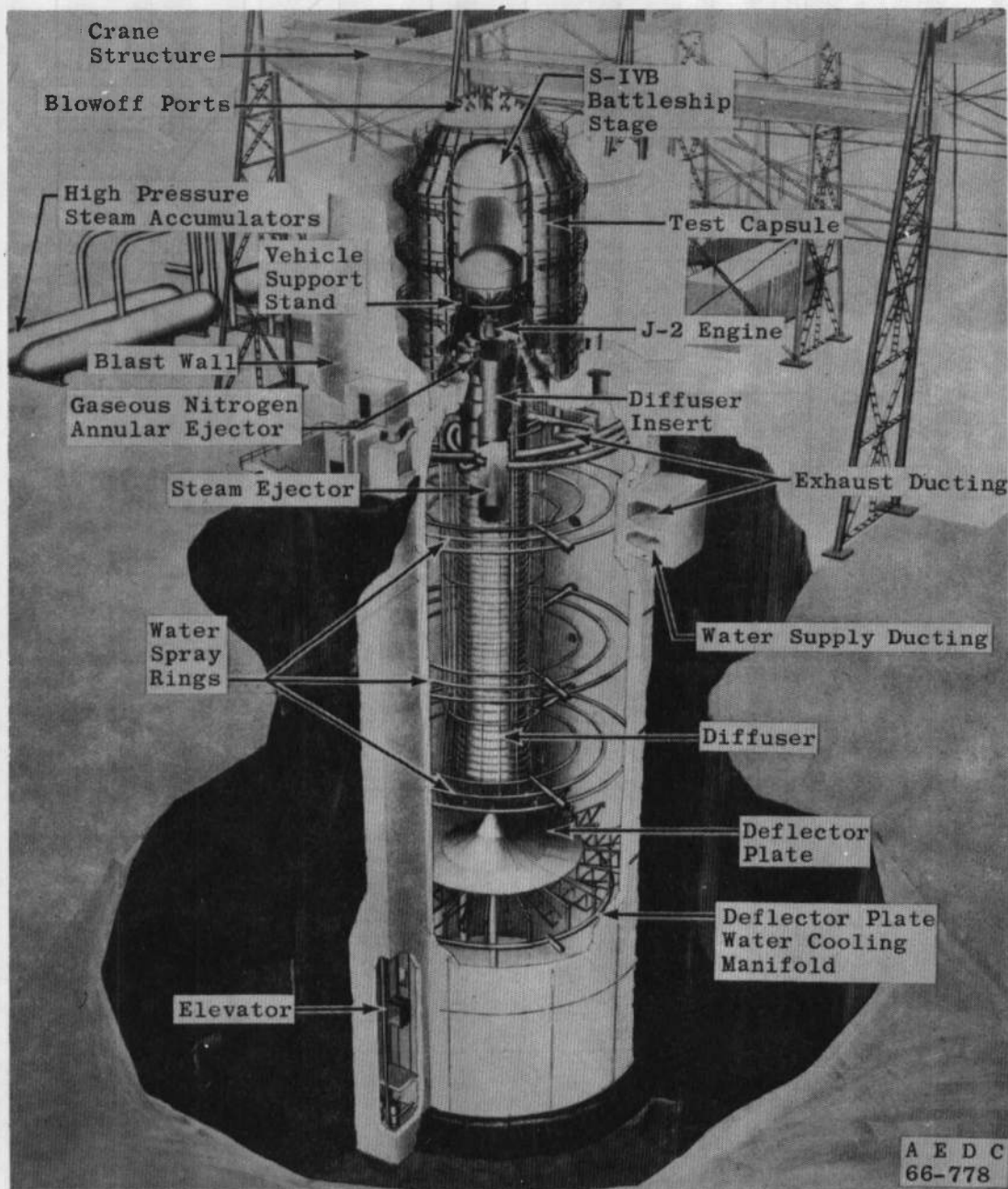


Fig. 2 Test Cell J-4, Artist's Conception

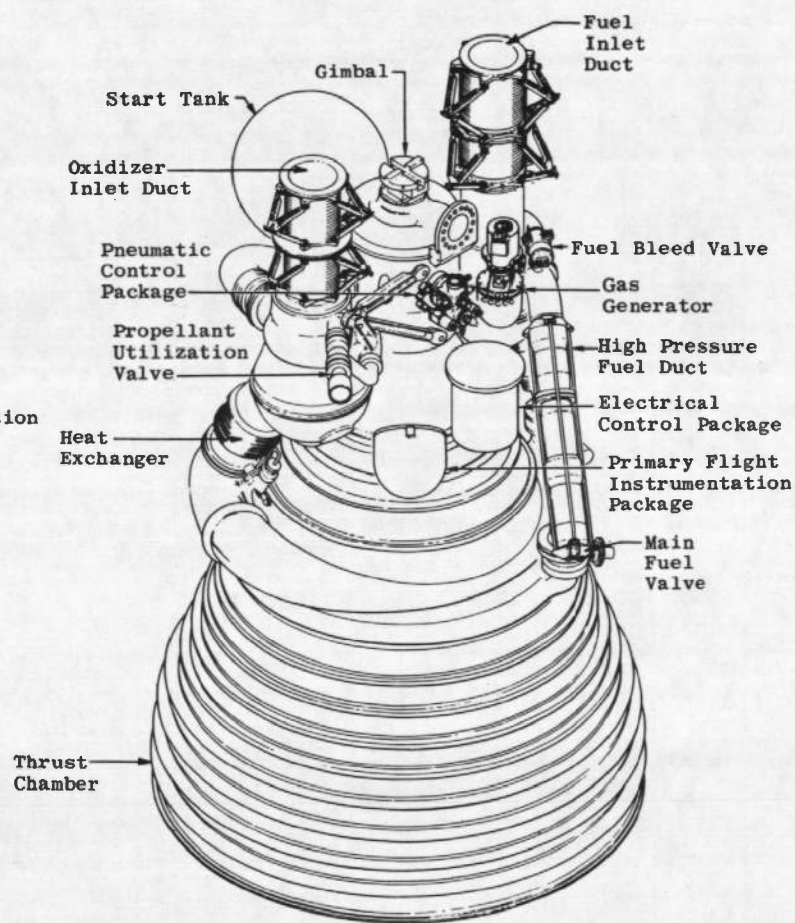
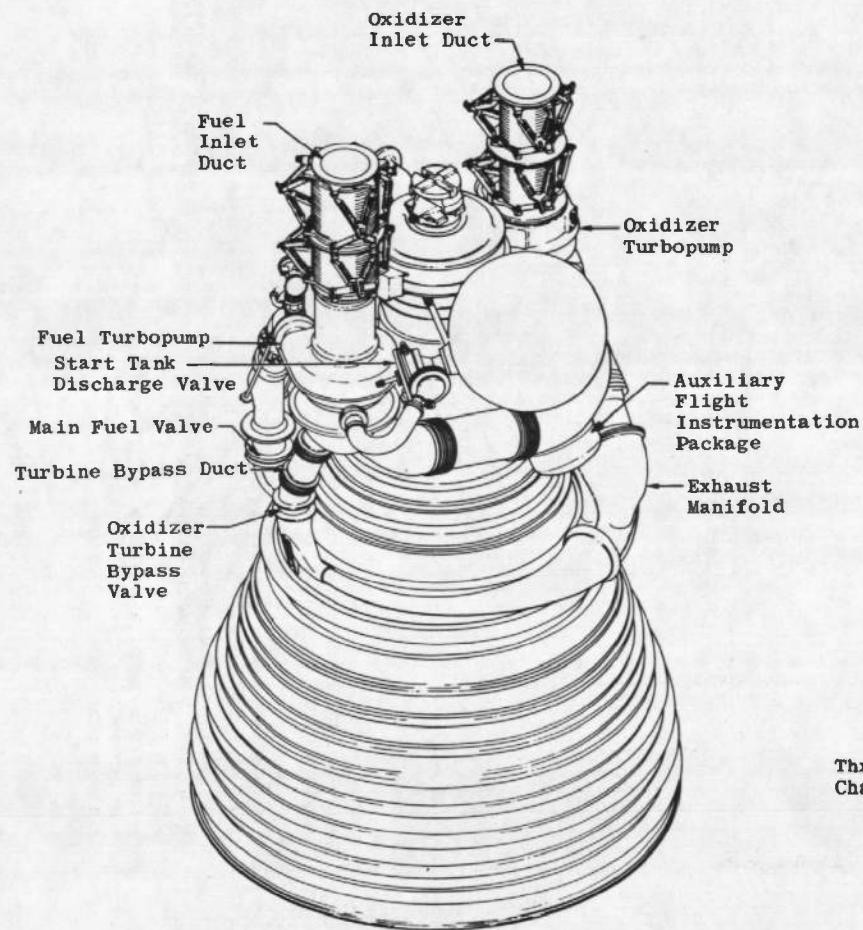
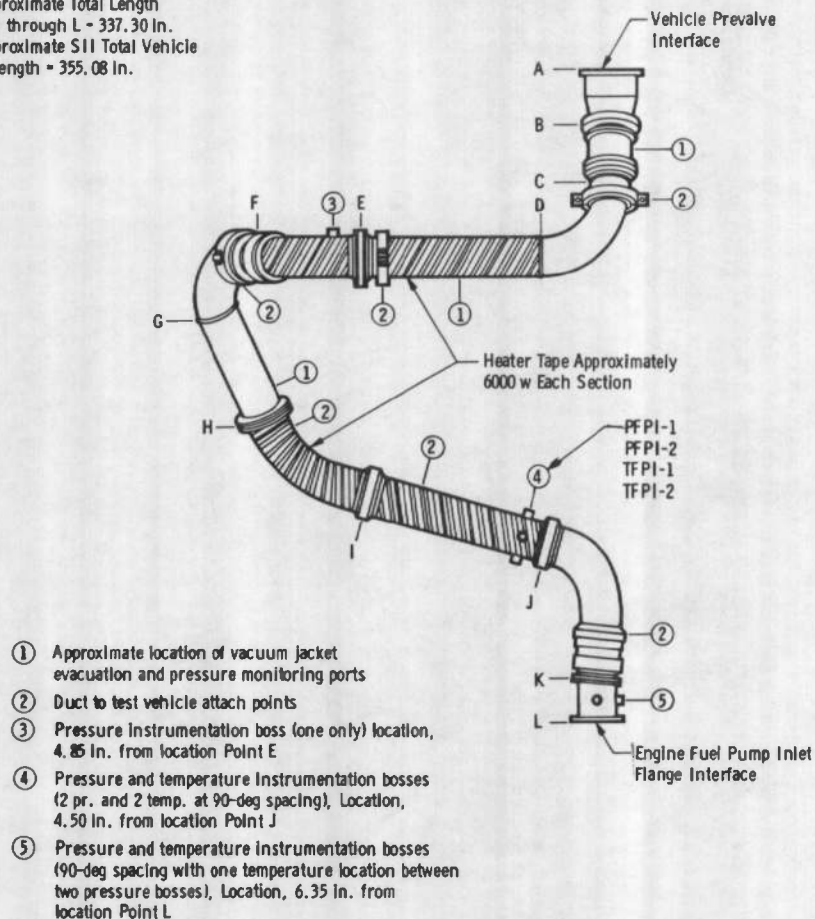


Fig. 3 Engine Details

SII Fuel Duct Configuration for AEDC Test

| Location Point | Approximate Length, in. | Approximate Minimum ID, in. | Type of Insulation |            | Type of Joint |               |
|----------------|-------------------------|-----------------------------|--------------------|------------|---------------|---------------|
|                |                         |                             | Vac. Jacket        | ILARO-dyne | Upper         | Lower         |
| A to B         | 13.72                   | 7.944                       |                    | X          | Marmon Flange | Bolted Flange |
| B to C         | 11.00                   | 7.950                       | X                  |            | Bolted Flange | Bellows       |
| C to D         | 29.63                   | 7.900                       |                    | X          | Bellows       | Welded        |
| D to E         | 41.14                   | 7.950                       | X                  |            | Welded        | Bellows       |
| E to F         | 28.71                   | 7.950                       | X                  |            | Bellows       | Bolted Flange |
| F to G         | 26.63                   | 7.900                       |                    | X          | Bolted Flange | Welded        |
| G to H         | 29.13                   | 7.950                       | X                  |            | Welded        | Bolted Flange |
| H to I         | 44.88                   | 7.950                       | X                  |            | Bolted Flange | Bellows       |
| I to J         | 61.18                   | 7.950                       | X                  |            | Bellows       | Bellows       |
| J to K         | 41.78                   | 7.890                       | X                  |            | Bellows       | Bolted Flange |
| K to L         | 9.50                    | 8.280                       |                    | X          | Bolted Flange | Bolted Flange |

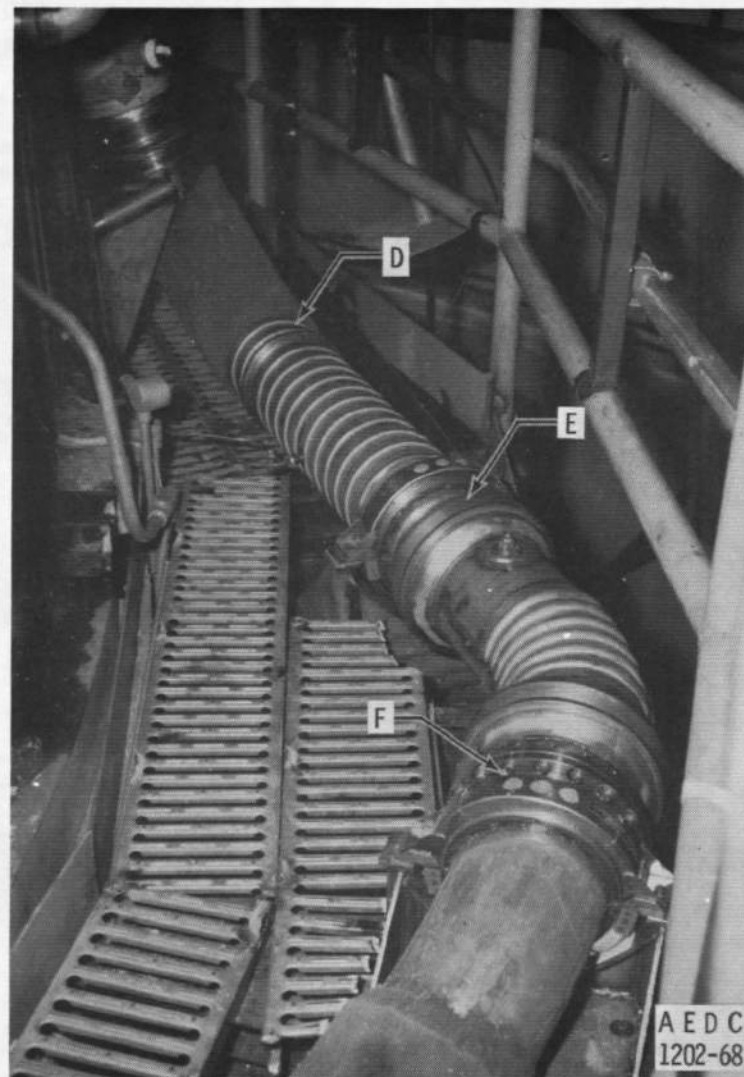
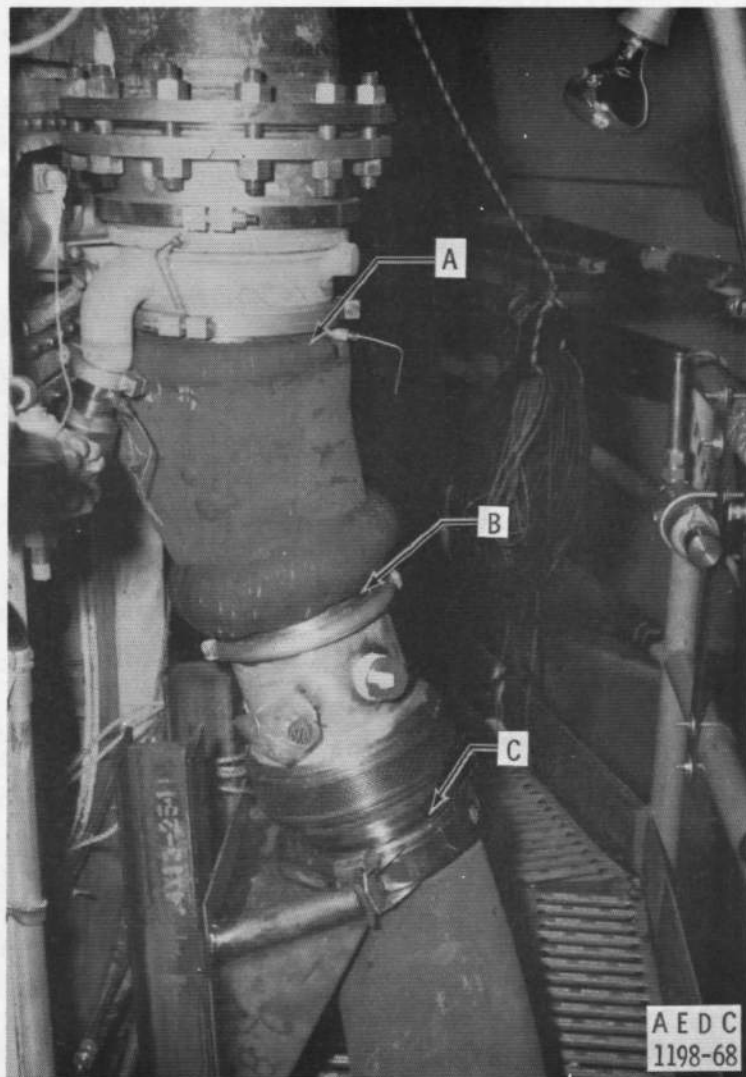
Approximate Total Length  
A through L - 337.30 in.  
Approximate SII Total Vehicle  
Length - 355.08 in.



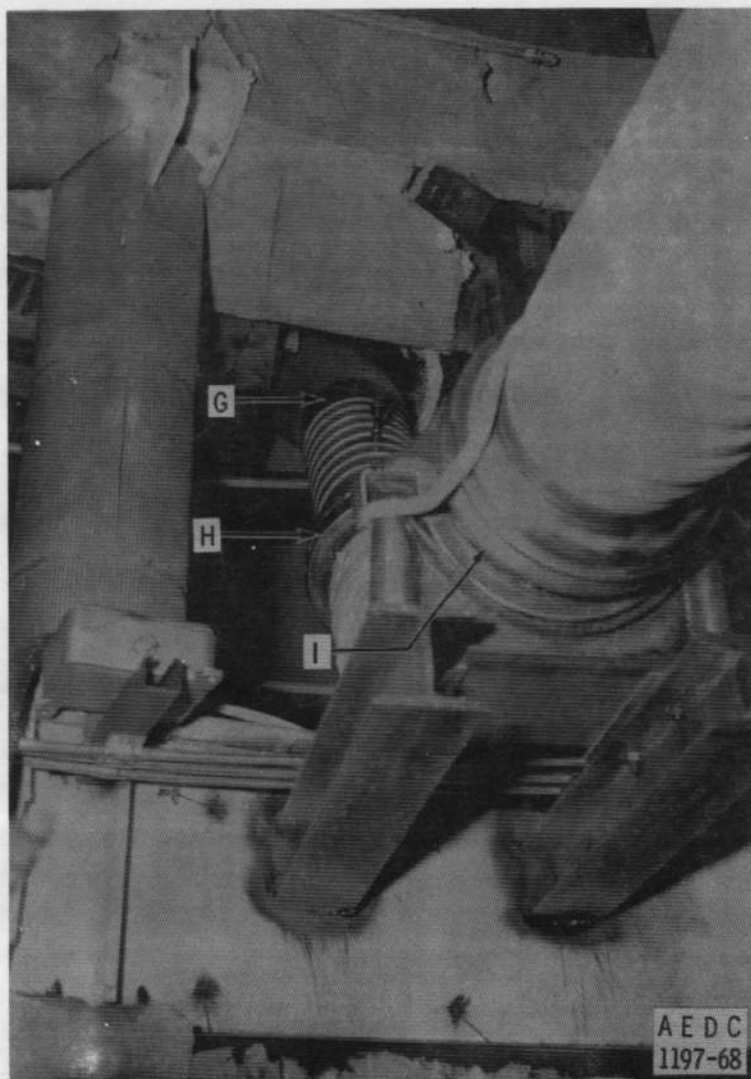
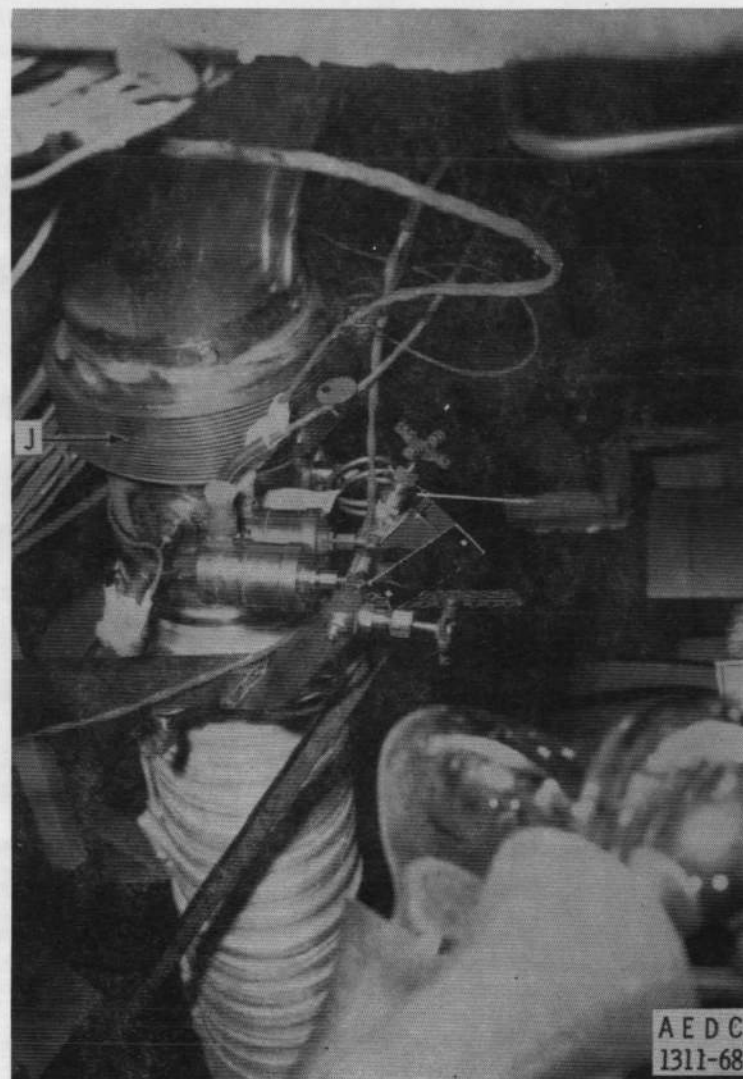
a. Schematic

Fig. 4 S-II Center Engine Configuration Fuel Low Pressure Duct

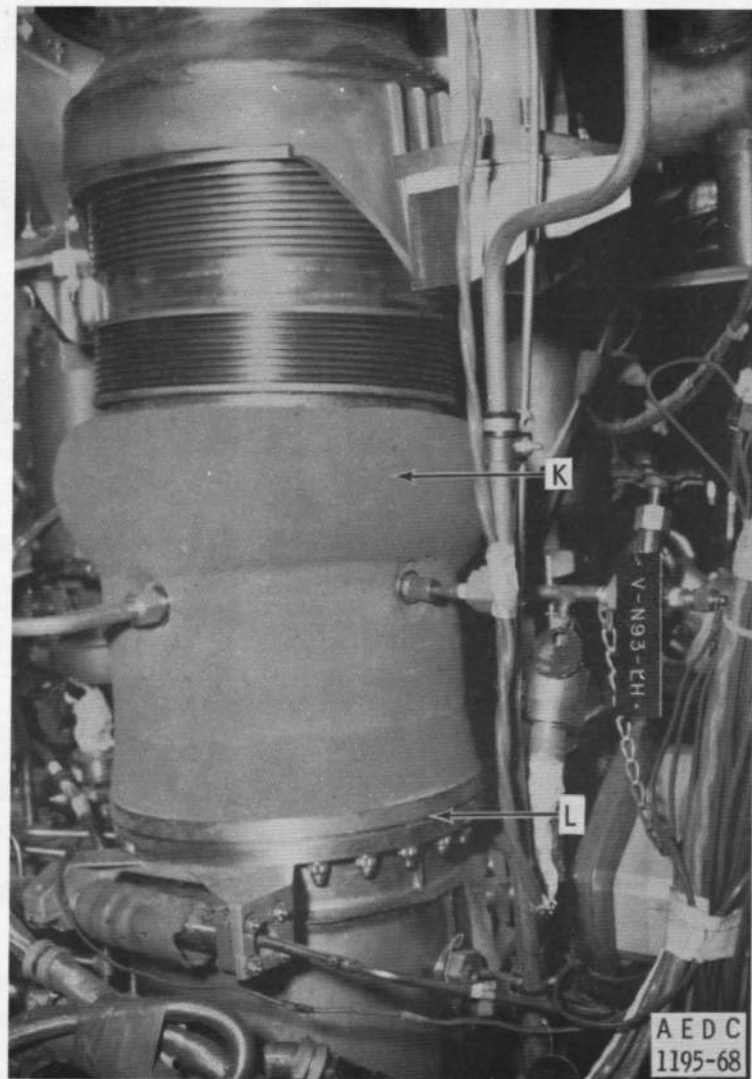




b. Photographs  
Fig. 4 Continued



b. Continued  
Fig. 4 Continued



b. Concluded  
Fig. 4 Concluded



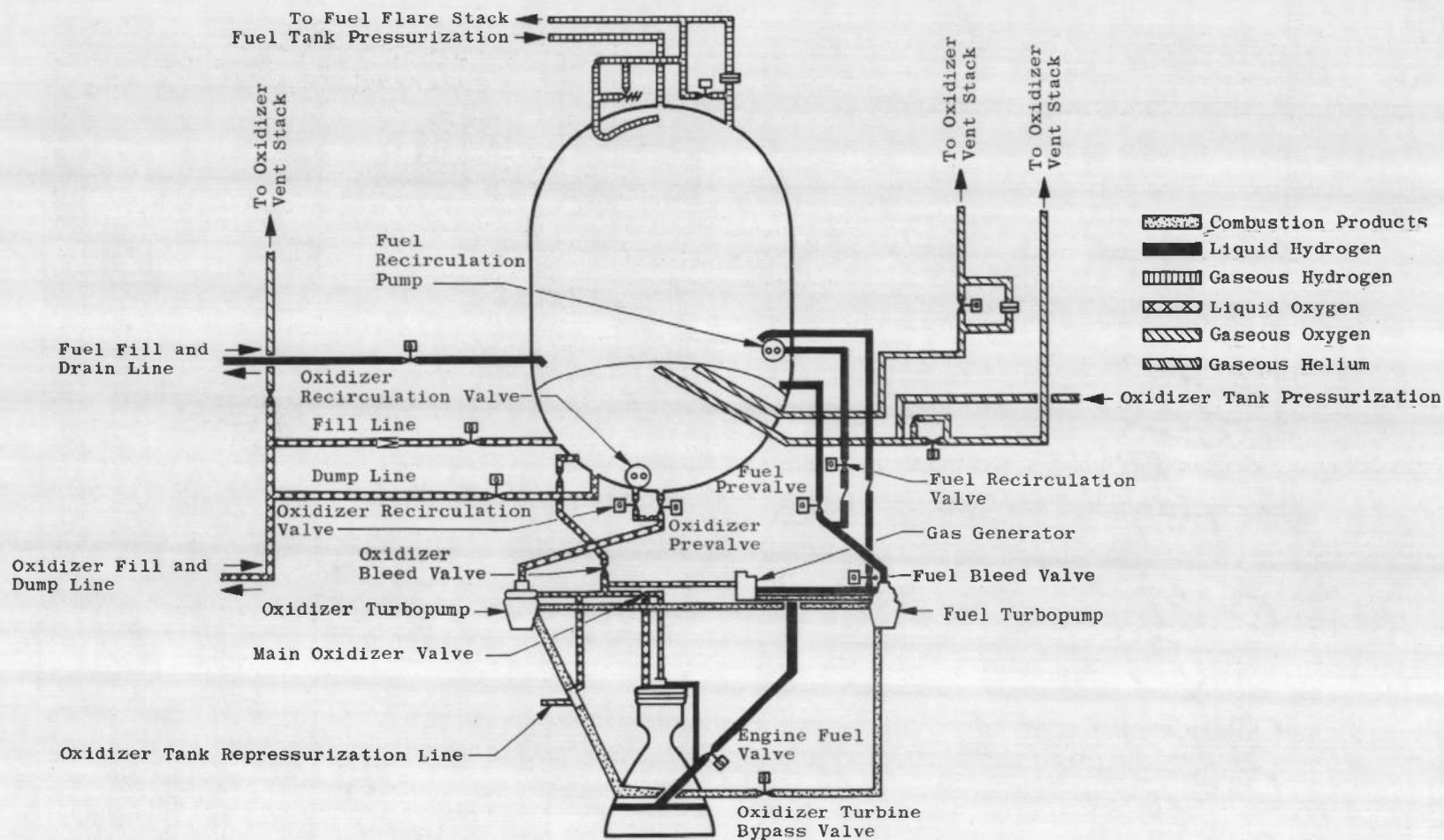


Fig. 5 S-IVB Battleship Stage/J-2 Engine Schematic

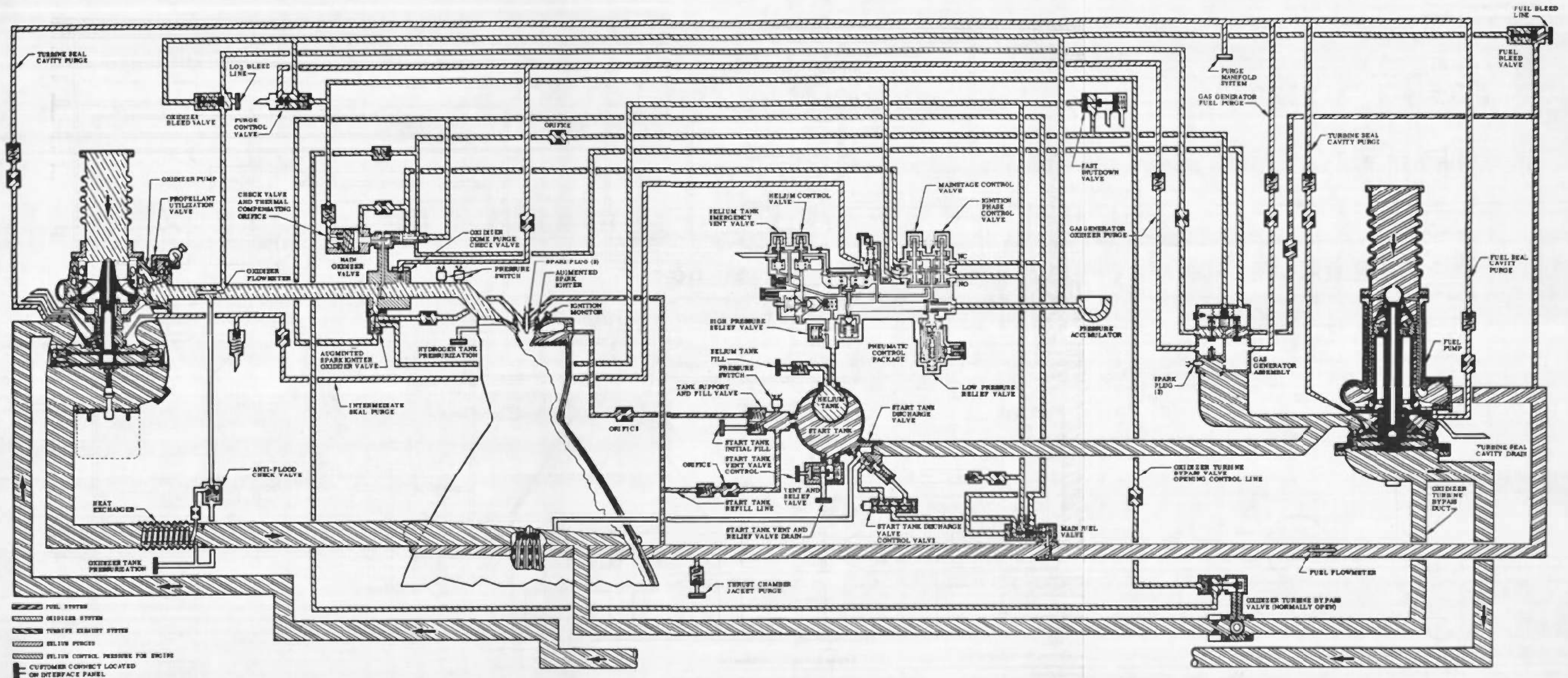


Fig. 6 Engine Schematic



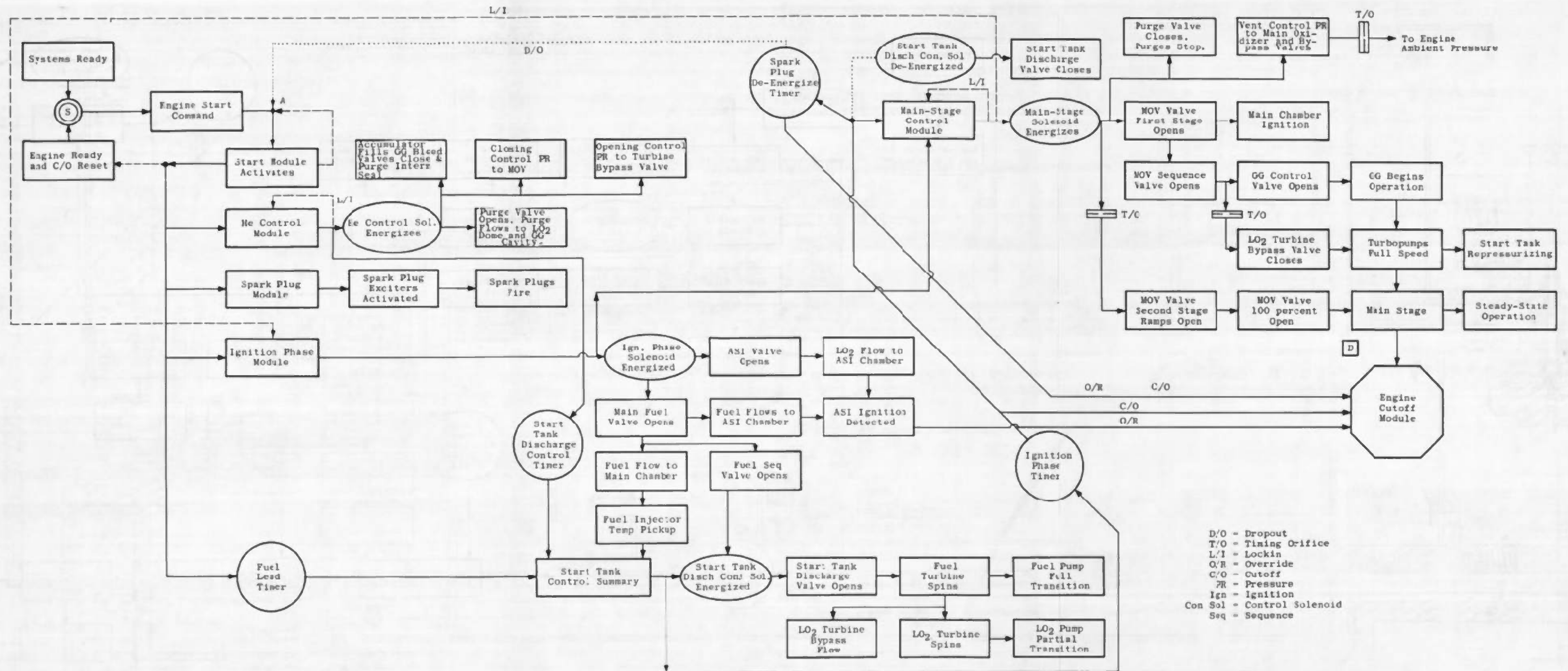
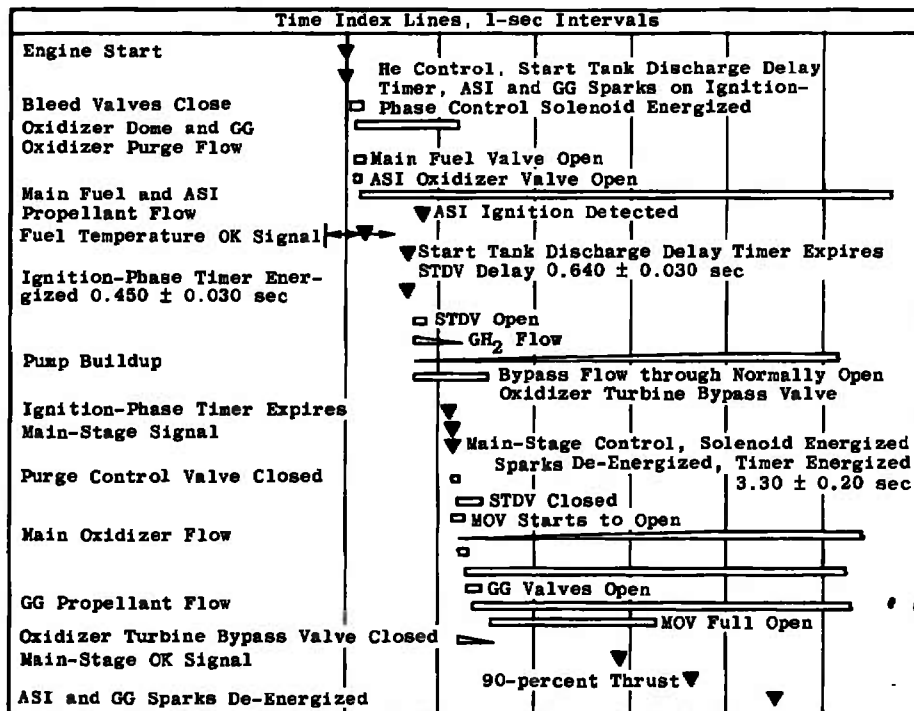
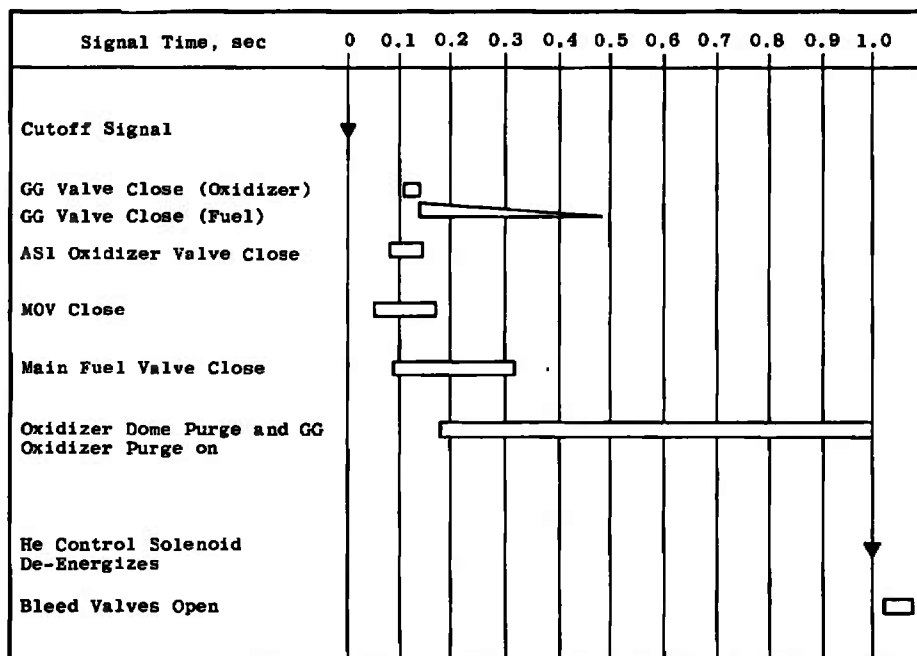


Fig. 7 Engine Start Logic Schematic

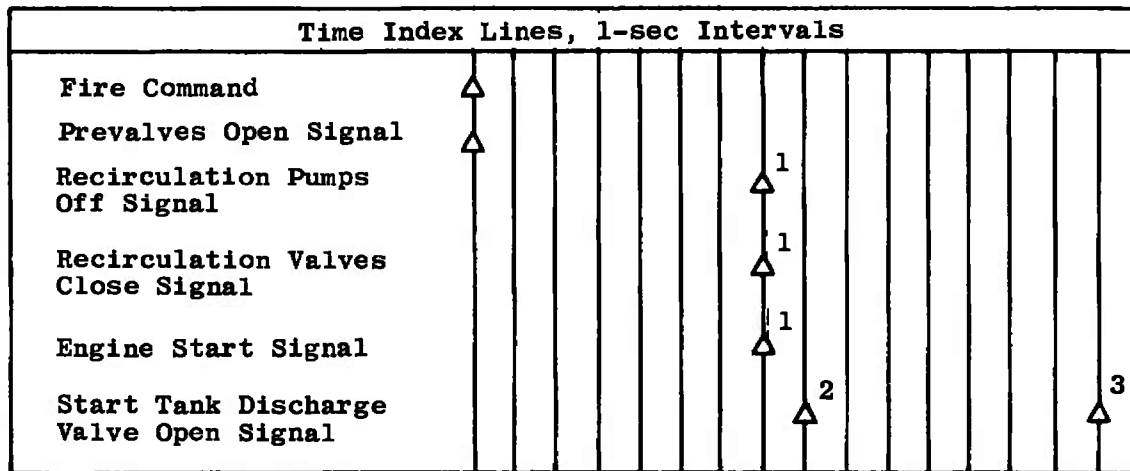


a. Start Sequence



b. Shutdown Sequence

Fig. 8 Engine Start and Shutdown Sequence

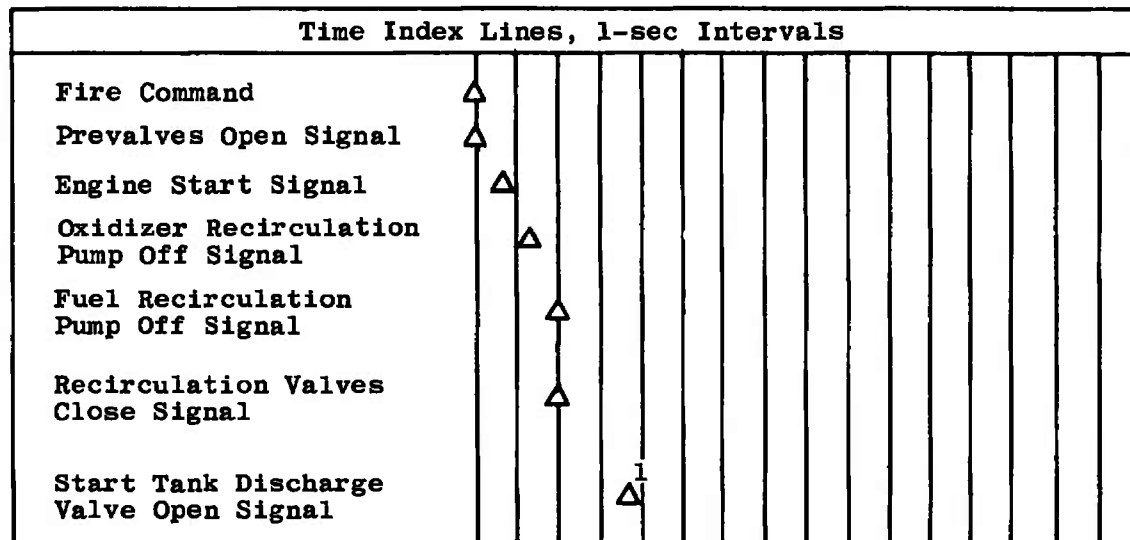


<sup>1</sup>Nominal Occurrence Time (Function of Prevalves Opening Time)

<sup>2</sup>One-sec Fuel Lead (S-II/S-V and S-IVB/S-IB)

<sup>3</sup>Eight-sec Fuel Lead (S-IVB/S-V and S-IB Orbital Restart)

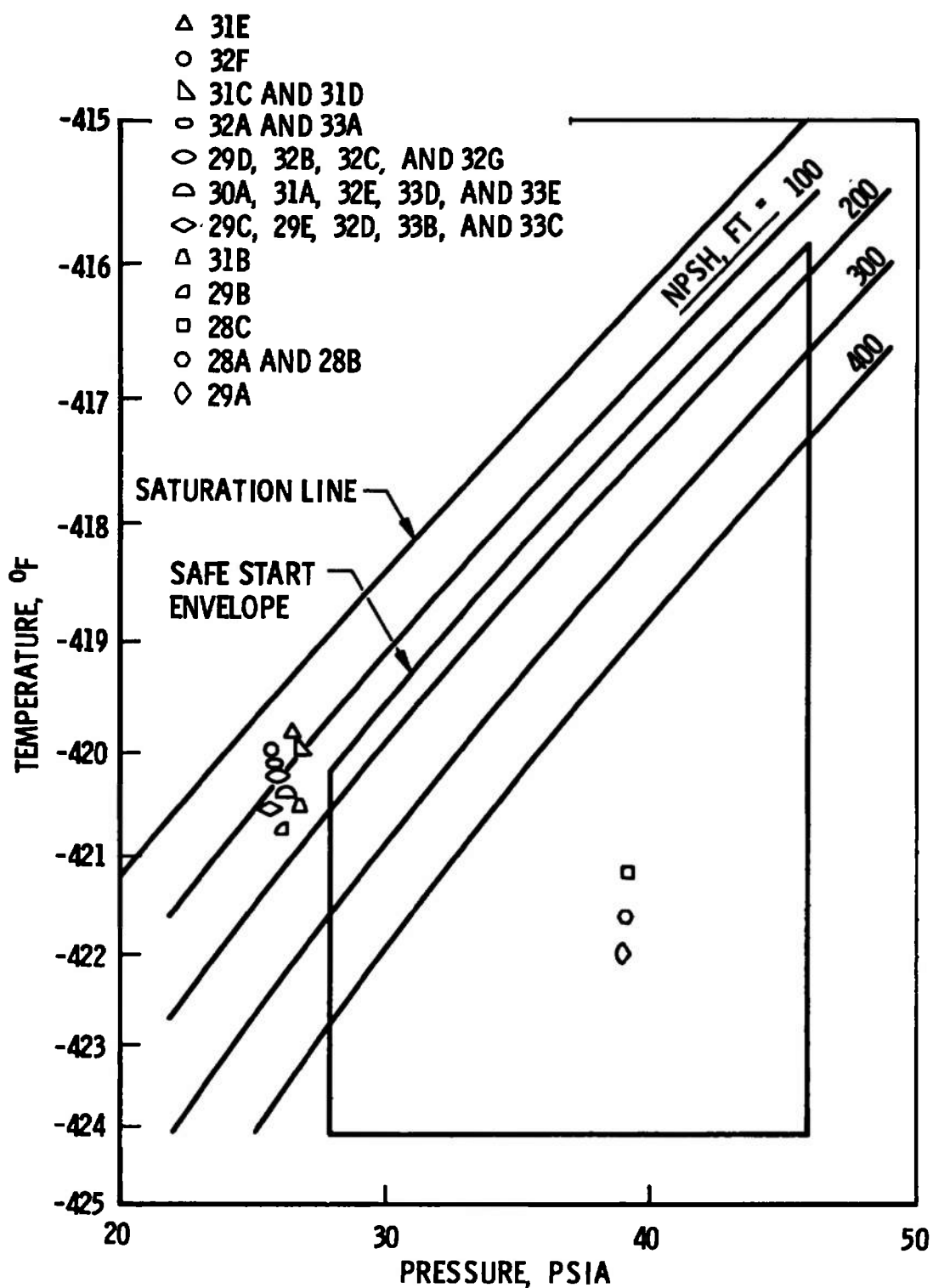
#### c. "Normal" Start Sequence



<sup>1</sup>Three-sec Fuel Lead (S-IVB/S-V First Burn)

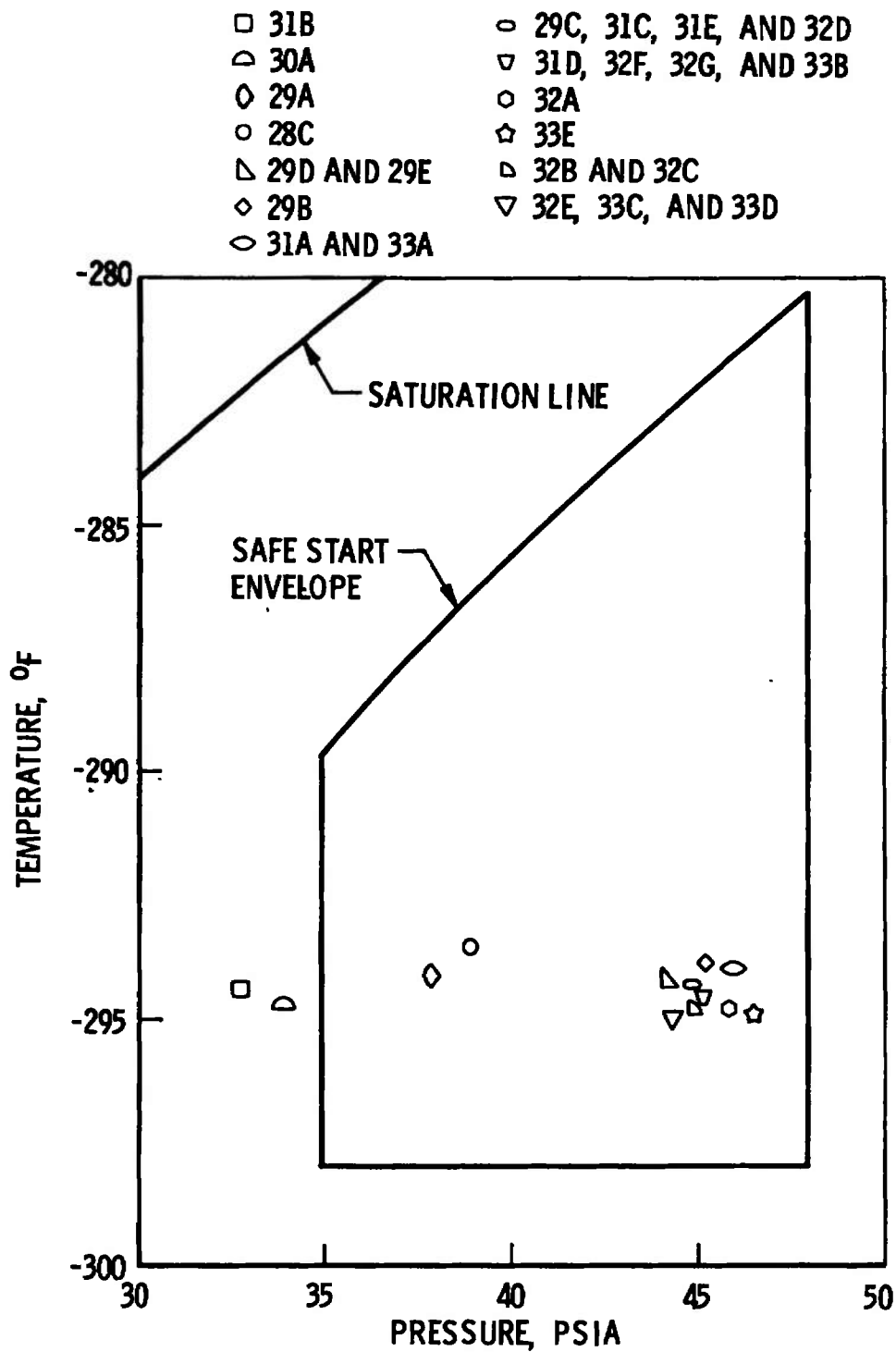
#### d. "Auxiliary" Start Sequence

Fig. 8 Concluded



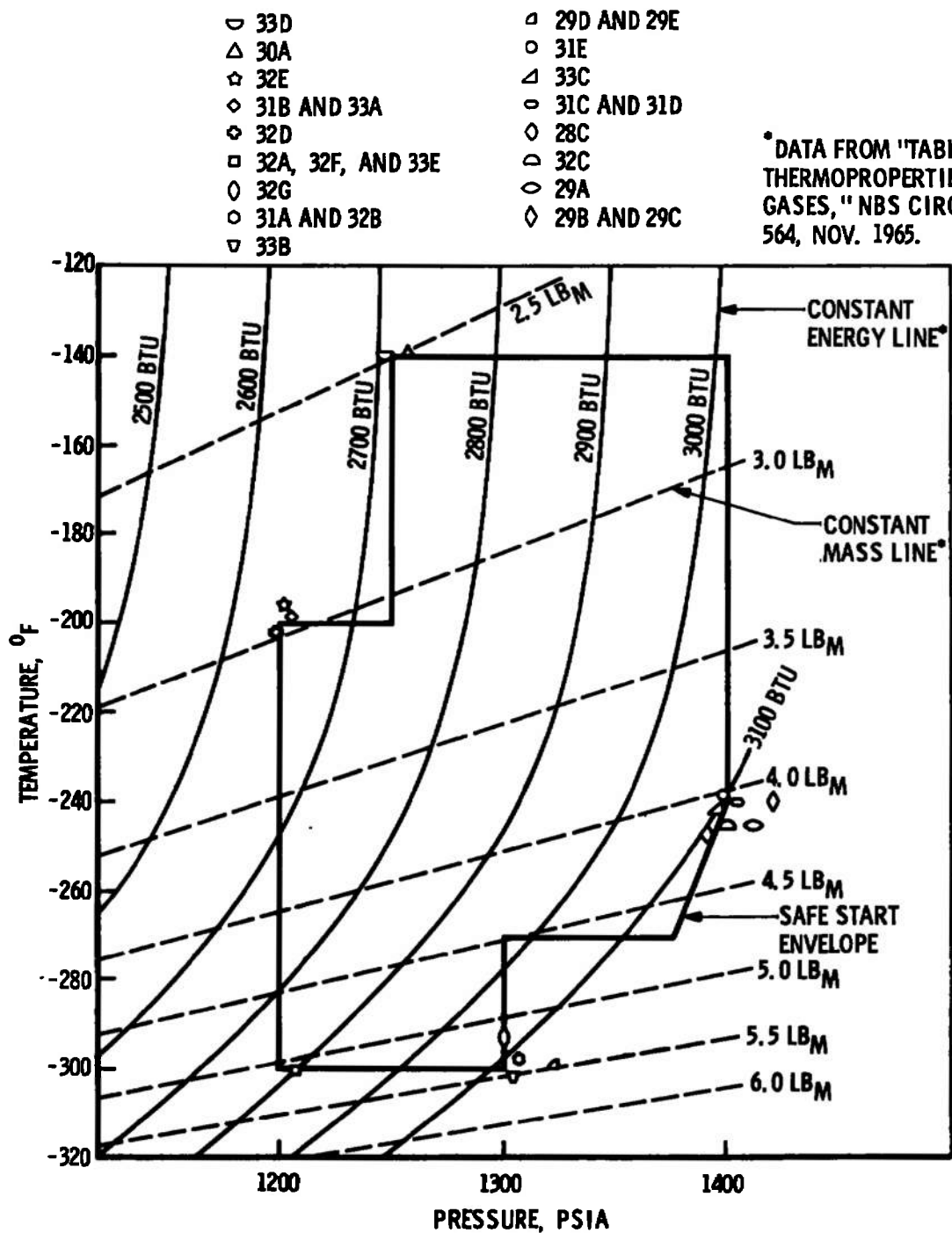
a. Fuel Pump Inlet Start Conditions

Fig. 9 Engine Start Conditions for Pump Inlets and the Start Tank



b. Oxidizer Pump Inlet Start Conditions

Fig. 9 Continued



c. Start Tank Starting Conditions  
Fig. 9 Concluded



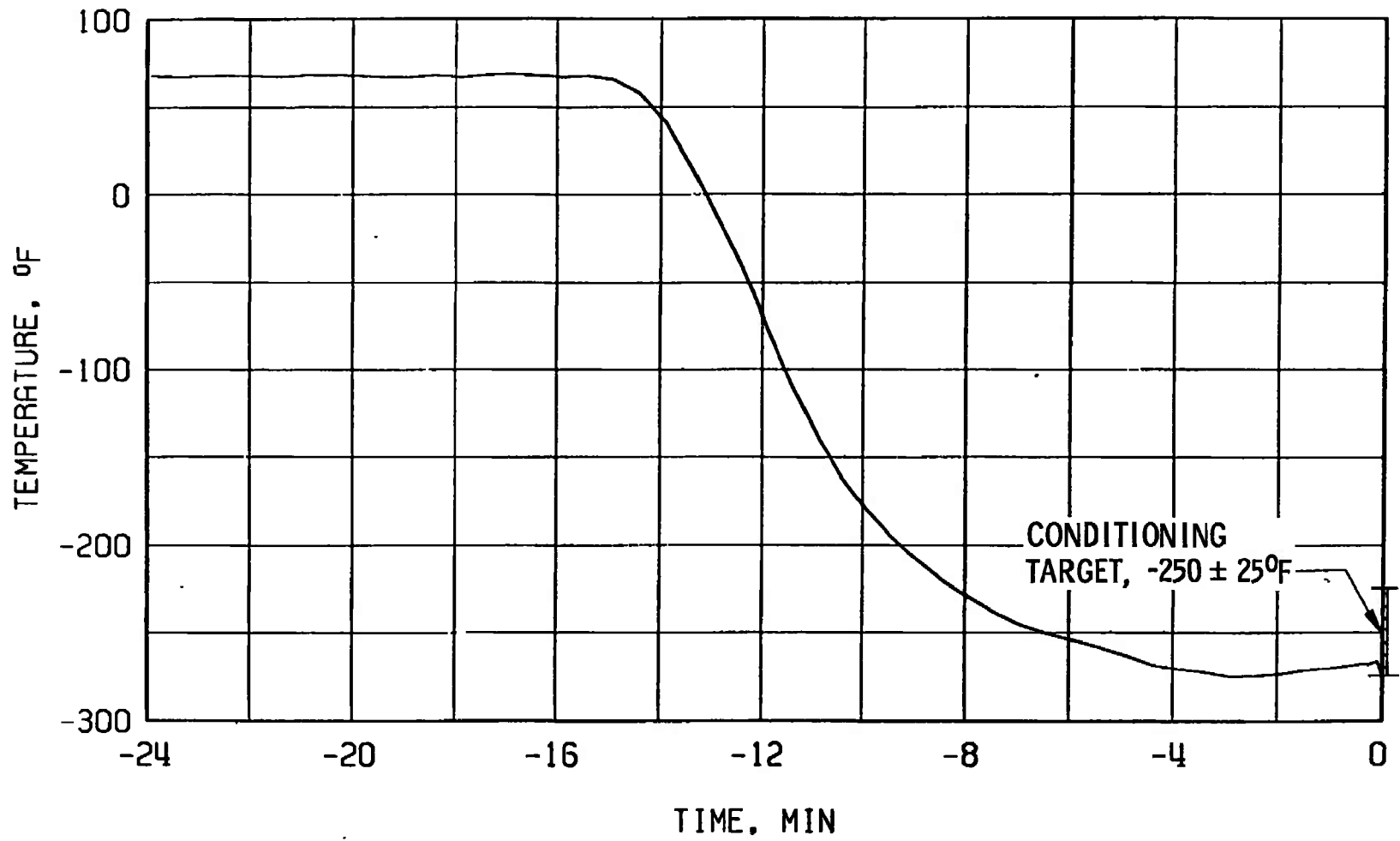


Fig. 10 Thrust Chamber Thermal Conditioning History, Test 28A

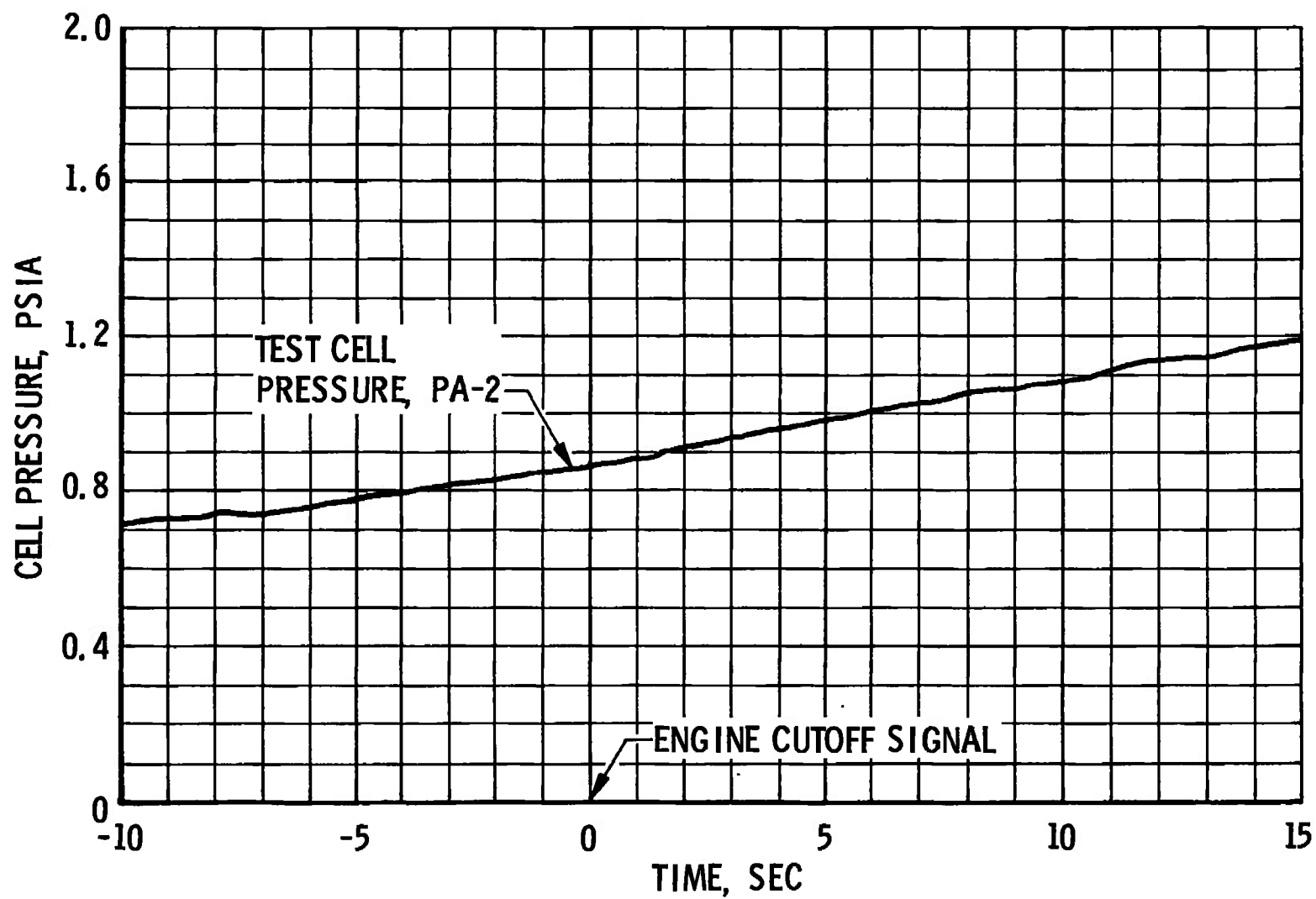


Fig. 11 Engine Ambient Pressure, Test 28A

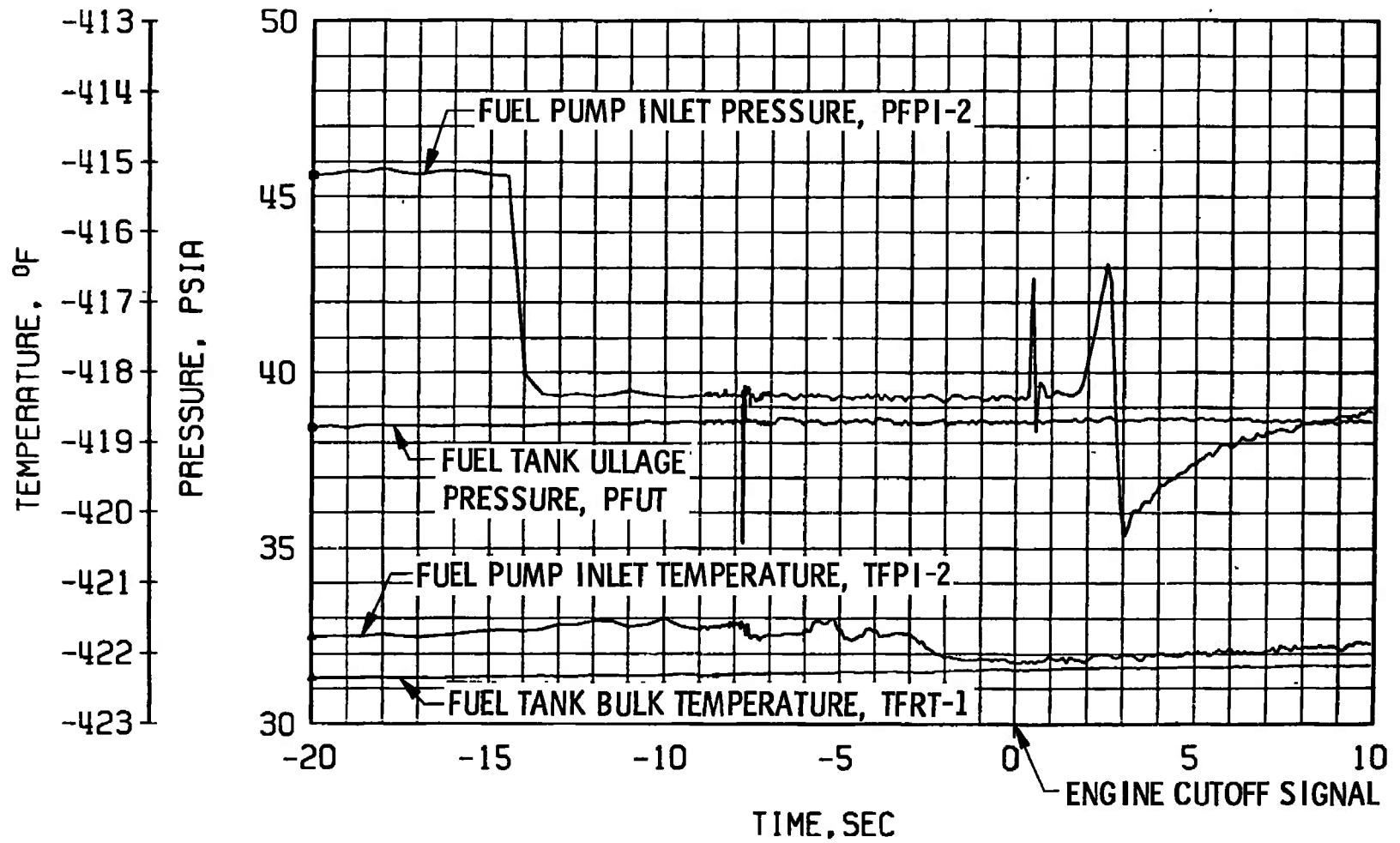


Fig. 12 Fuel Low Pressure Duct Temperature and Pressure Transients, Test 28A

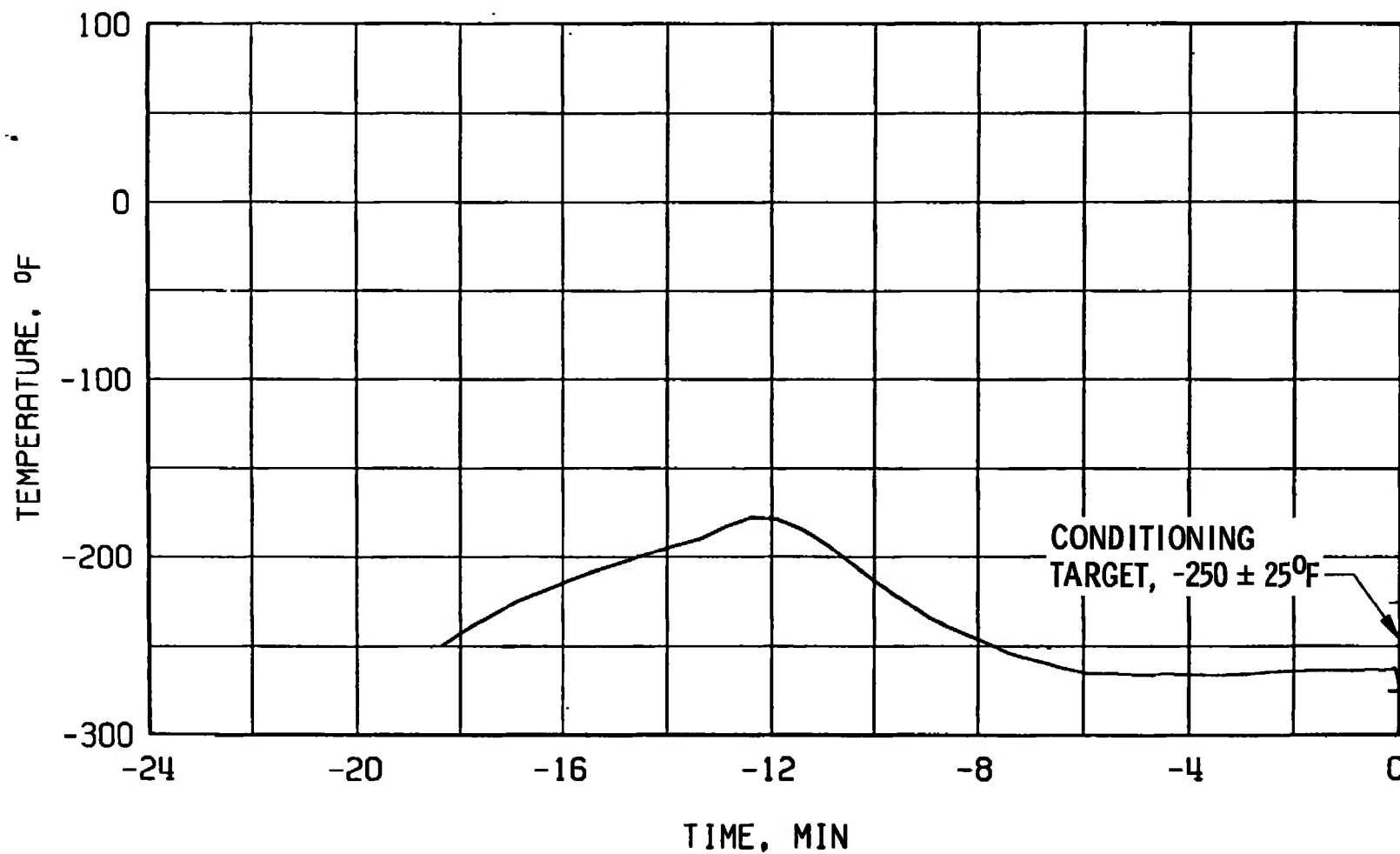


Fig. 13 Thrust Chamber Thermal Conditioning History, Test 28B

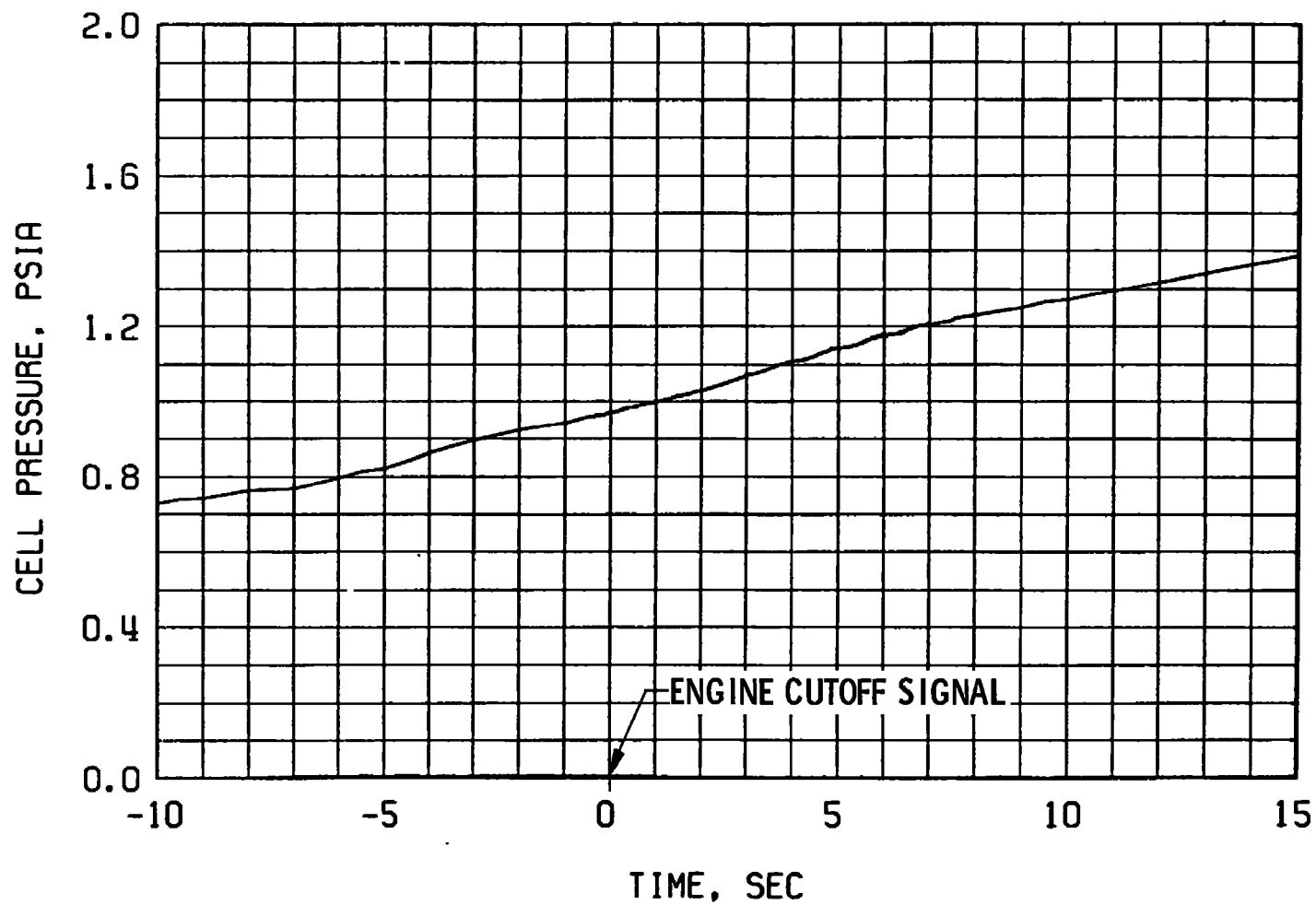


Fig. 14 Engine Ambient Pressure, Test 28B

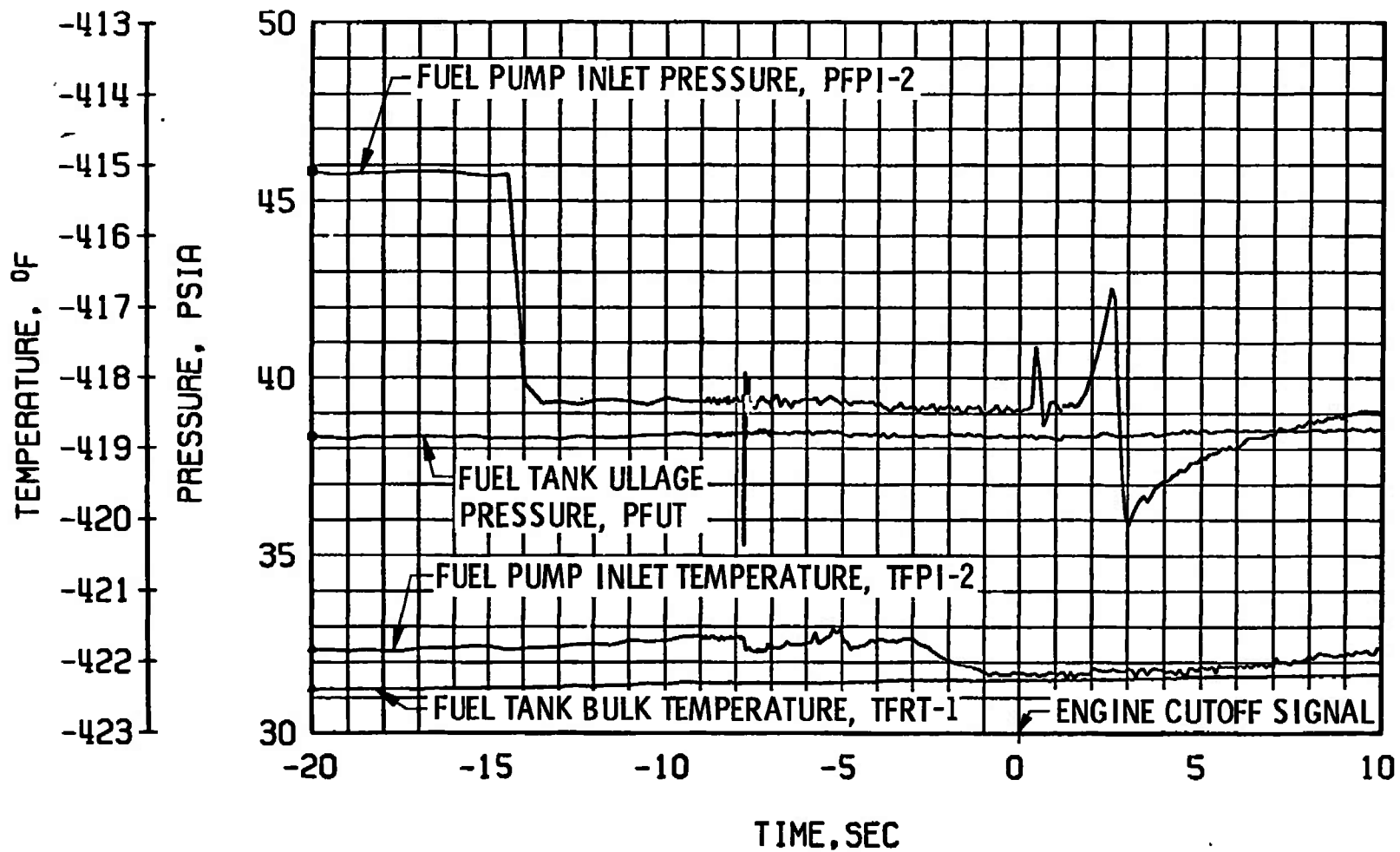


Fig. 15 Fuel Low Pressure Duct Temperature and Pressure Transients, Test 28B

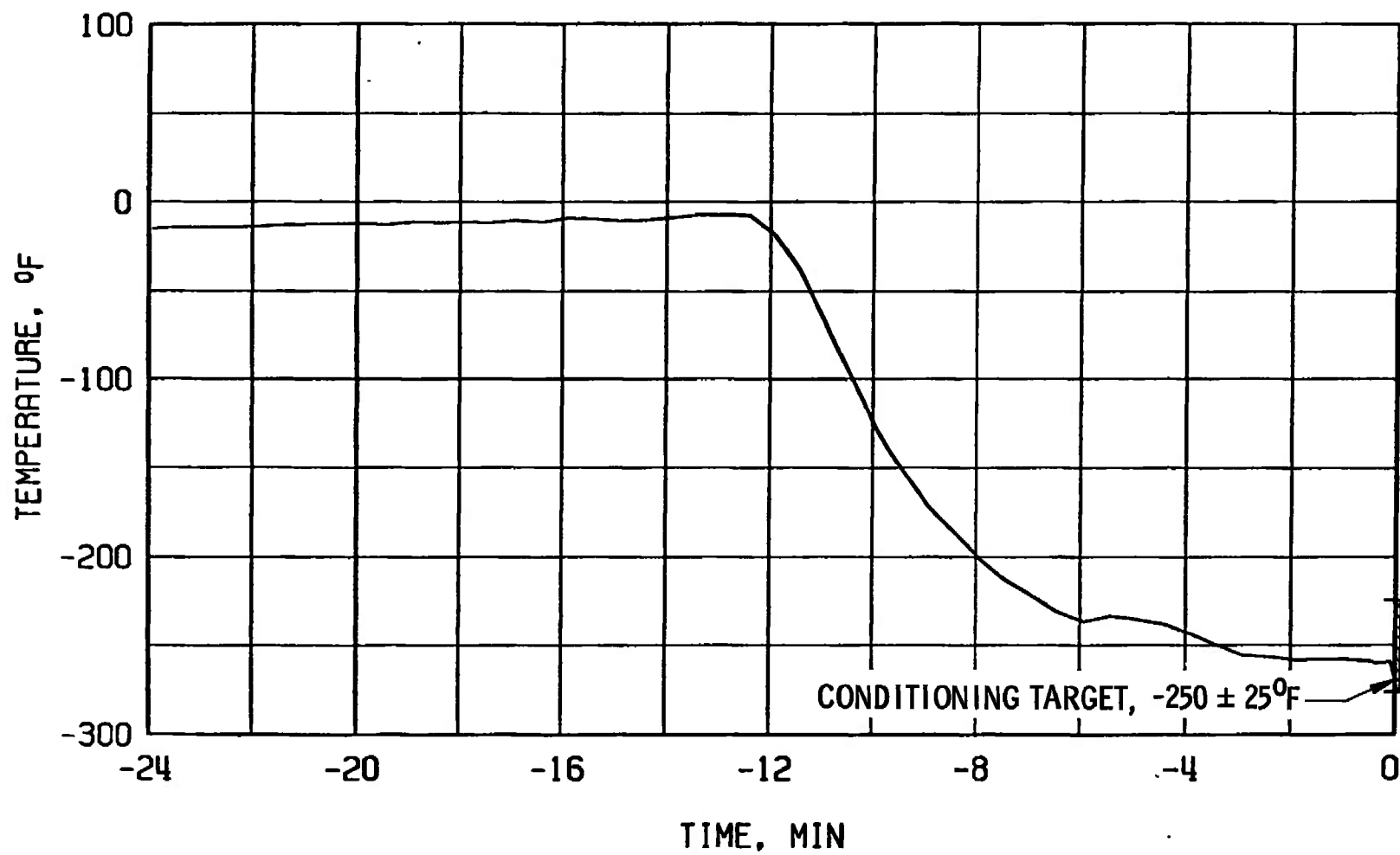


Fig. 16 Thrust Chamber Thermal Conditioning History, Firing 28C

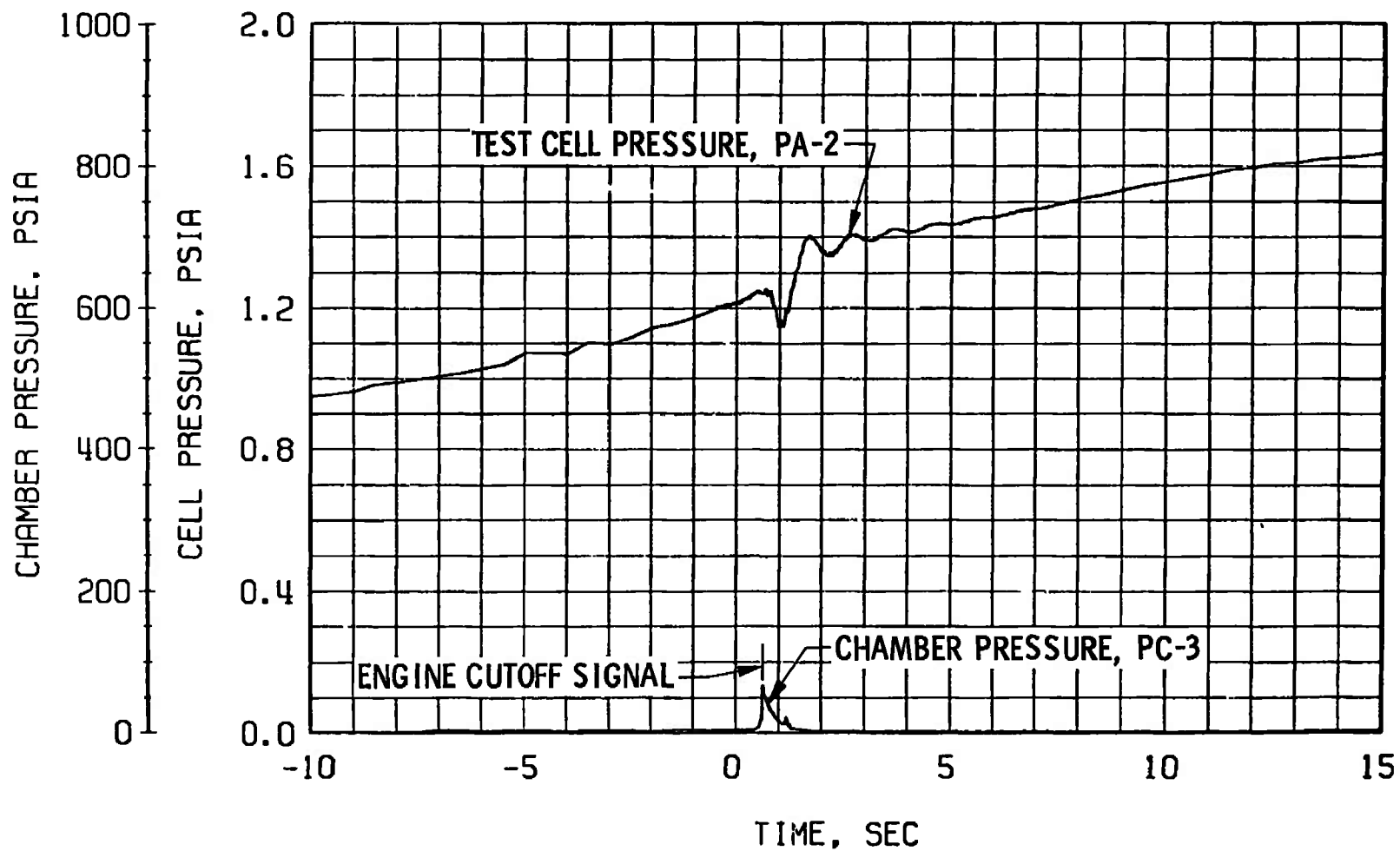
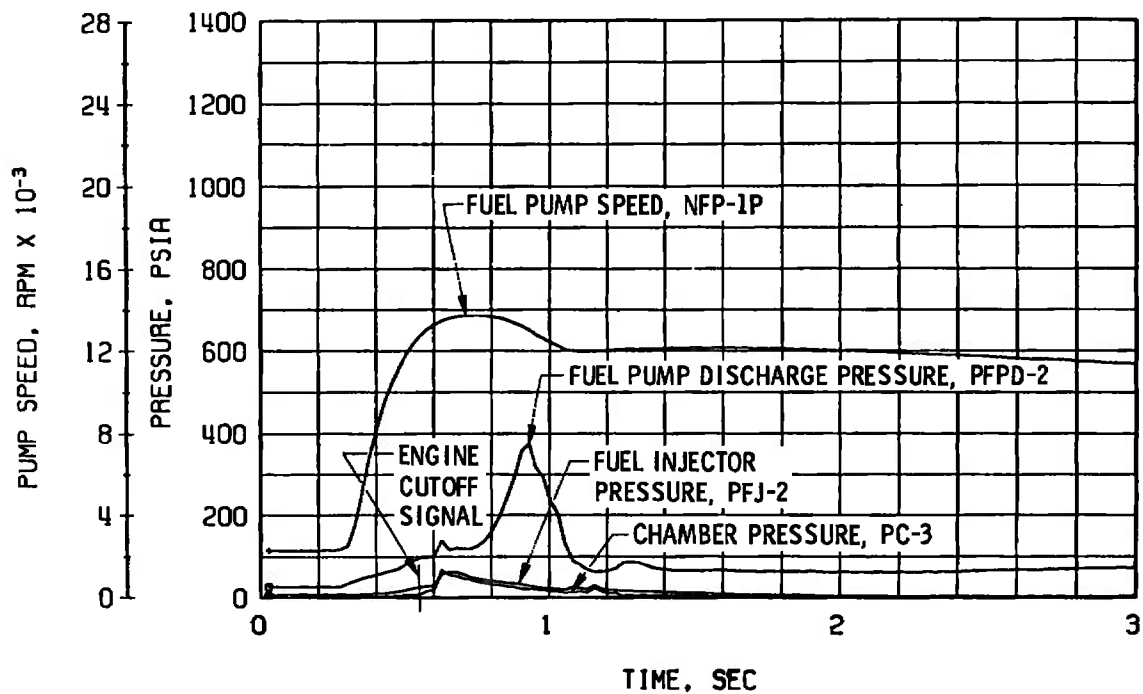
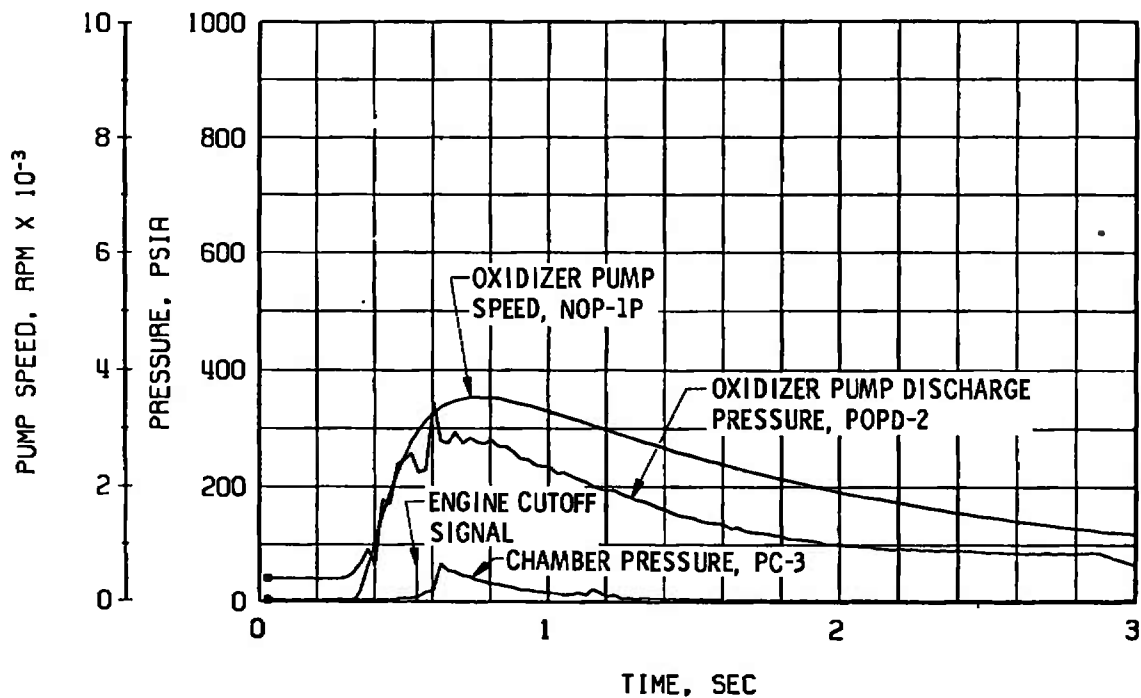


Fig. 17 Engine Ambient and Combustion Chamber Pressures, Firing 28C



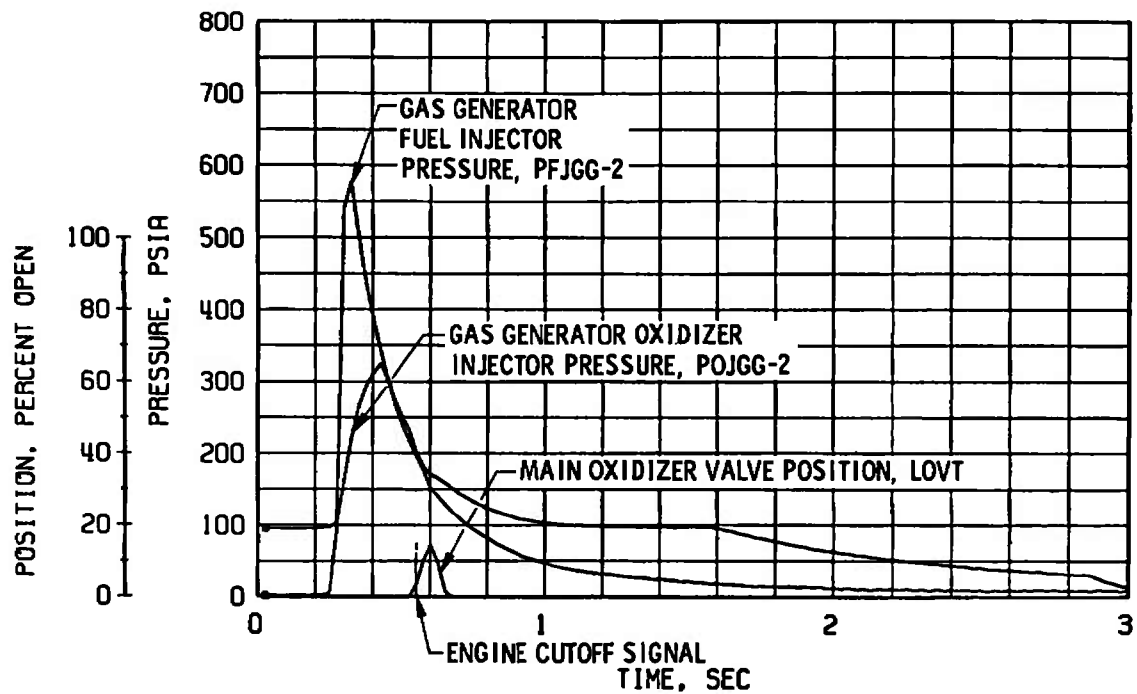


a. Thrust Chamber Fuel System, Start and Shutdown

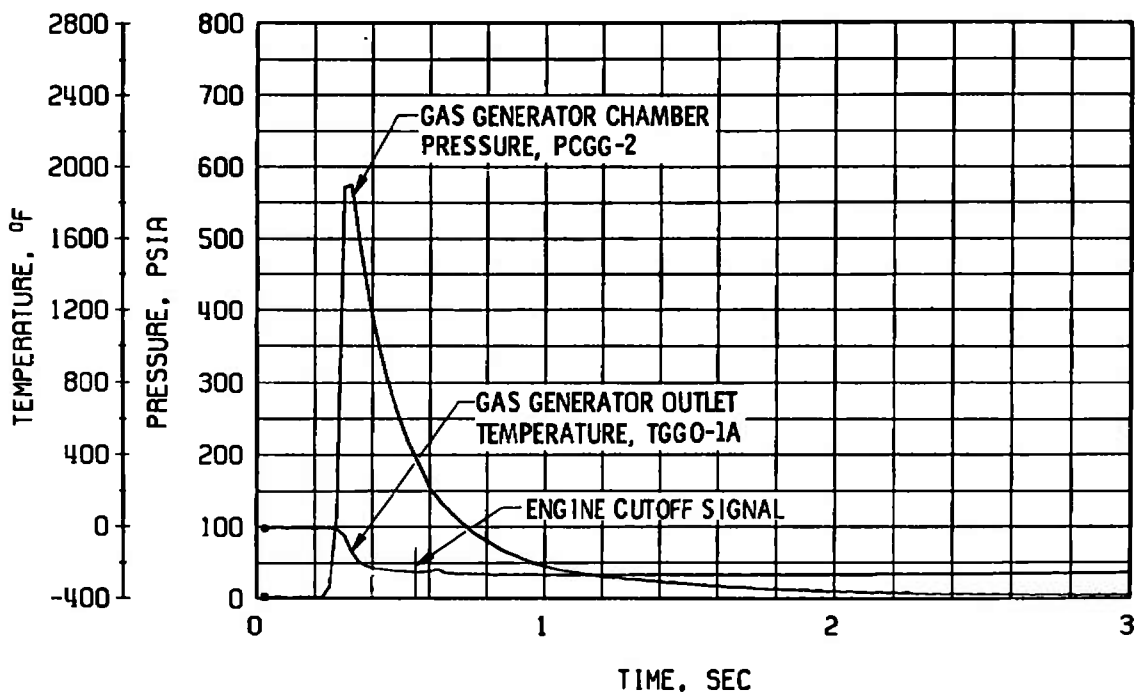


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 18 Engine Transient Operation, Firing 28C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 18 Concluded

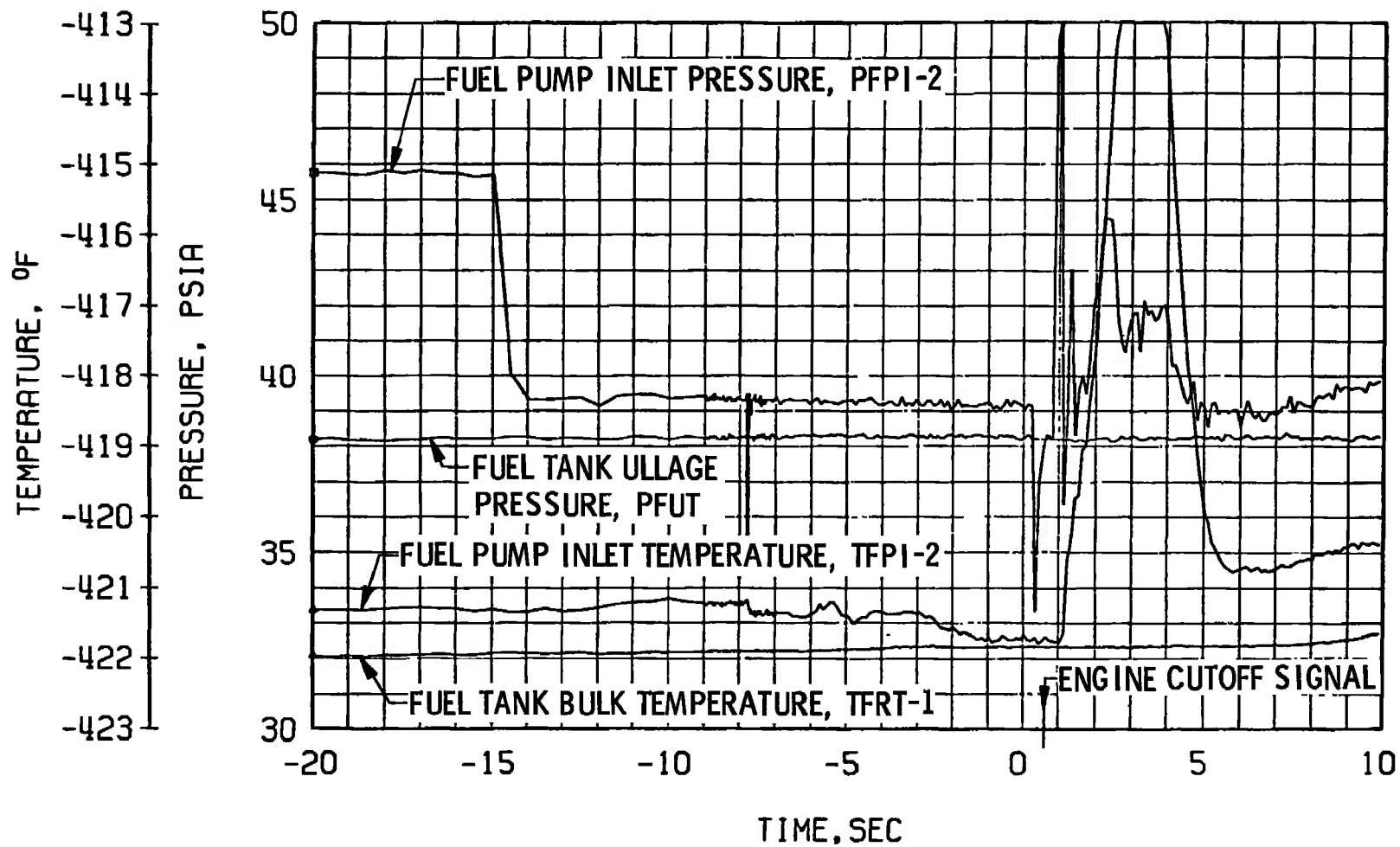
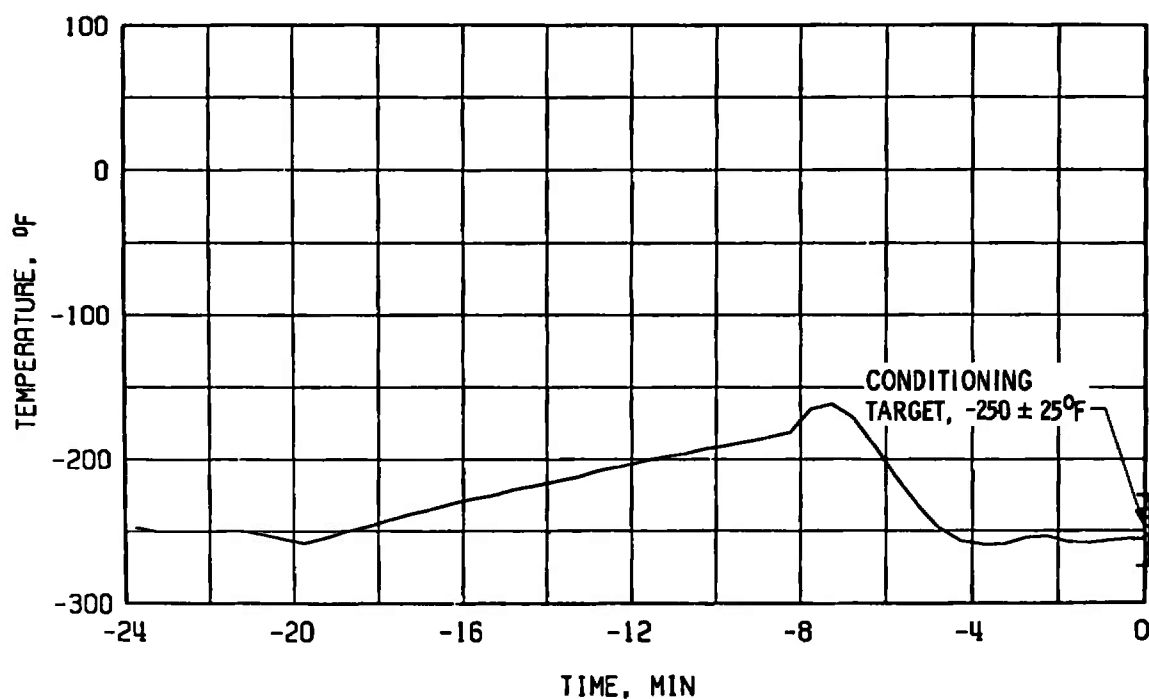
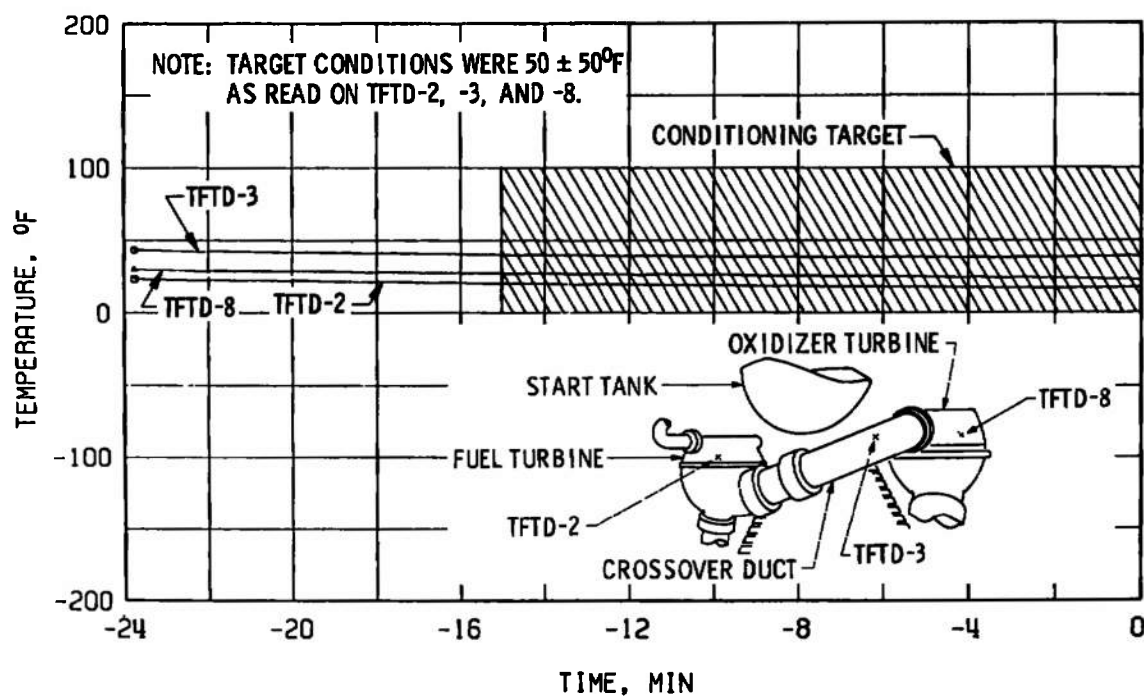


Fig. 19 Fuel Low Pressure Duct Temperature and Pressure Transients, Firing 28C

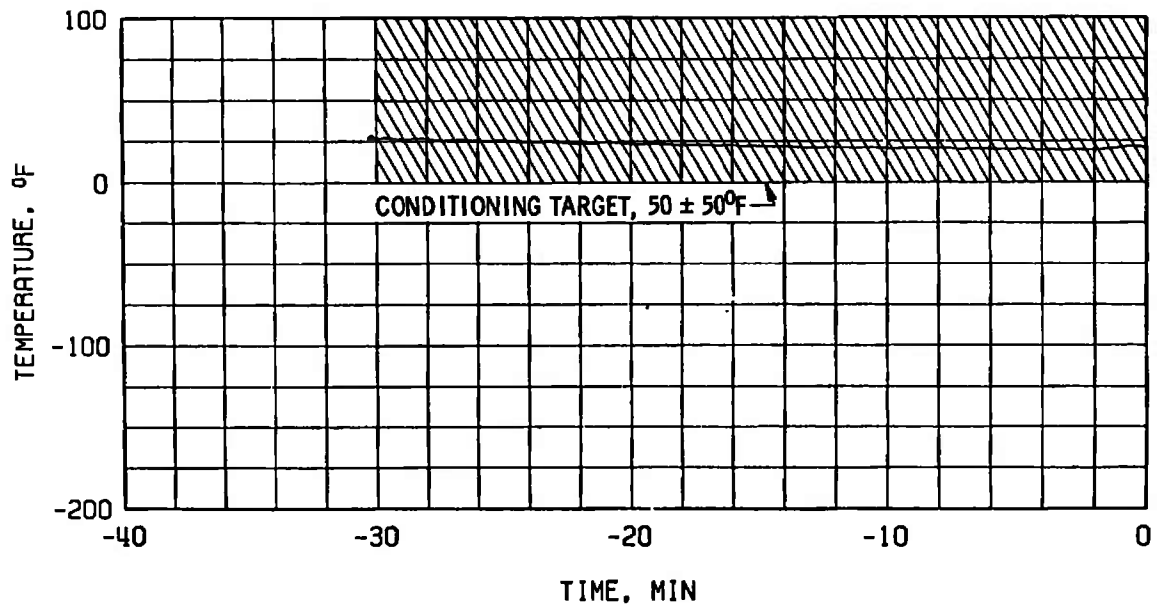


a. Thrust Chamber Throat, TTC-1P

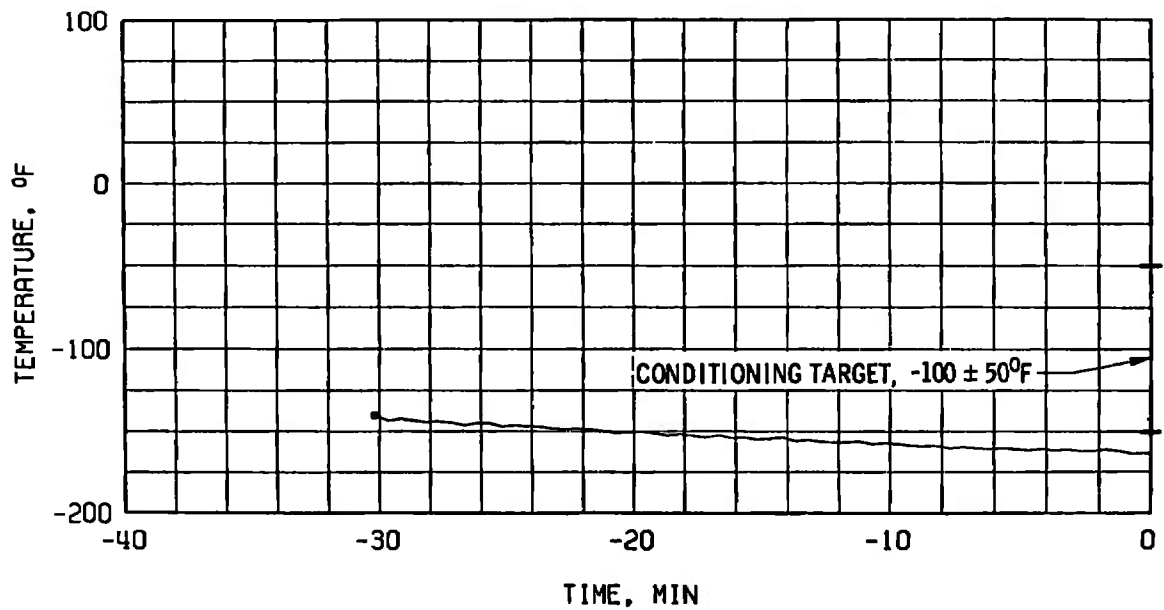


b. Crossover Duct, TFTD

Fig. 20 Thermal Conditioning History of Engine Components, Firing 29A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 20 Concluded

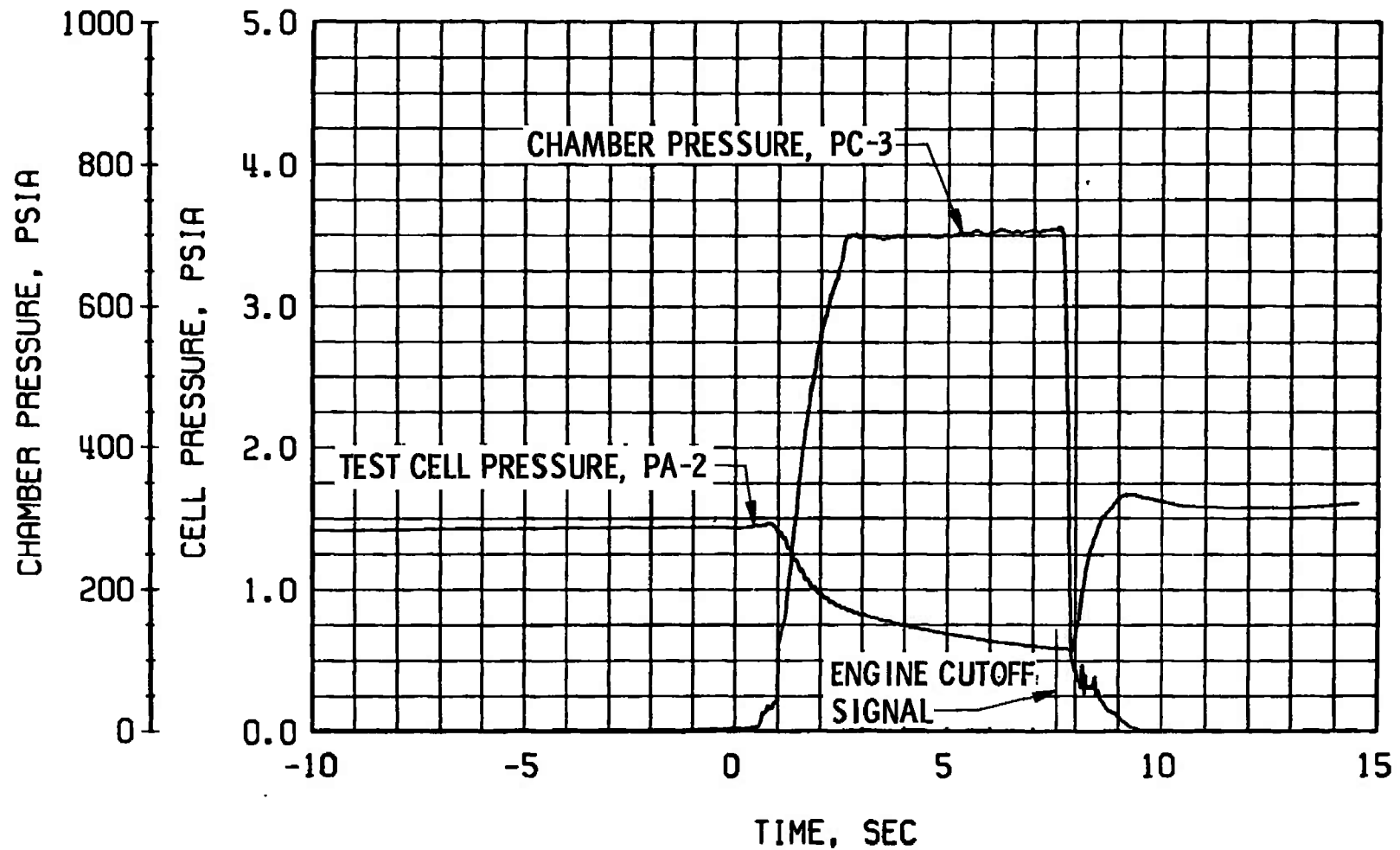
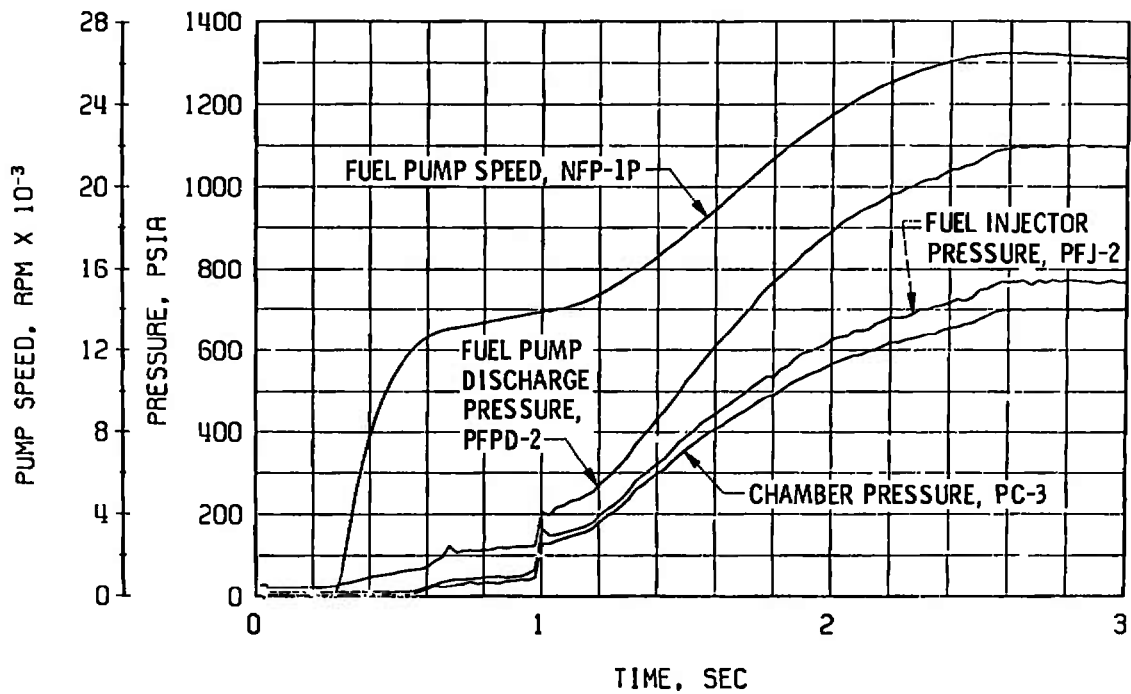
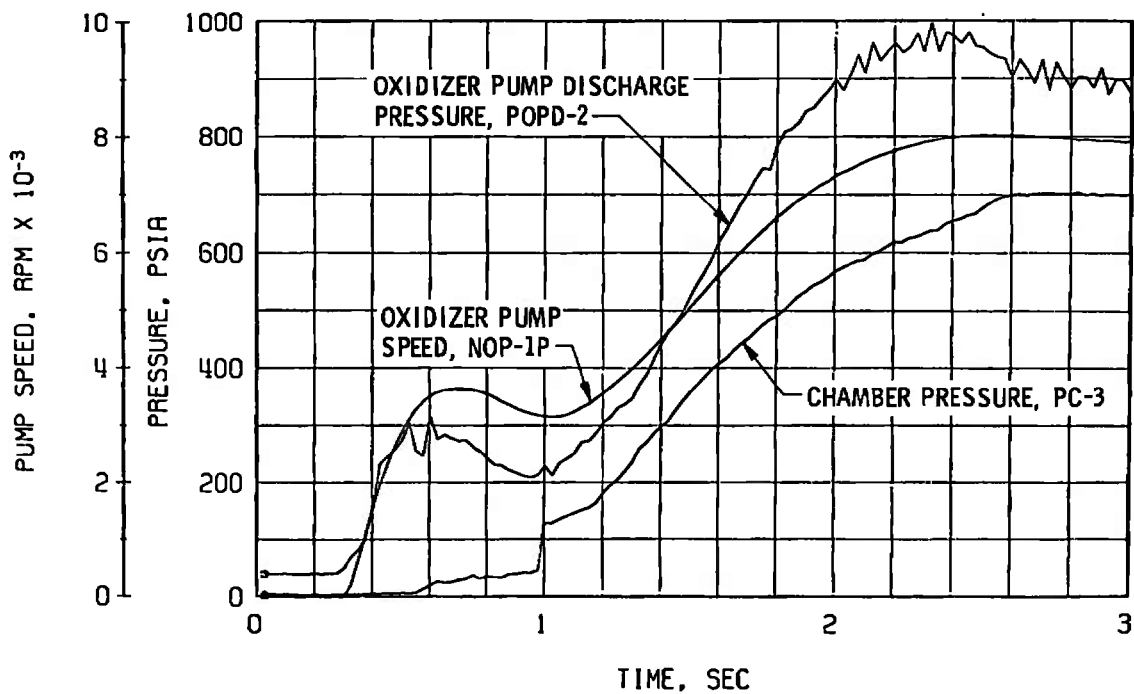


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 29A

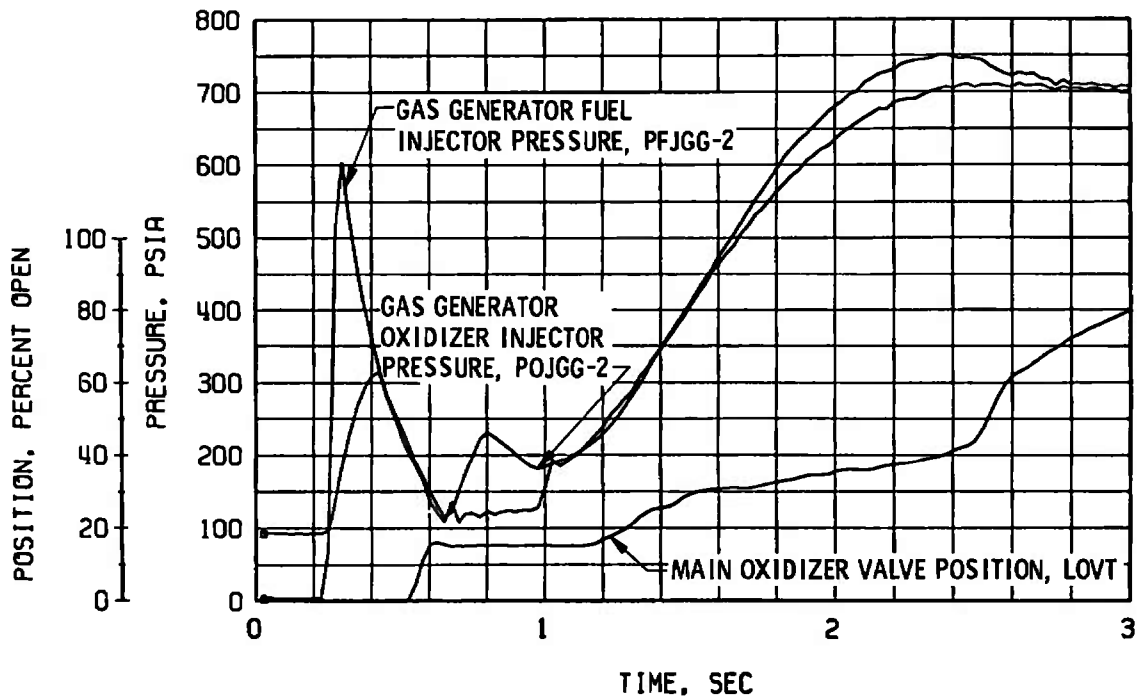


a. Thrust Chamber Fuel System, Start

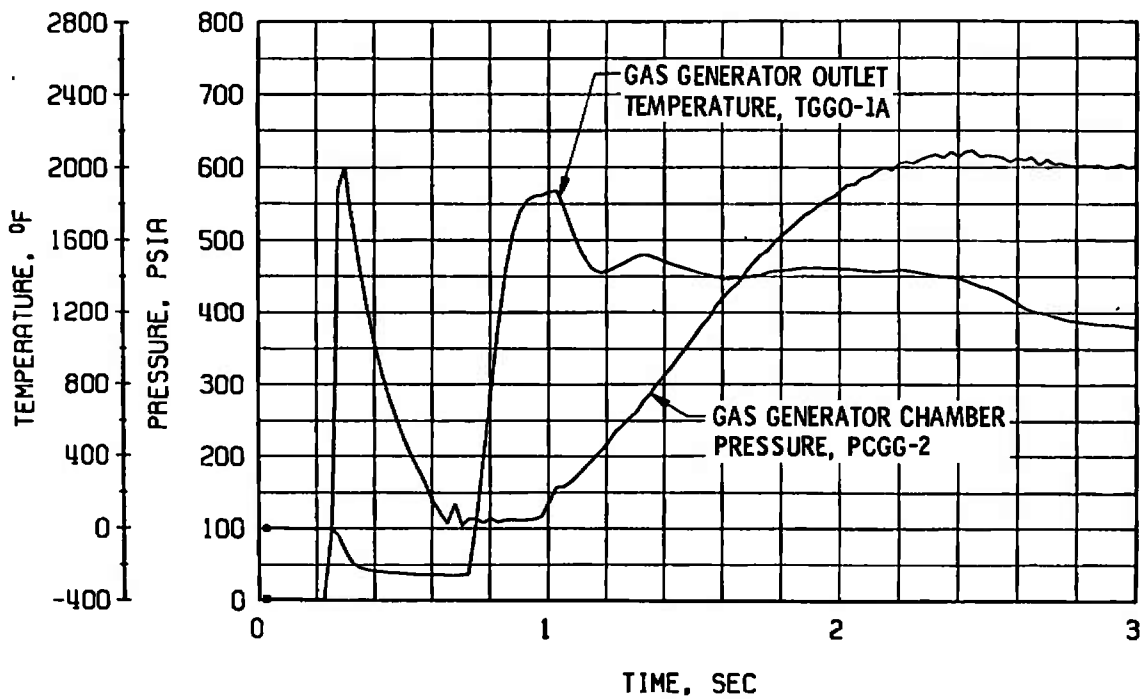


b. Thrust Chamber Oxidizer System, Start

Fig. 22 Engine Transient Operation, Firing 29A



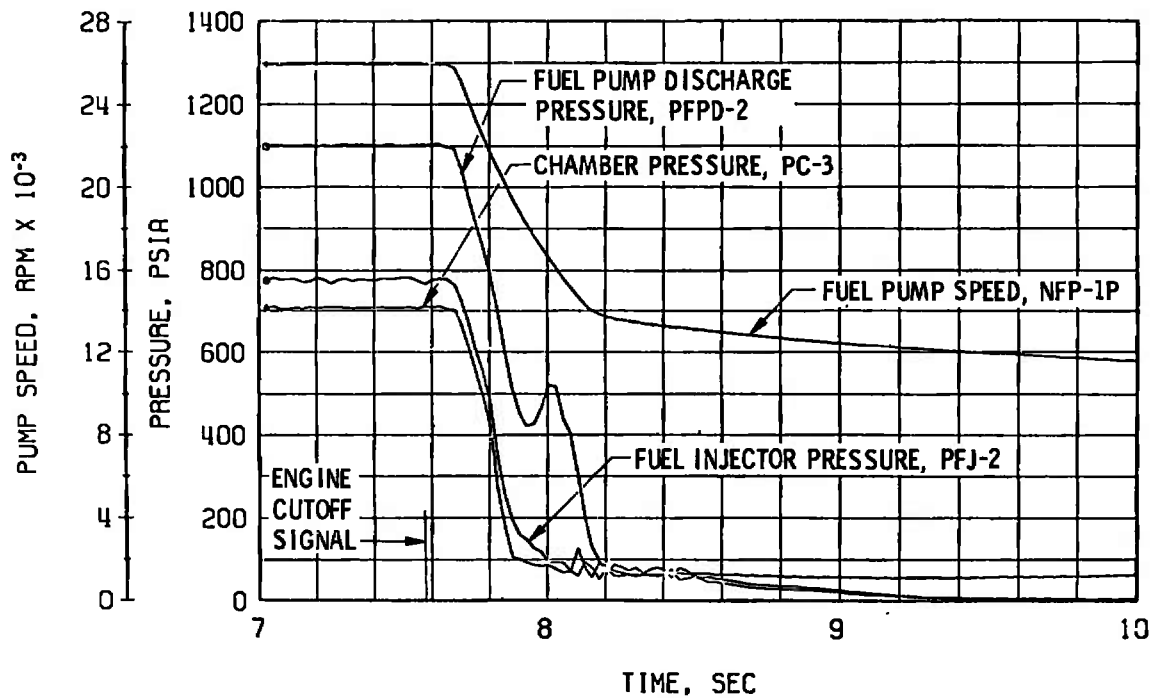
c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start



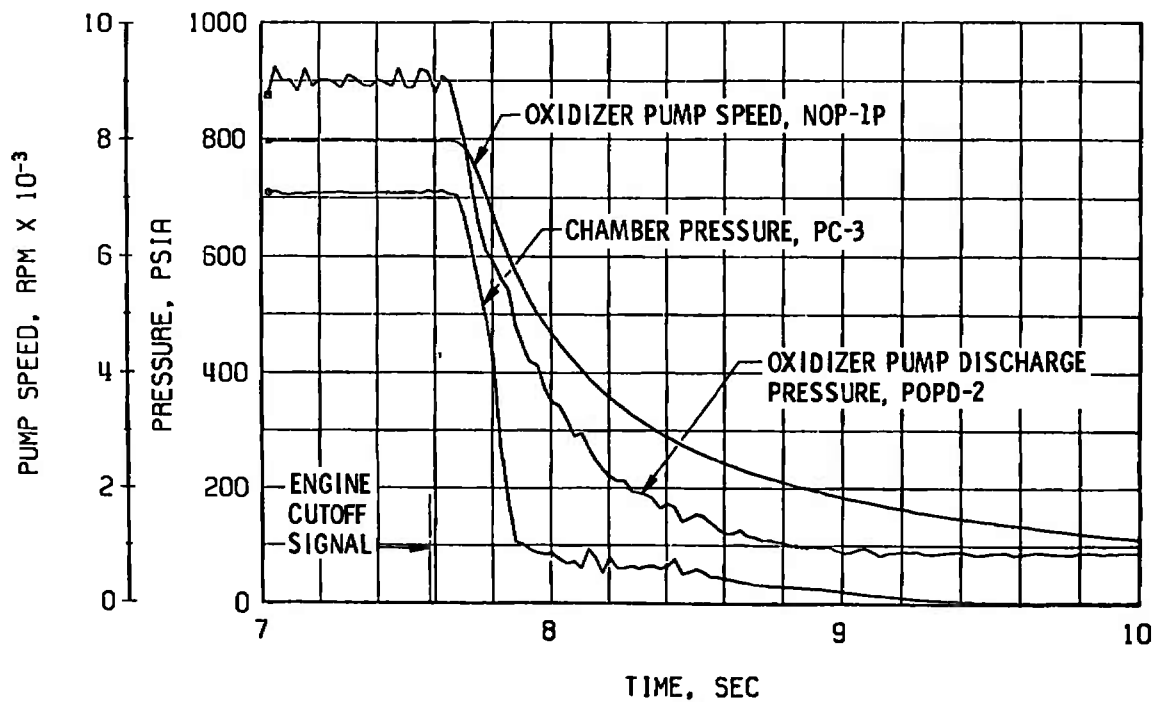
d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 22 Continued



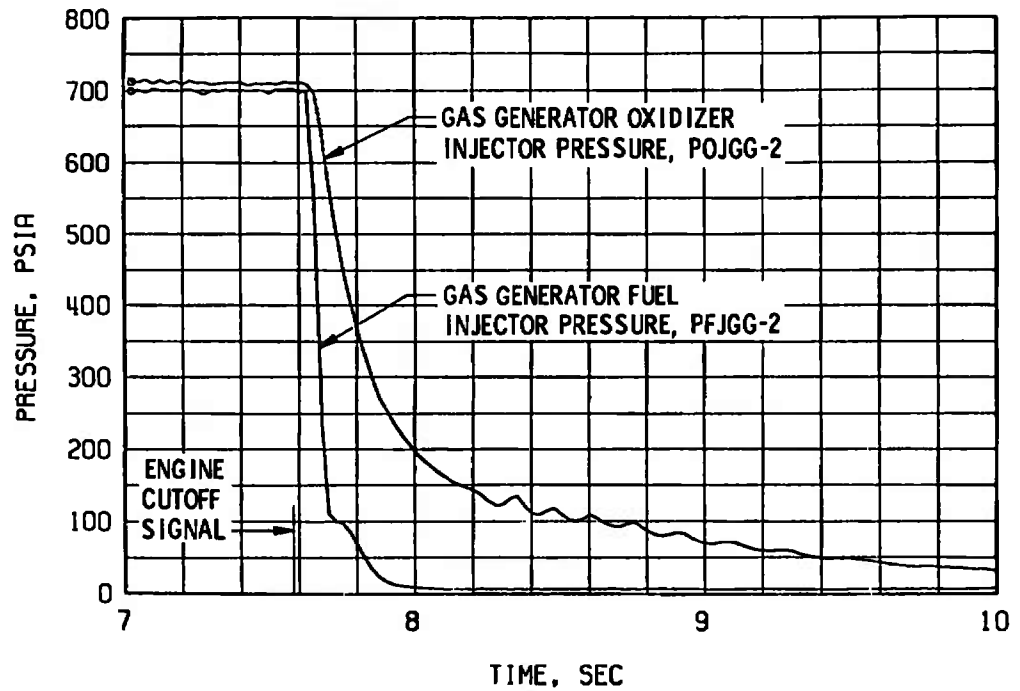


e. Thrust Chamber Fuel System, Shutdown

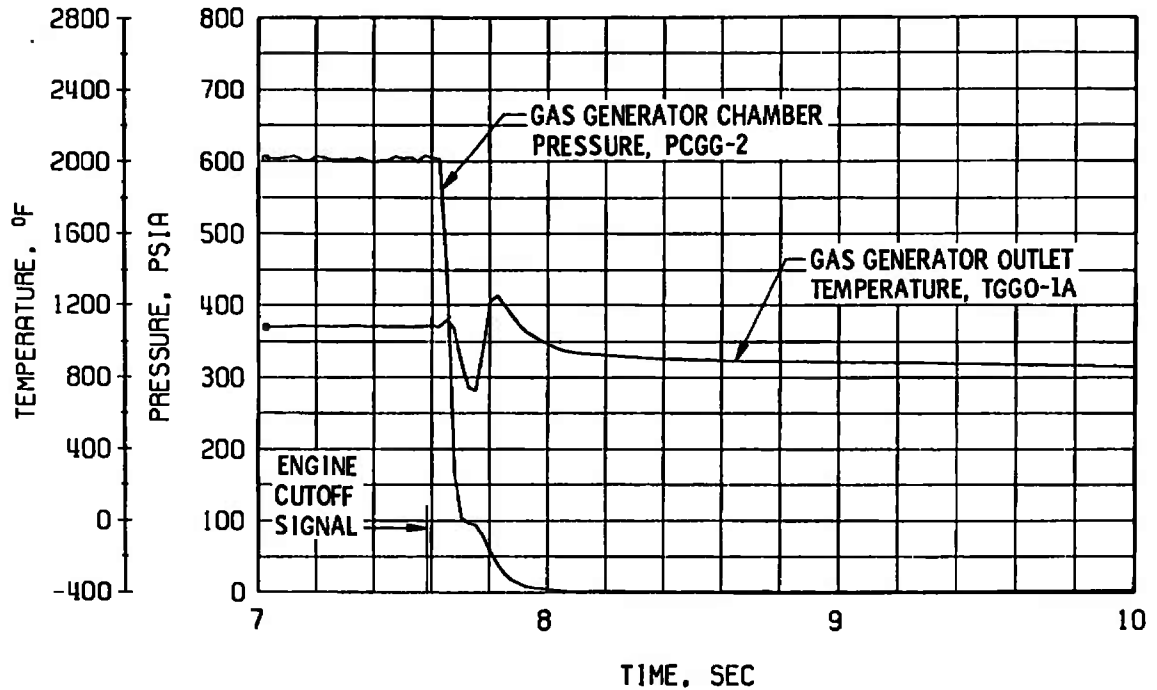


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 22 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 22 Concluded

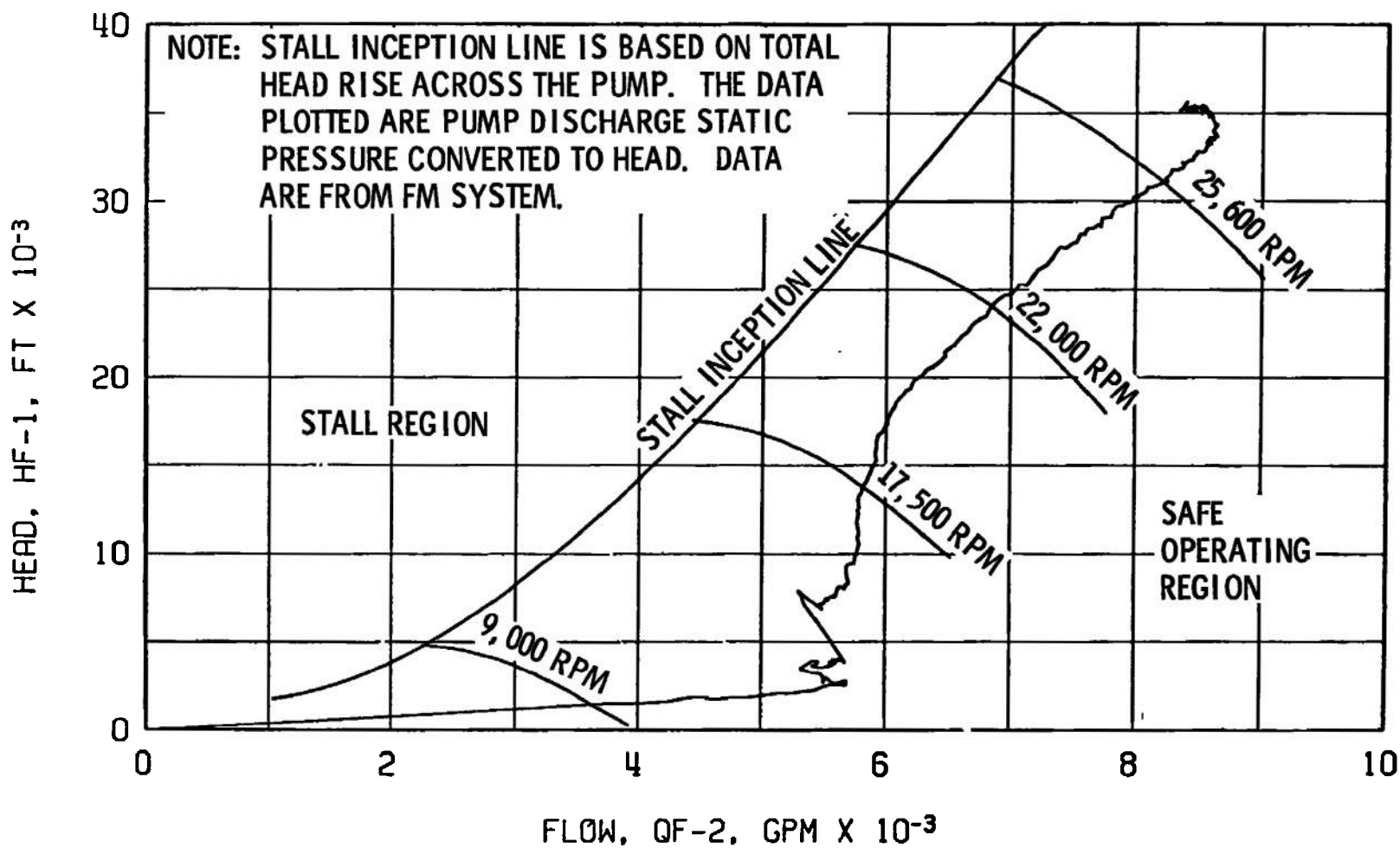
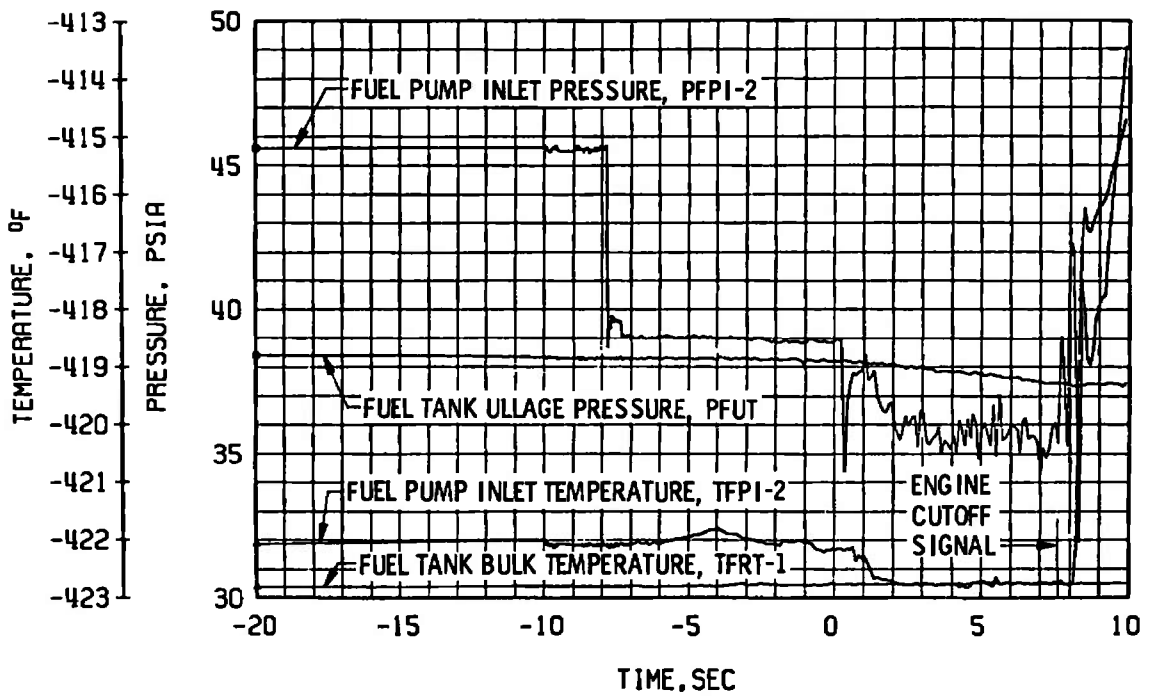
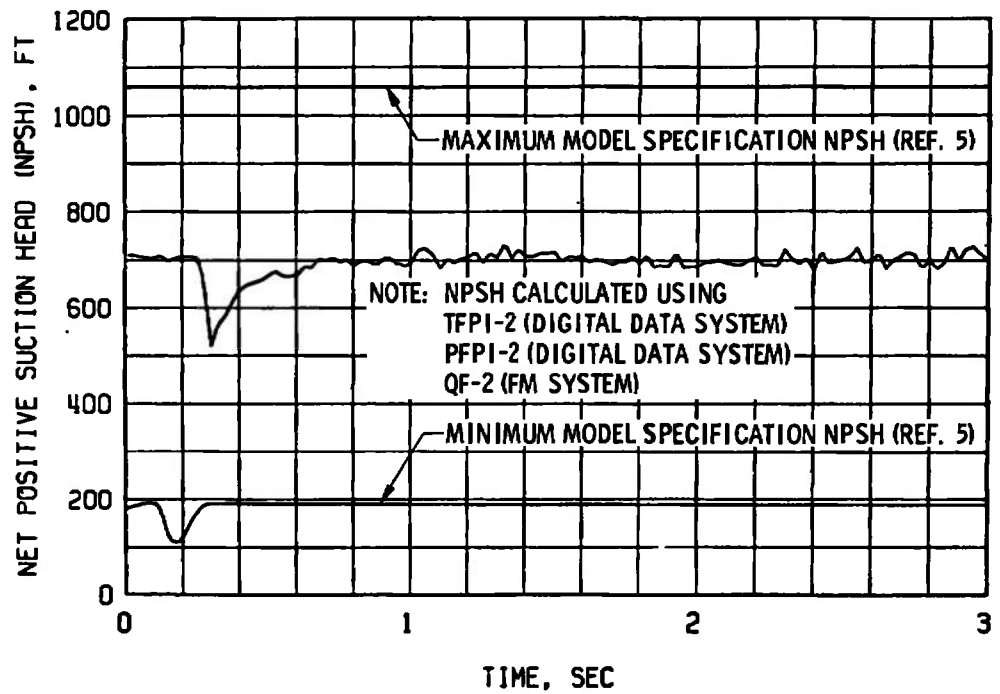


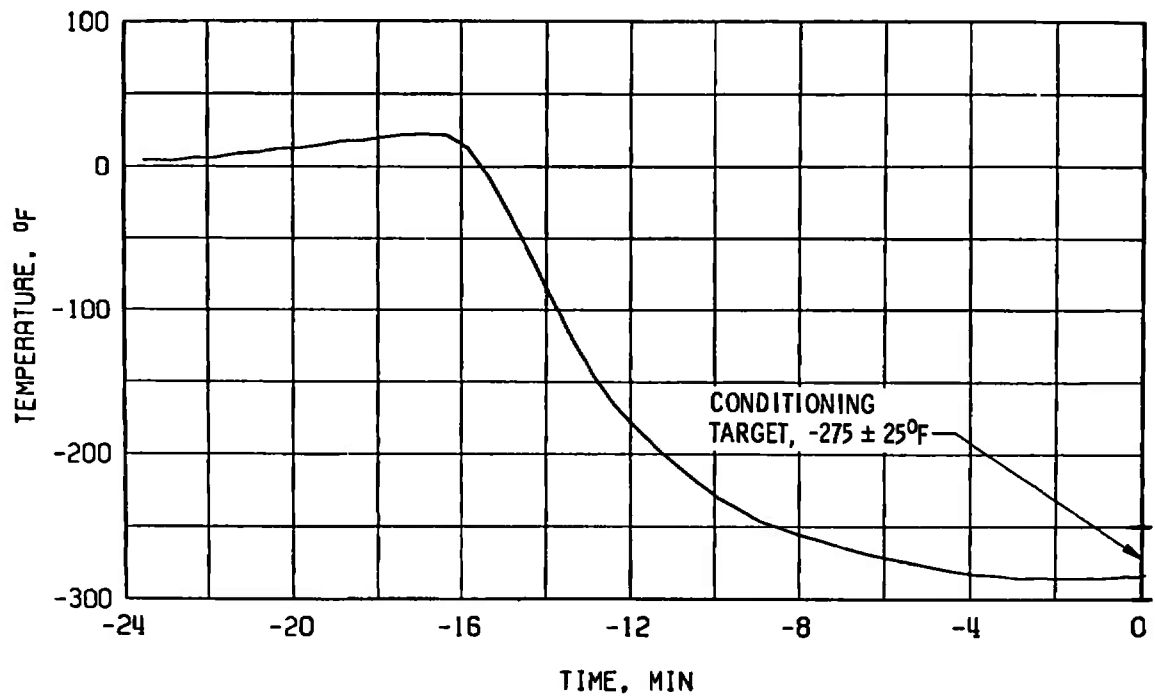
Fig. 23 Fuel Pump Stall Transient Performance, Firing 29A



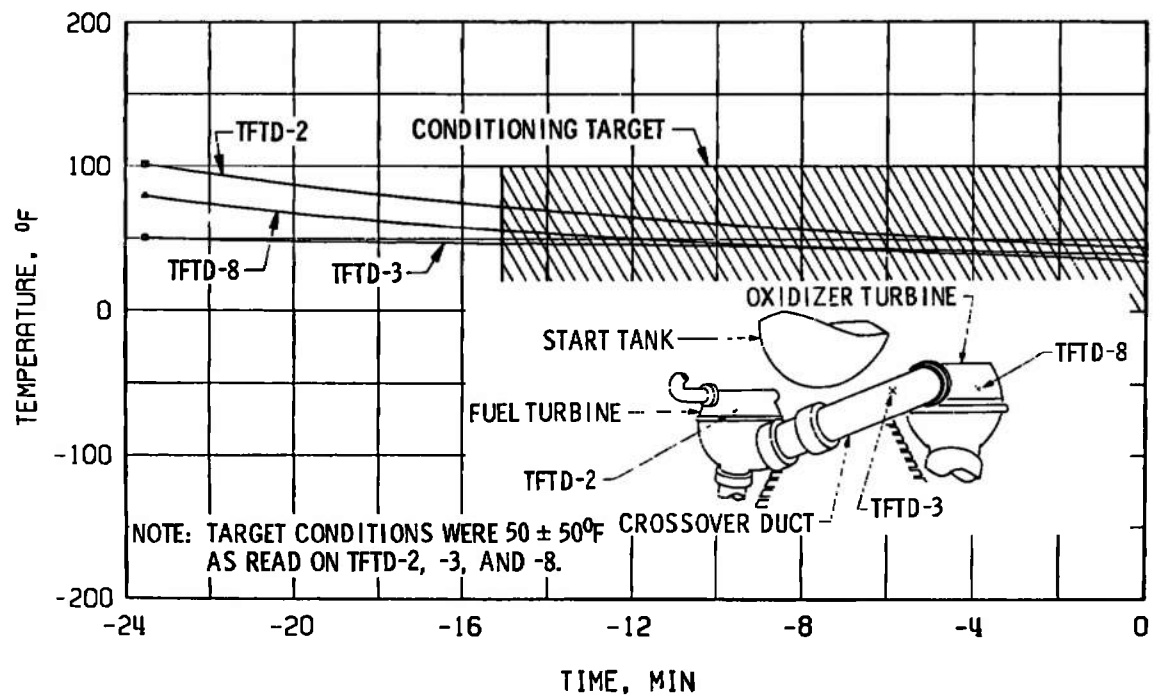
a. Duct Pressure and Temperature Transients



b. Fuel Pump NPSH during Start Transient, Firing 29A  
 Fig. 24 Fuel Low Pressure Duct Performance, Firing 29A

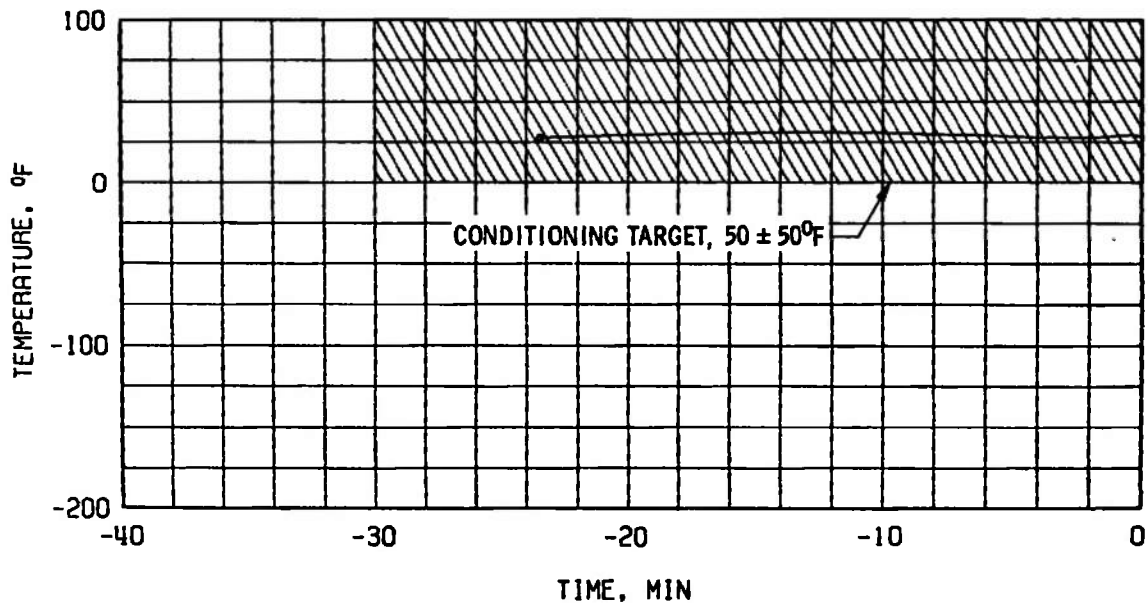


a. Thrust Chamber Throat, TTC-1P

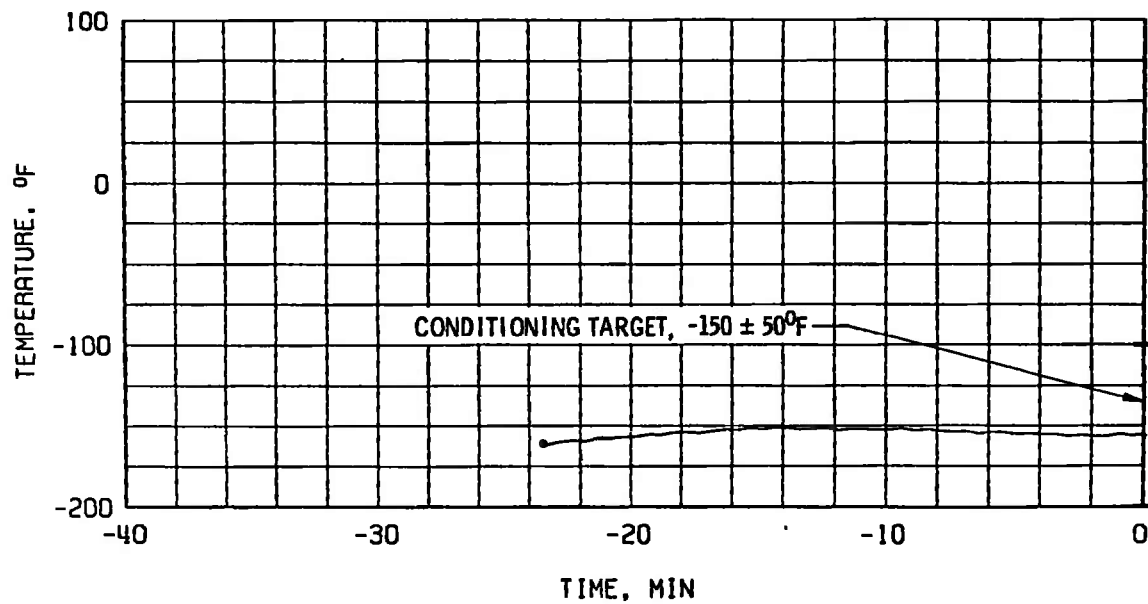


b. Crossover Duct, TFTD

Fig. 25 Thermal Conditioning History of Engine Components, Firing 29B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 25 Concluded

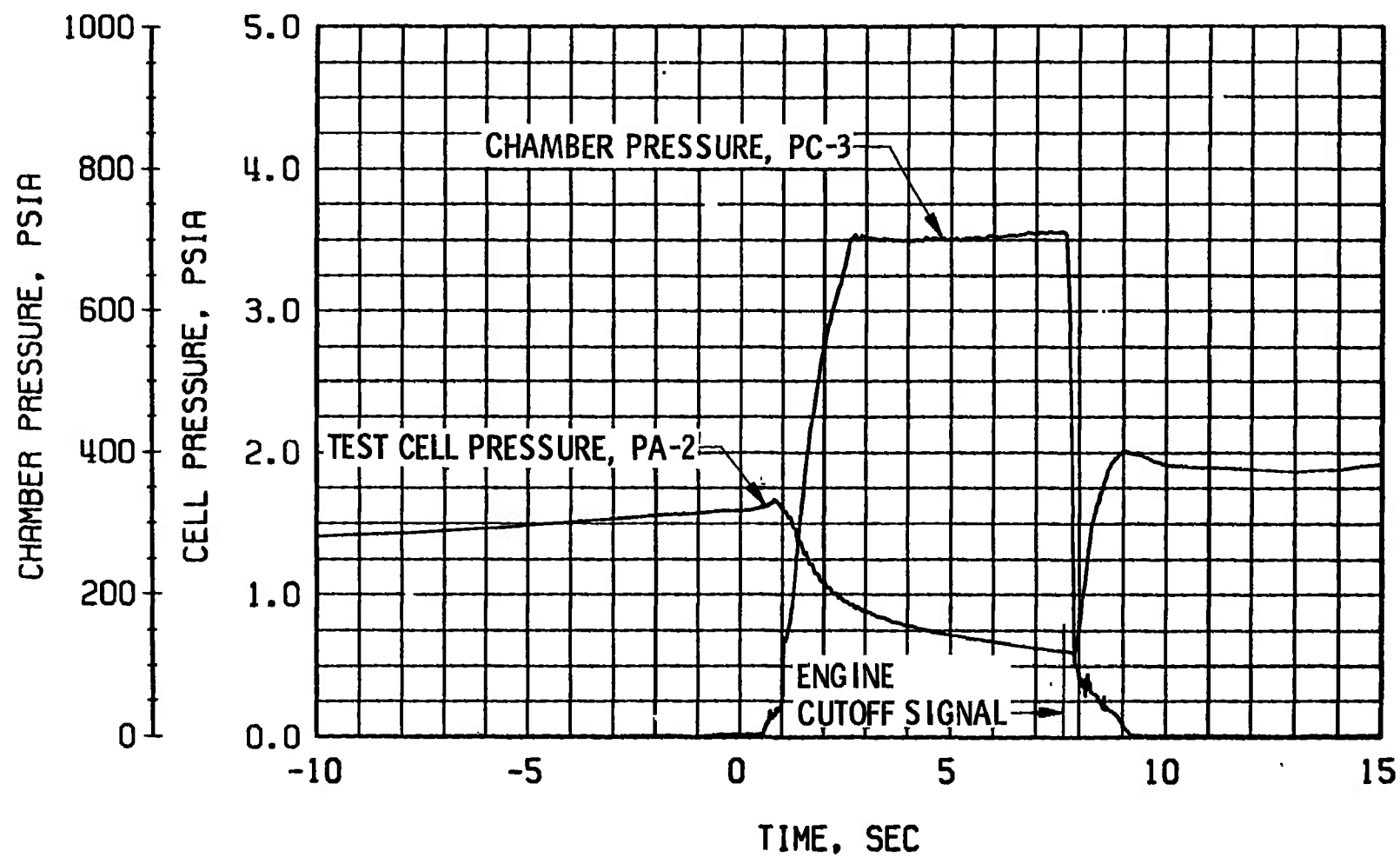
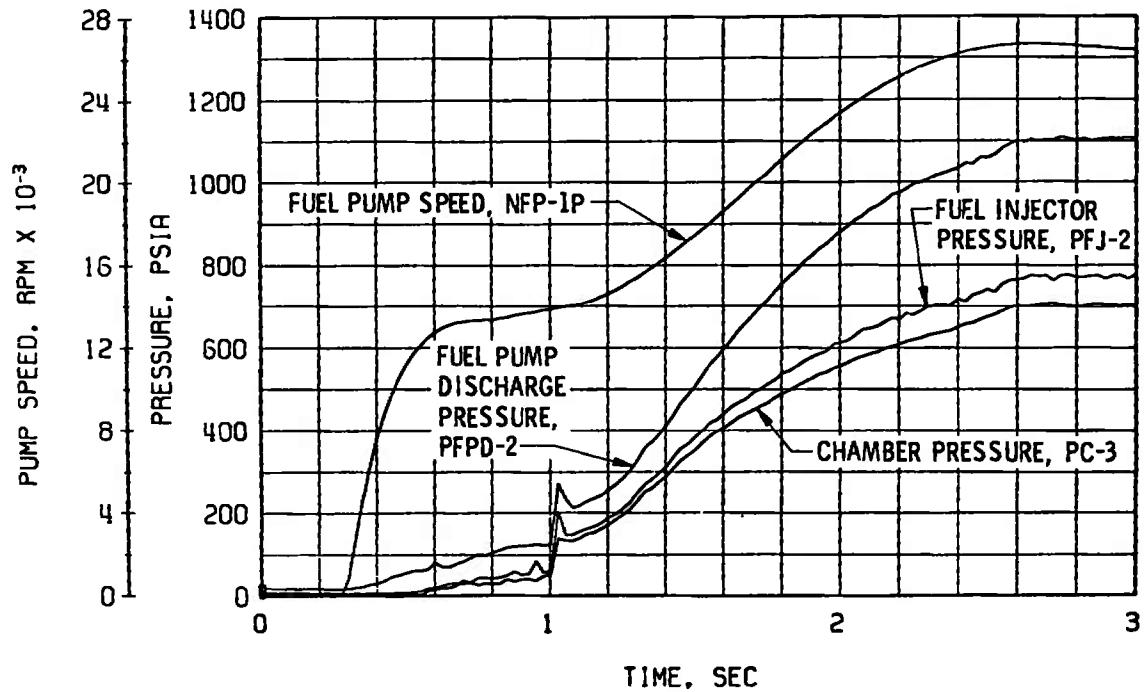
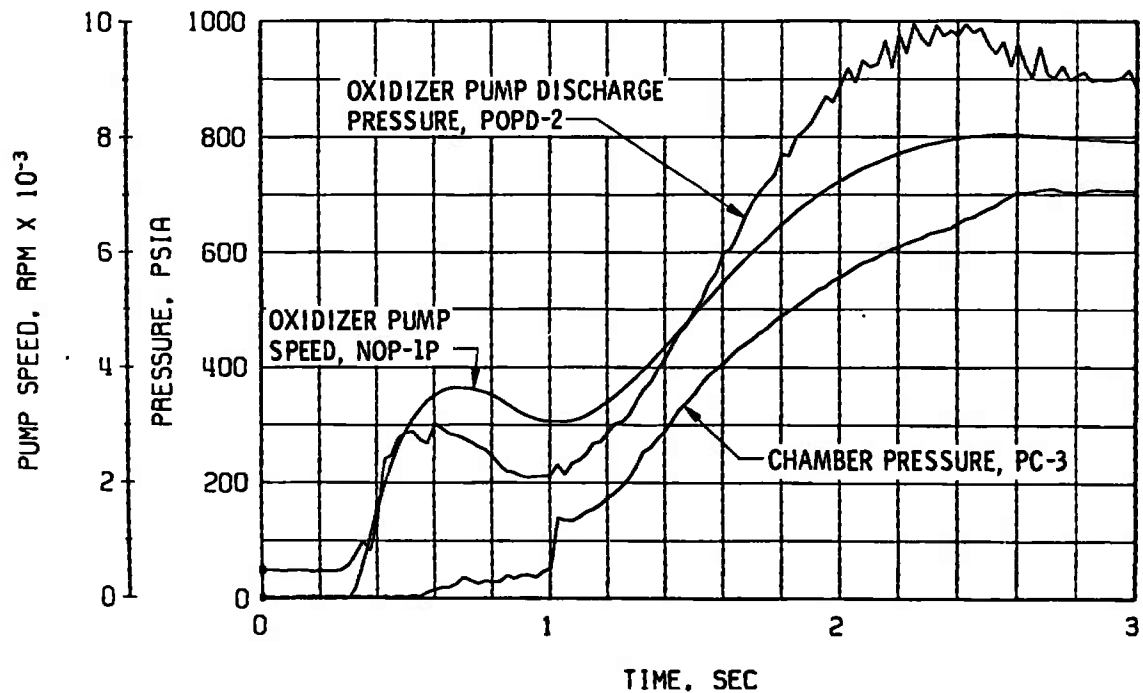


Fig. 26 Engine Ambient and Combustion Chamber Pressures, Firing 29B



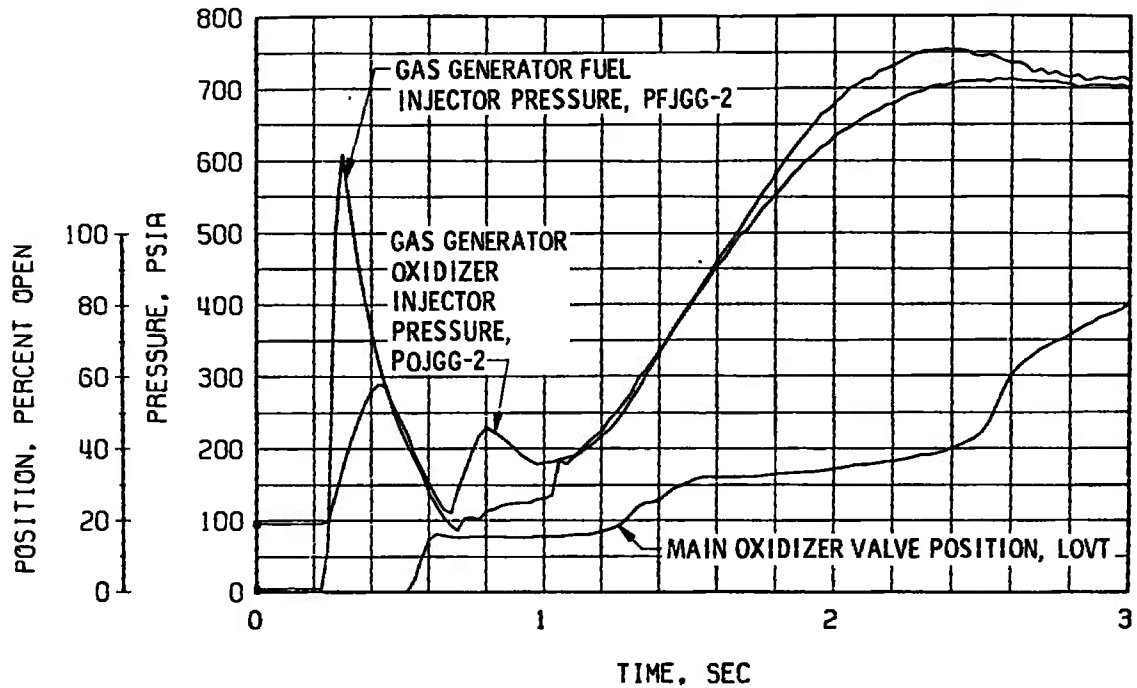
a. Thrust Chamber Fuel System, Start



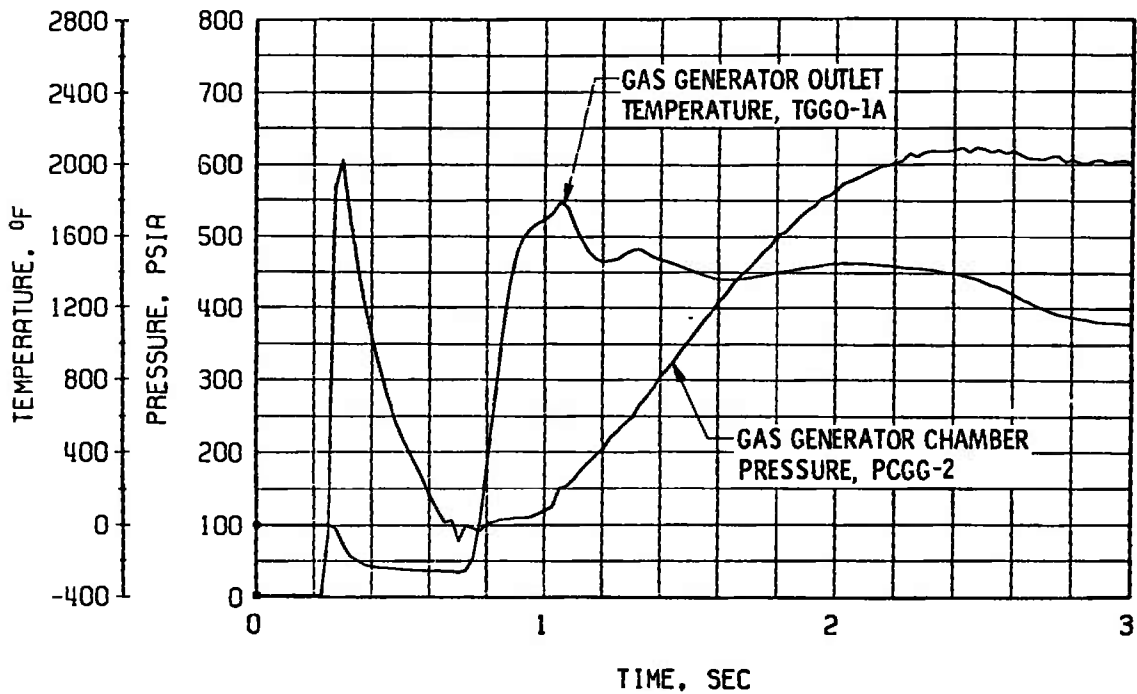
b. Thrust Chamber Oxidizer System, Start

Fig. 27 Engine Transient Operation, Firing 29B



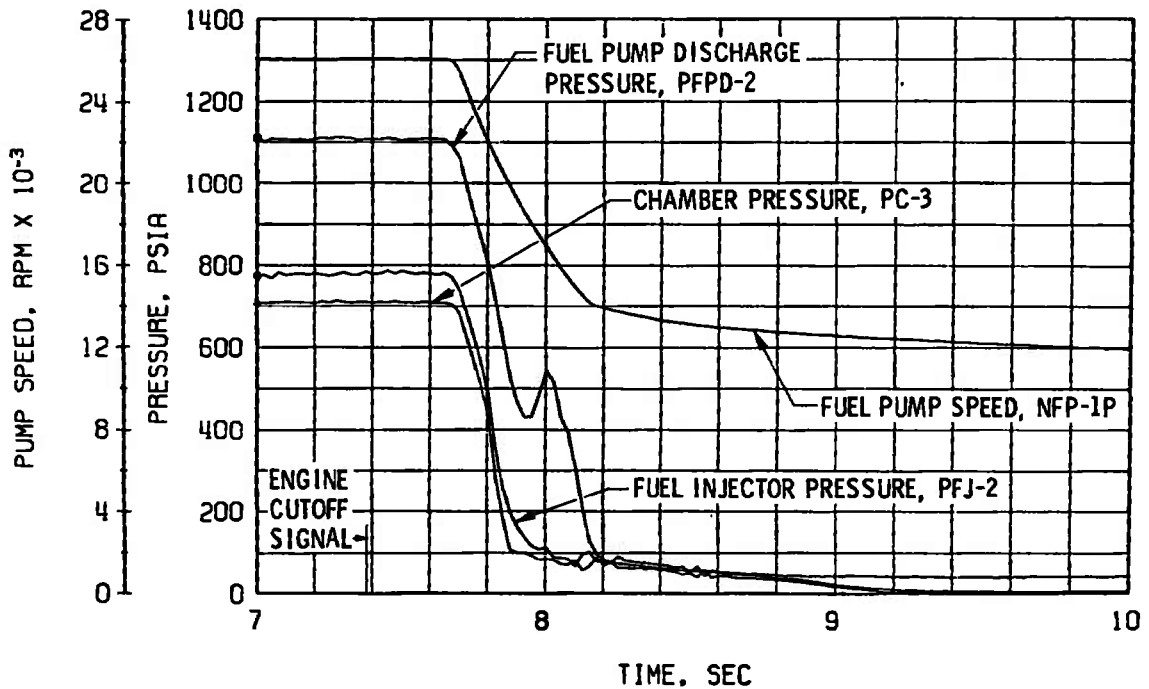


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

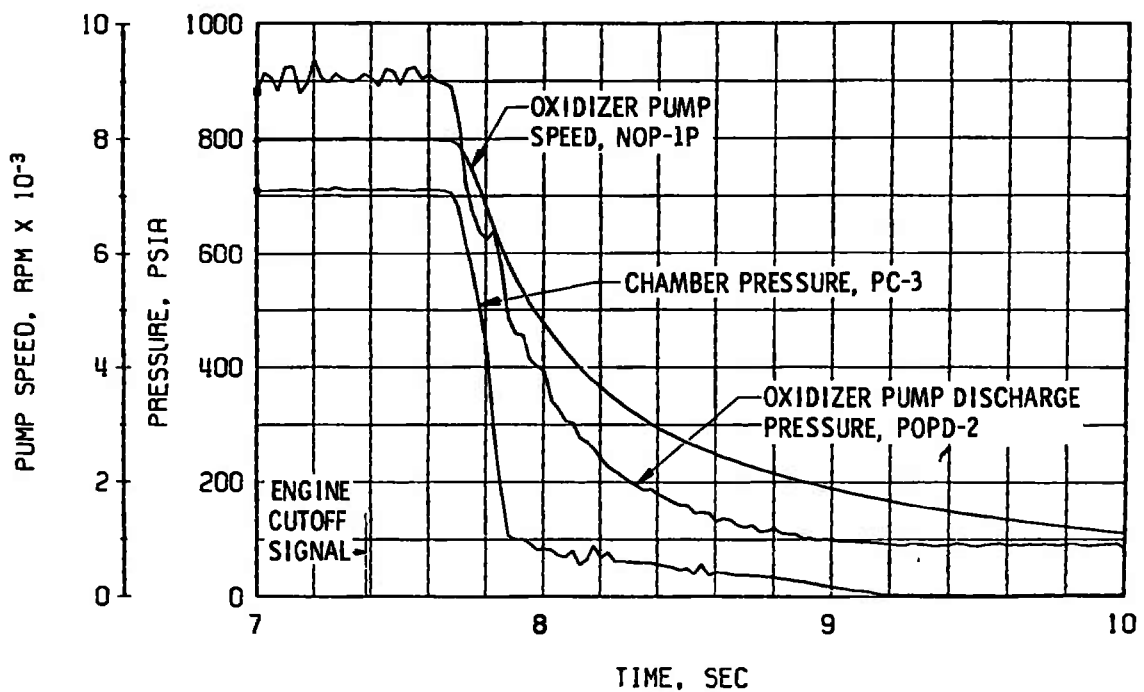


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 27 Continued

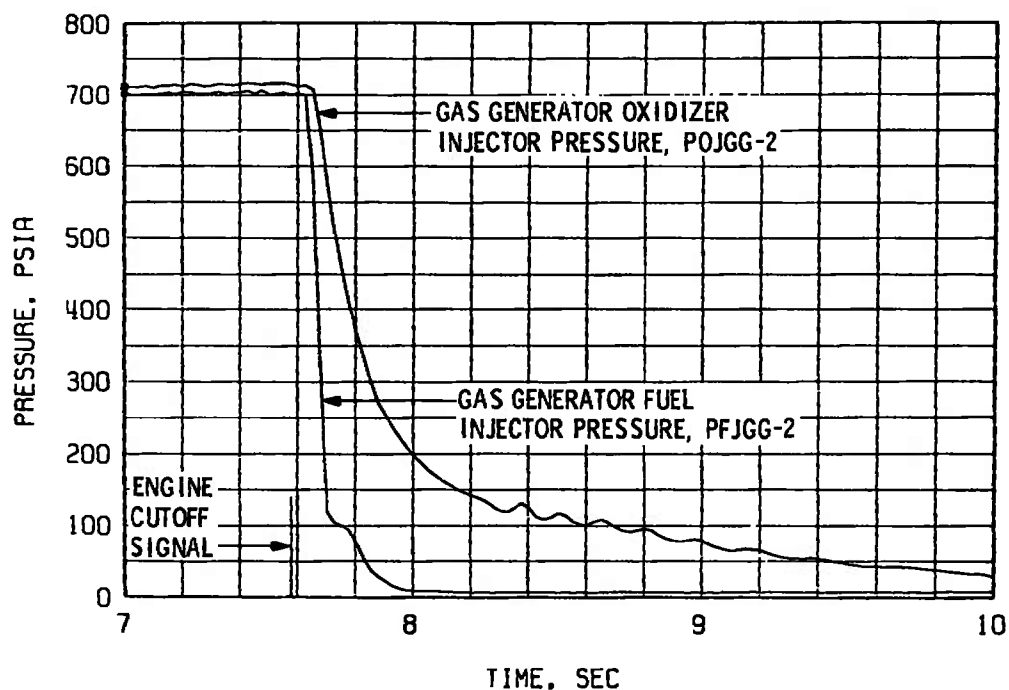


e. Thrust Chamber Fuel System, Shutdown

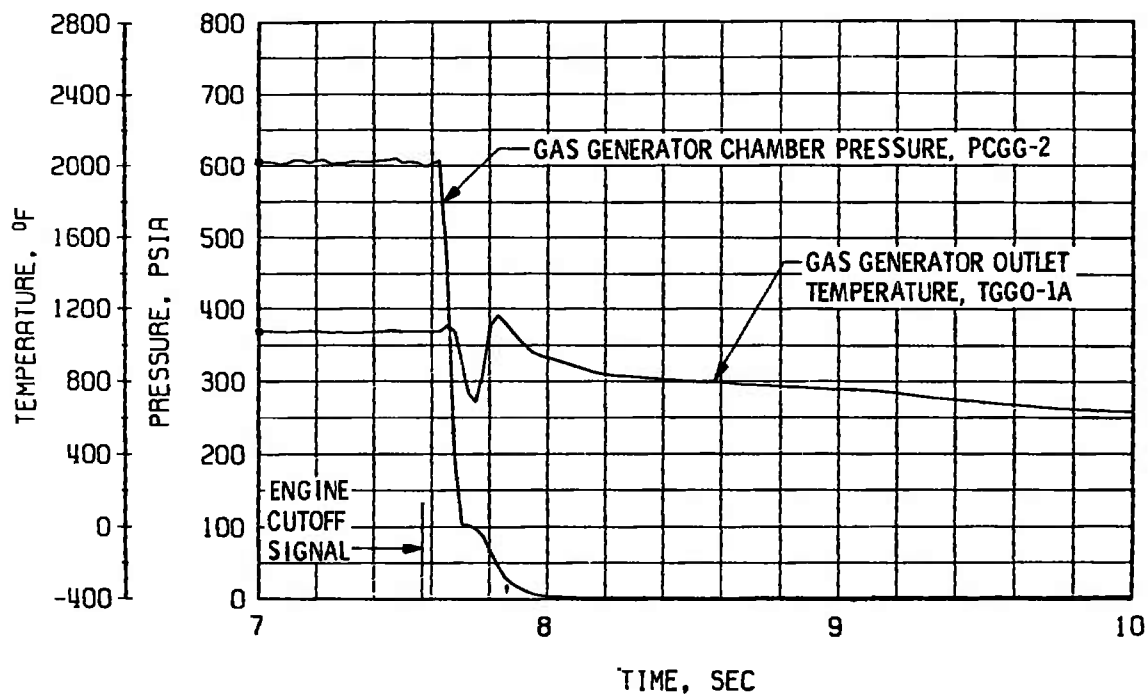


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 27 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 27 Concluded

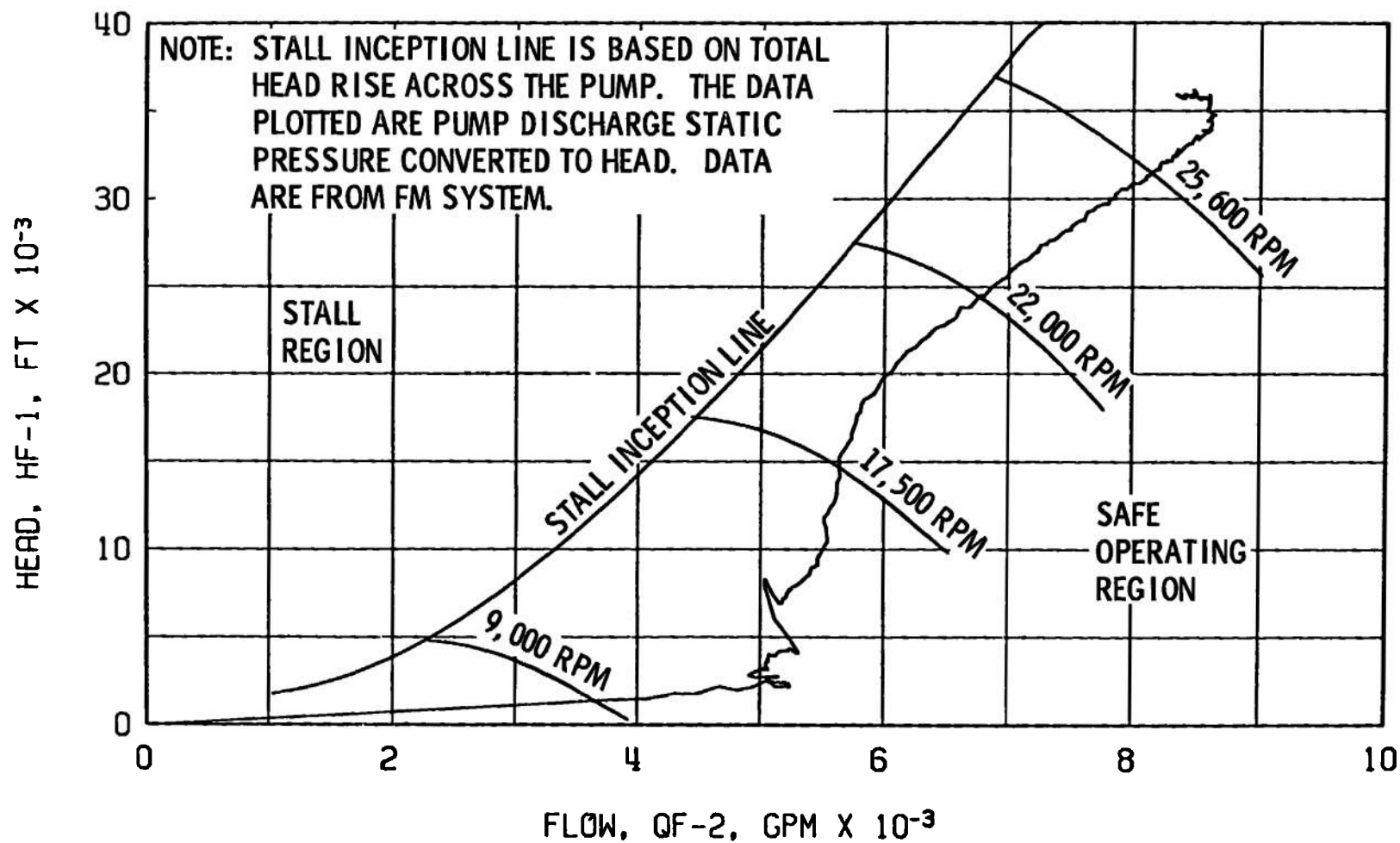
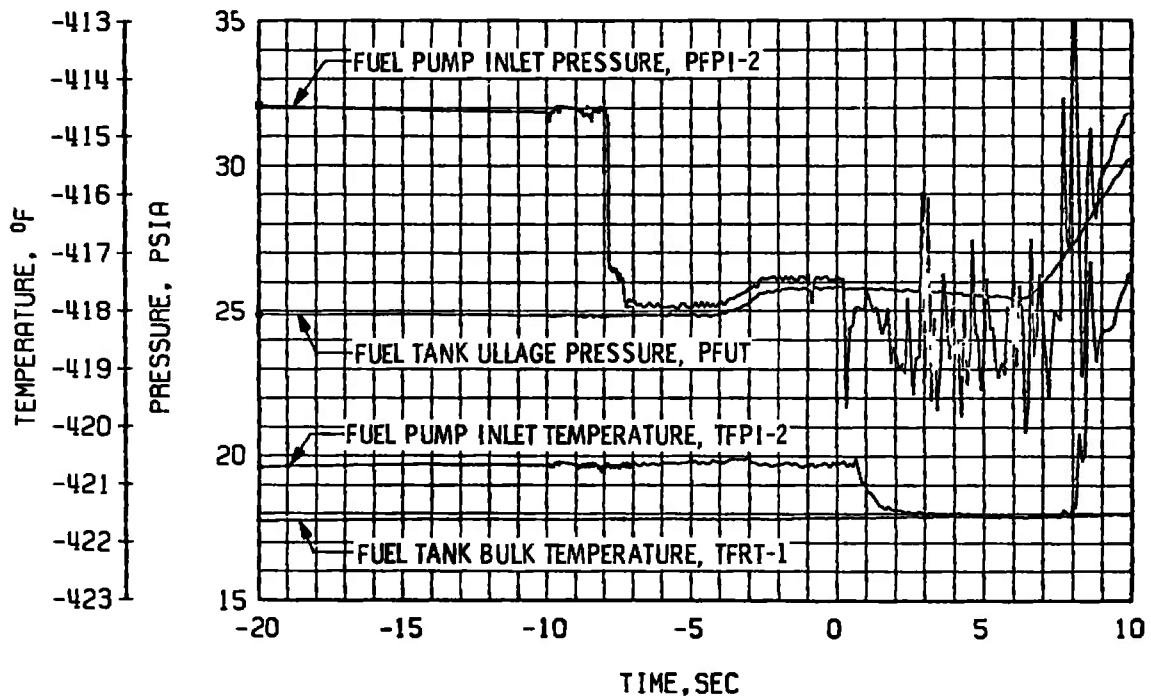
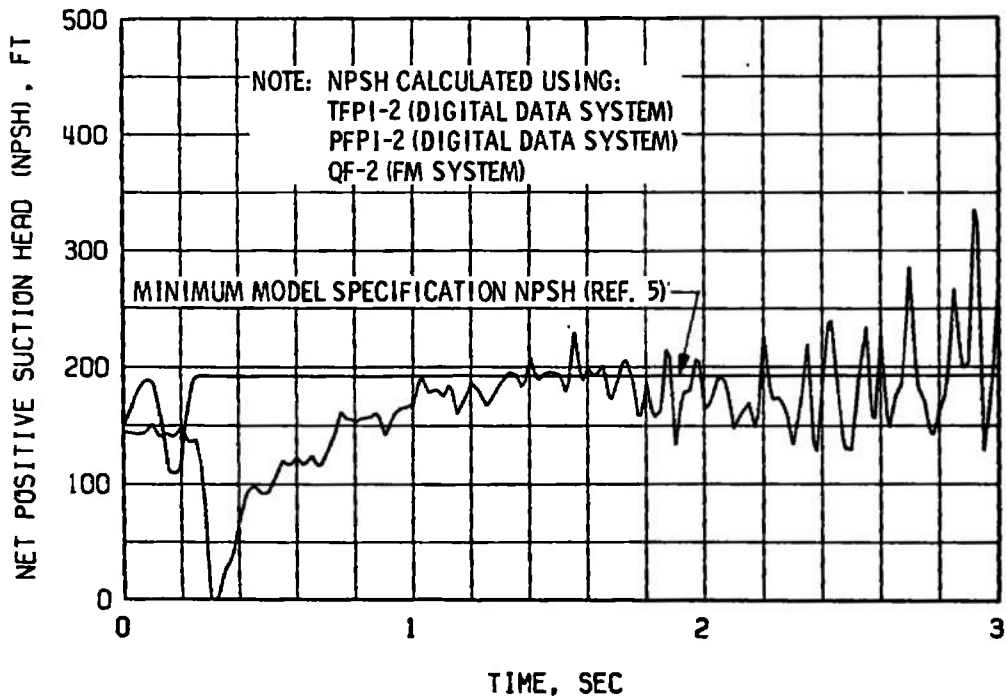


Fig. 28 Fuel Pump Start Transient Performance, Firing 29B

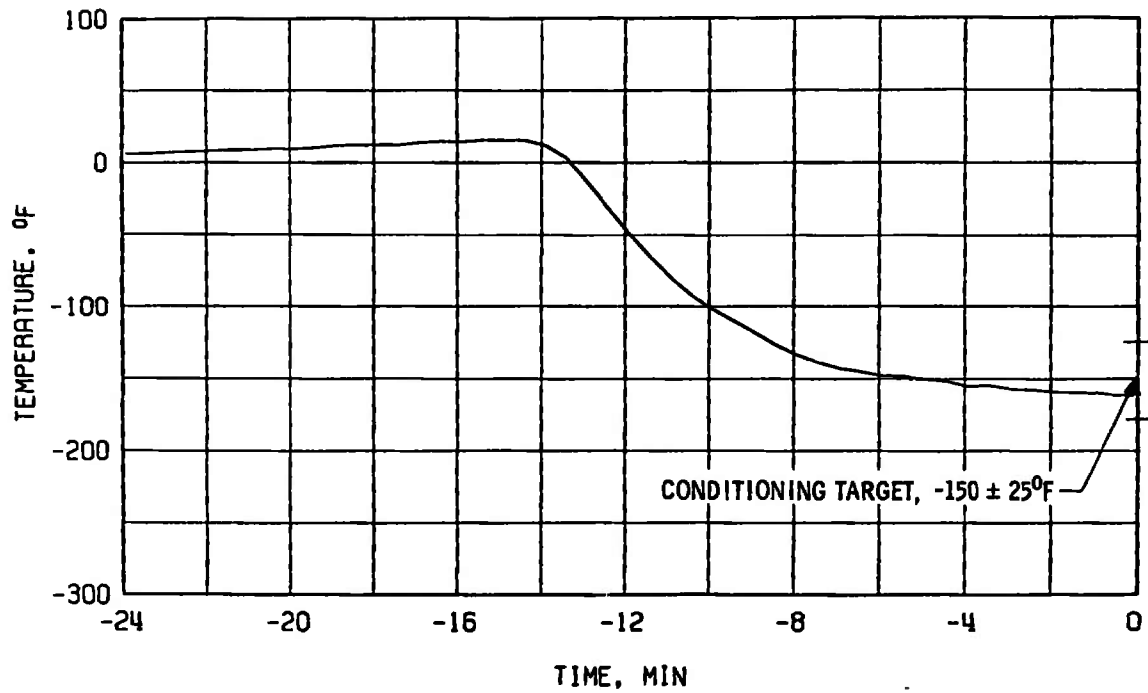


a. Duct Pressure and Temperature Transients

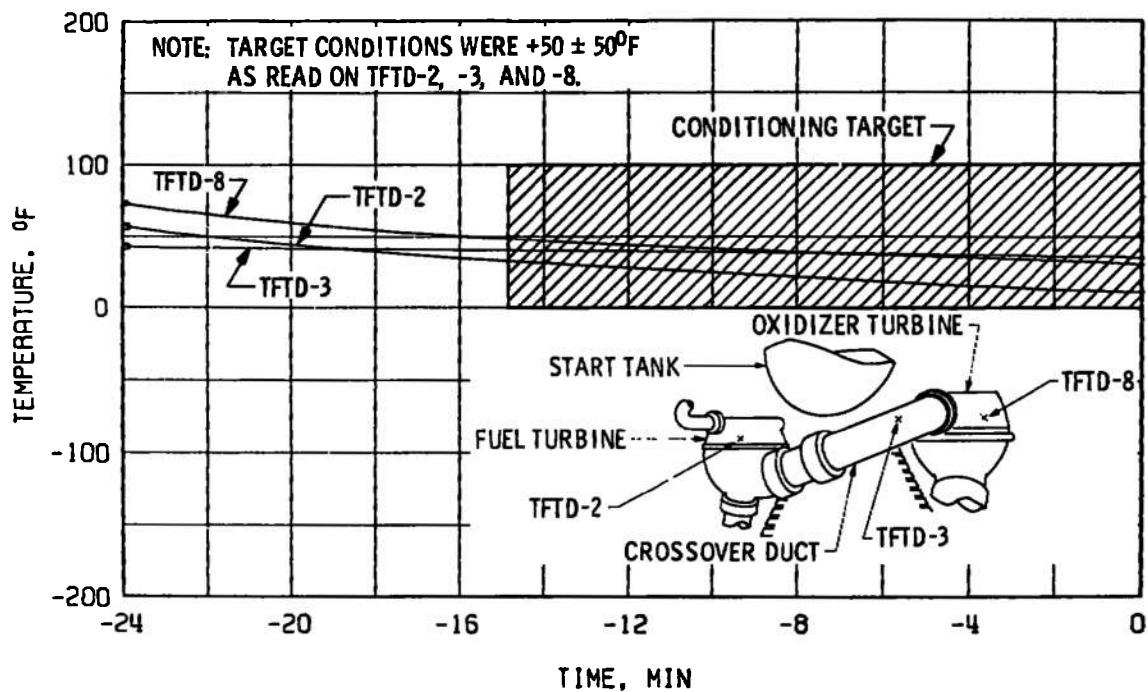


b. Fuel Pump NPSH during Start Transient, Firing 29B

Fig. 29 Fuel Low Pressure Duct Performance, Firing 29B

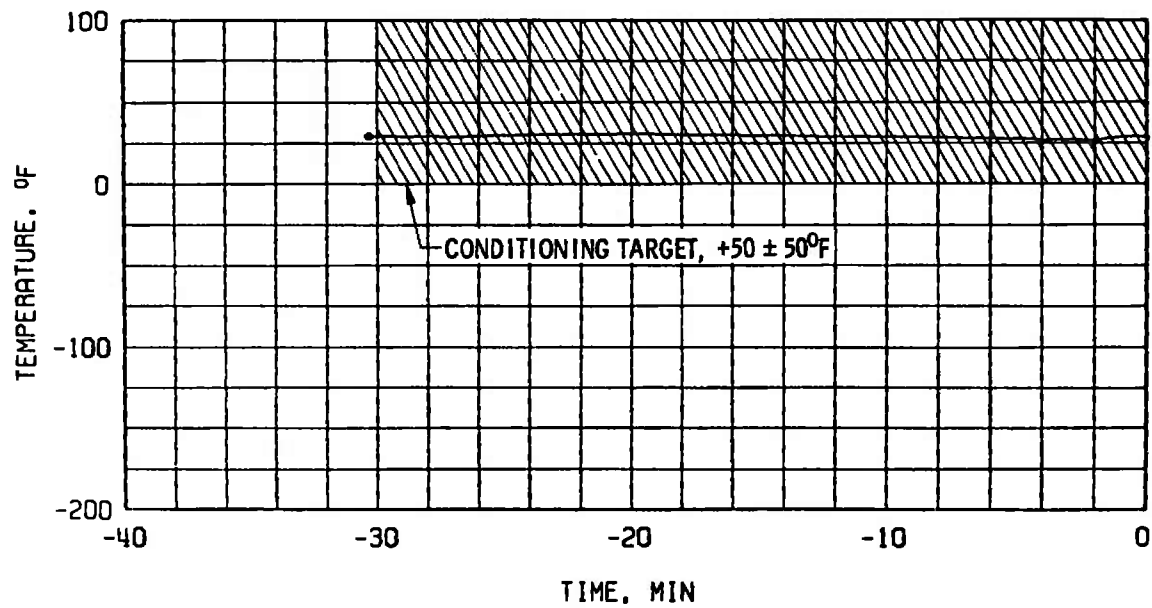


a. Thrust Chamber Throat, TTC-1P

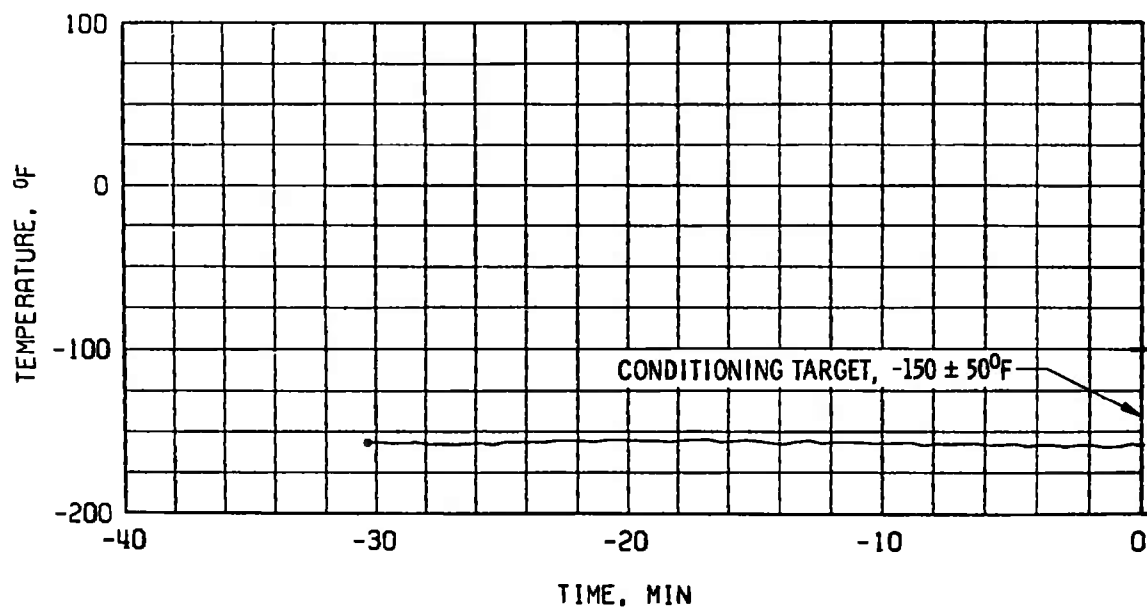


b. Crossover Duct, TFTD

Fig. 30 Thermal Conditioning History of Engine Components, Firing 29C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 30 Concluded

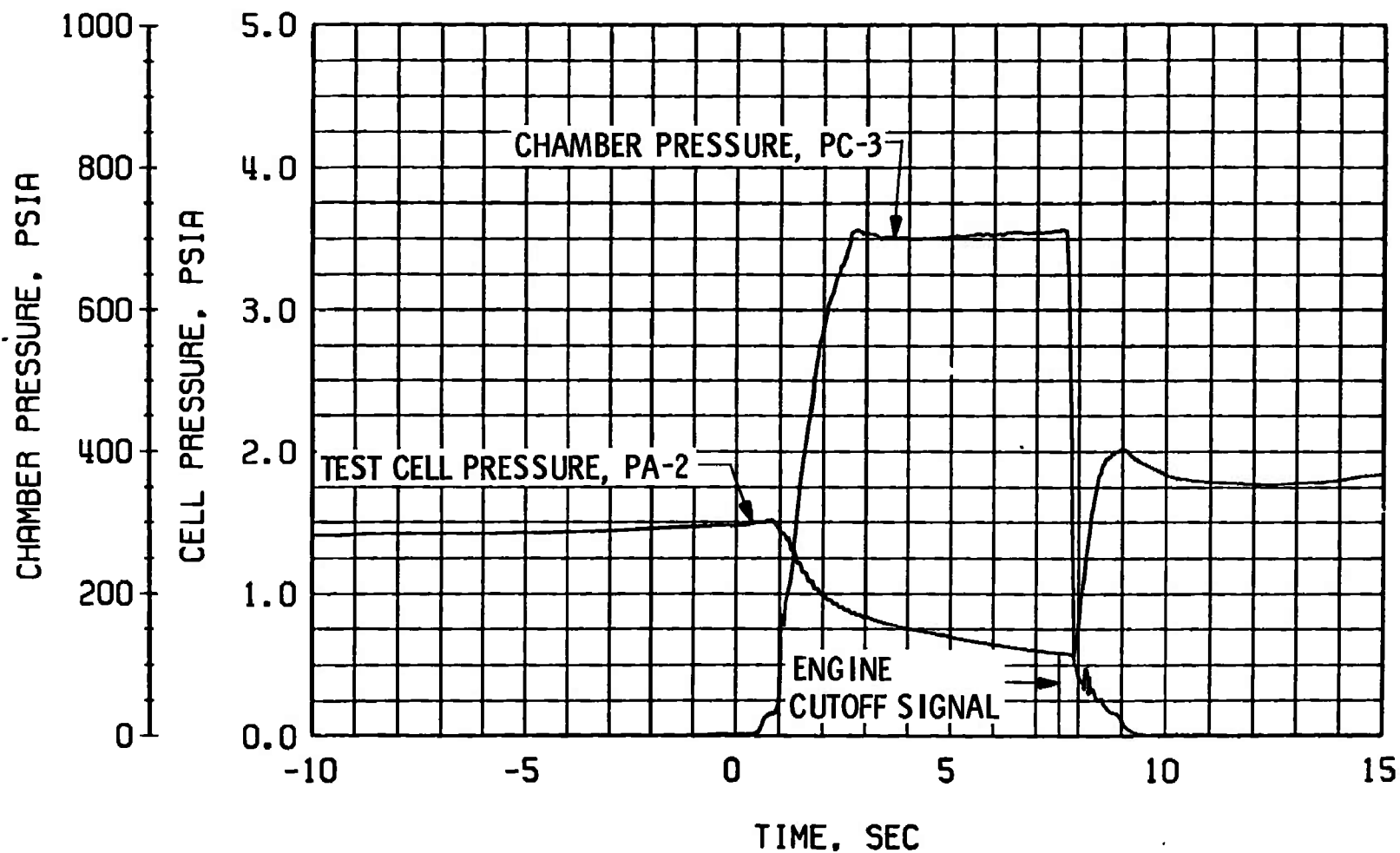
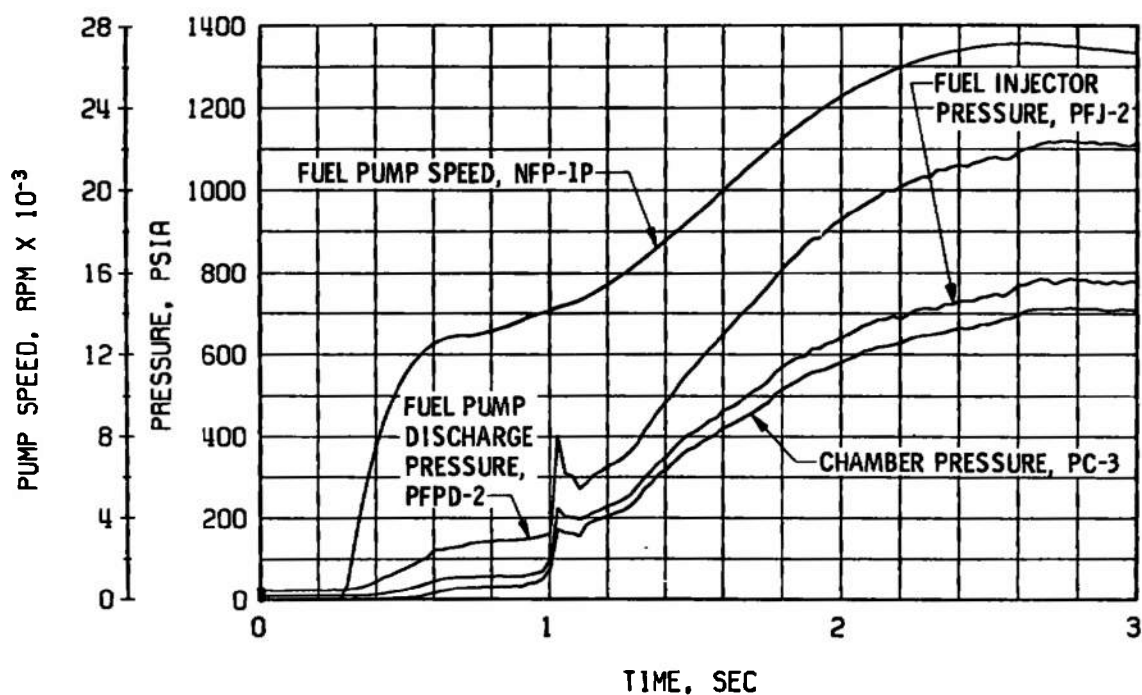
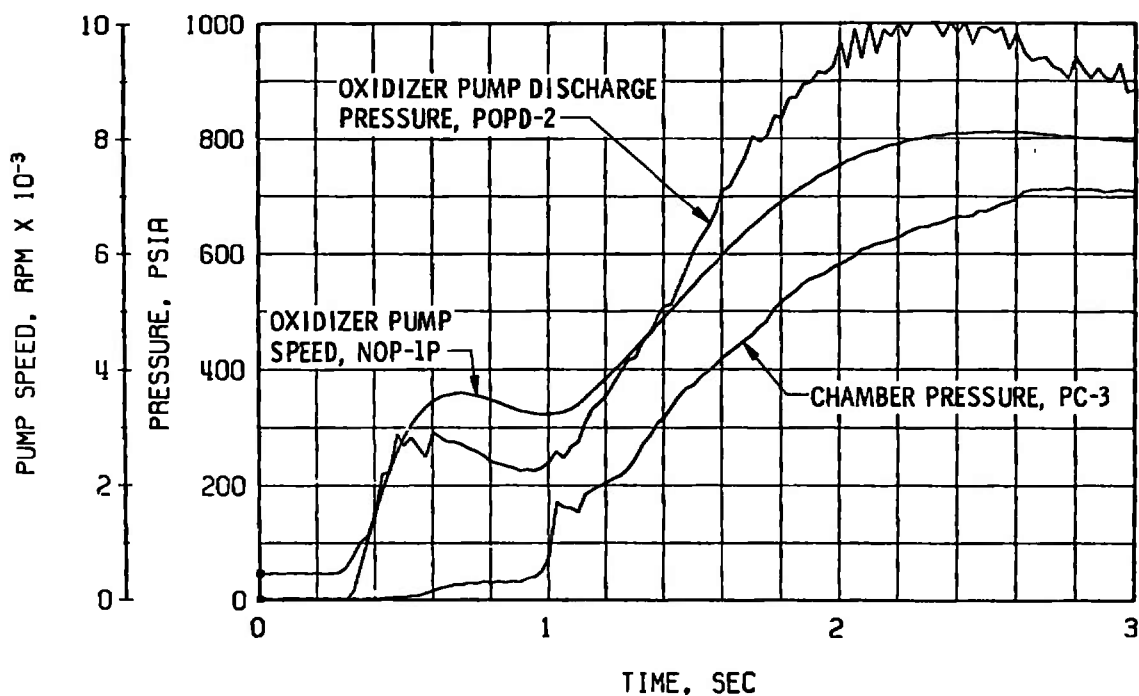


Fig. 31 Engine Ambient and Combustion Chamber Pressures, Firing 29C



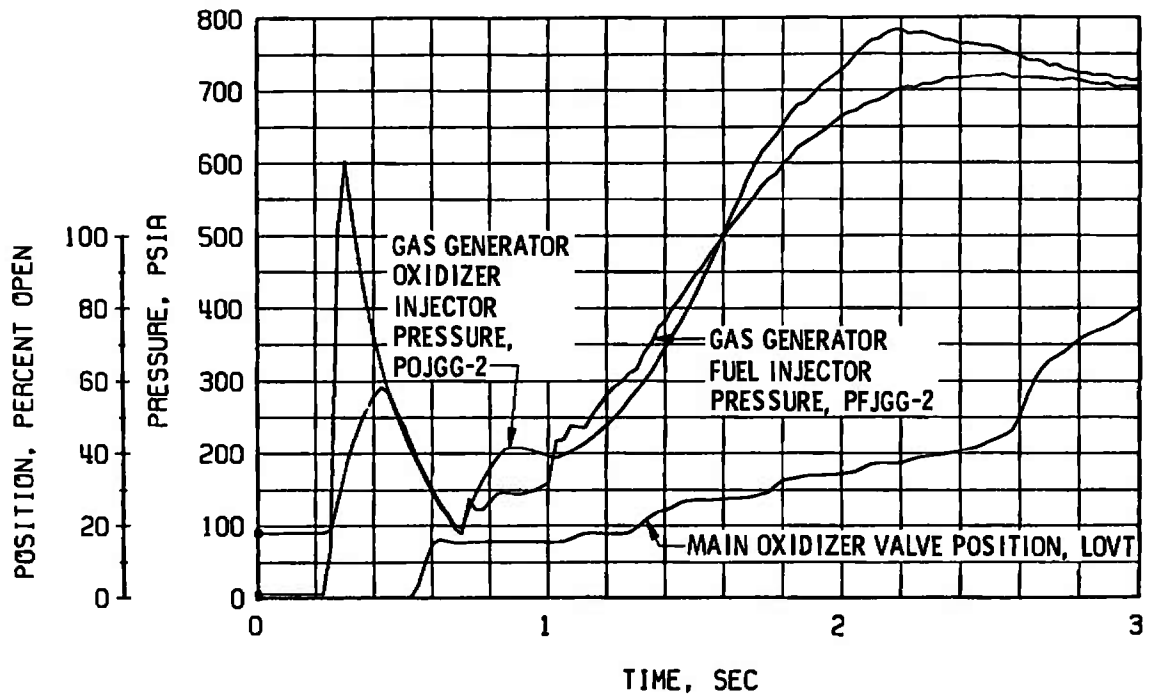


a. Thrust Chamber Fuel System, Start

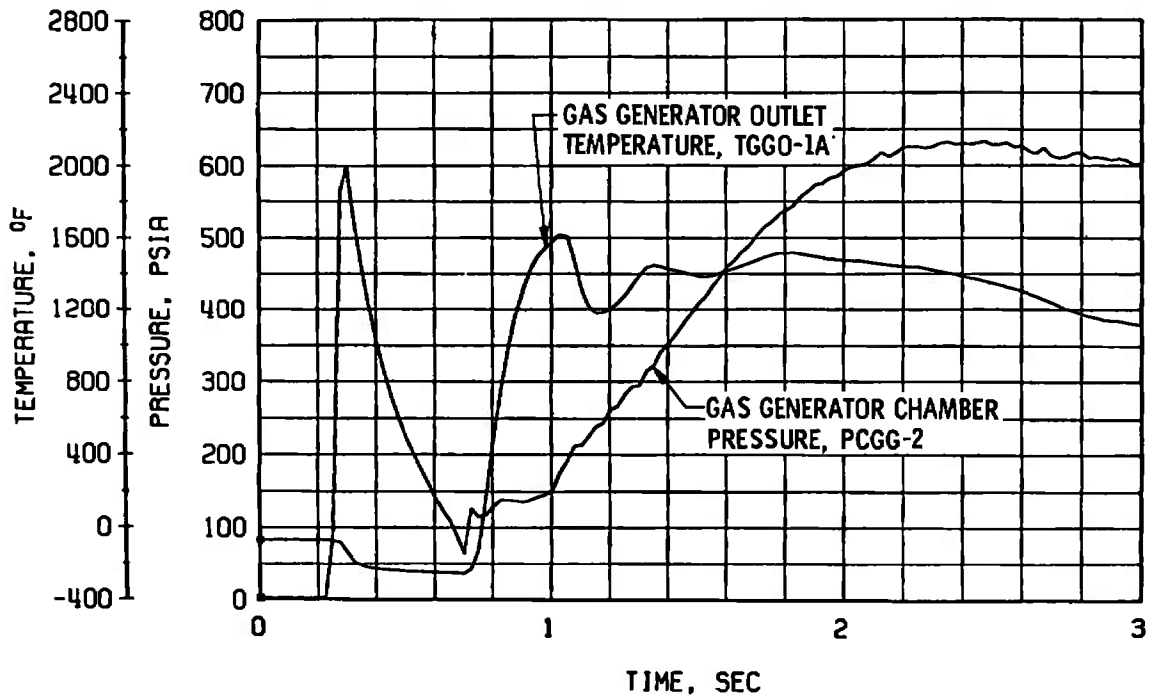


b. Thrust Chamber Oxidizer System, Start

Fig. 32 Engine Transient Operation, Firing 29C

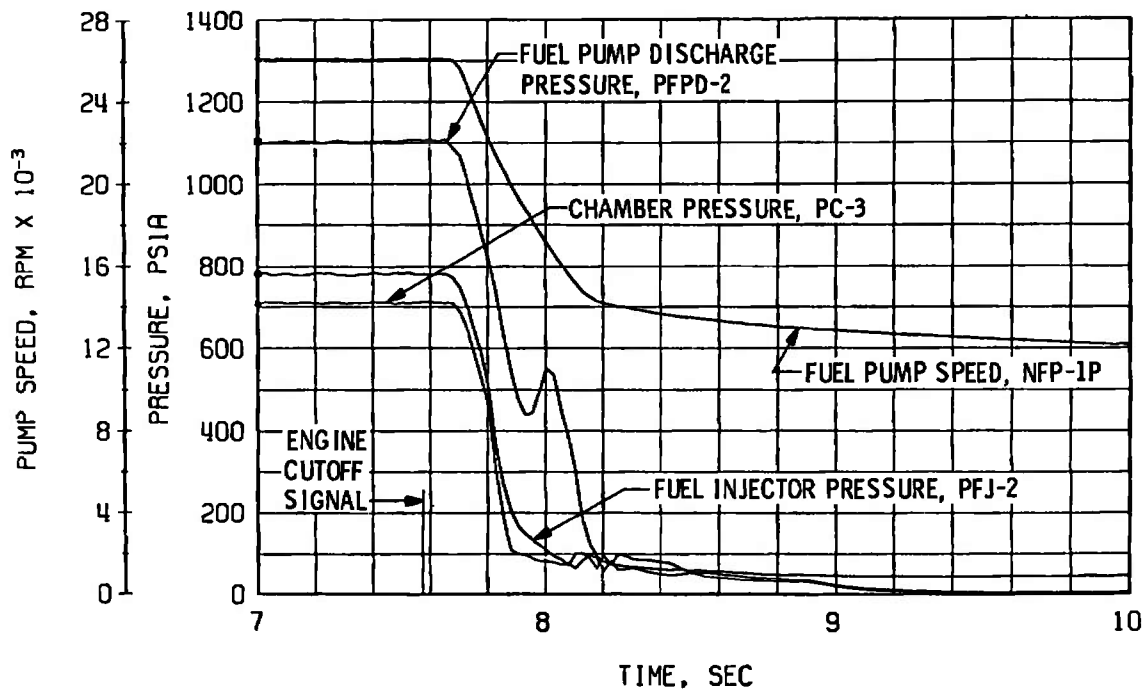


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

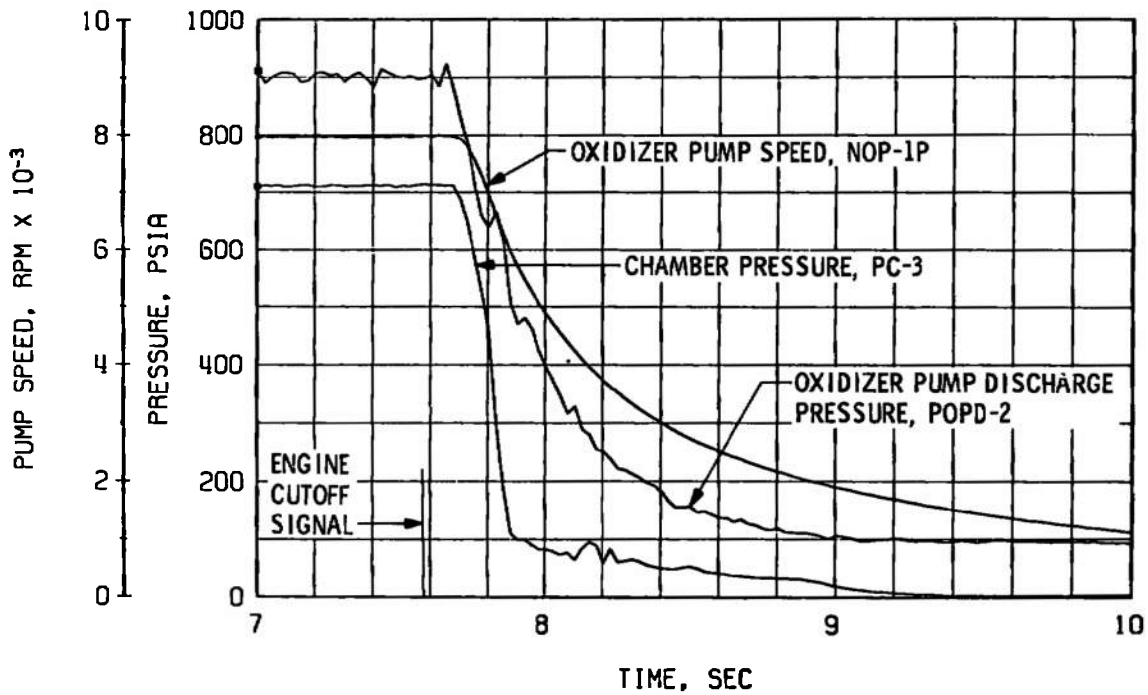


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 32 Continued

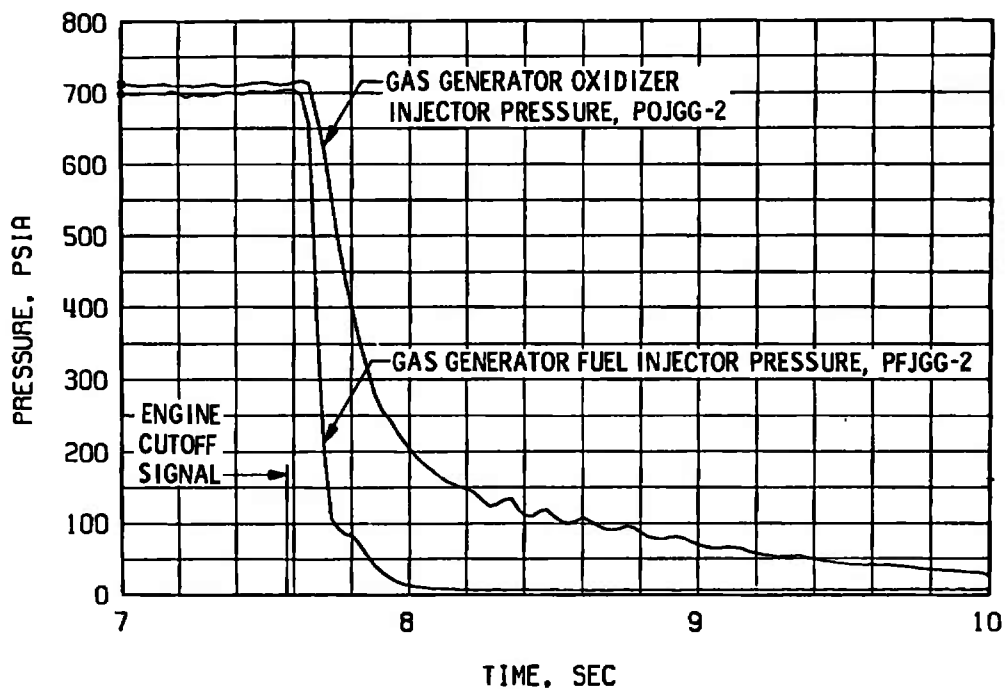


e. Thrust Chamber Fuel System, Shutdown

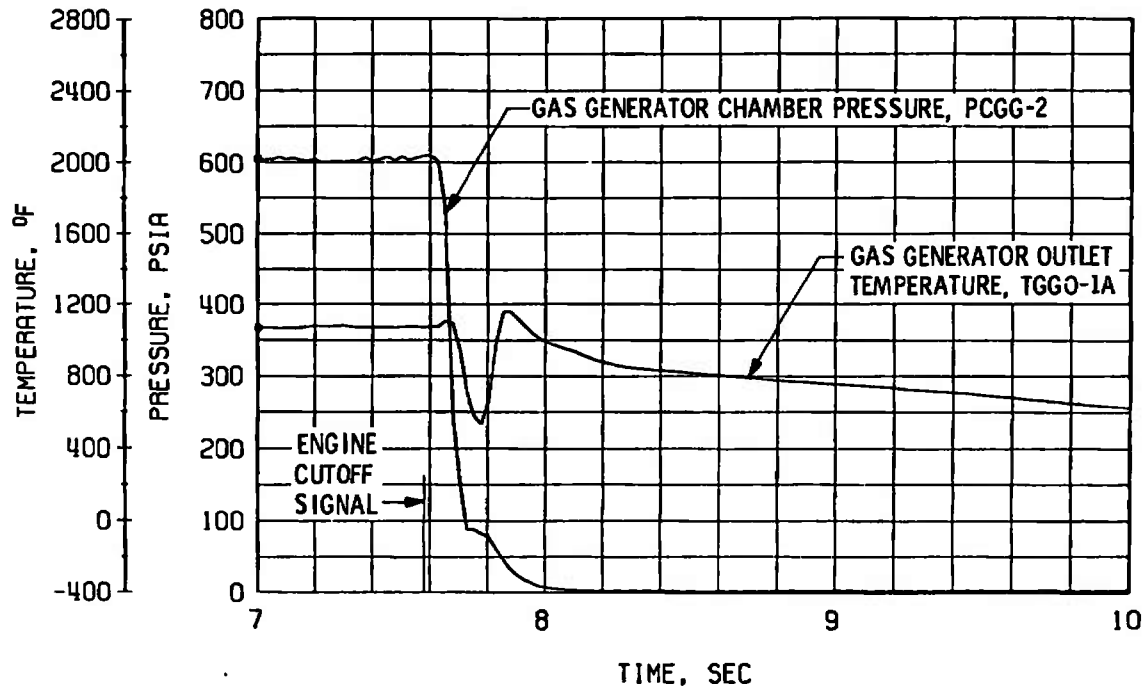


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 32 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 32 Concluded

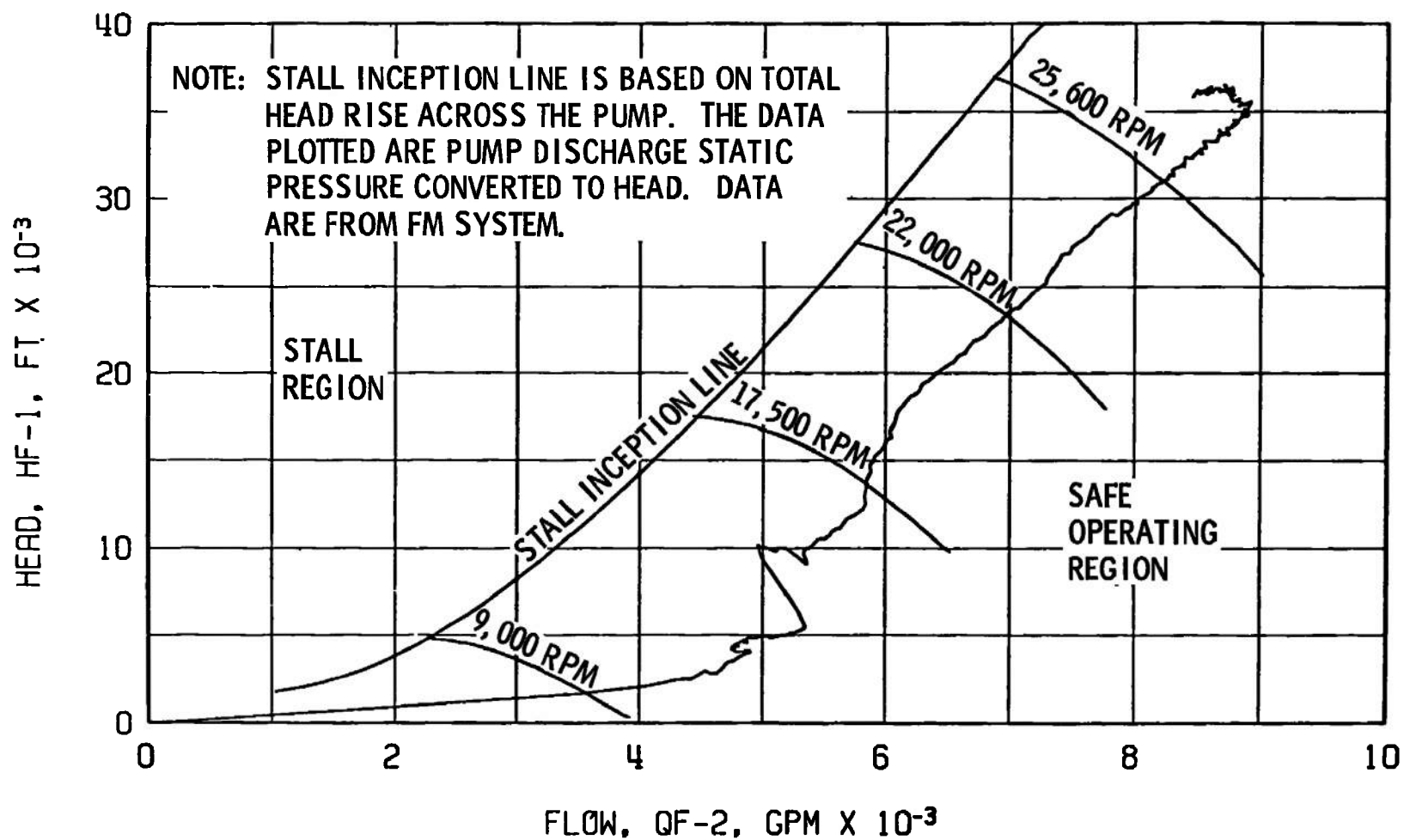
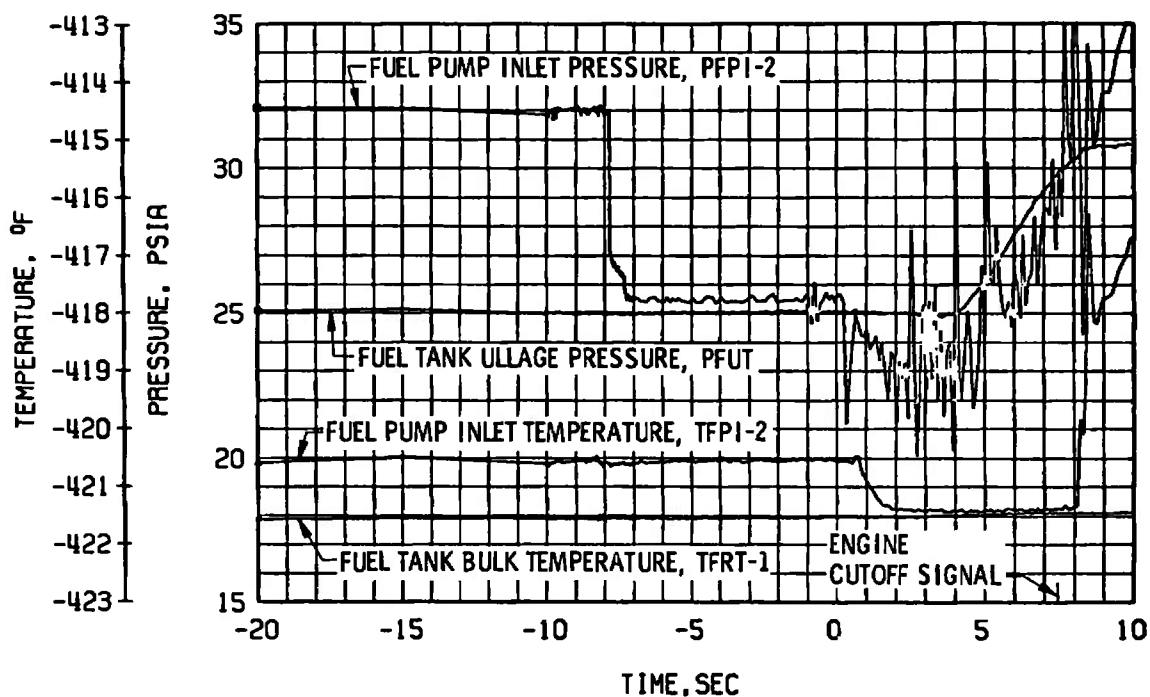
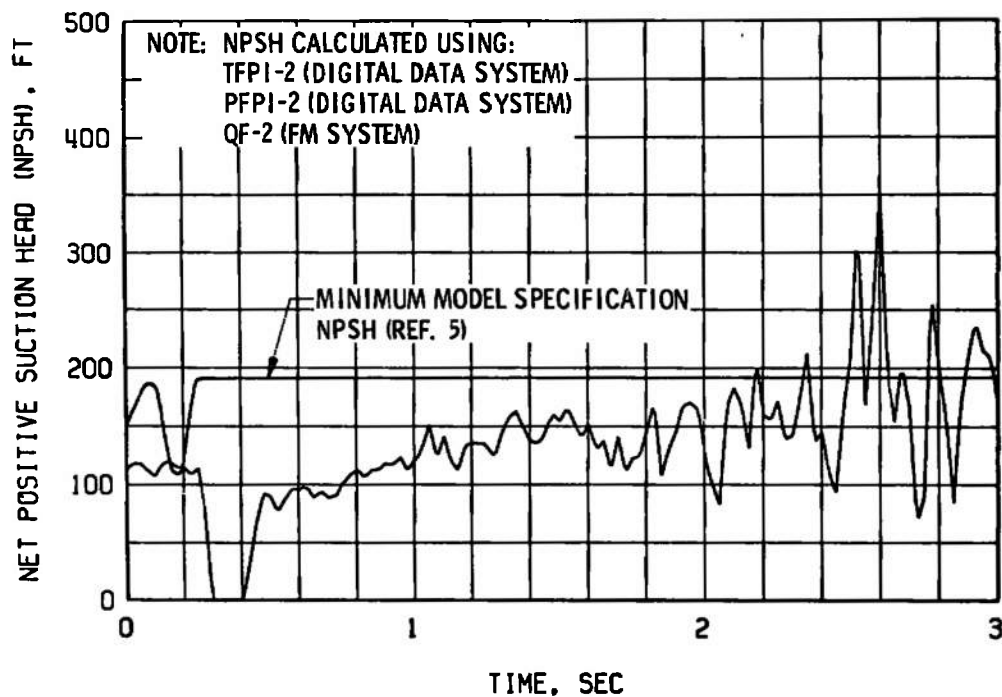


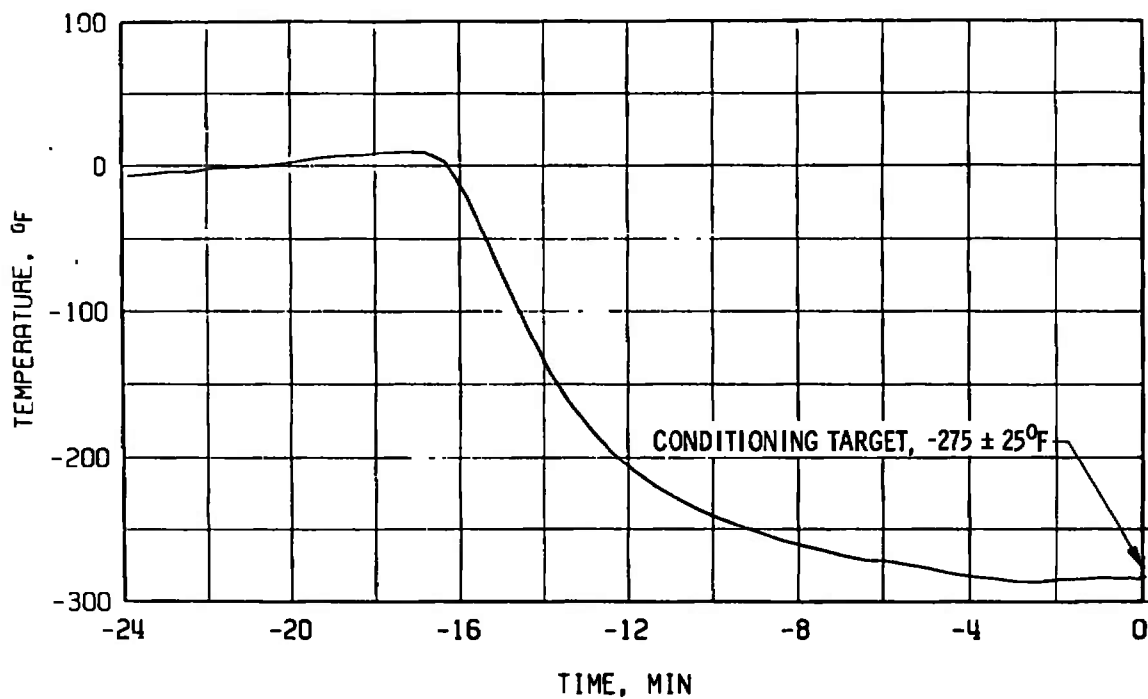
Fig. 33 Fuel Pump Start Transient Performance, Firing 29C



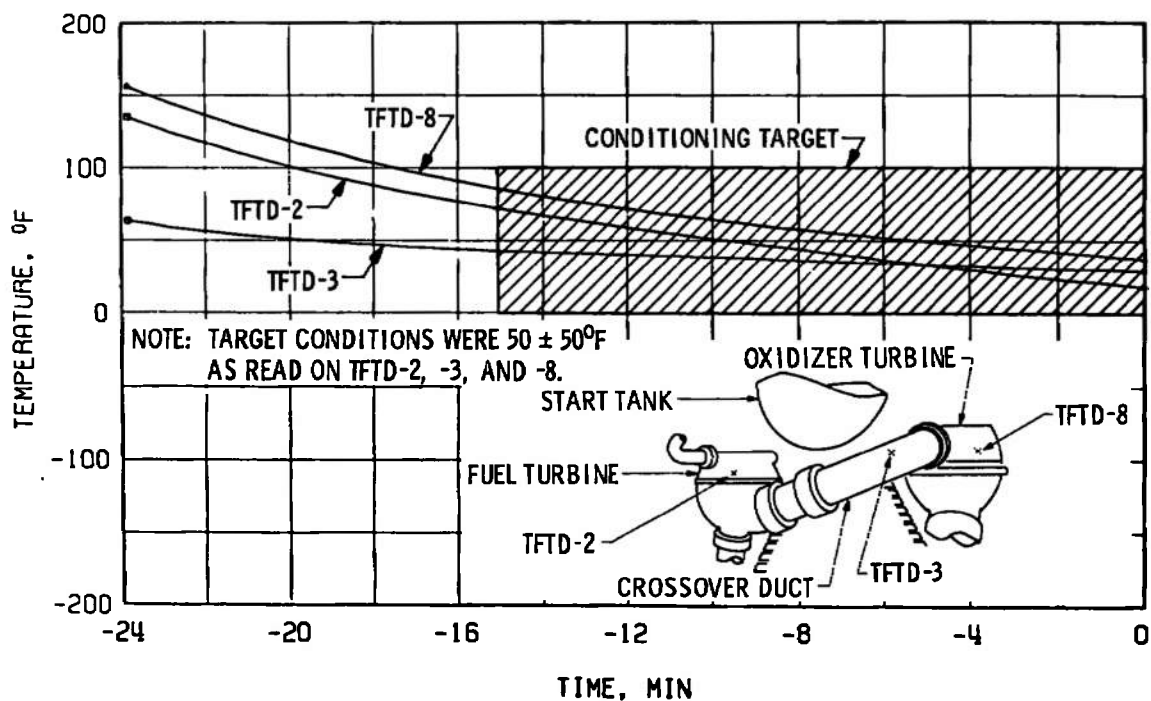
a. Duct Pressure and Temperature Transients



b. Fuel Pump NPSH during Start Transient, Firing 29C  
Fig. 34 Fuel Low Pressure Duct Performance, Firing 29C

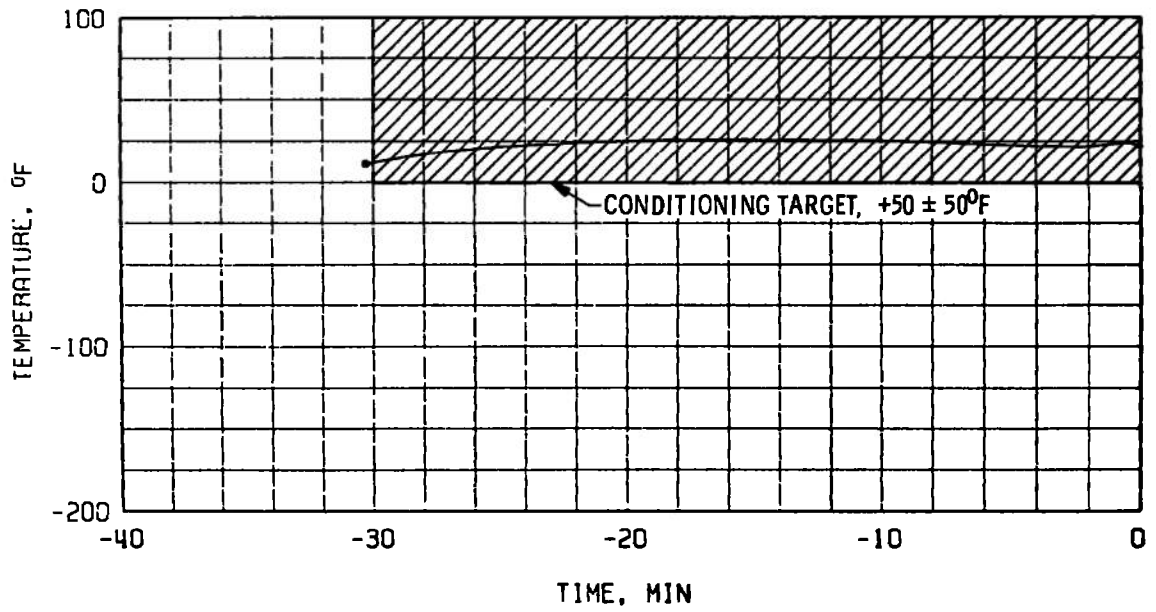


a. Thrust Chamber Throat, TTC-1P

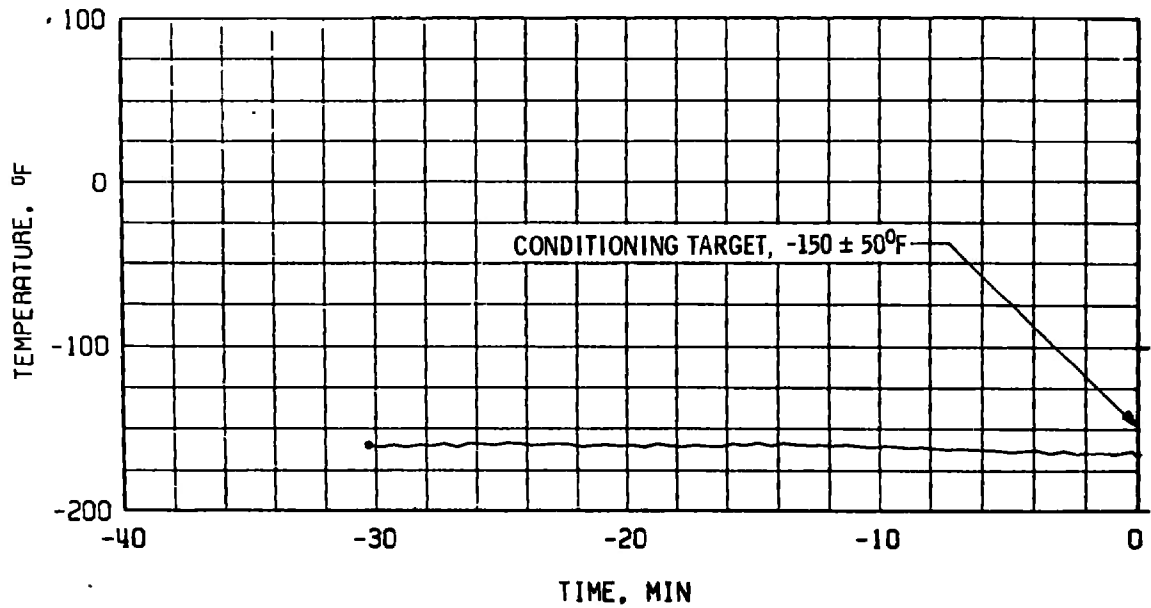


b. Crossover Duct, TFTD

Fig. 35 Thermal Conditioning History of Engine Components, Firing/29D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 35 Concluded



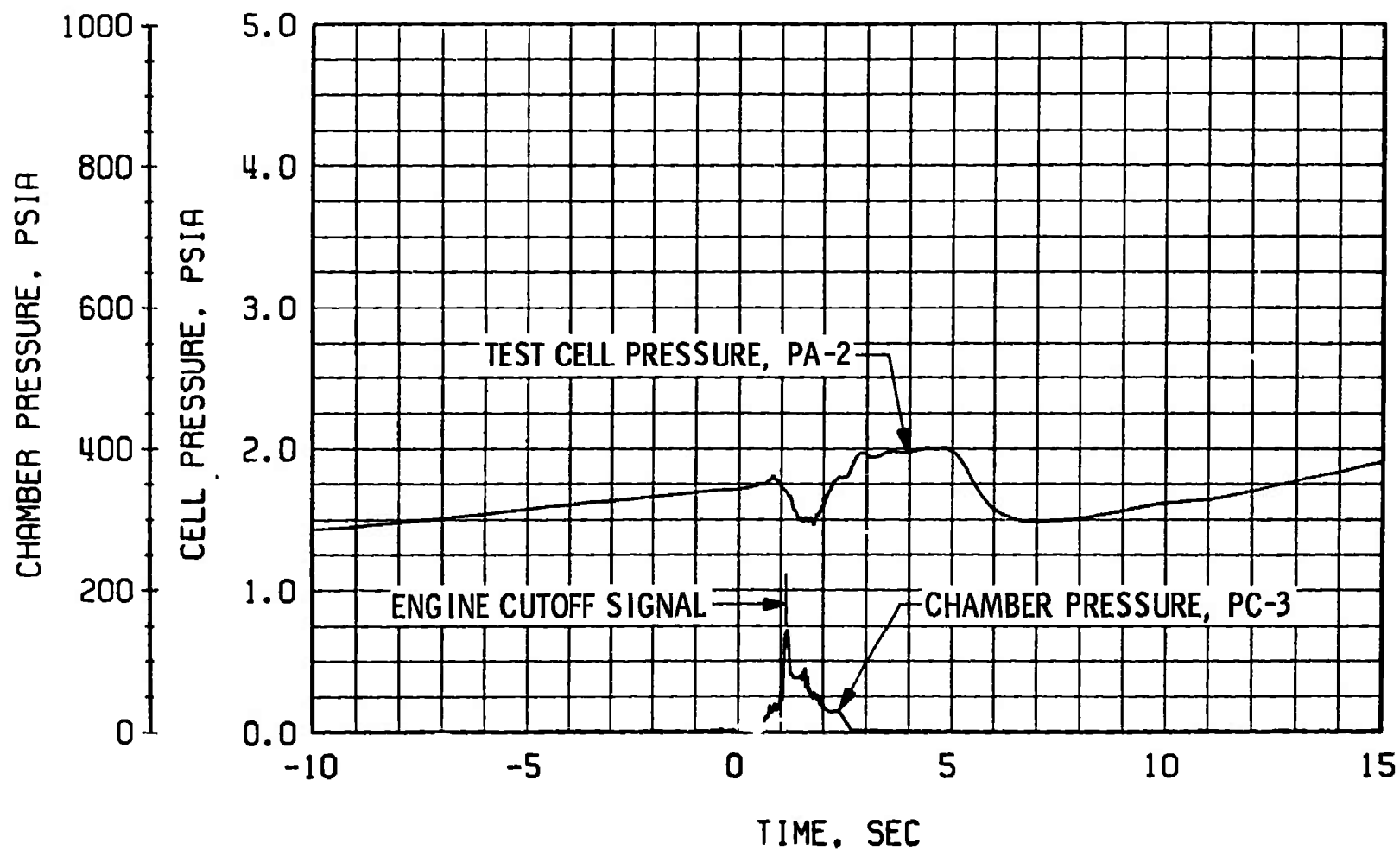
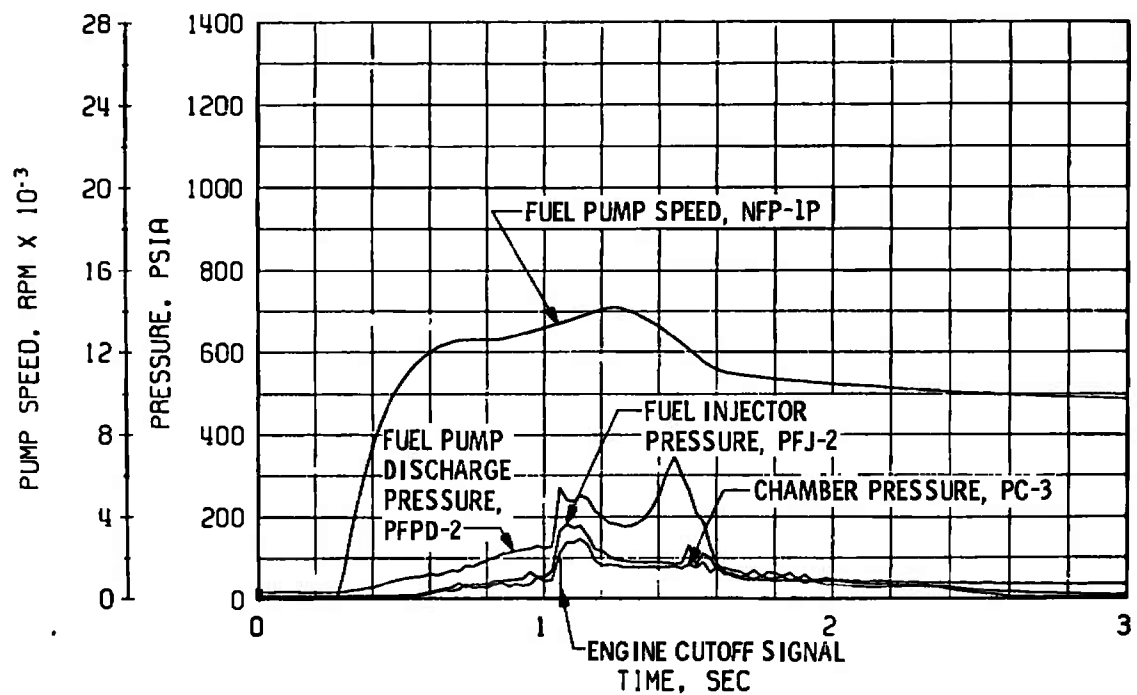
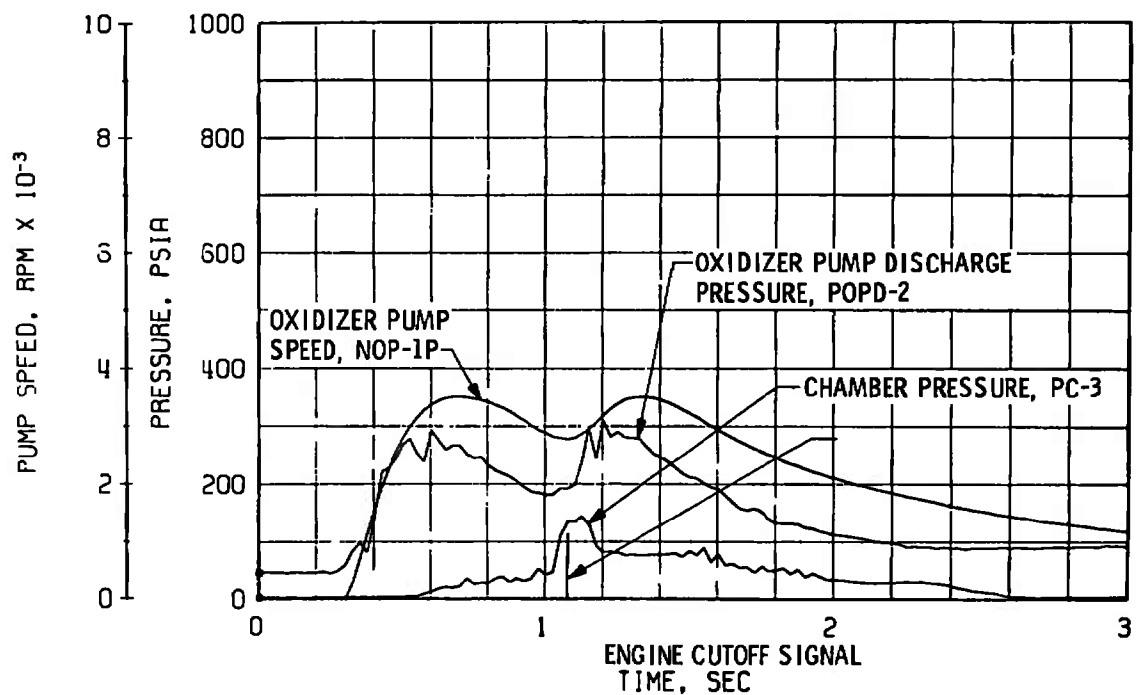


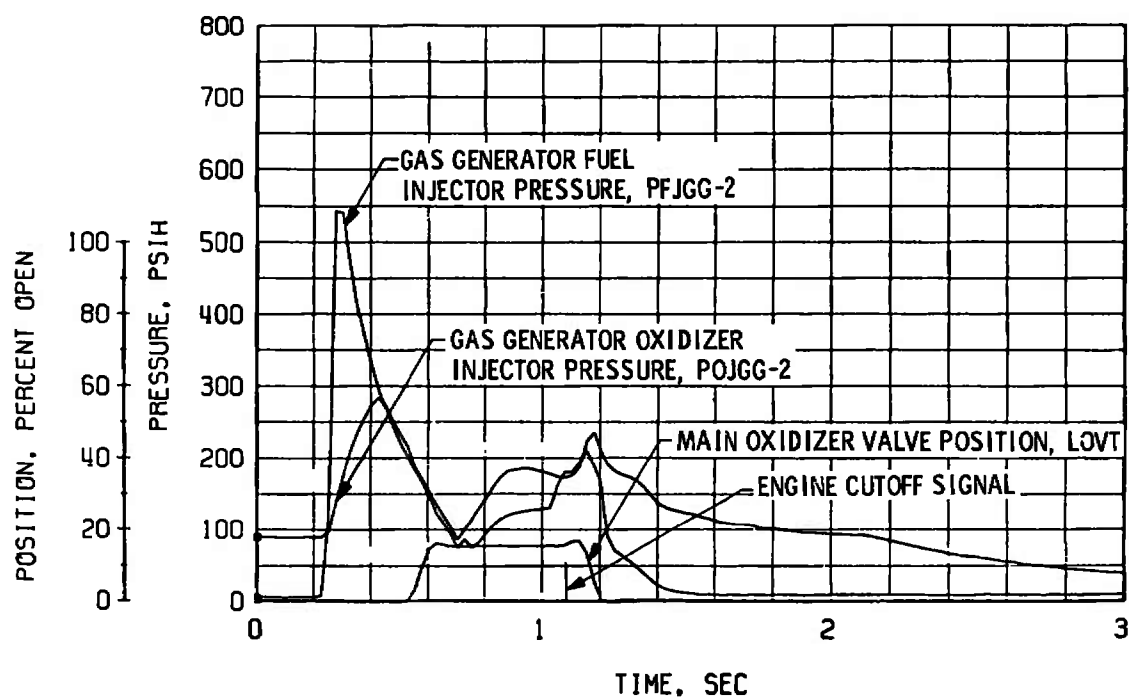
Fig.36 Engine Ambient and Combustion Chamber Pressures, Firing 29D



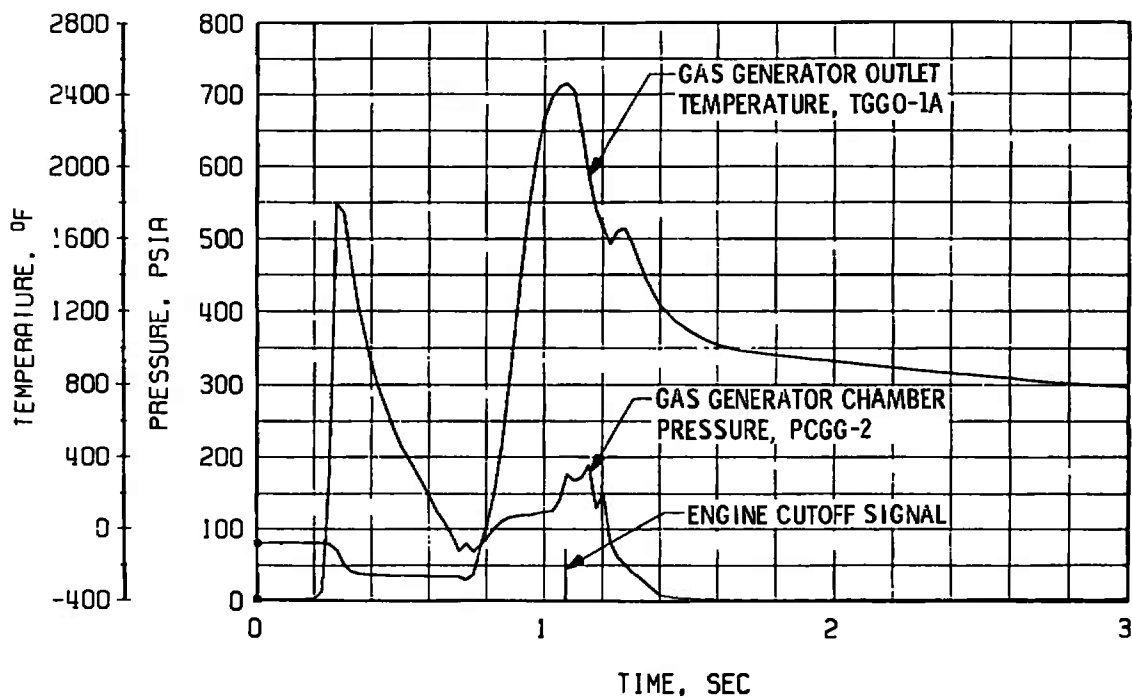
a. Thrust Chamber Fuel System, Start and Shutdown



b. Thrust Chamber Oxidizer System, Start and Shutdown  
Fig. 37 Engine Transient Operation, Firing 29D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 37 Concluded

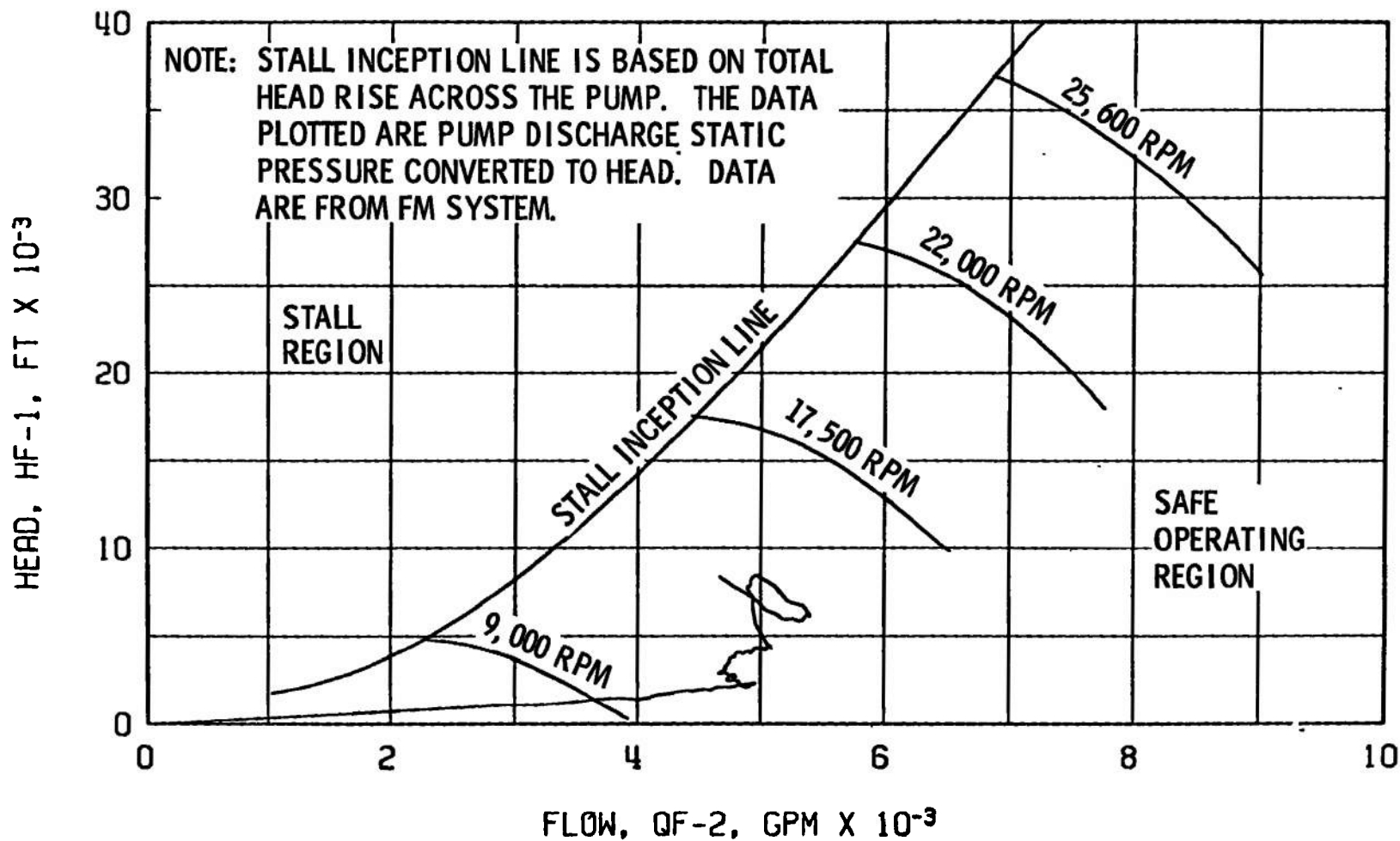
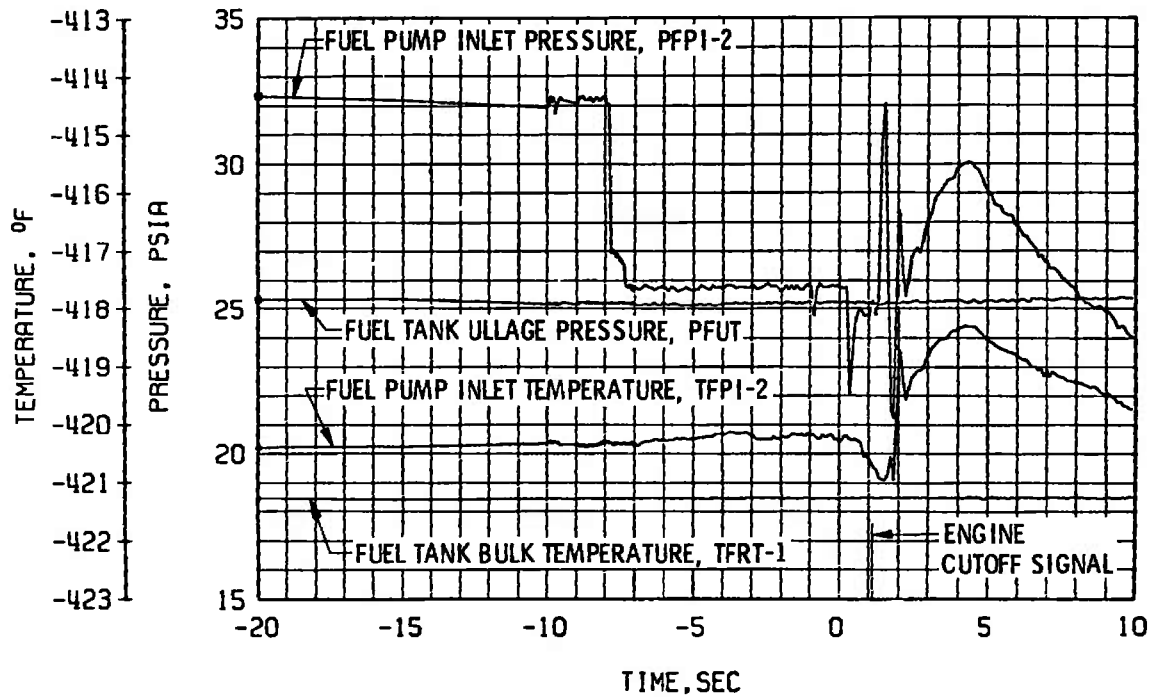
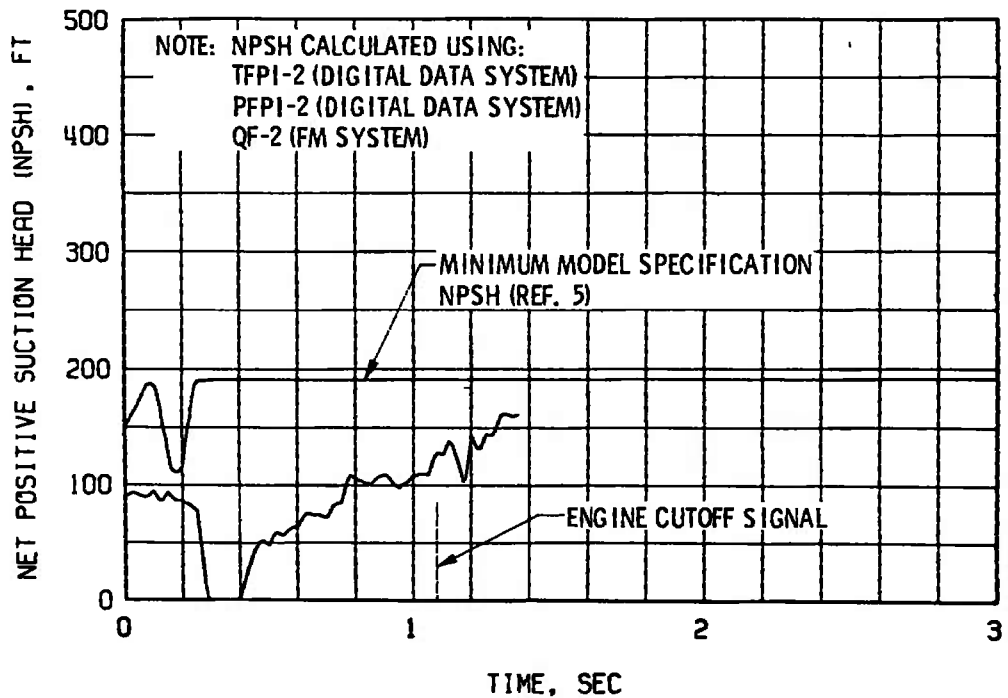


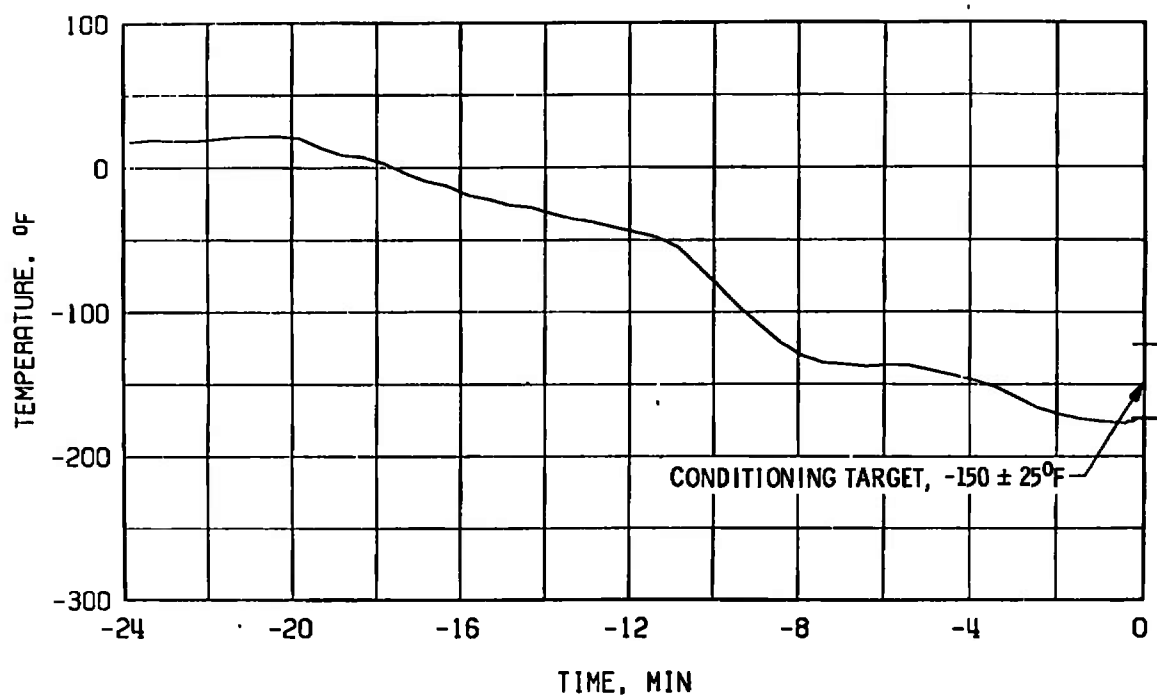
Fig. 38 Fuel Pump Start Transient Performance, Firing 29D



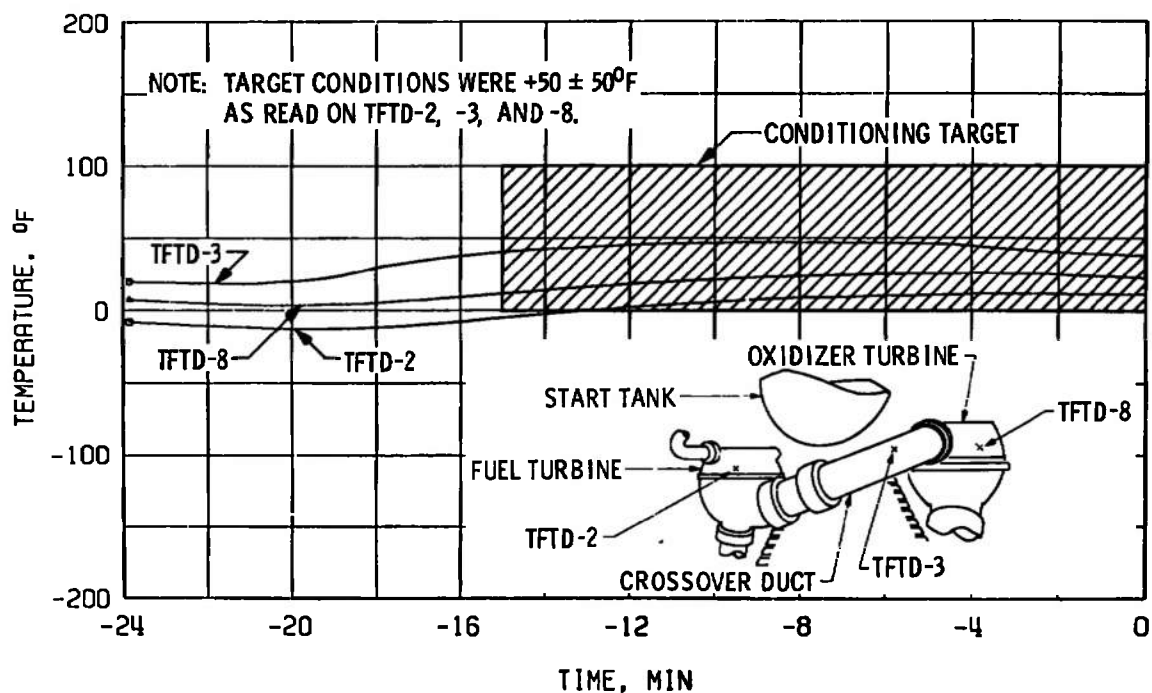
a. Duct Pressure and Temperature Transients



b. Fuel Pump NPSH during Start Transient, Firing 29D  
 Fig. 39 Fuel Low Pressure Duct Performance, Firing 29D

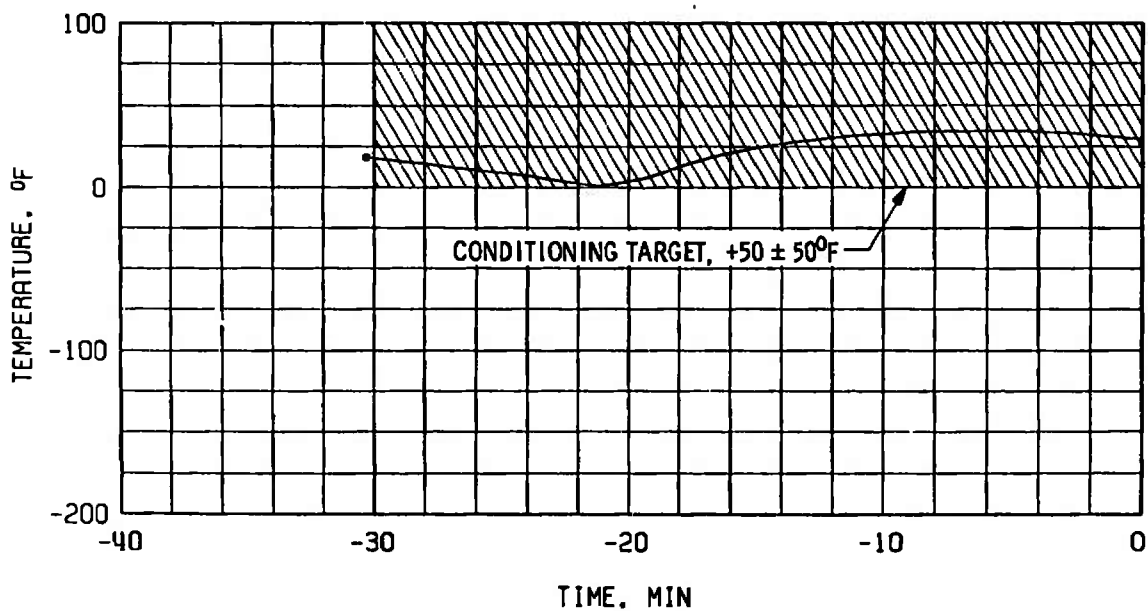


a. Thrust Chamber Throat, TTC-1P

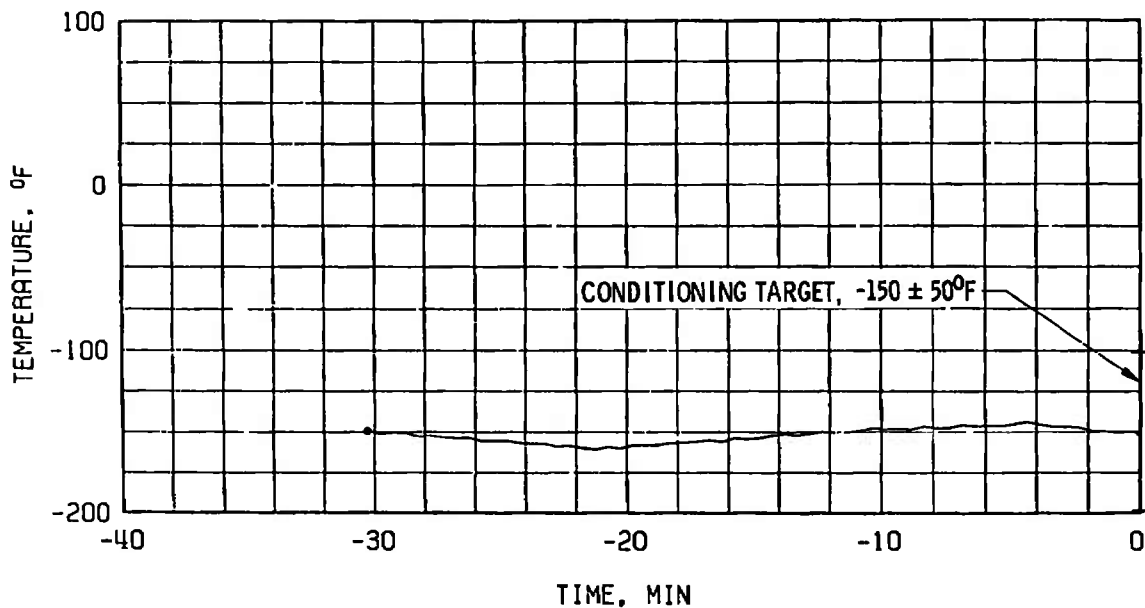


b. Crossover Duct, TFTD

Fig. 40 Thermal Conditioning History of Engine Components, Firing 29E



c. Start Tank Discharge Valve, TSTDYOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 40 Concluded

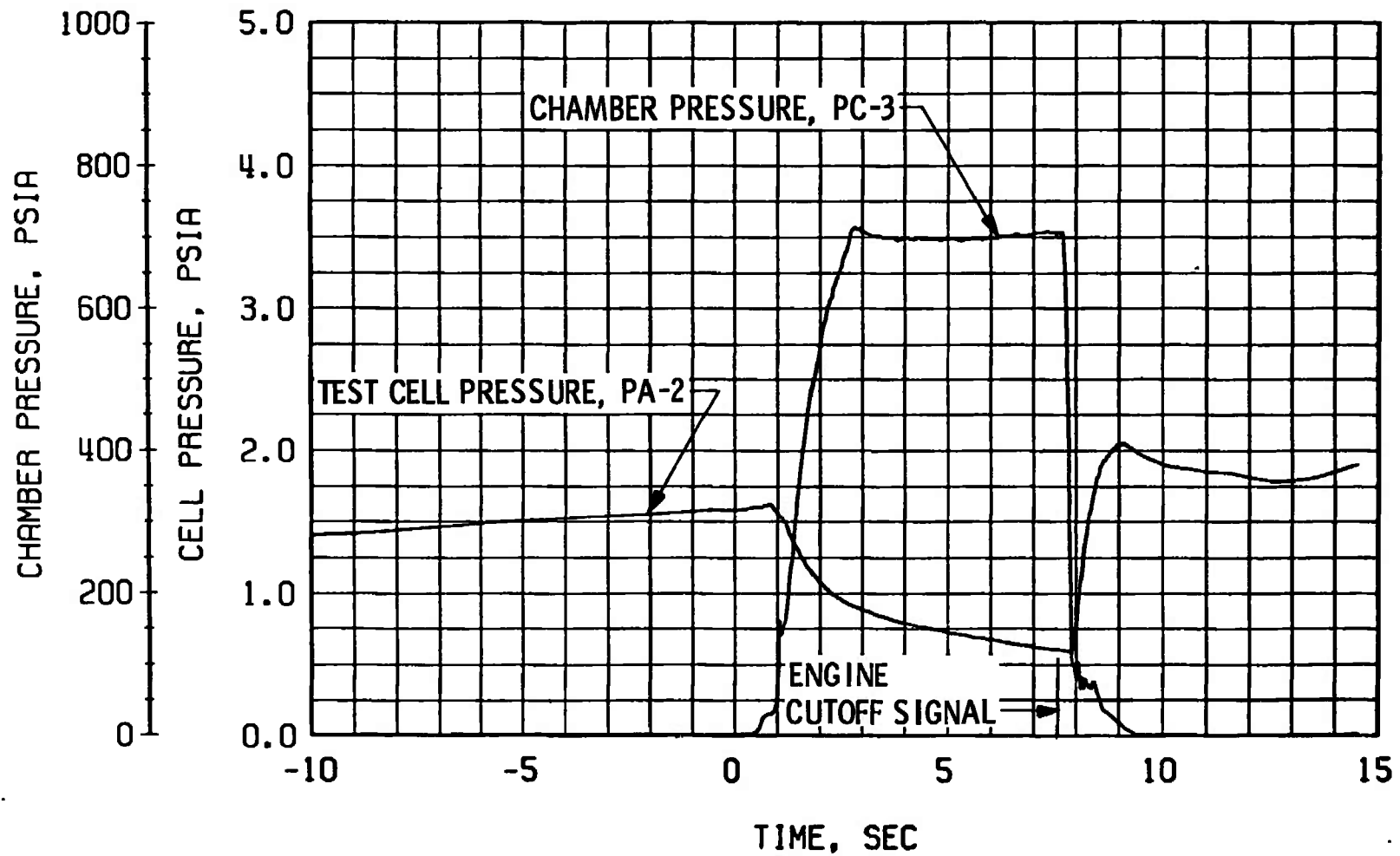
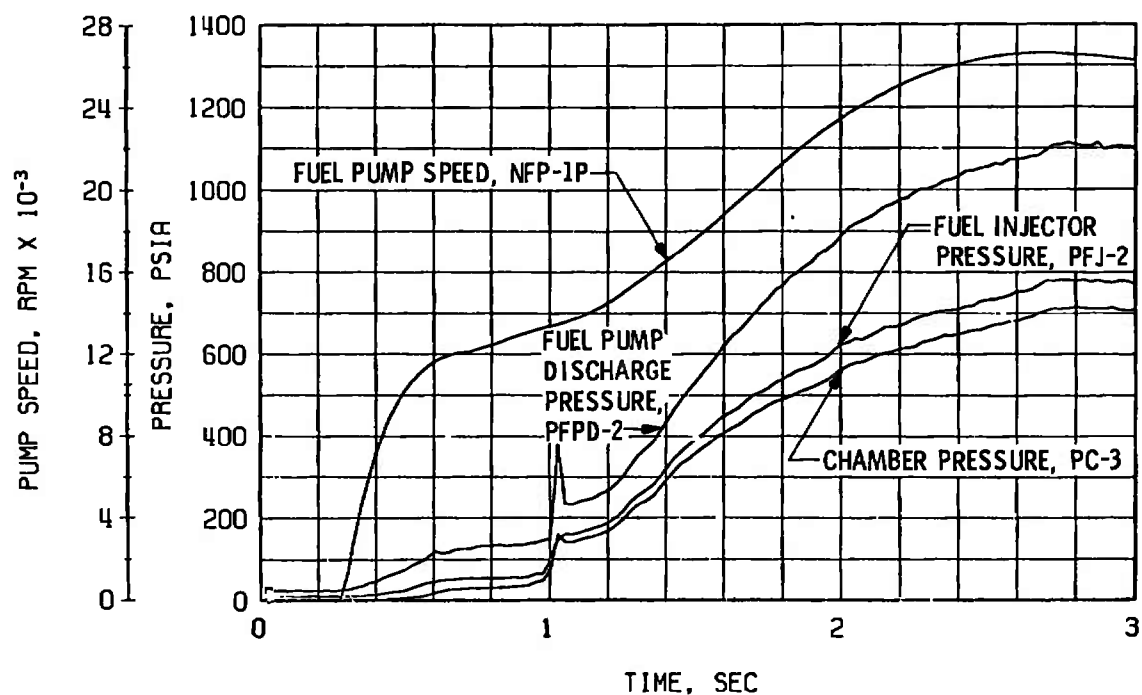
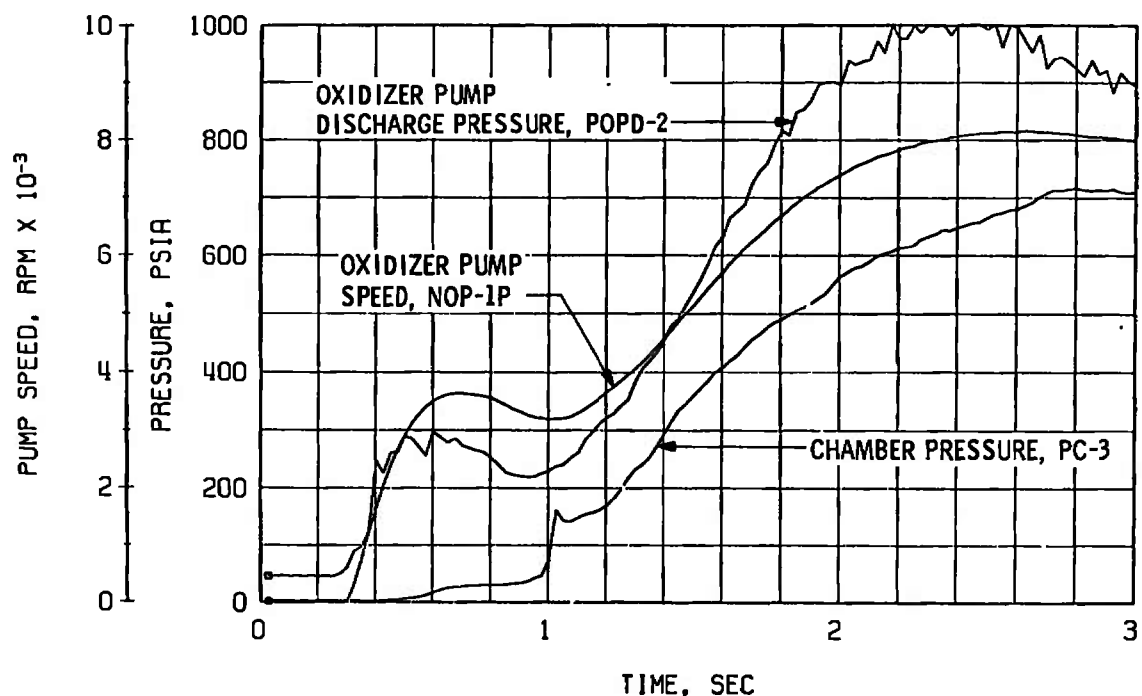


Fig. 41 Engine Ambient and Combustion Chamber Pressures, Firing 29E



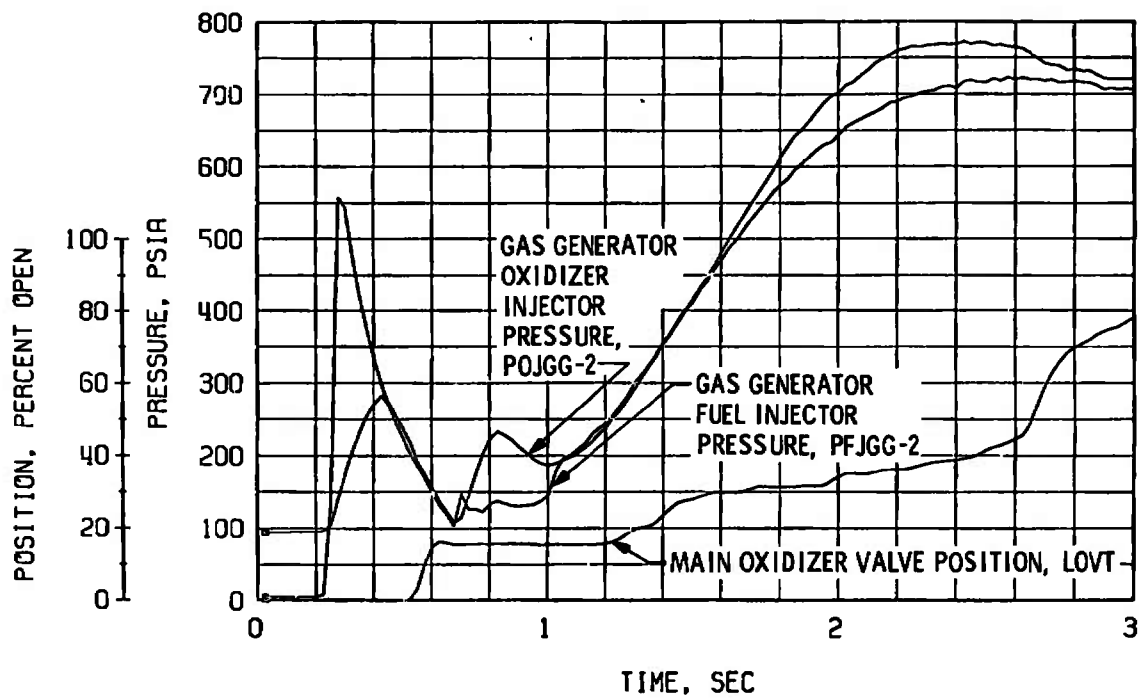


a. Thrust Chamber Fuel System, Start

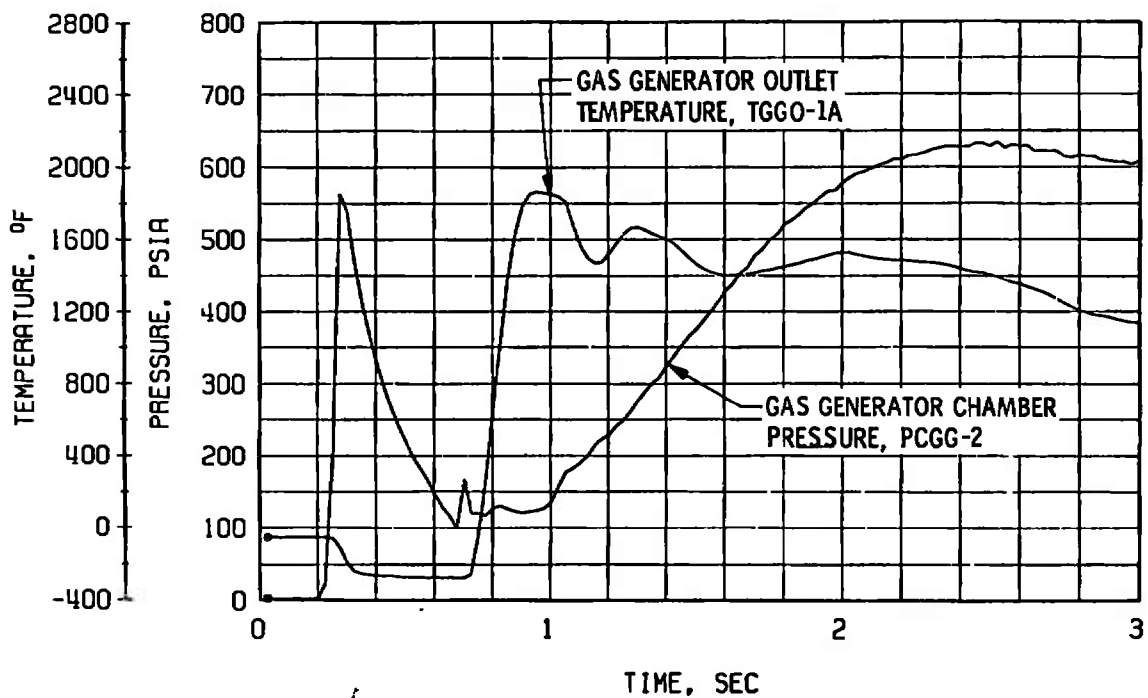


b. Thrust Chamber Oxidizer System, Start

Fig. 42 Engine Transient Operation, Firing 29E

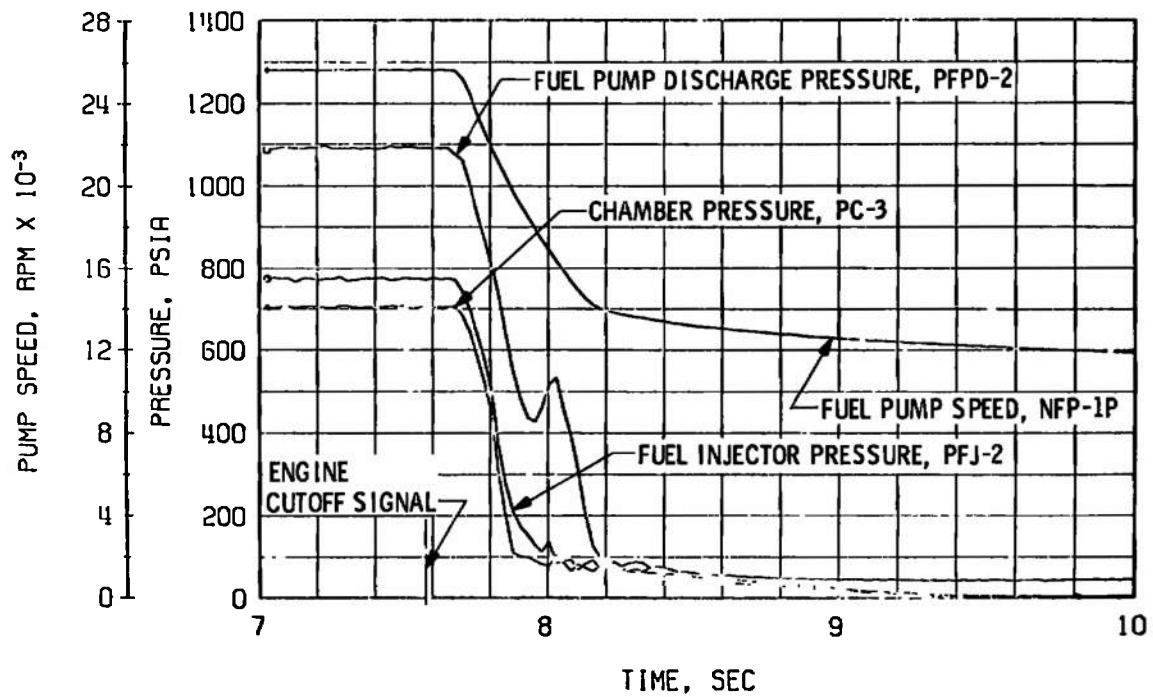


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

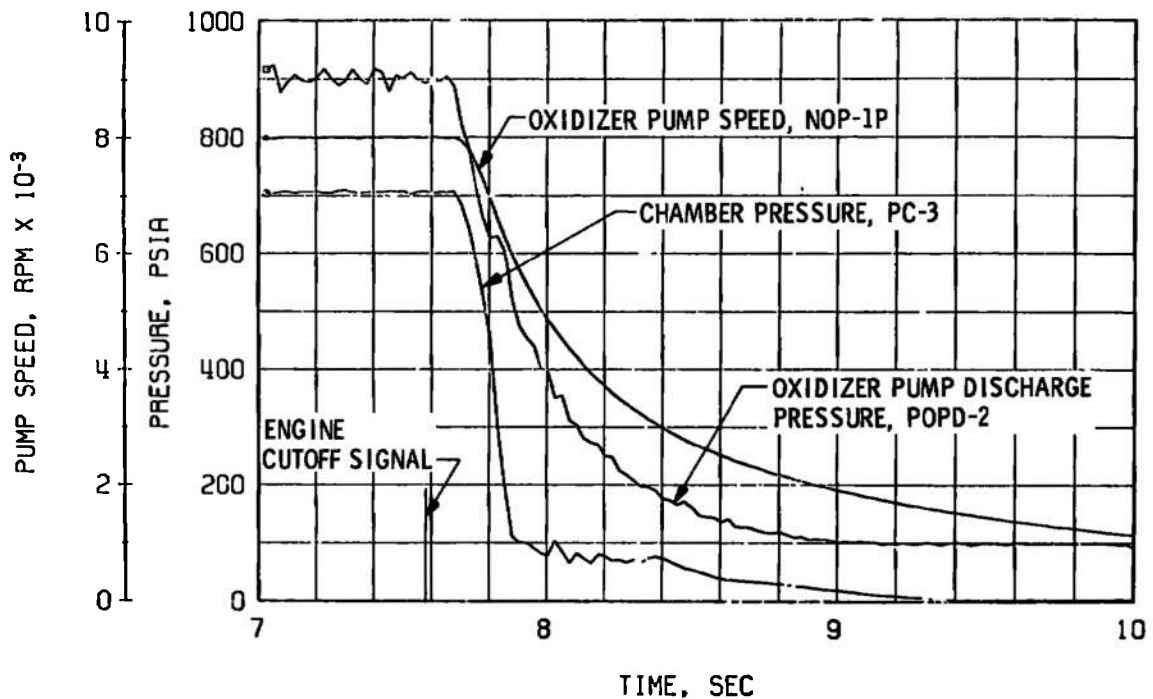


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 42 Continued

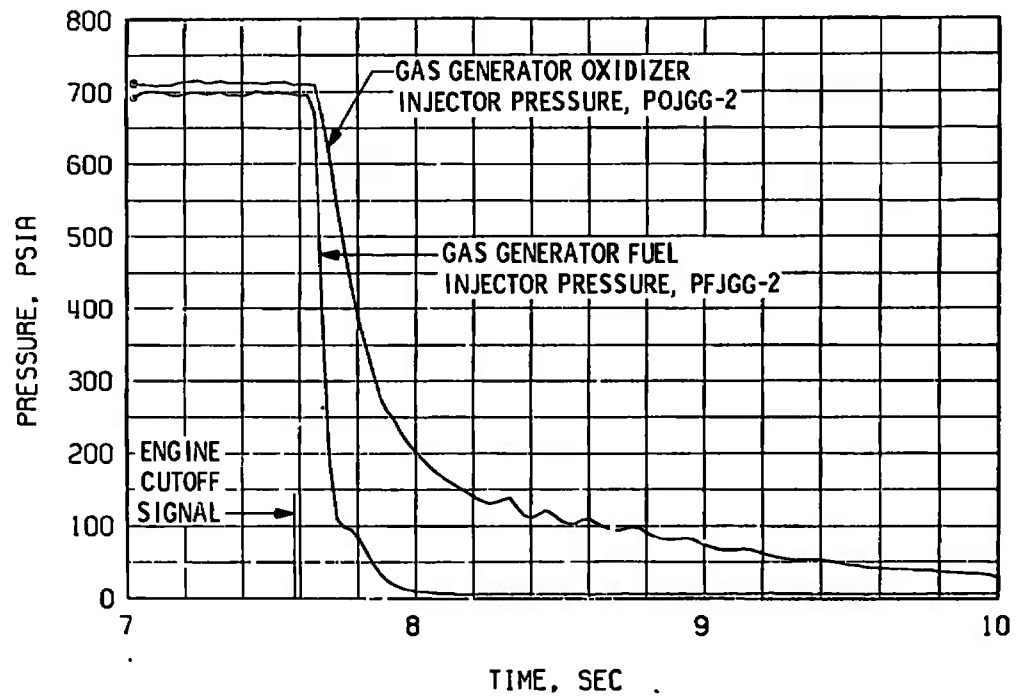


e. Thrust Chamber Fuel System, Shutdown

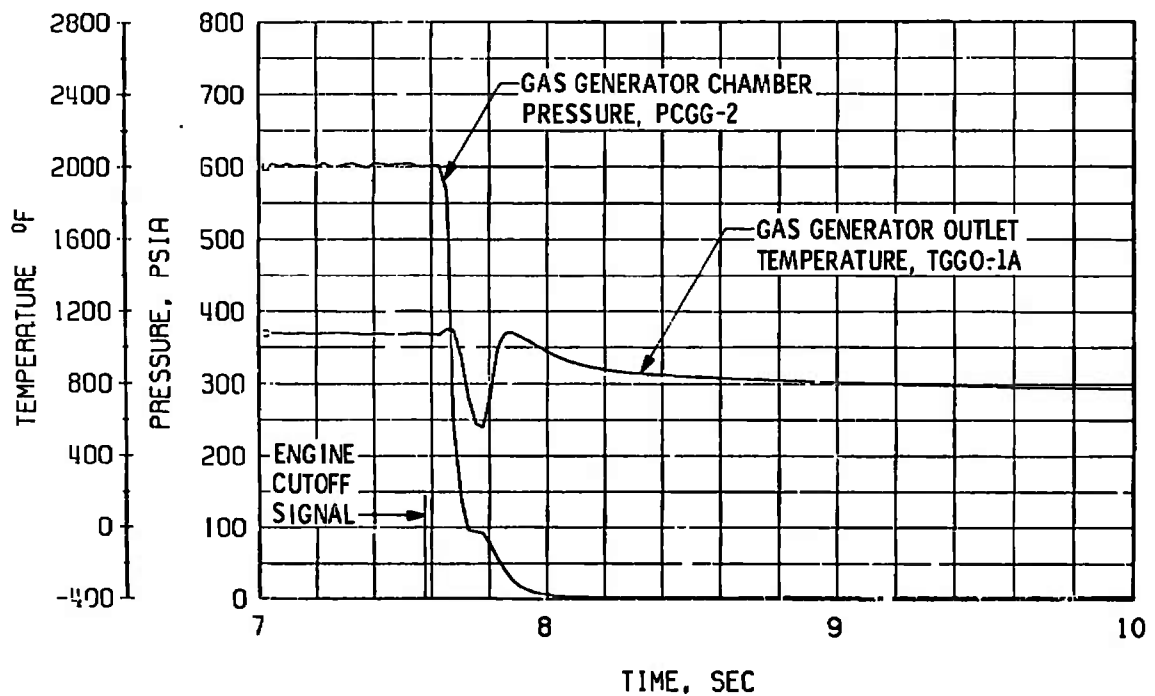


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 42 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 42 Concluded

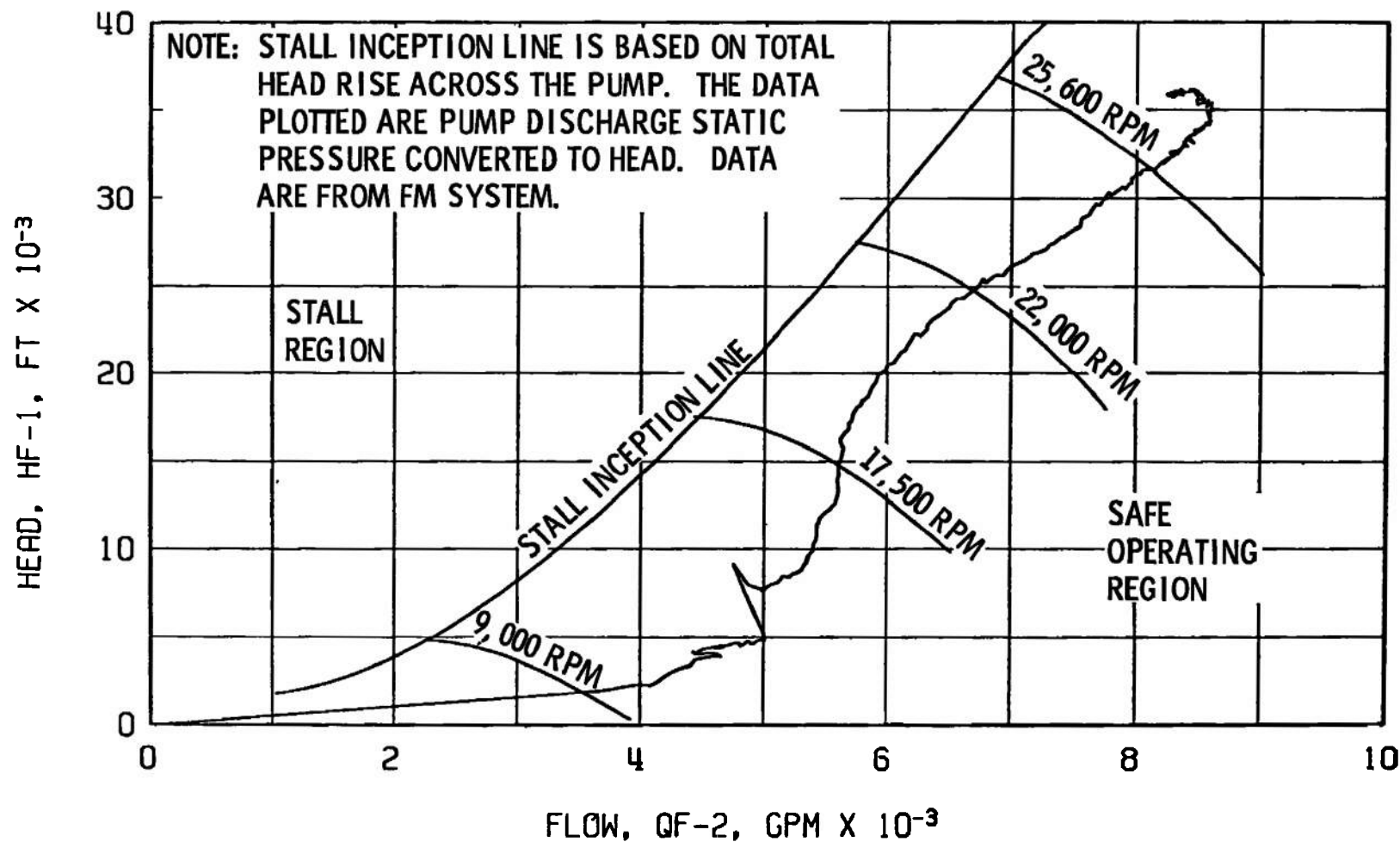
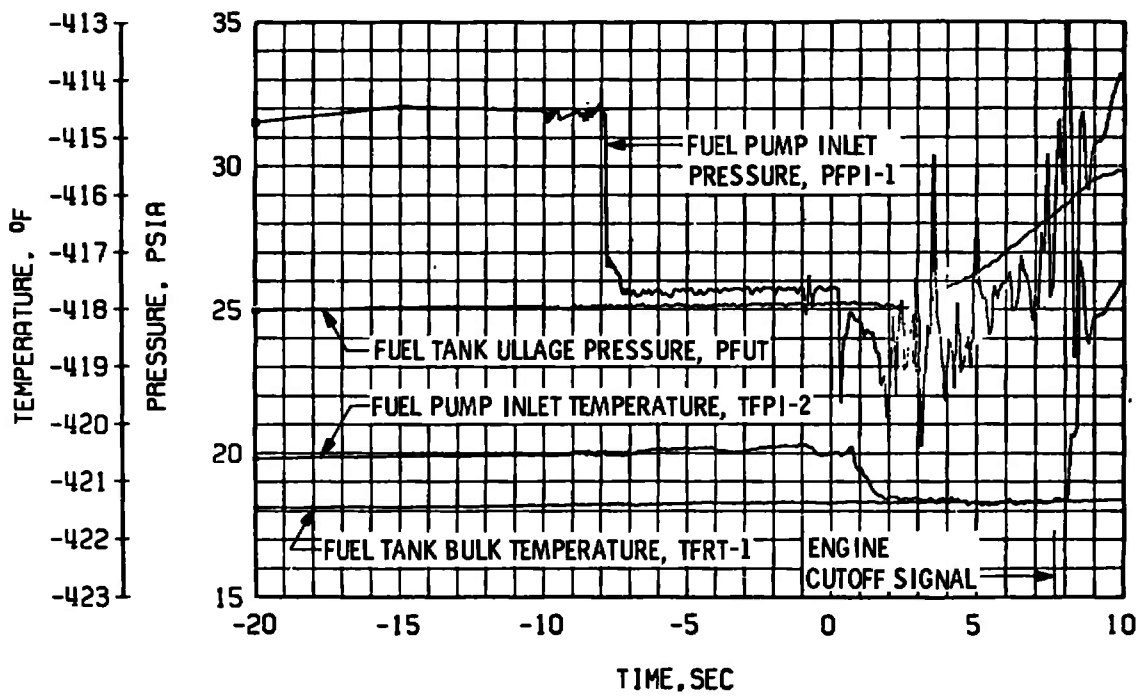
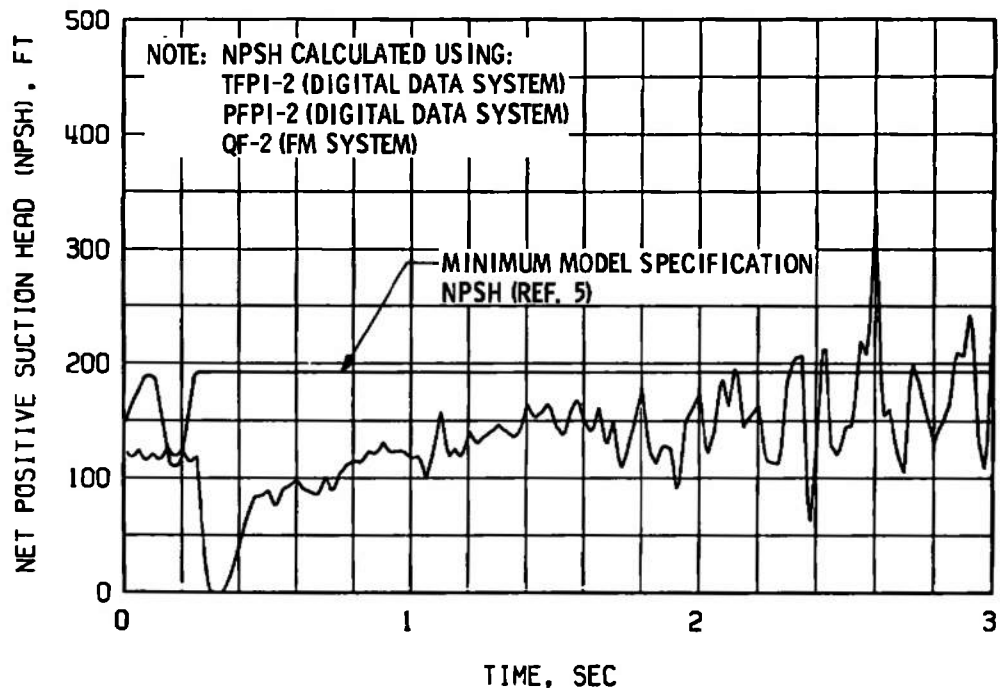


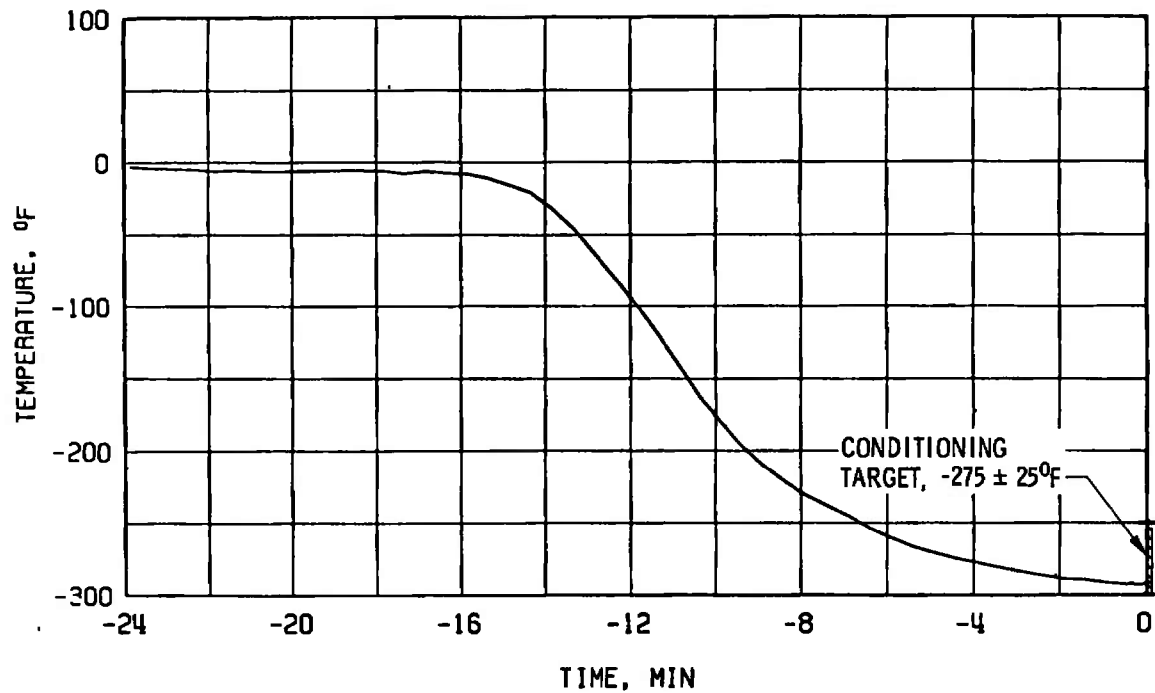
Fig. 43 Fuel Pump Start Transient Performance, Firing 29E



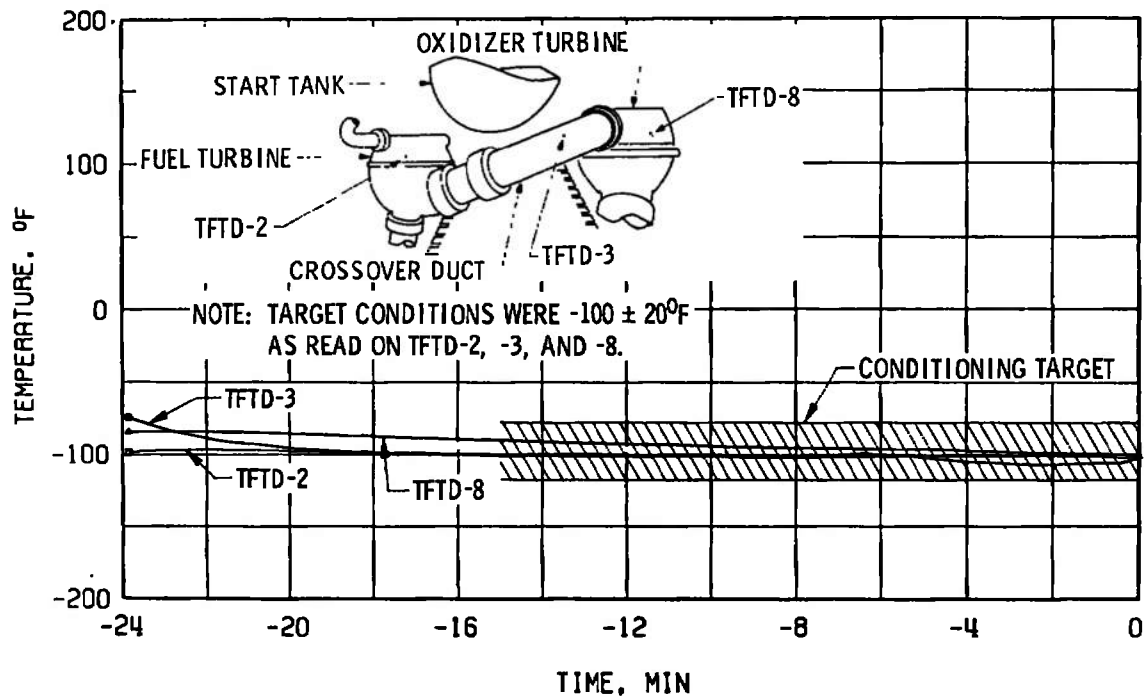
a. Duct Pressure and Temperature Transients



b. Fuel Pump NPSH during Start Transient, Firing 29E  
 Fig. 44 Fuel Low Pressure Duct Performance, Firing 29E

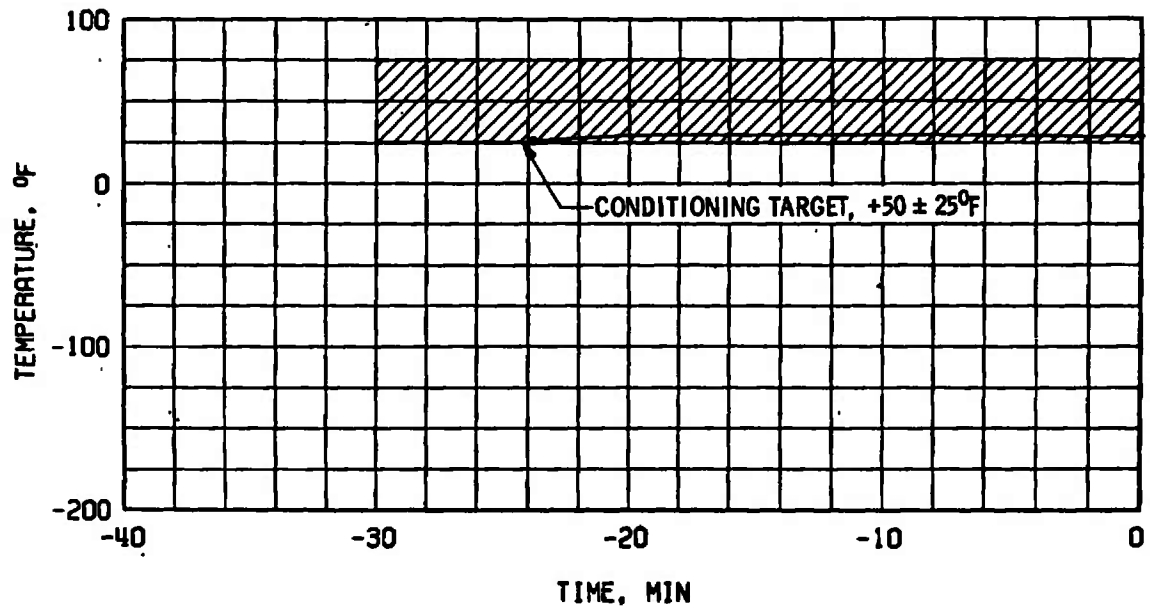


a. Thrust Chamber Throat, TTC-1P

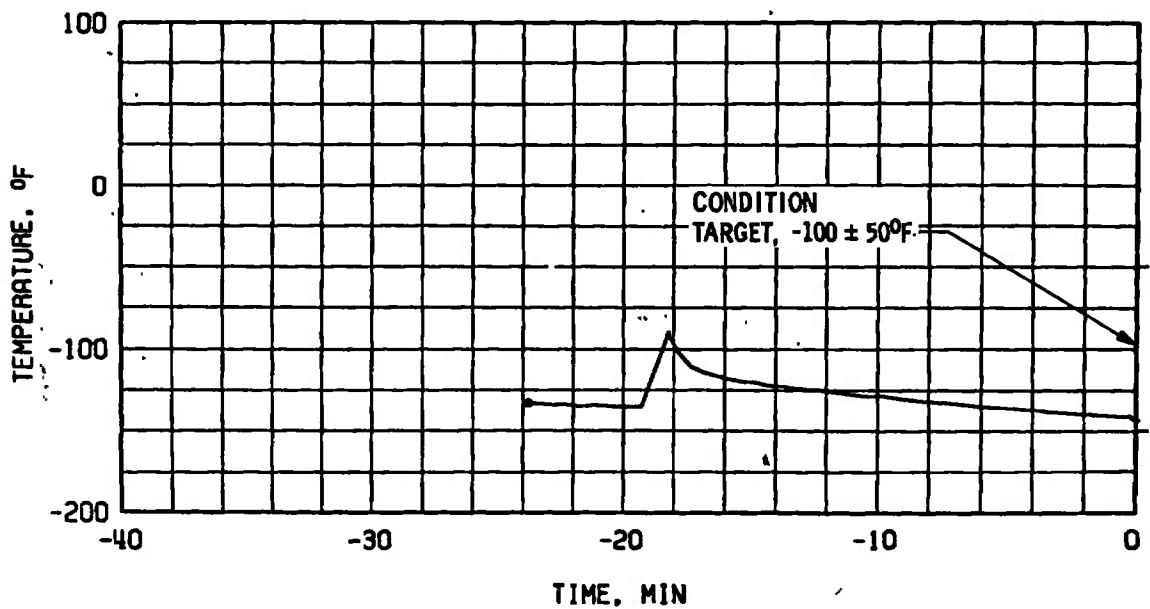


b. Crossover Duct, TTFD

Fig. 45 Thermal Conditioning History of Engine Components, Firing 30A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 45 Concluded



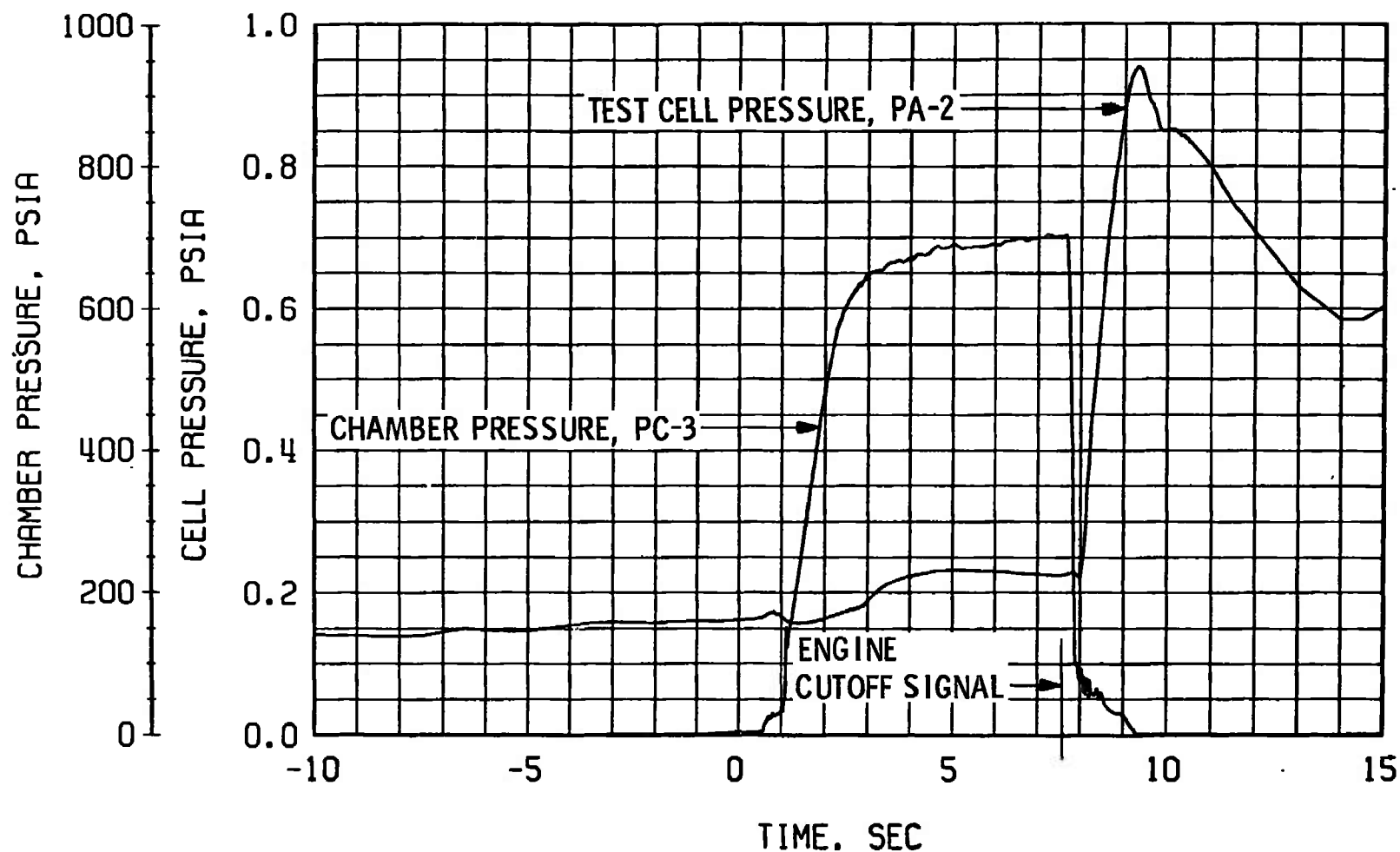
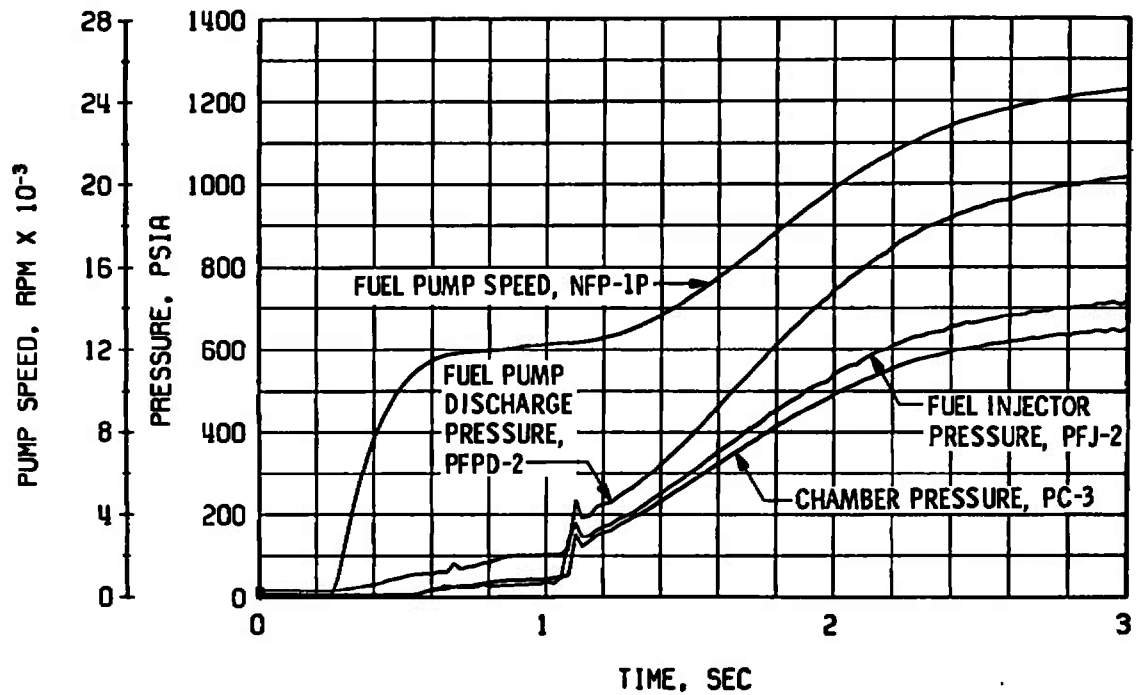
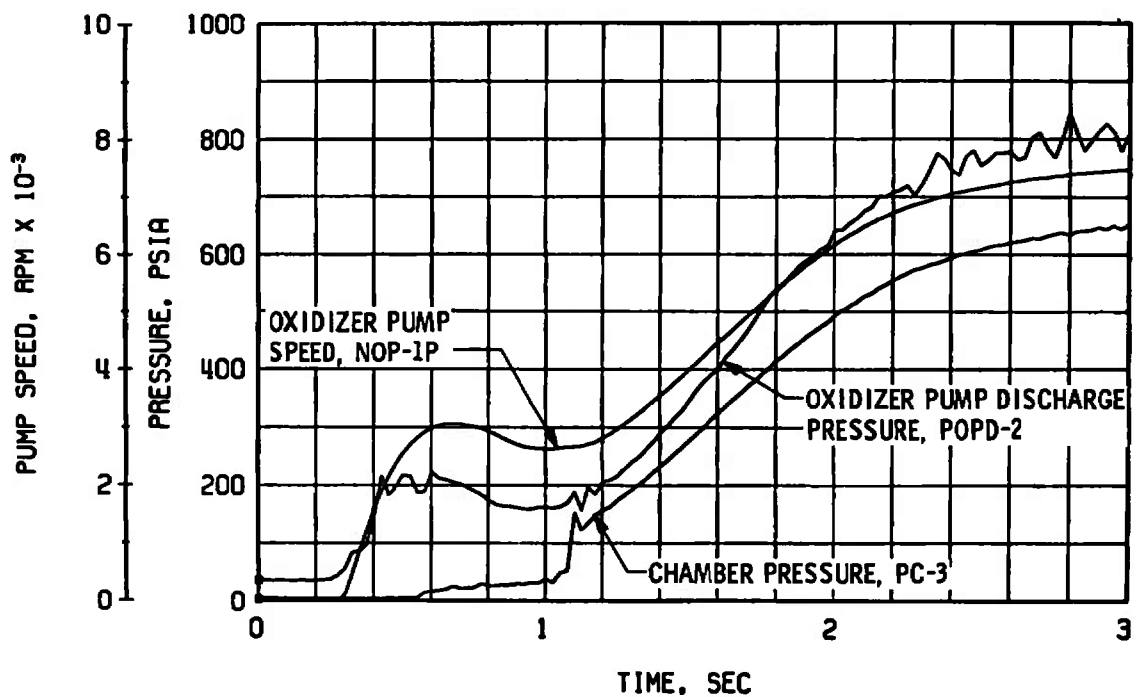


Fig. 46 Engine Ambient and Combustion Chamber Pressures, Firing 30A

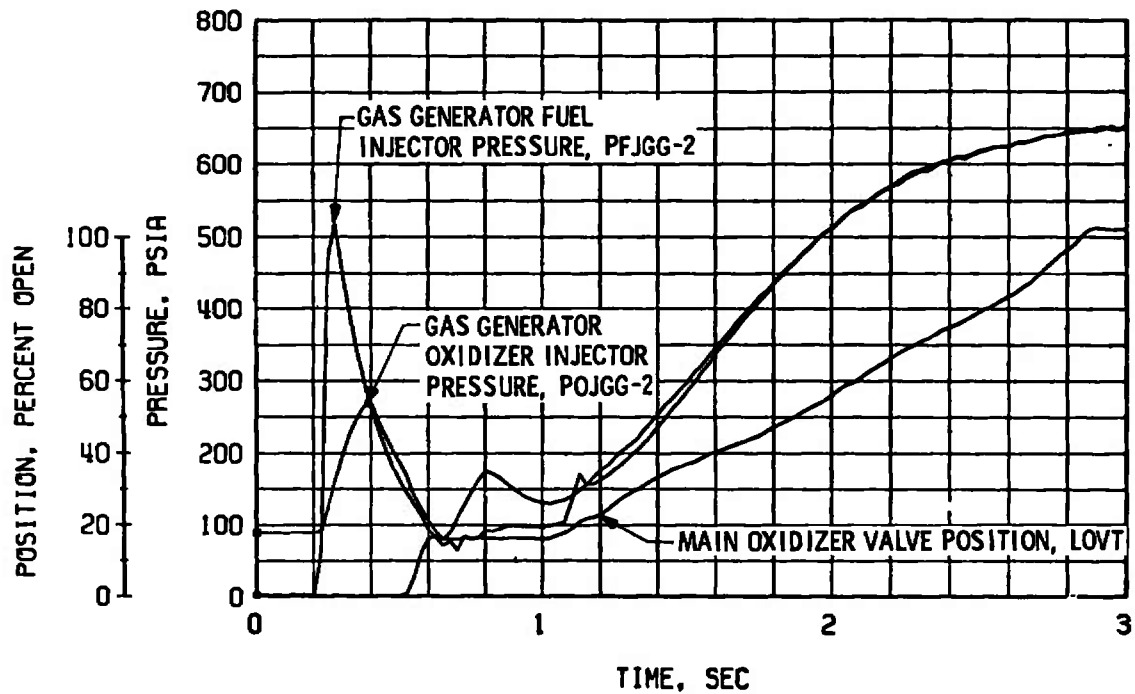


a. Thrust Chamber Fuel System, Start

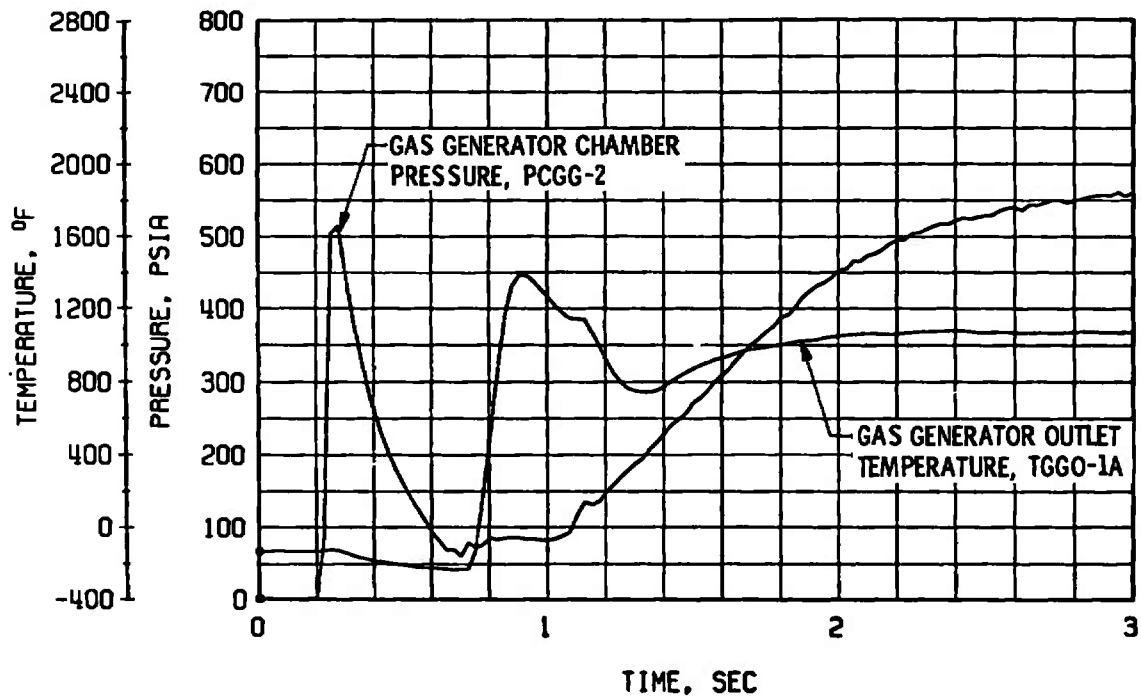


b. Thrust Chamber Oxidizer System, Start

Fig. 47 Engine Transient Operation, Firing 30A

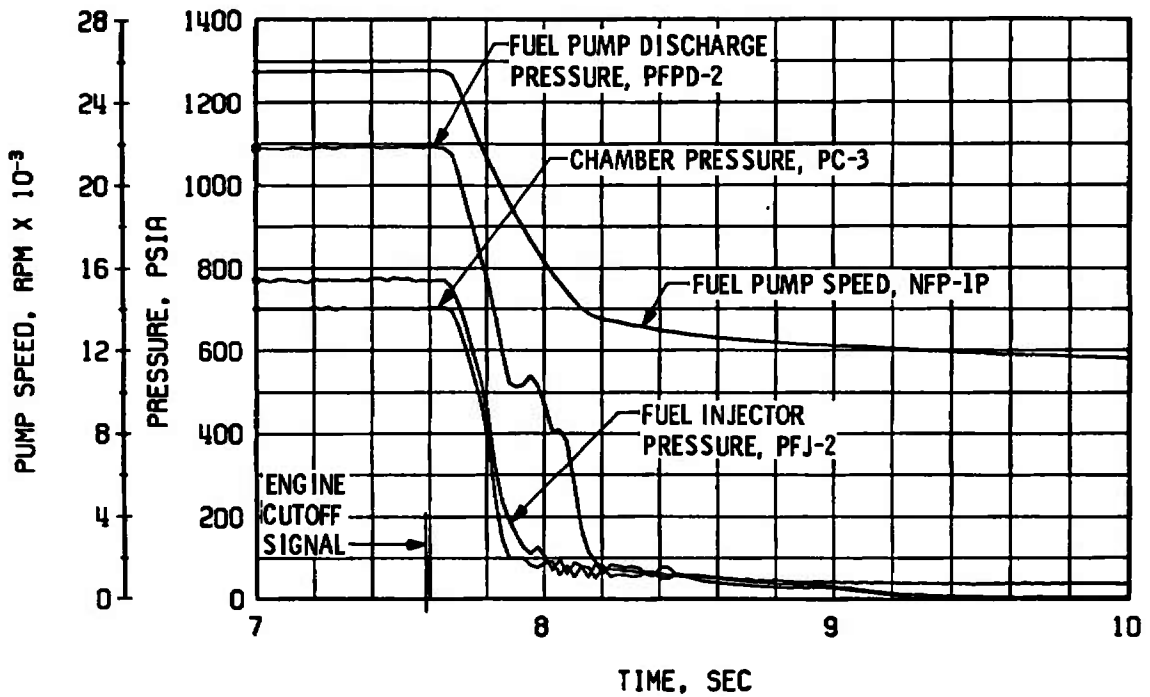


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

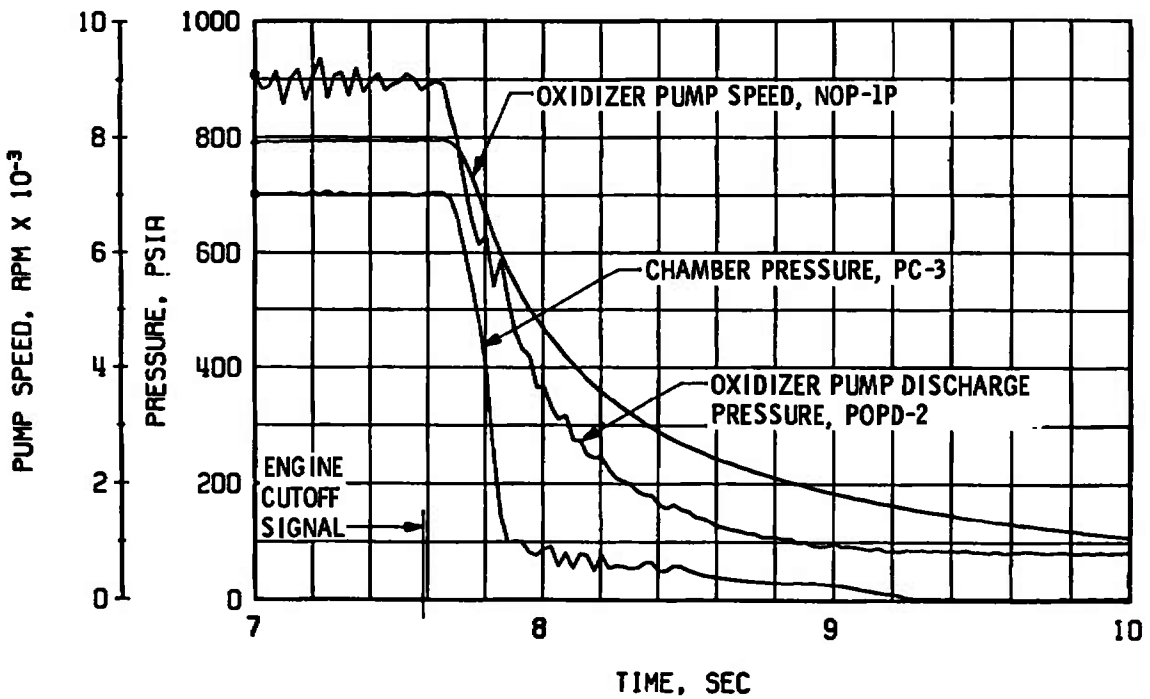


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 47 Continued



e. Thrust Chamber Fuel System, Shutdown



f. Thrust Chamber Oxidizer System, Shutdown

Fig. 47 Continued

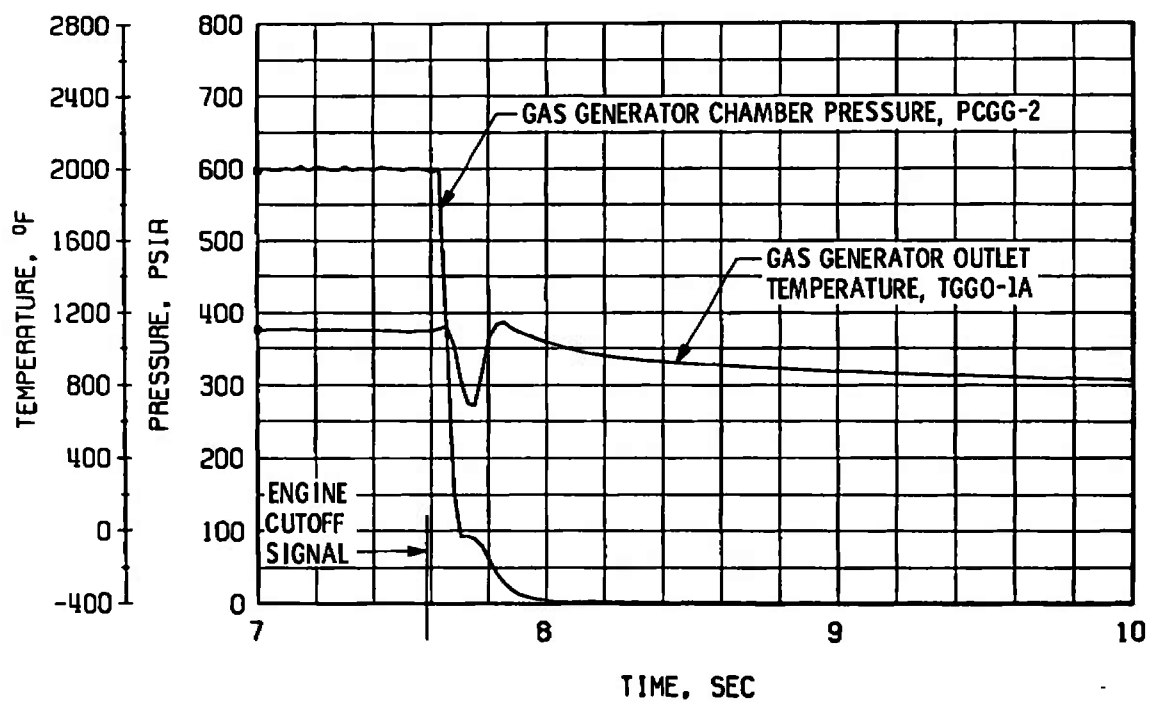
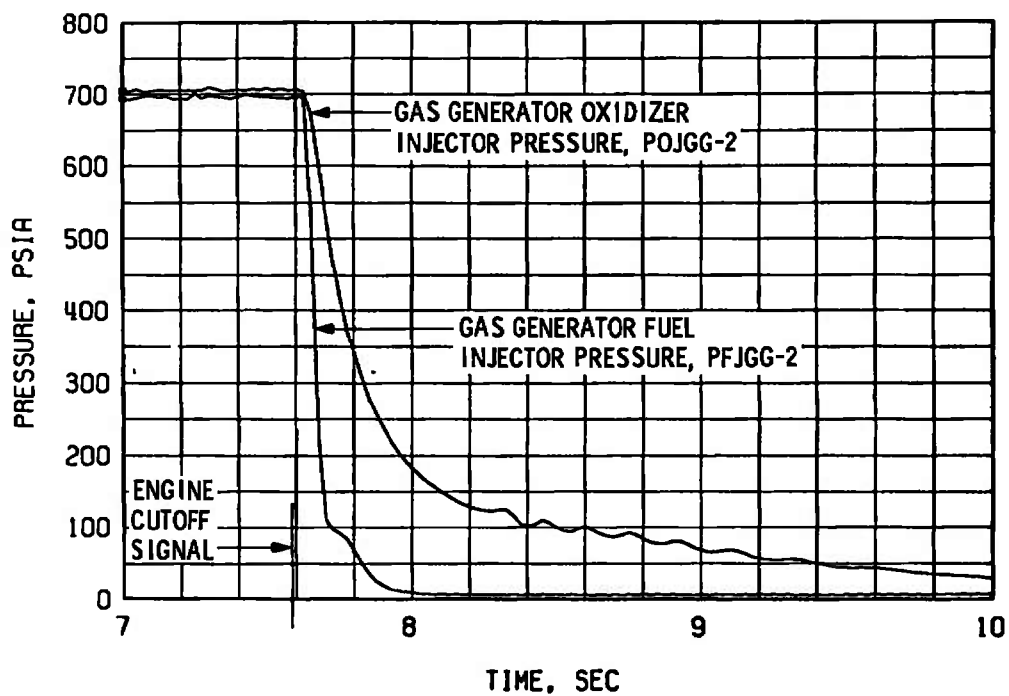


Fig. 47 Concluded

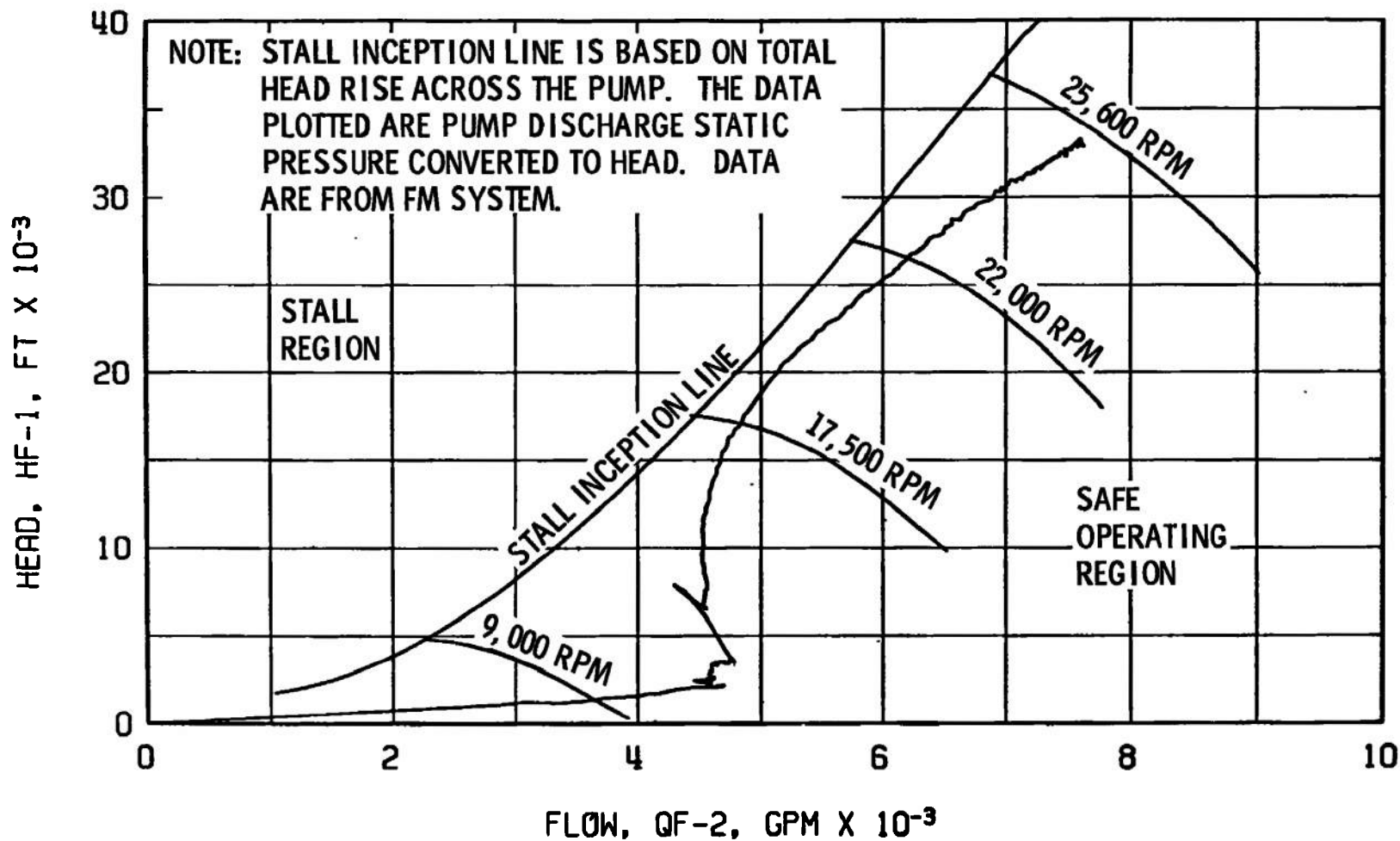
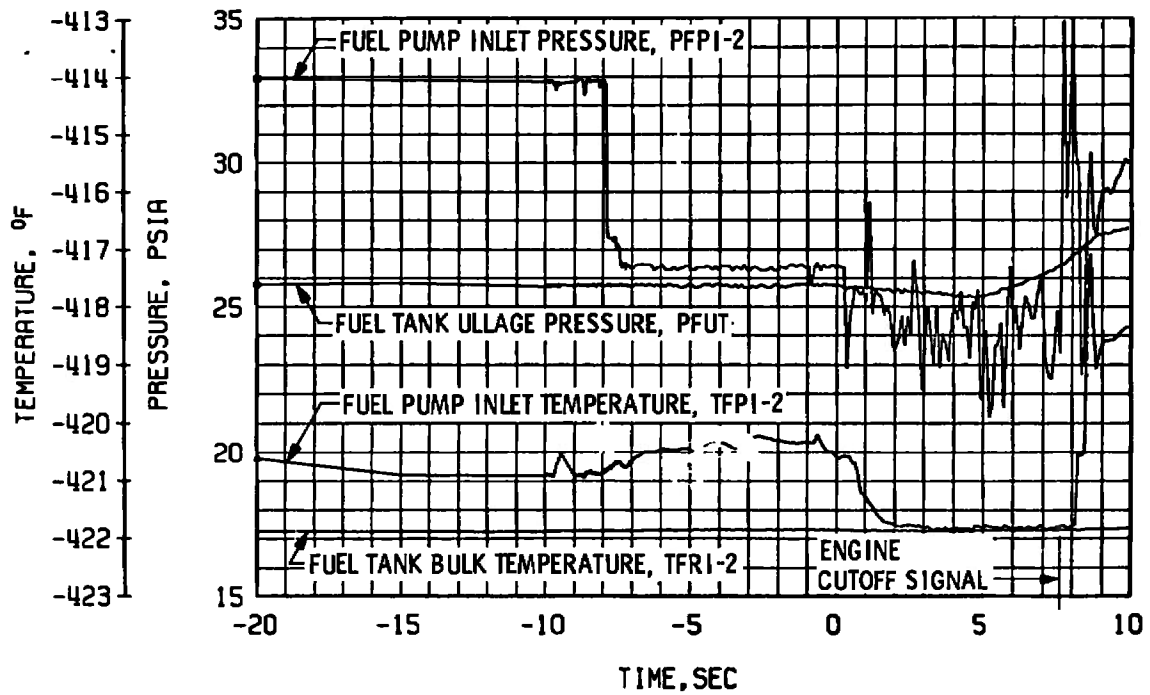
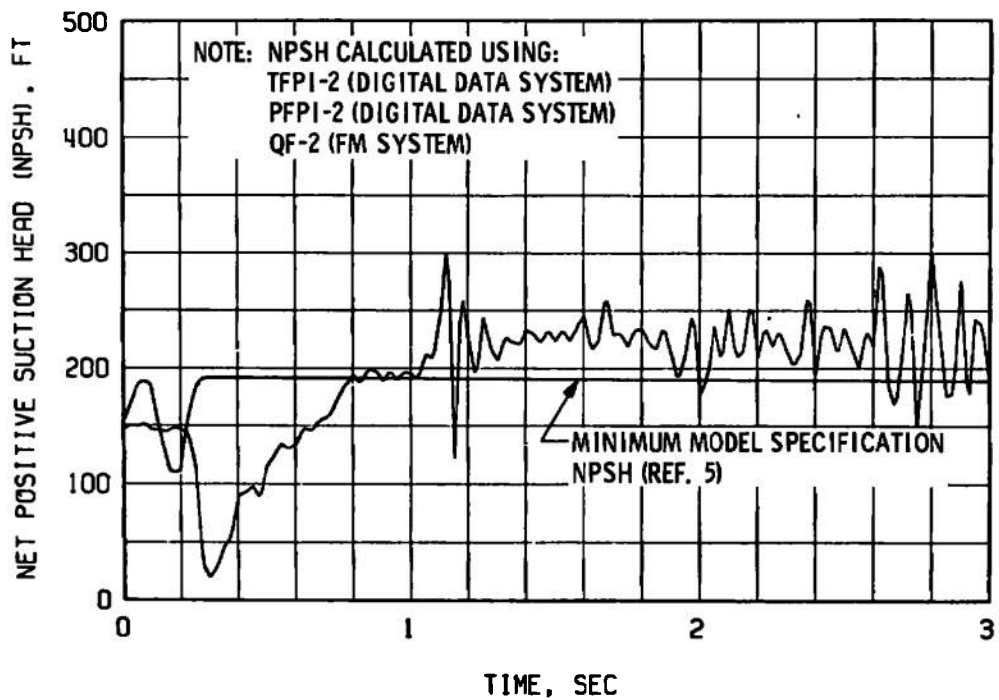


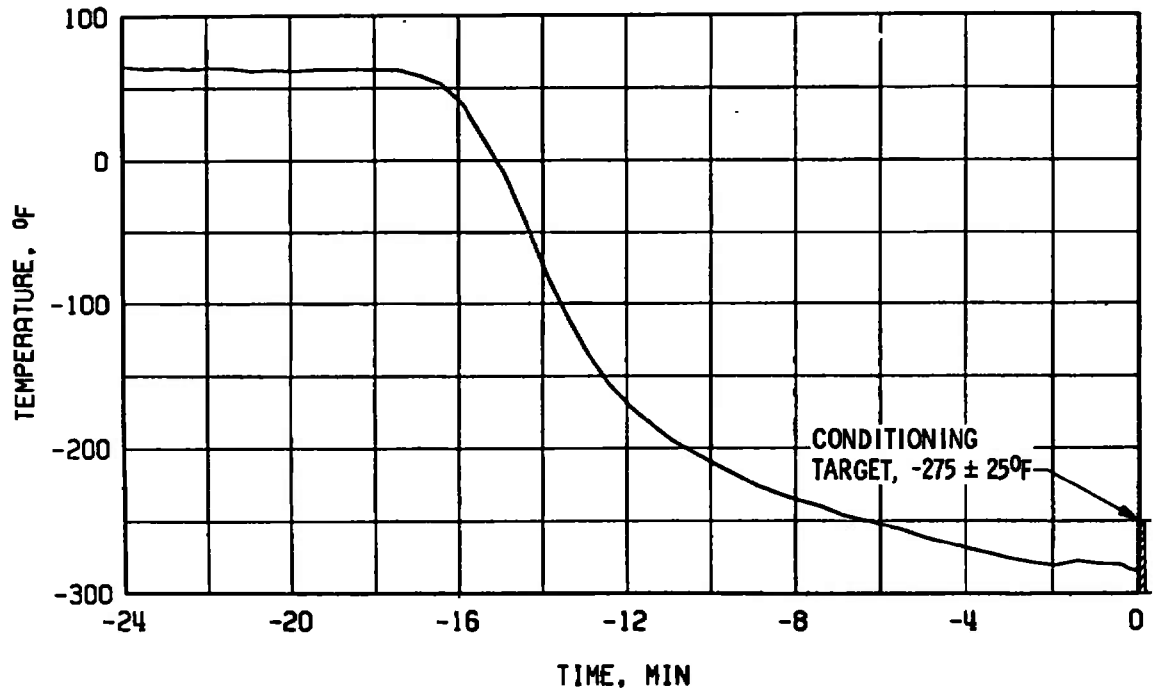
Fig. 48 Fuel Pump Start Transient Performance, Firing 30A



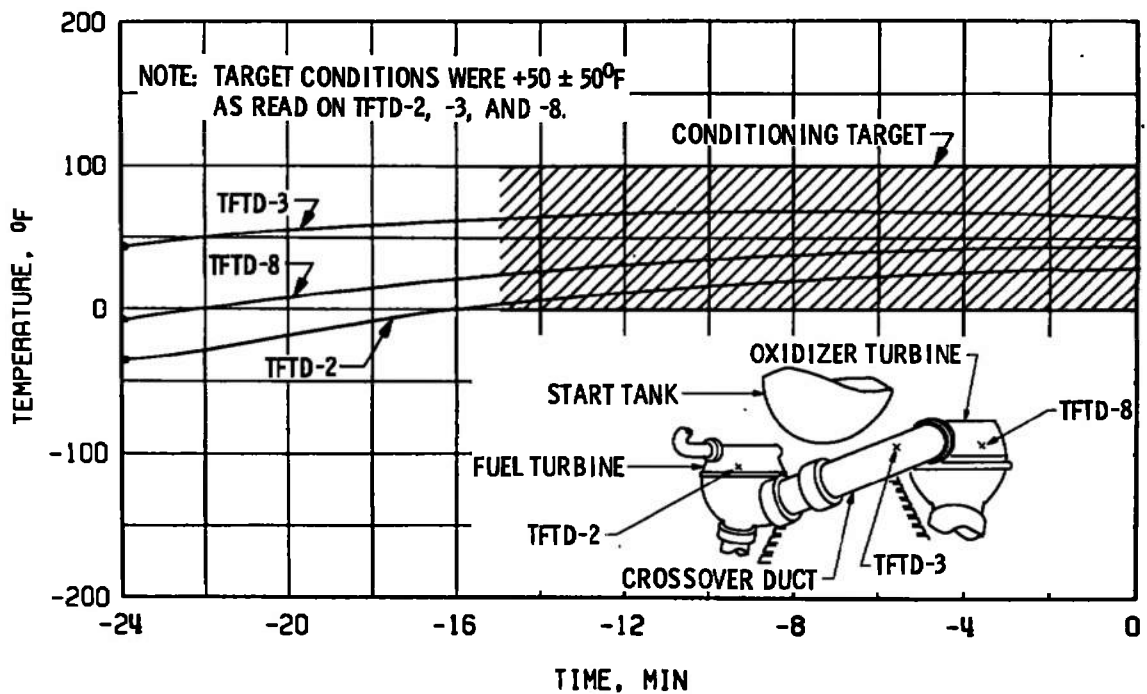
a. Duct Pressure and Temperature Transients



b. Fuel Pump NPSH during Start Transient, Firing 30A  
 Fig. 49 Fuel Low Pressure Duct Performance, Firing 30A



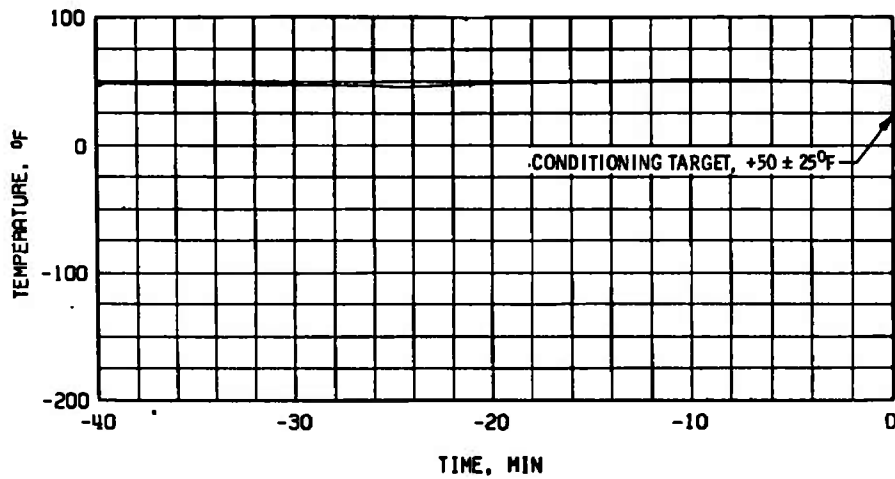
a. Thrust Chamber Throat, TTC-1P



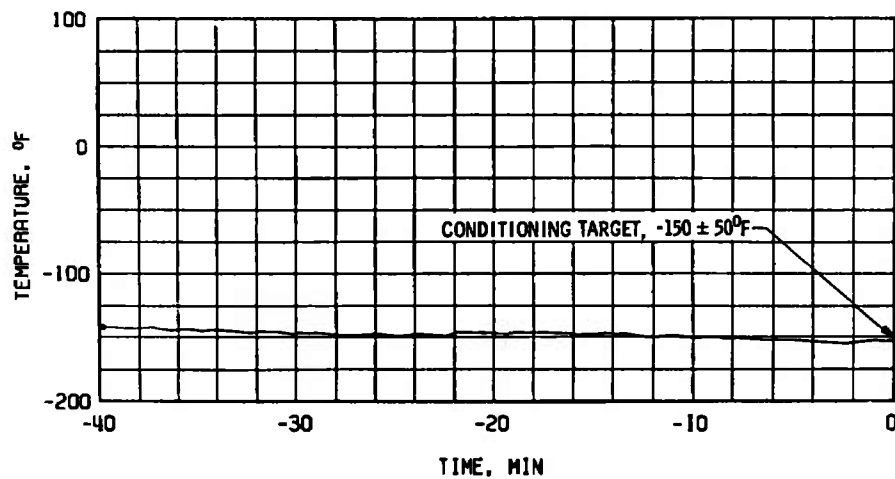
b. Crossover Duct, TFTD

Fig. 50 Thermal Conditioning History of Engine Components, Firing 31A

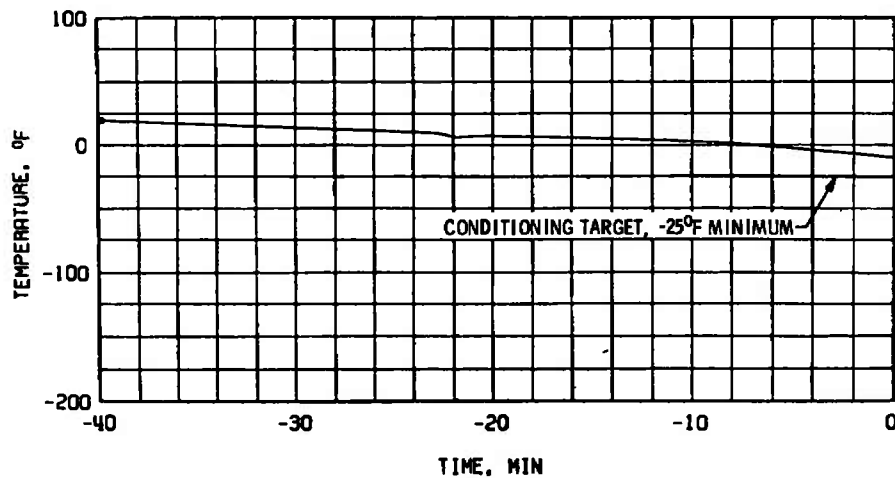




c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 50 Concluded

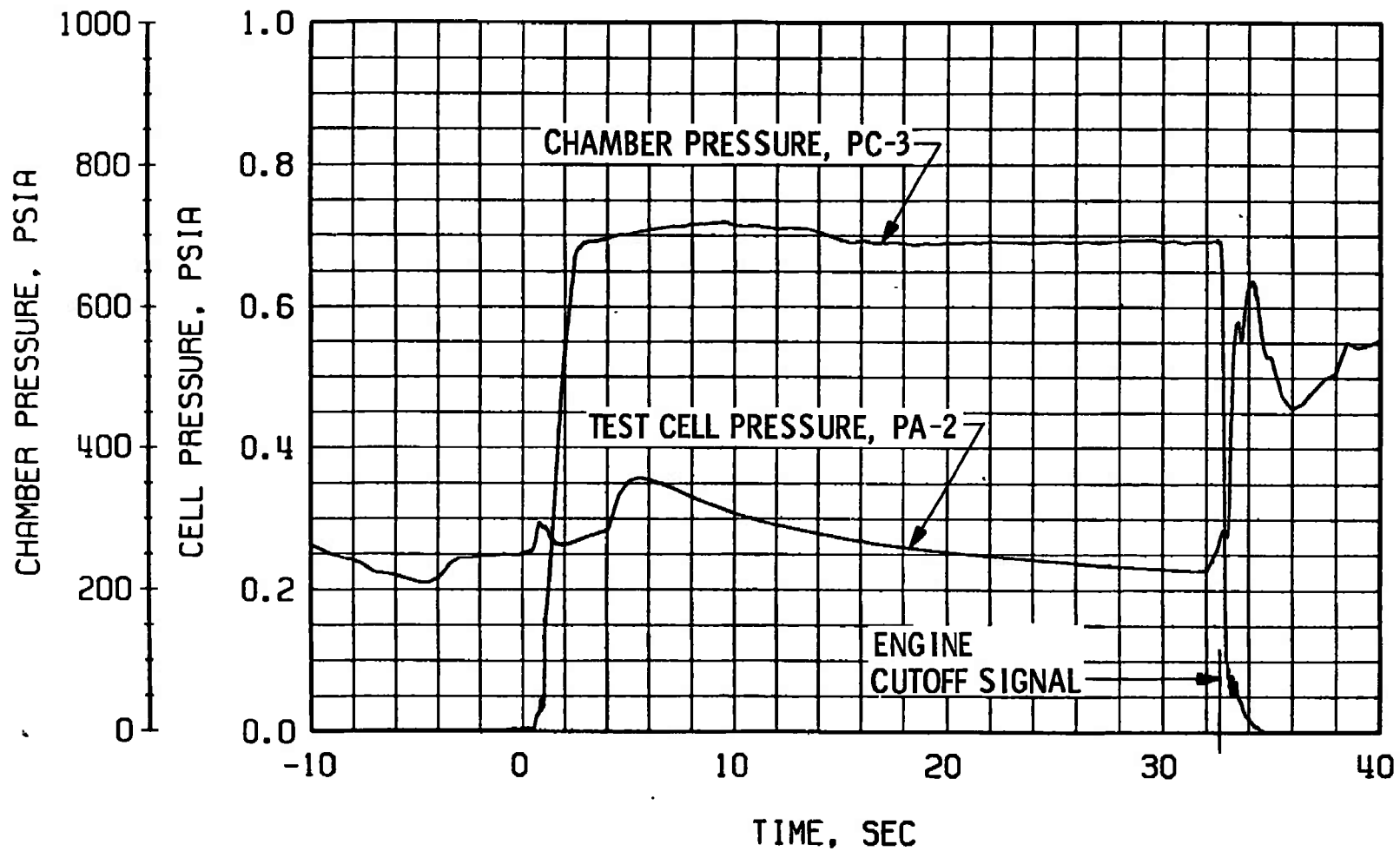
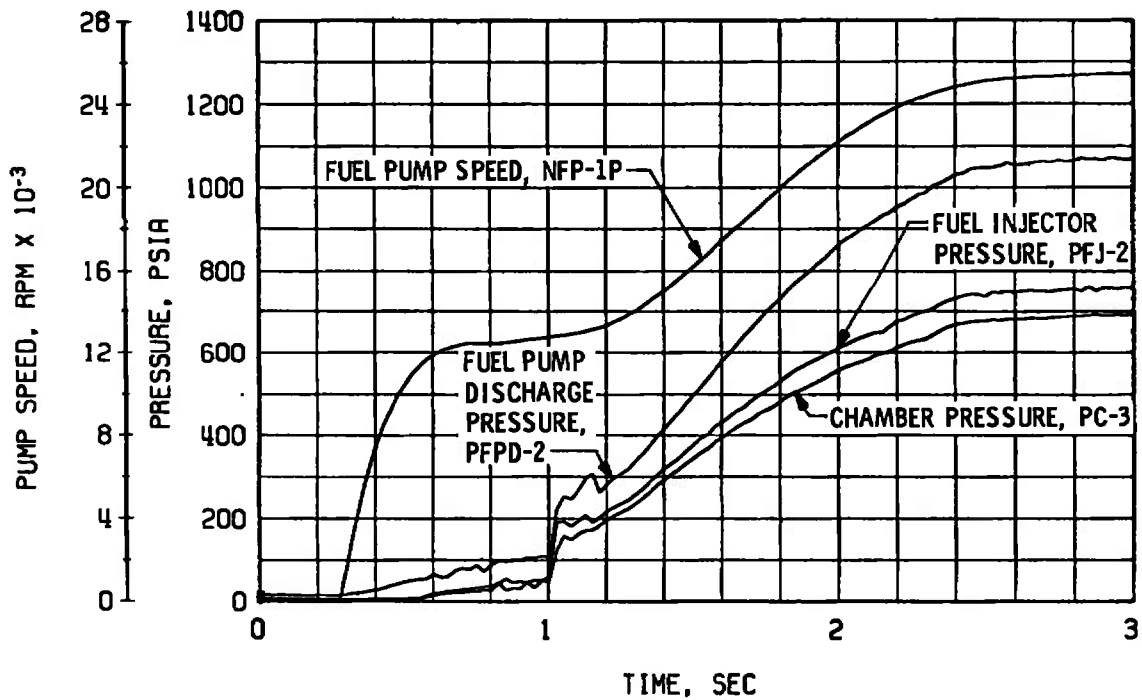
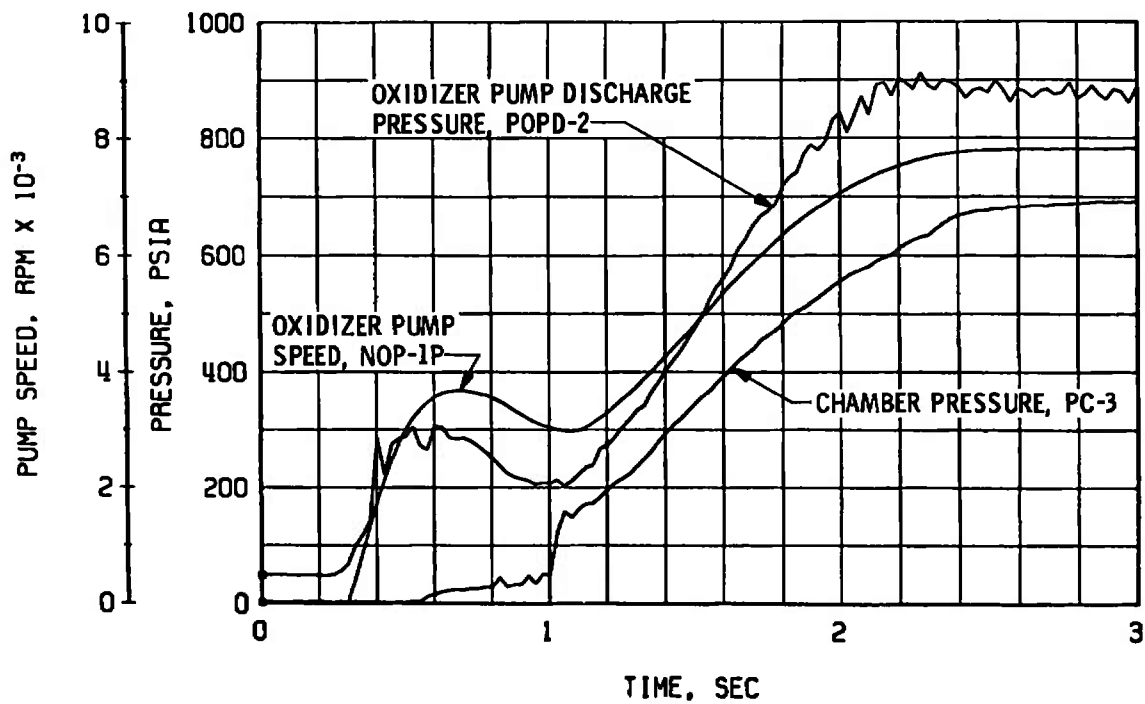


Fig. 51 Engine Ambient and Combustion Chamber Pressures, Firing 31A

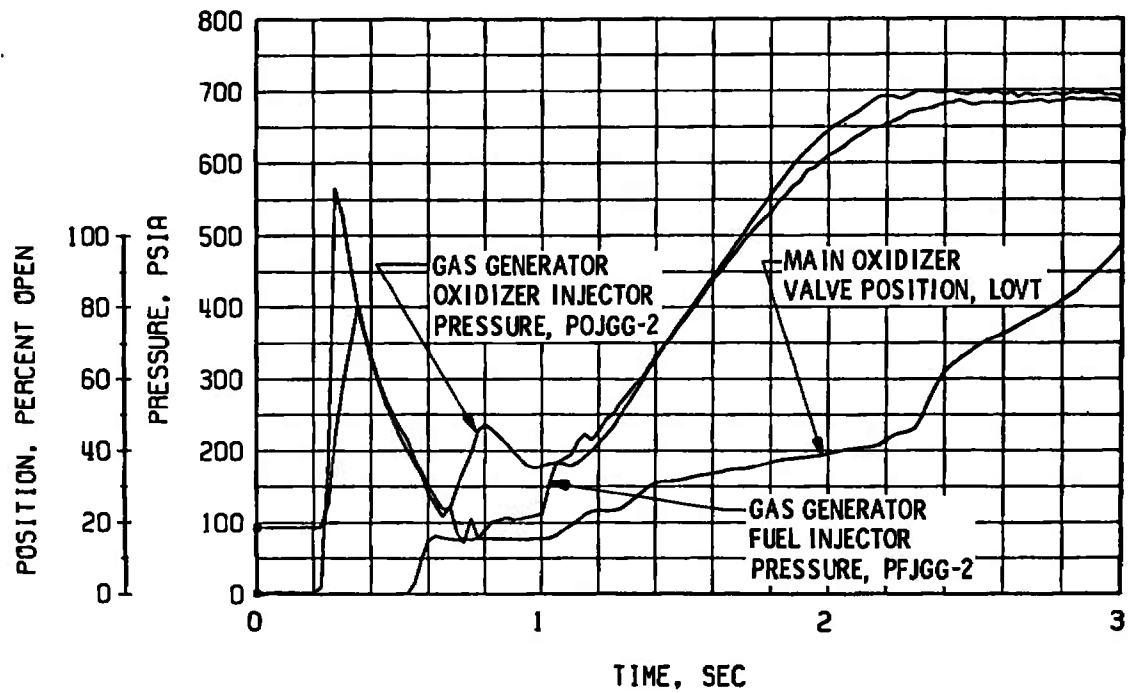


a. Thrust Chamber Fuel System, Start

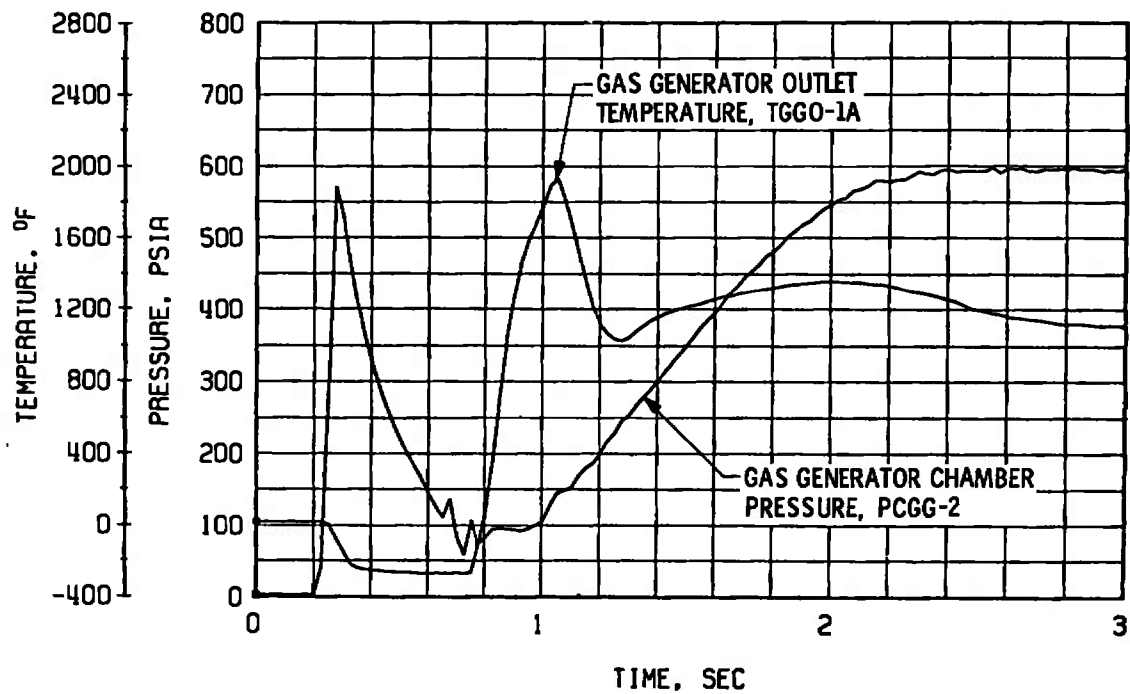


b. Thrust Chamber Oxidizer System, Start

Fig. 52 Engine Transient Operation, Firing 31A

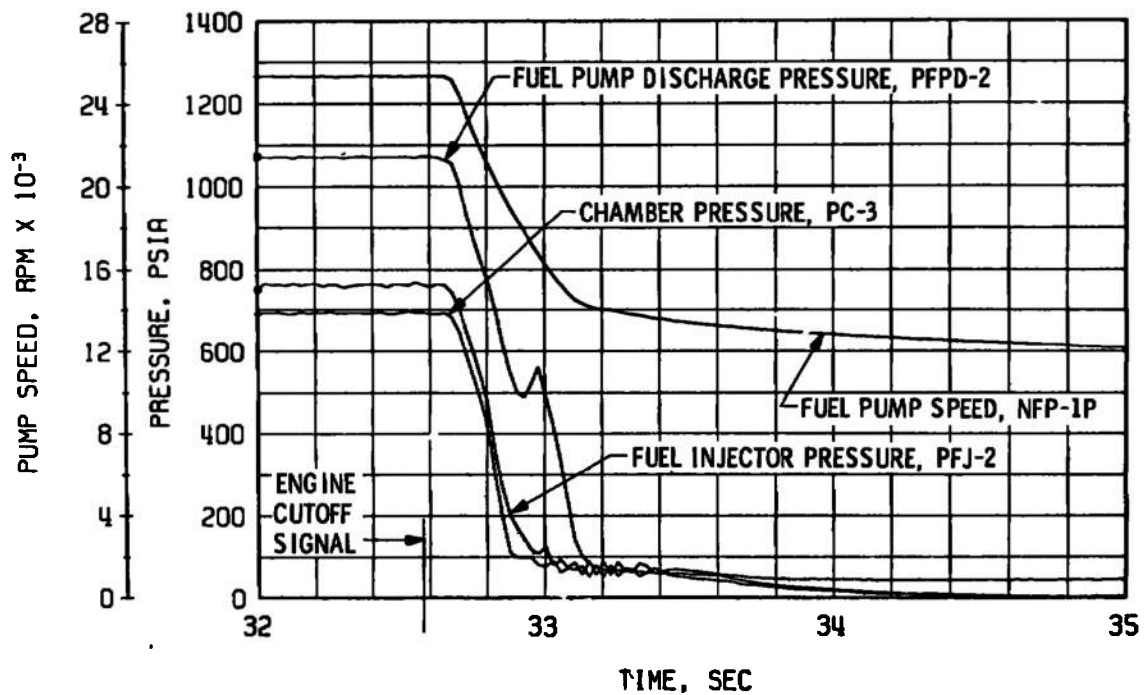


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

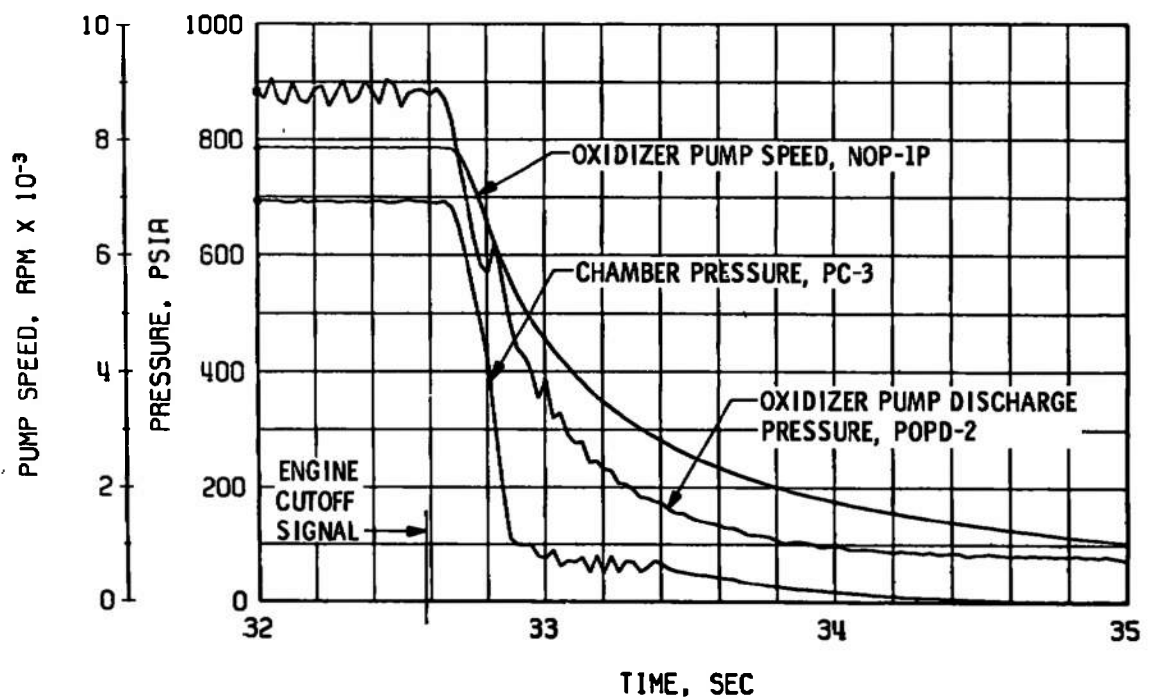


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 52 Continued

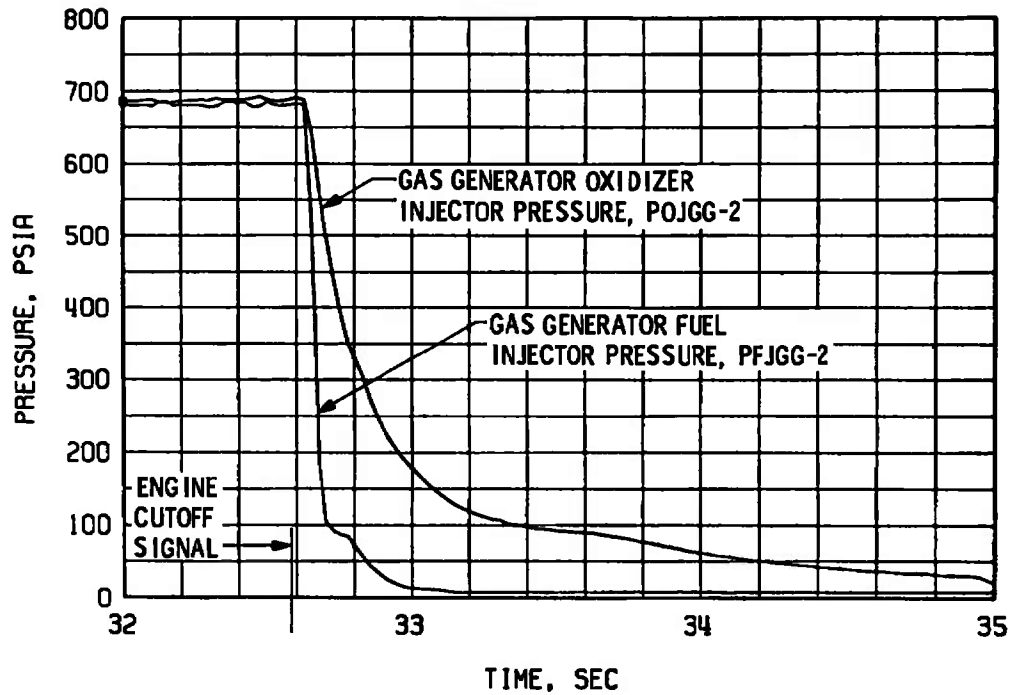


e. Thrust Chamber Fuel System, Shutdown

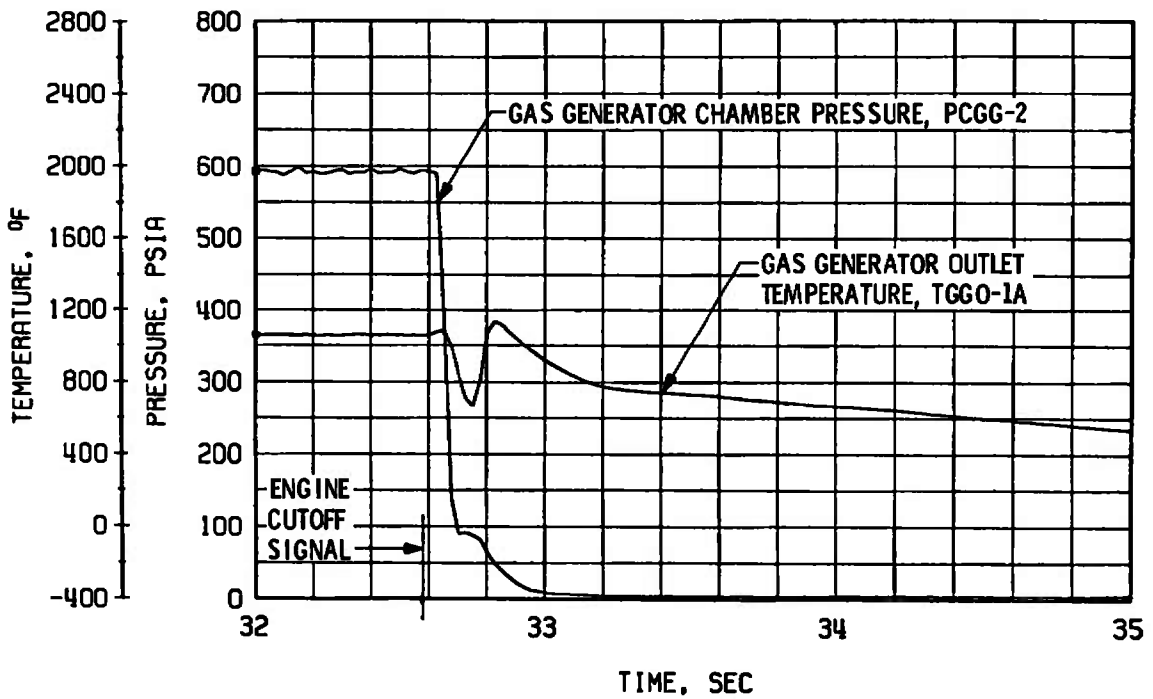


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 52 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 52 Concluded

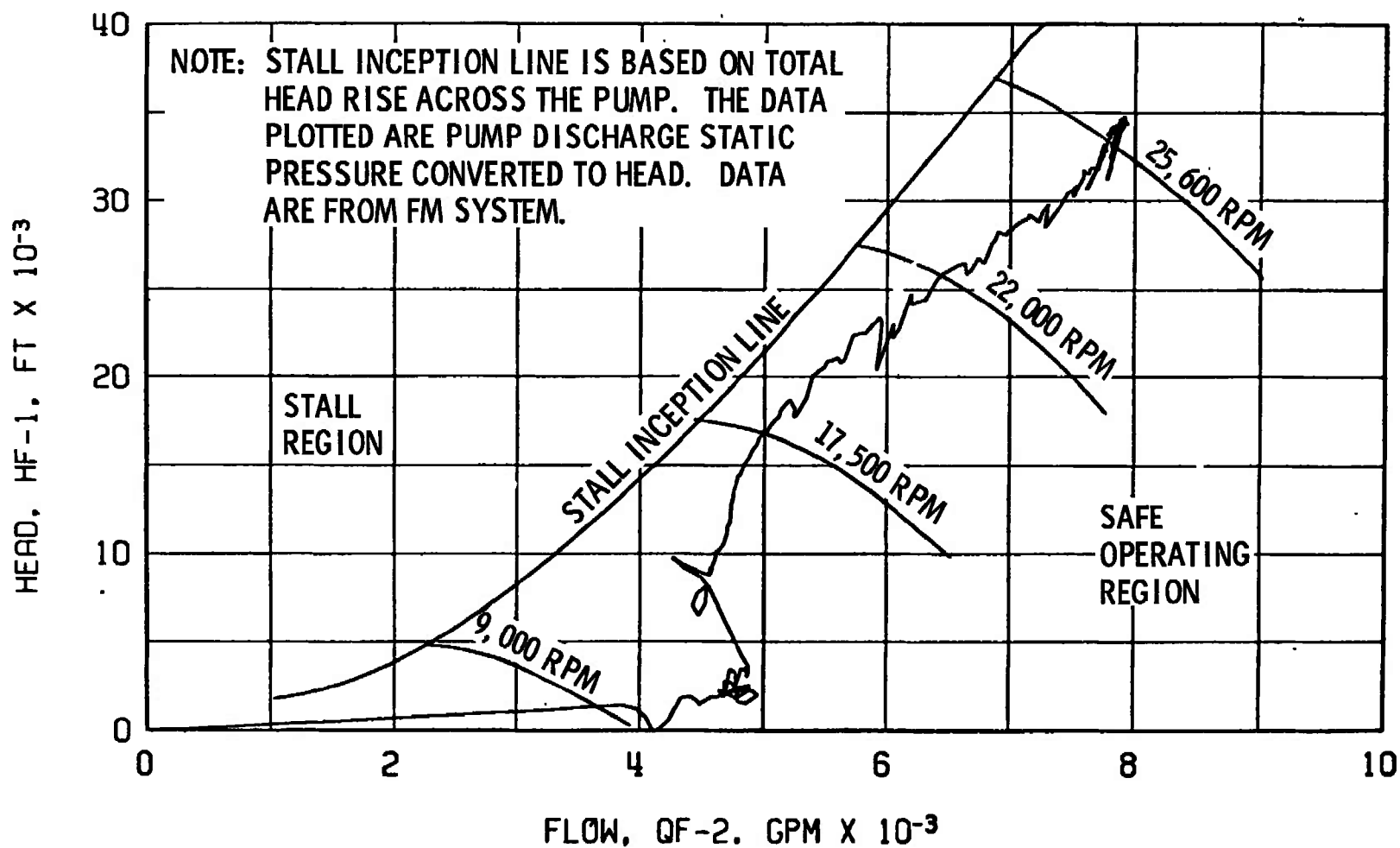
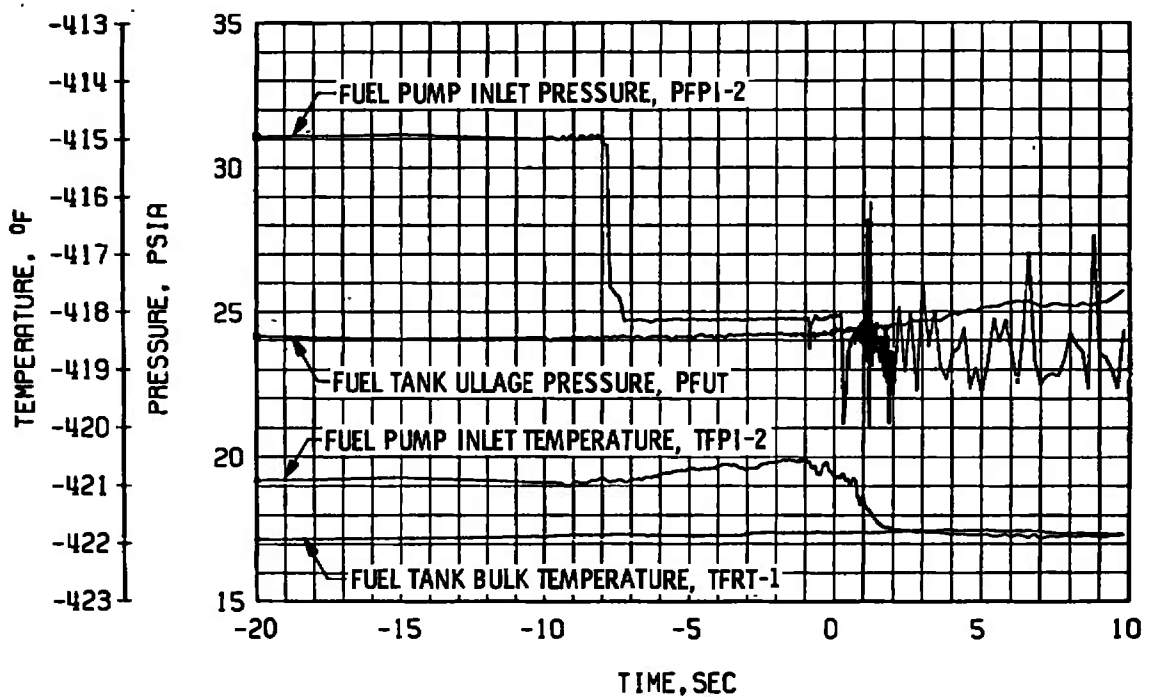
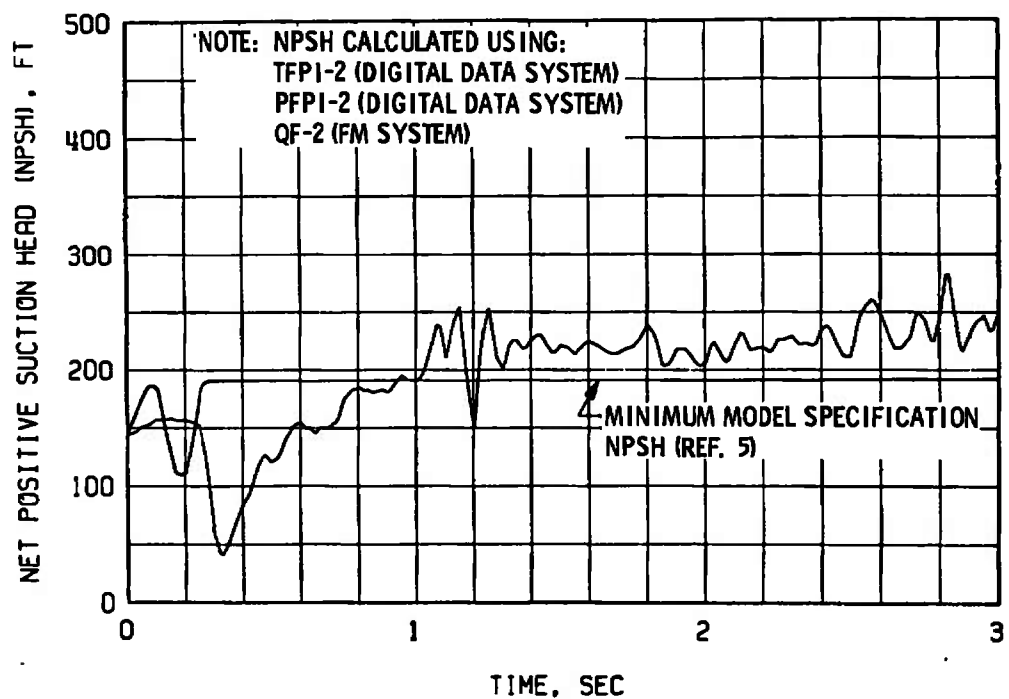


Fig. 53 Fuel Pump Start Transient Performance, Firing 31A

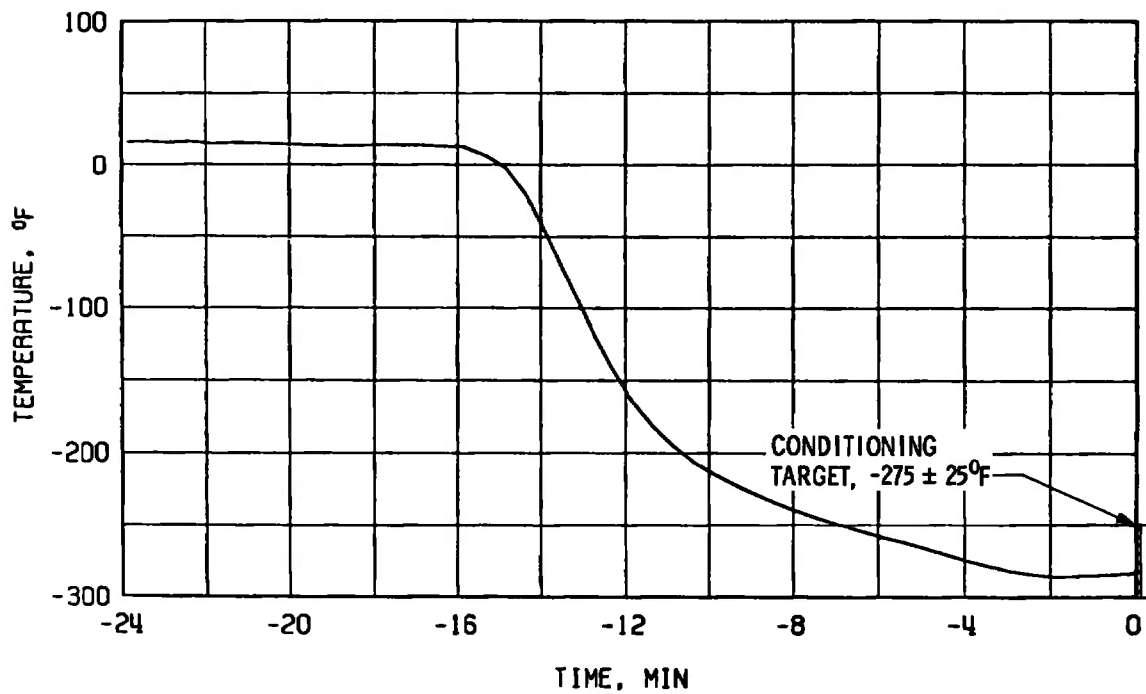


a. Duct Pressure and Temperature Transients

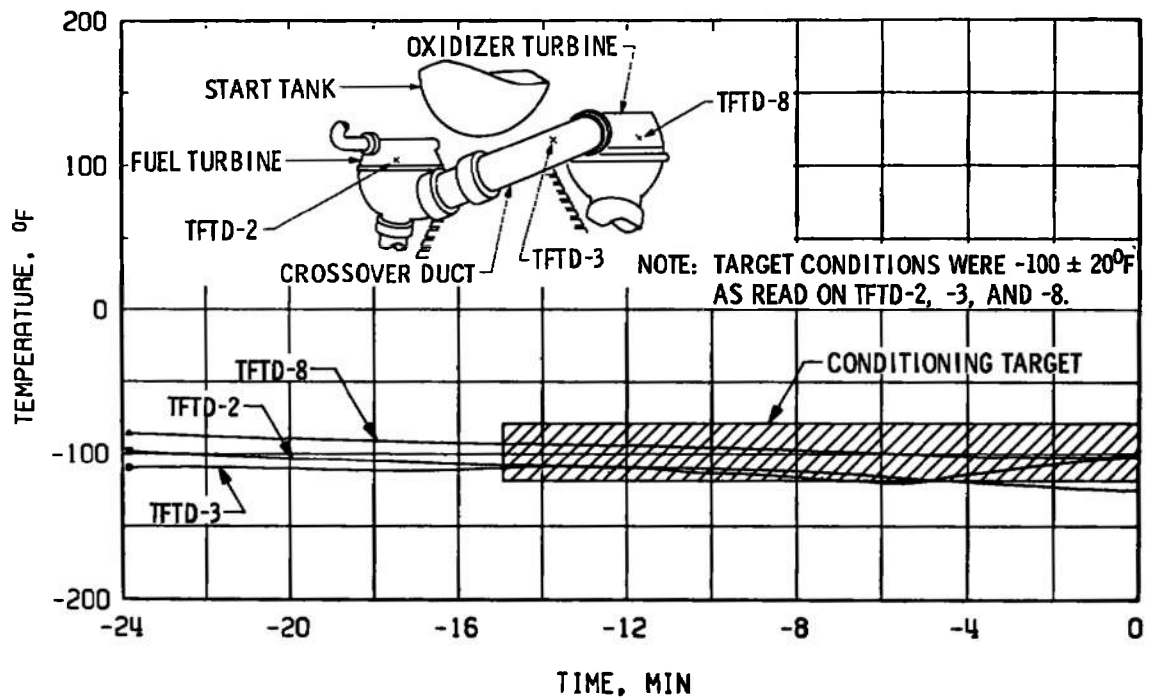


b. Fuel Pump NPSH during Start Transient, Firing 31A  
 Fig. 54 Fuel Low Pressure Duct Performance, Firing 31A



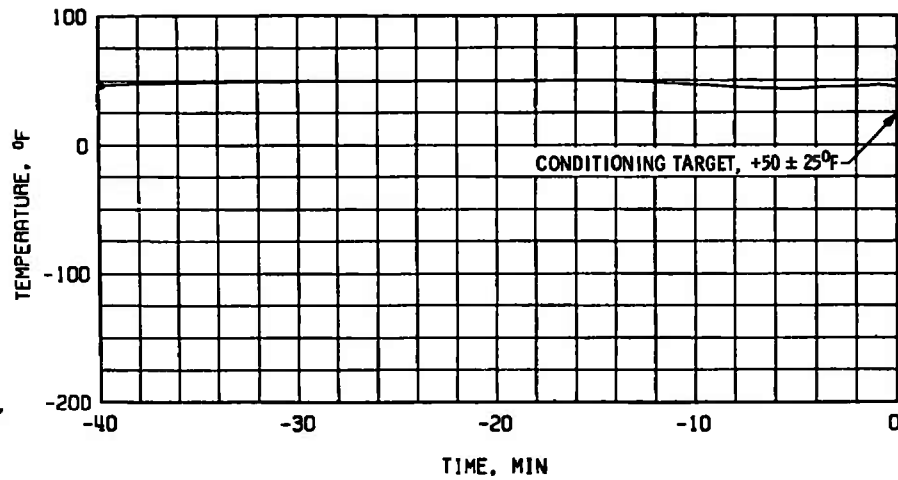


a. Thrust Chamber Throat, TTC-1P

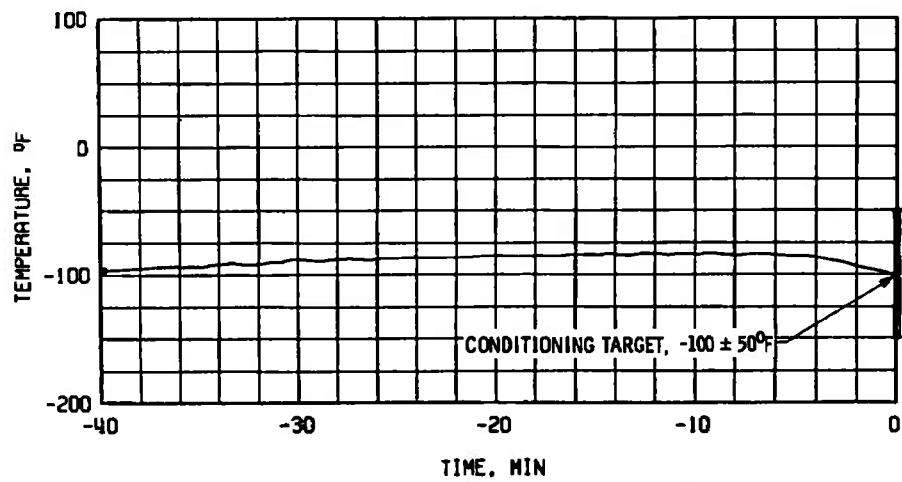


b. Crossover Duct, TFTD

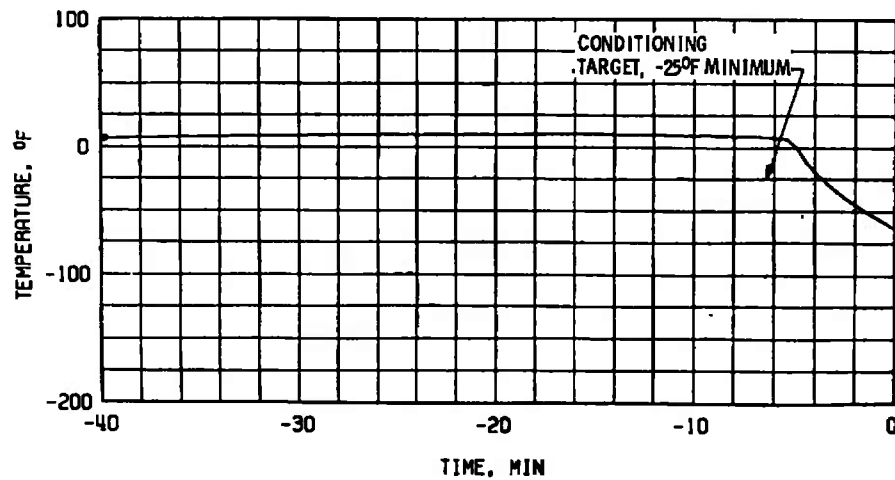
Fig. 55 Thermal Conditioning History of Engine Components, Firing 31B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 55 Concluded

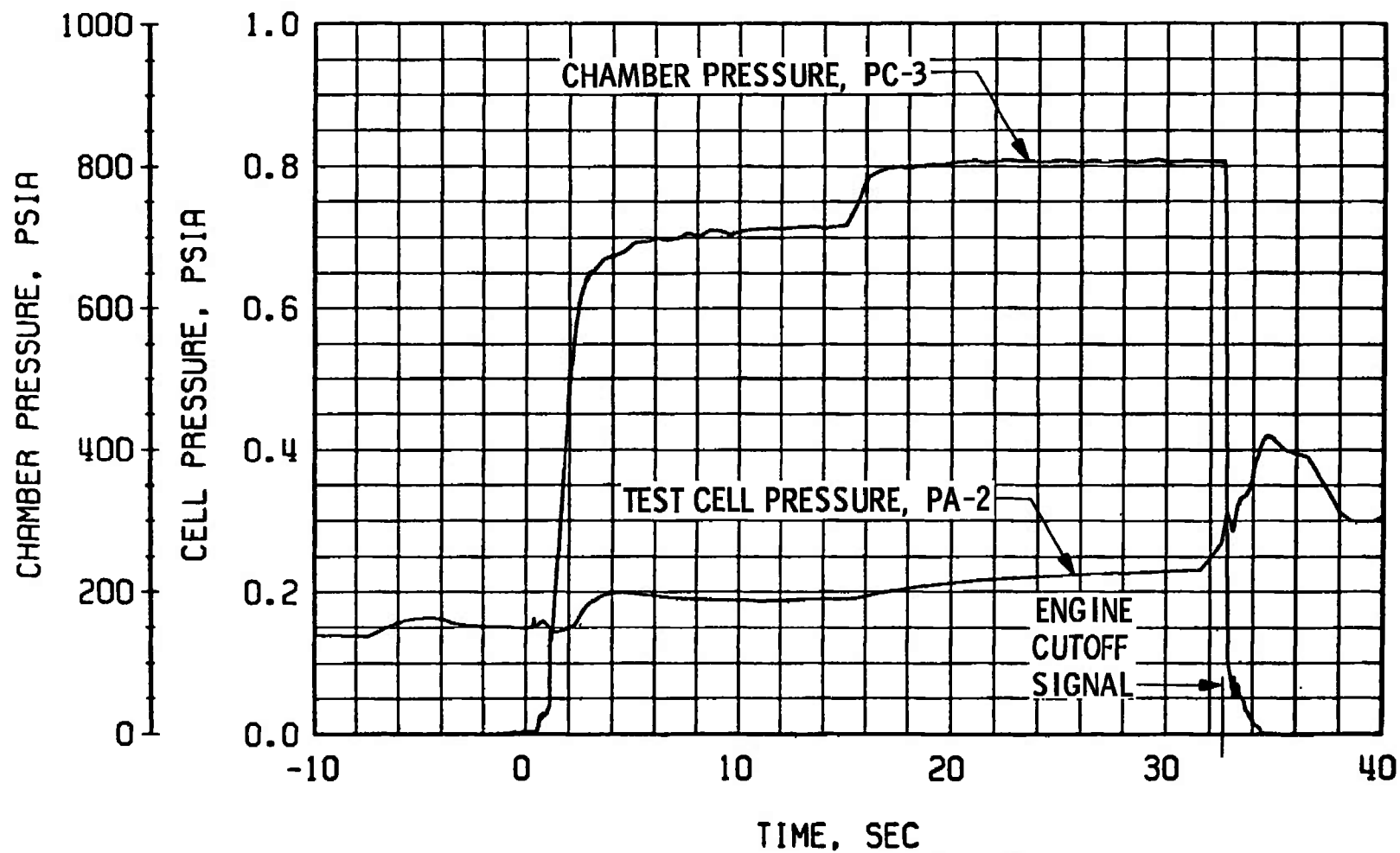
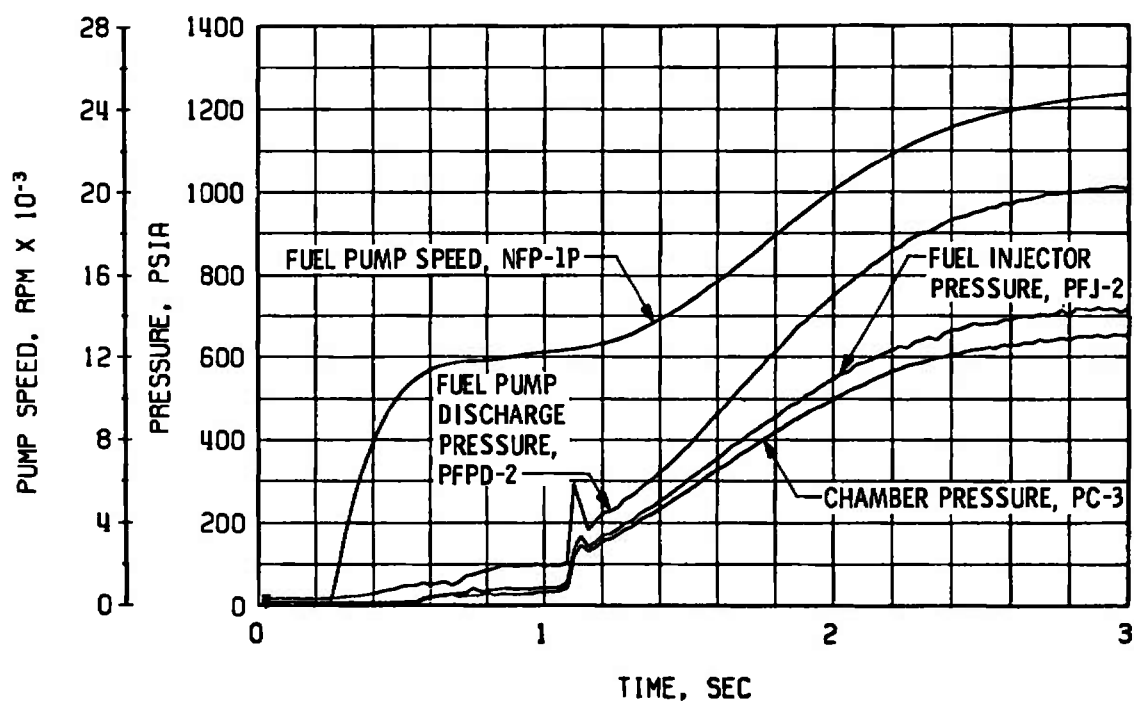
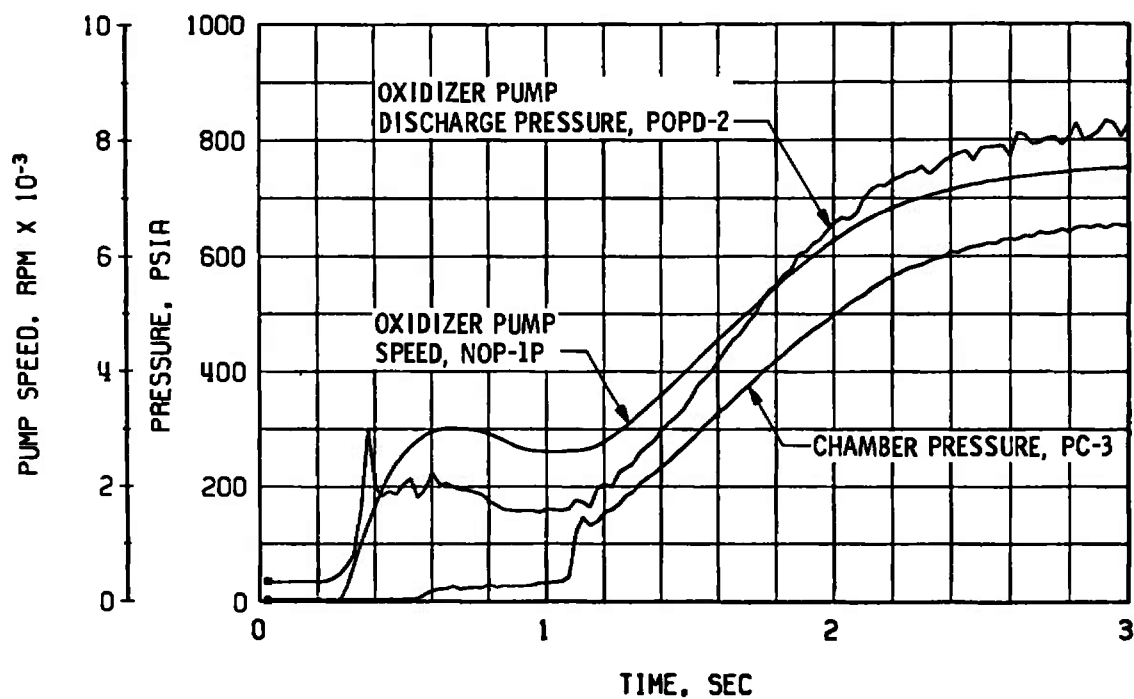
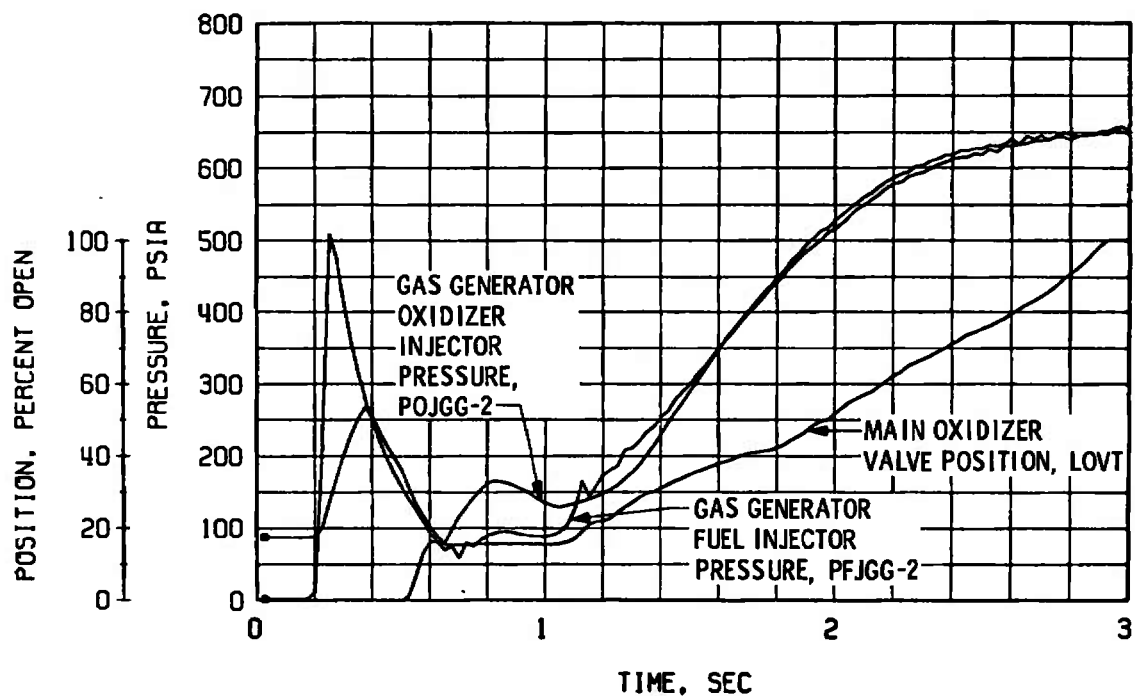


Fig. 56 Engine Ambient and Combustion Chamber Pressures, Firing 31B

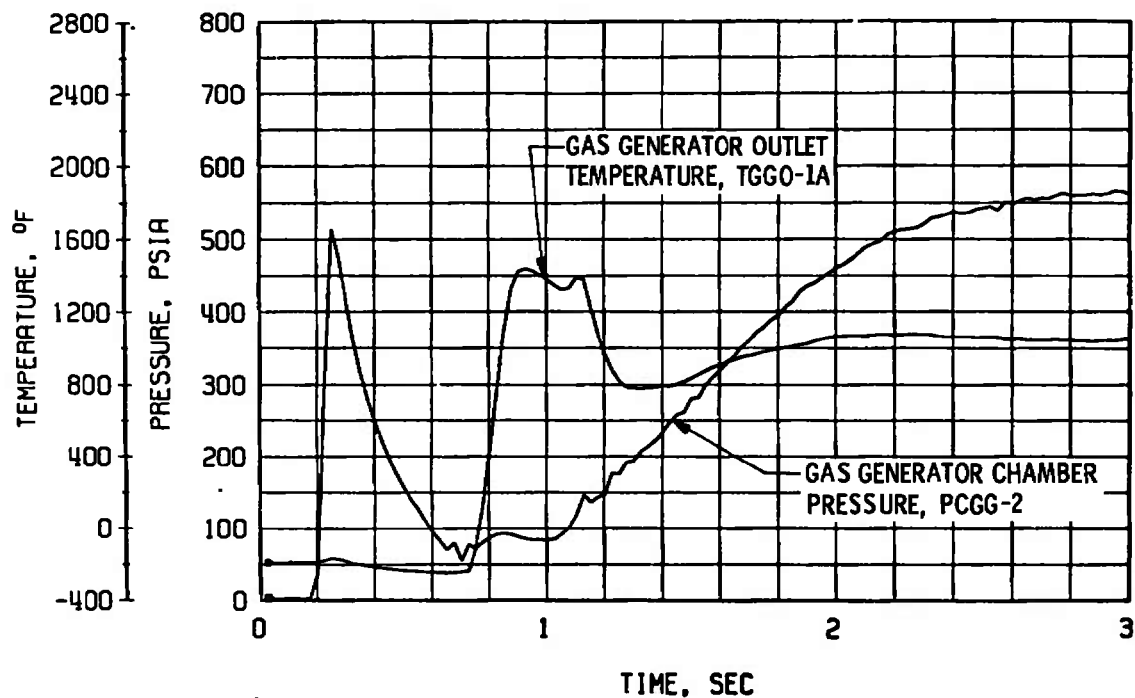


a. Thrust Chamber Fuel System, Start

b. Thrust Chamber Oxidizer System, Start  
Fig. 57 Engine Transient Operation, Firing 31B

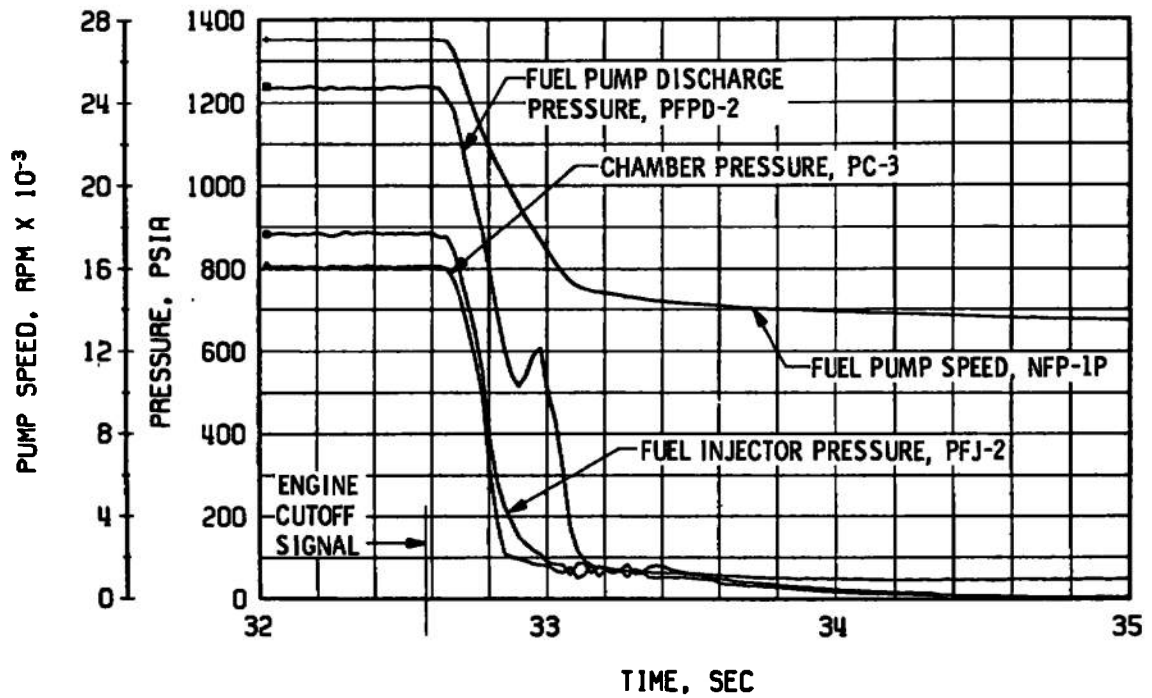


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

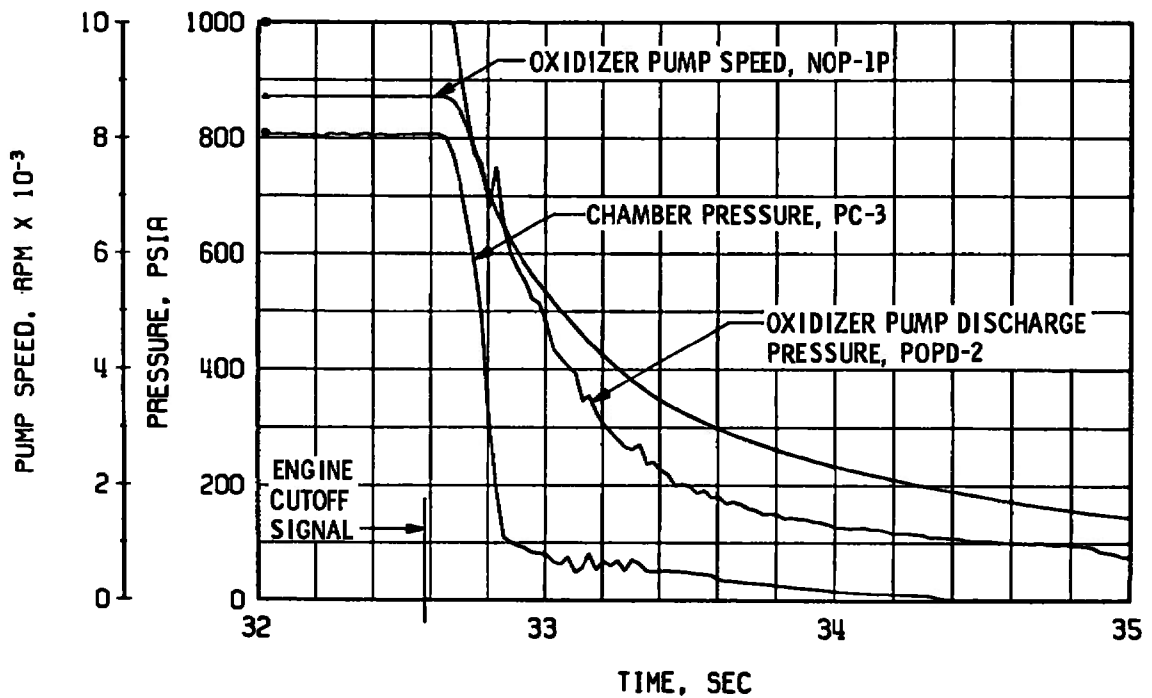


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 57 Continued

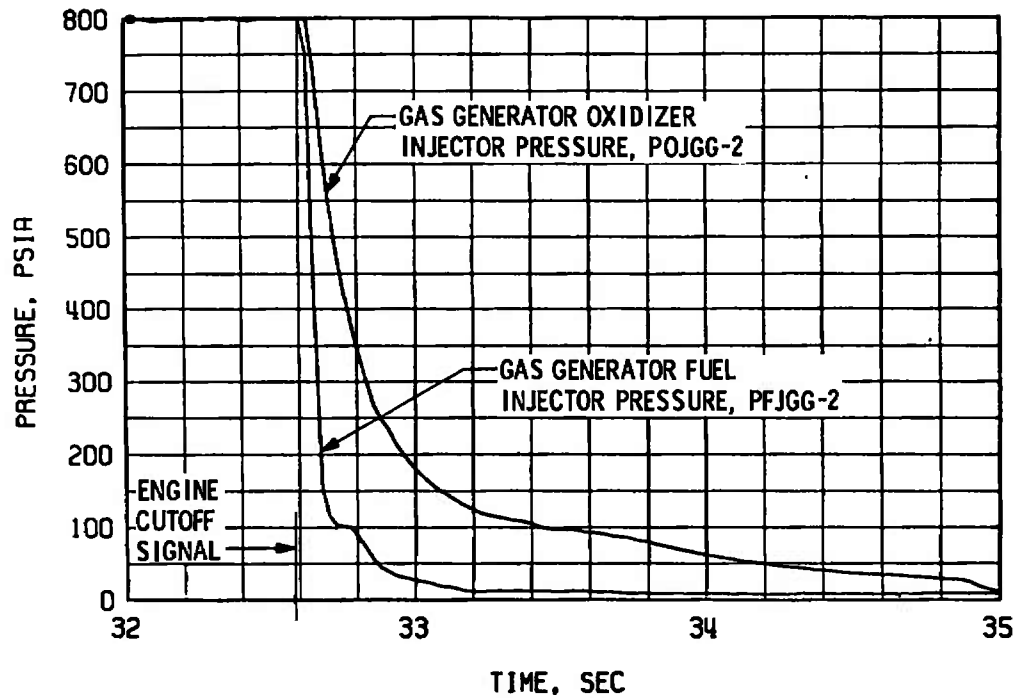


e. Thrust Chamber Fuel System, Shutdown

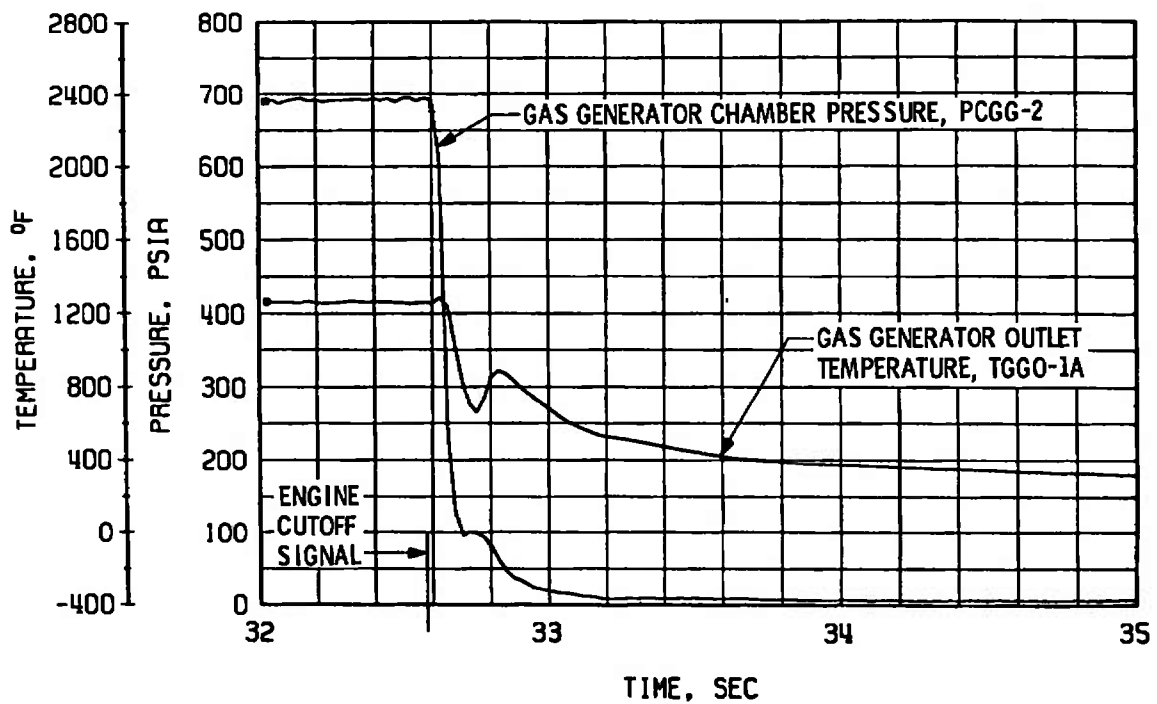


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 57 Continued



g. Gas Generator Injector Pressures, Shutdown

h. Gas Generator Chamber Pressure and Temperature, Shutdown  
Fig. 57 Concluded

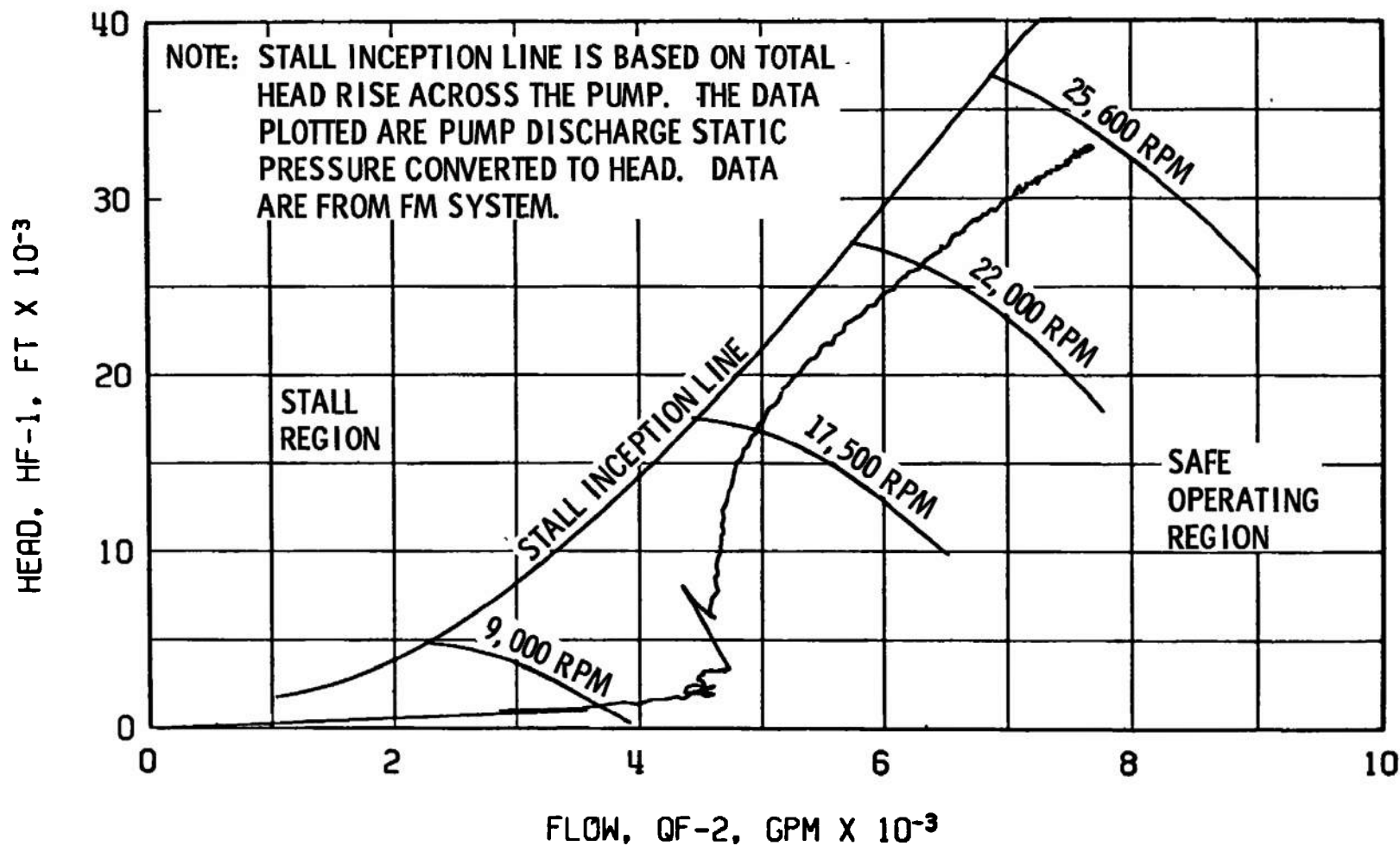
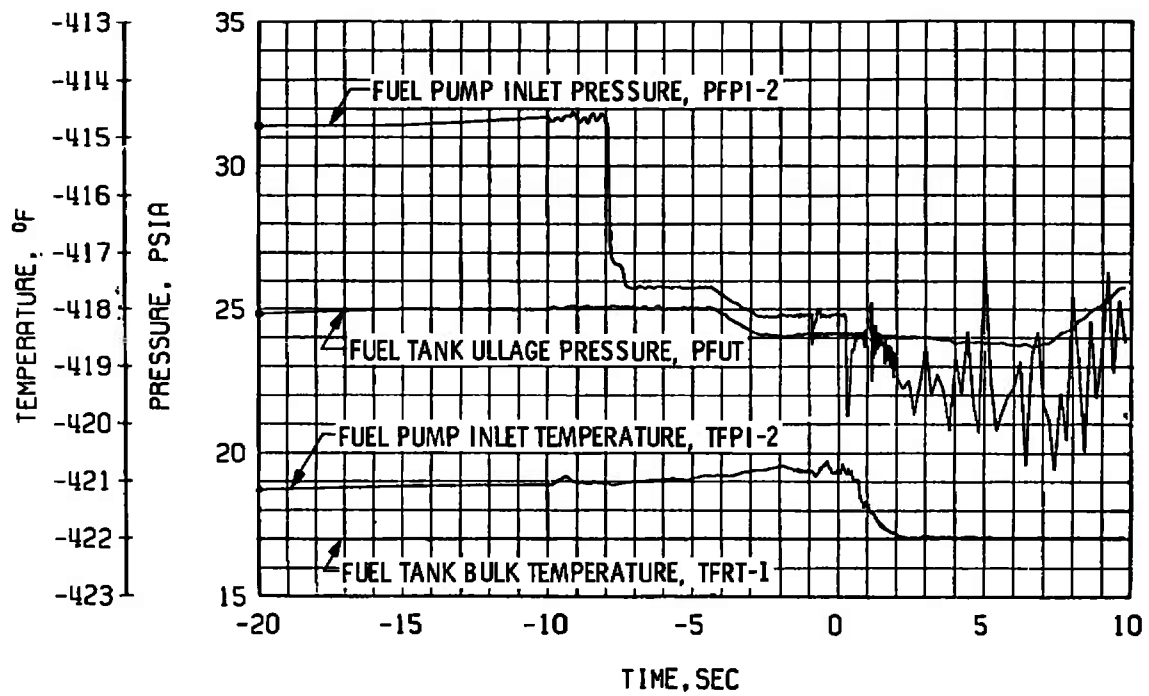
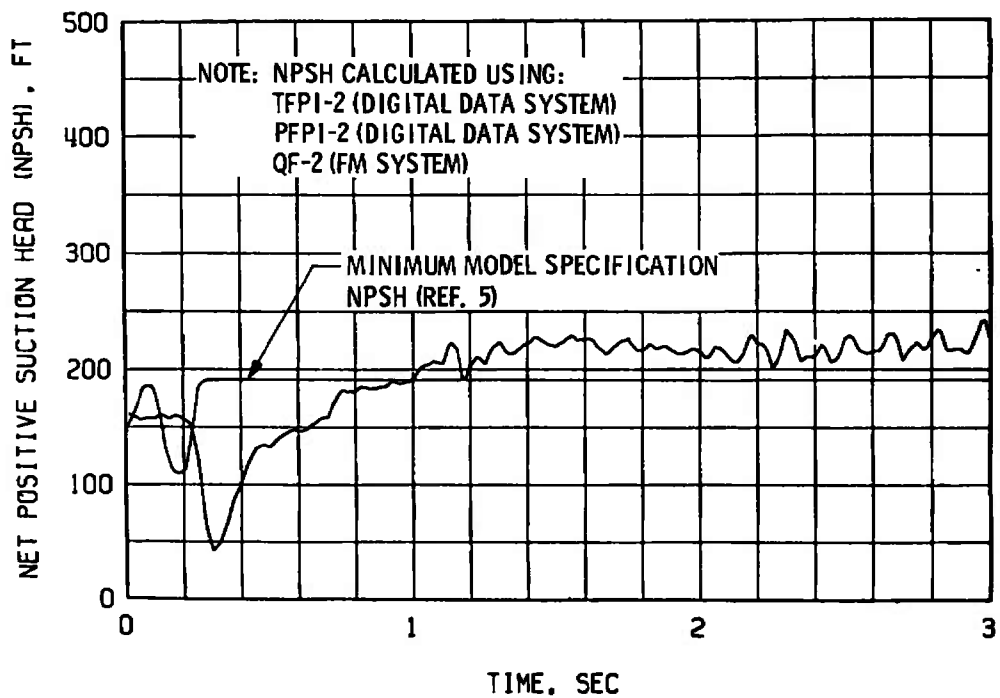


Fig. 58 Fuel Pump Start Transient Performance, Firing 31B



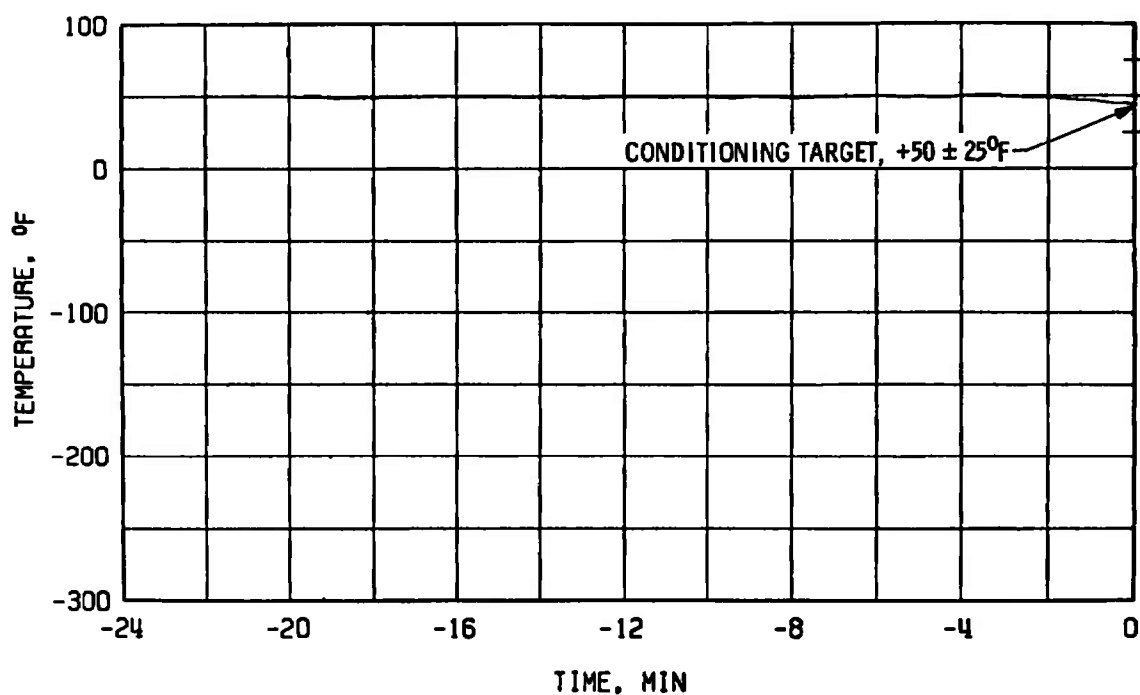


a. Duct Pressure and Temperature Transients

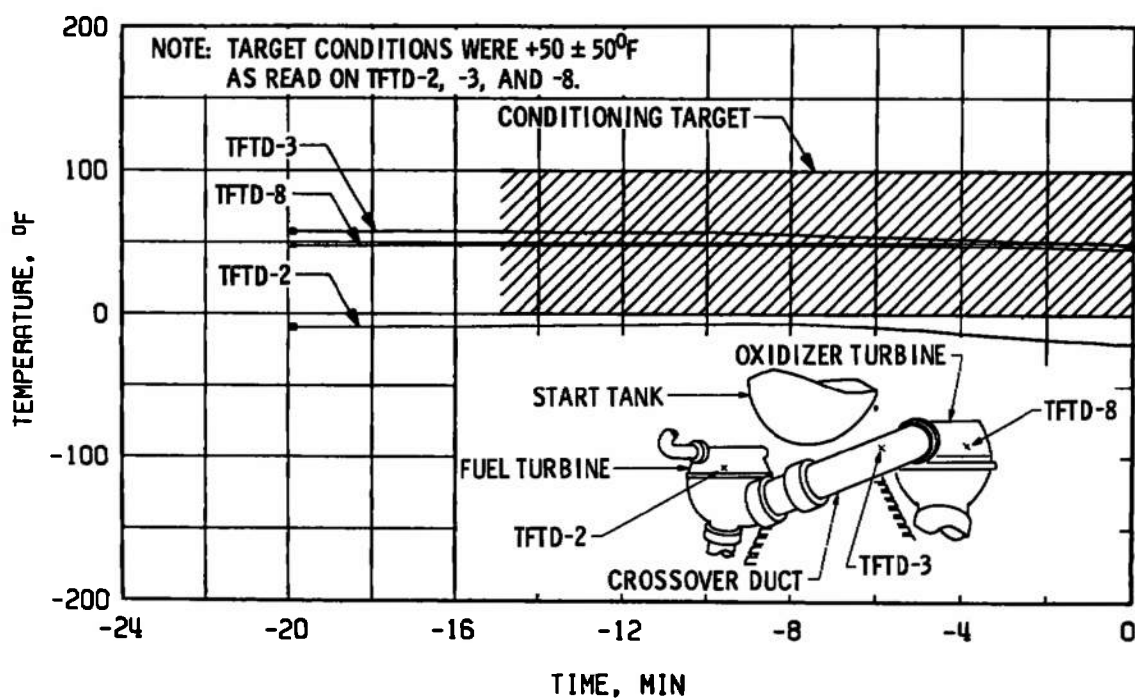


b. Fuel Pump NPSH during Start Transient, Firing 31B

Fig. 59 Fuel Low Pressure Duct Performance, Firing 31B

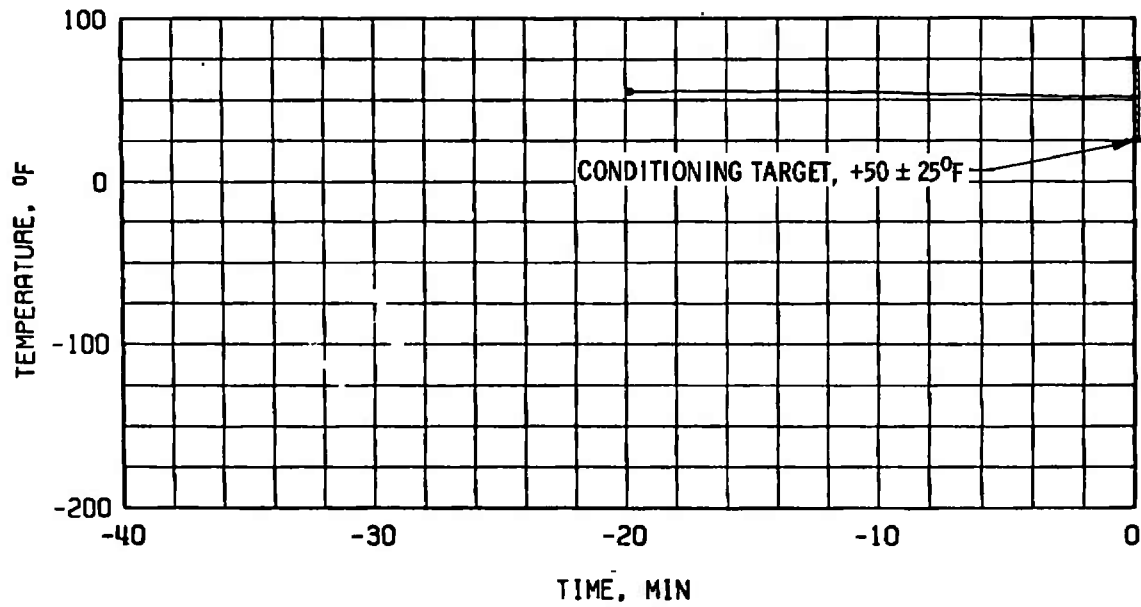


a. Thrust Chamber Throat, TTC-1P

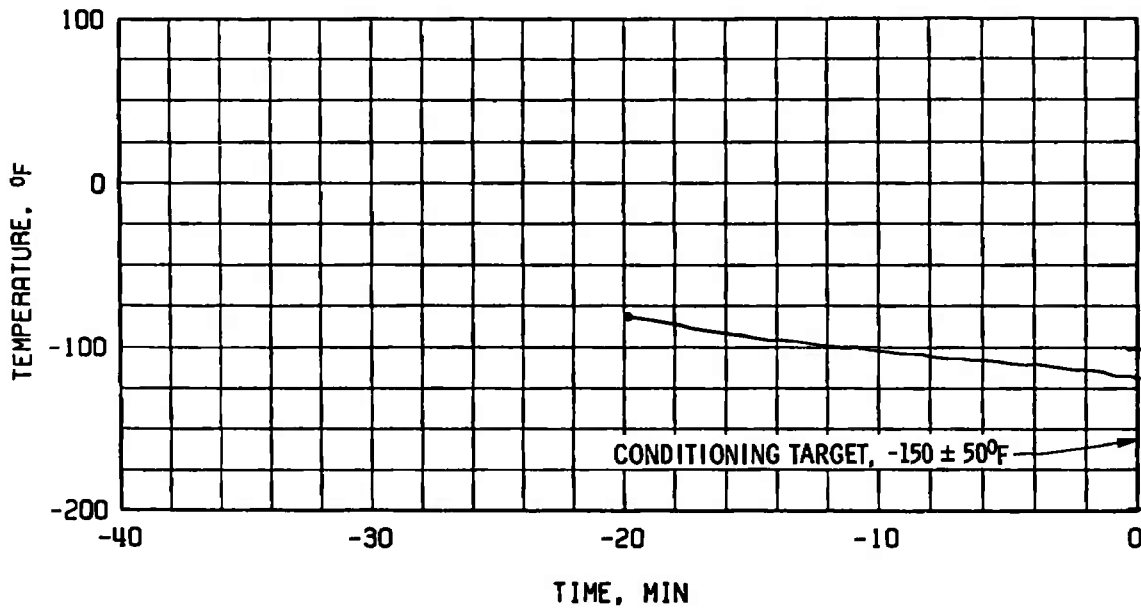


b. Crossover Duct, TTFD

Fig. 60 Thermal Conditioning History of Engine Components, Firing 31C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 60 Concluded

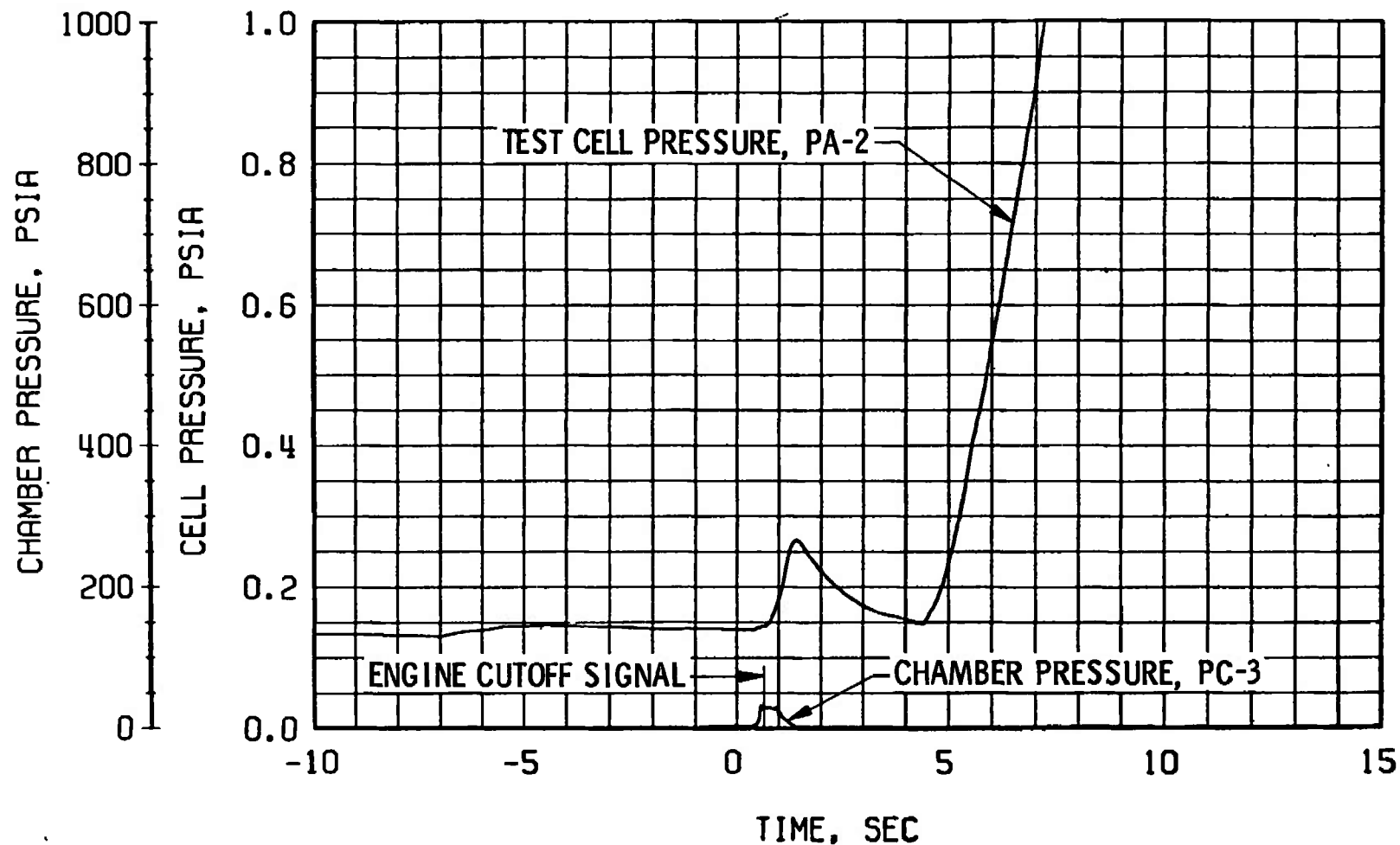
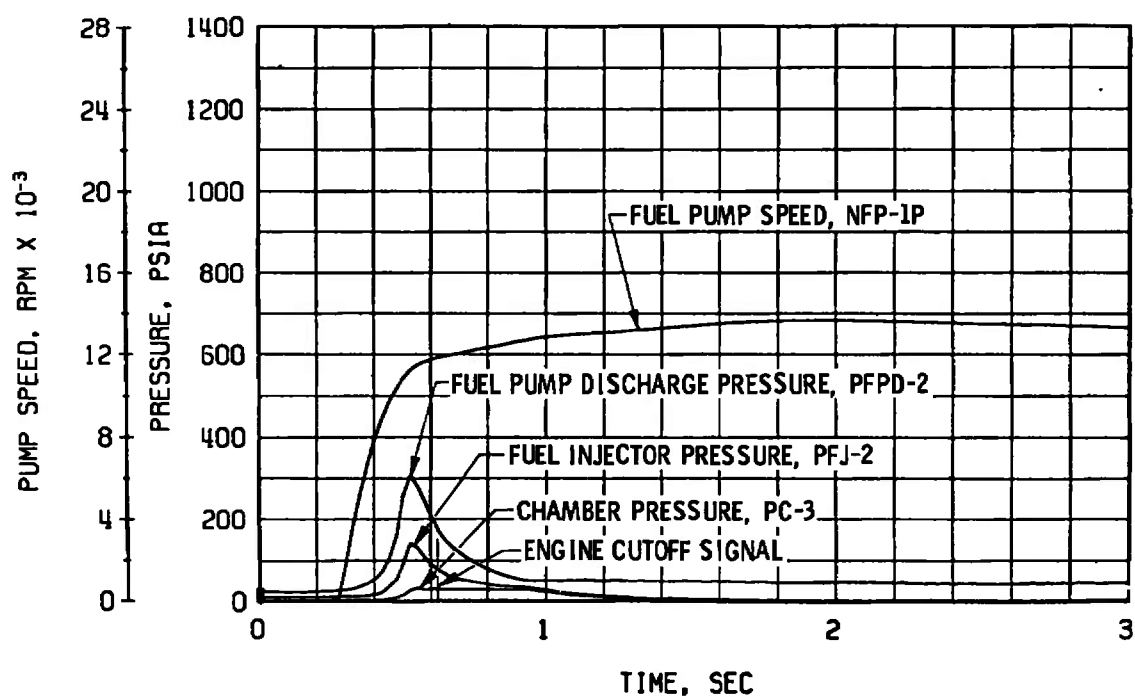
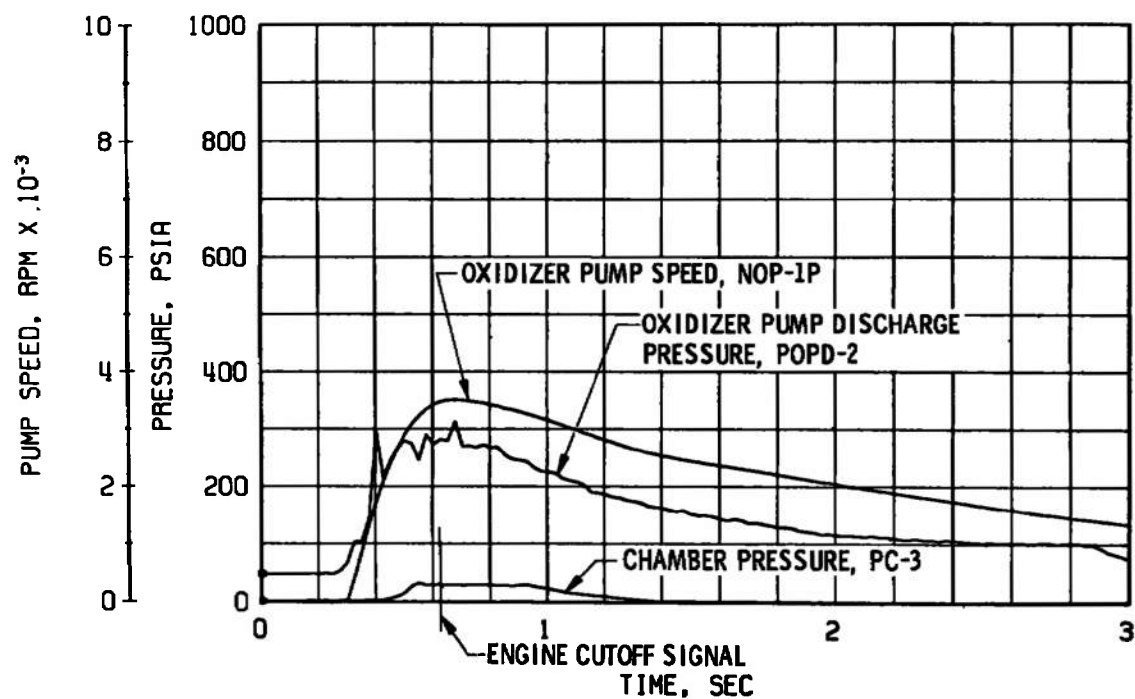


Fig. 61 Engine Ambient and Combustion Chamber Pressures, Firing 31C

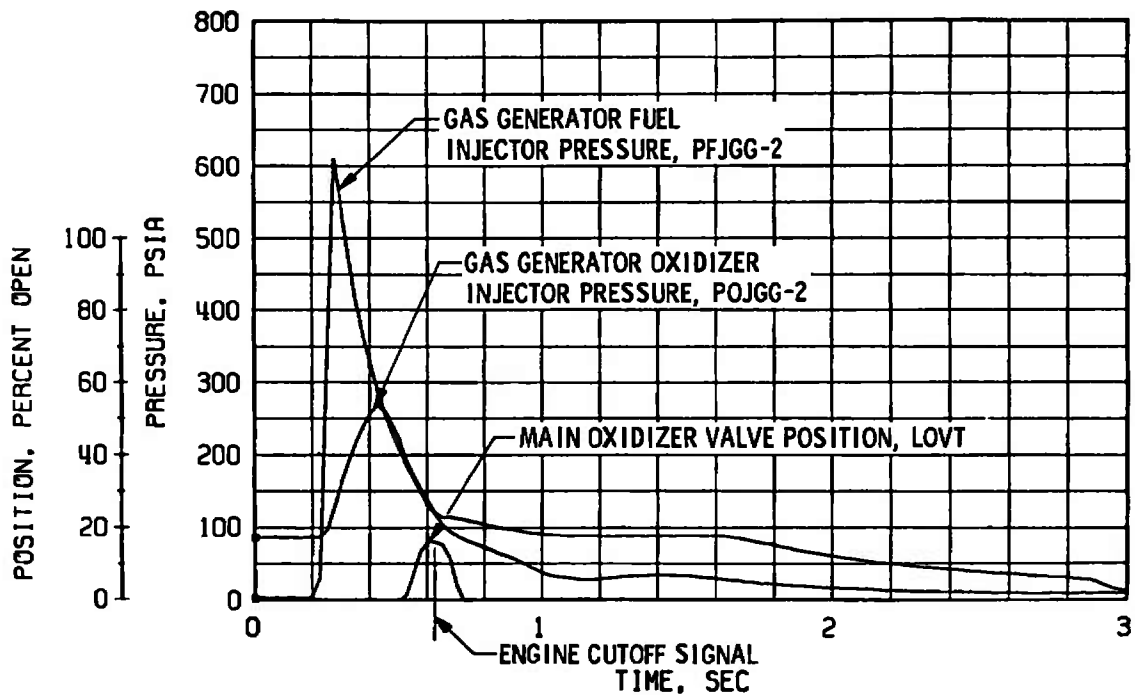


a. Thrust Chamber Fuel System, Start and Shutdown

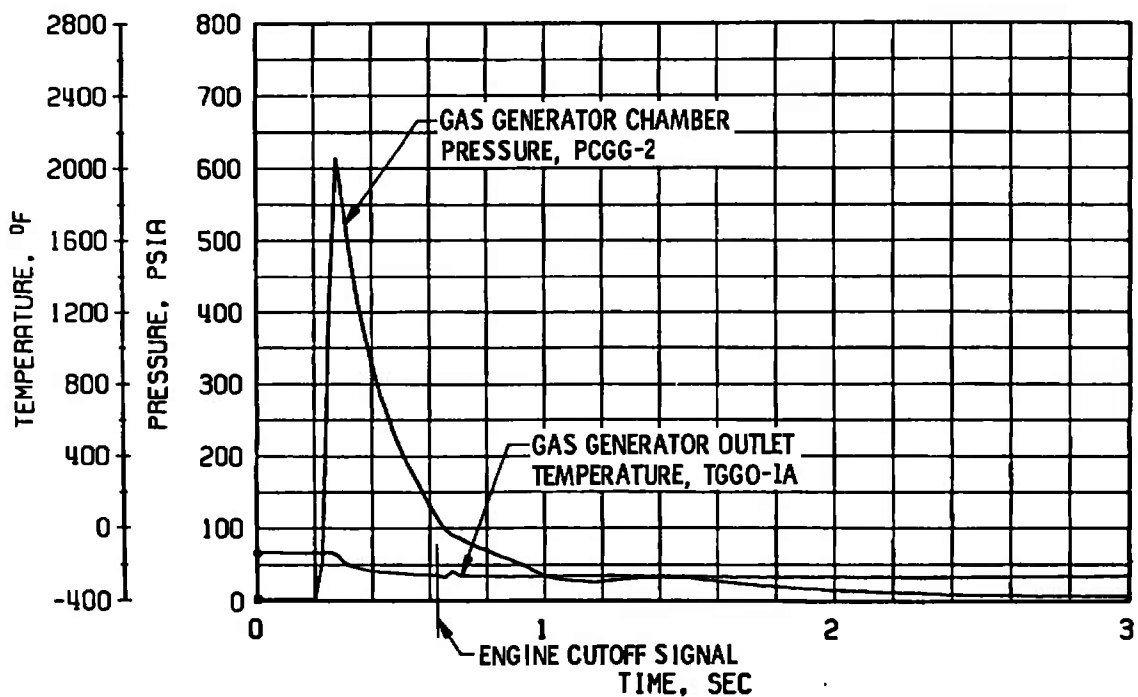


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 62 Engine Transient Operation, Firing 31C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Pressure and Temperature, Start and Shutdown

Fig. 62 Concluded

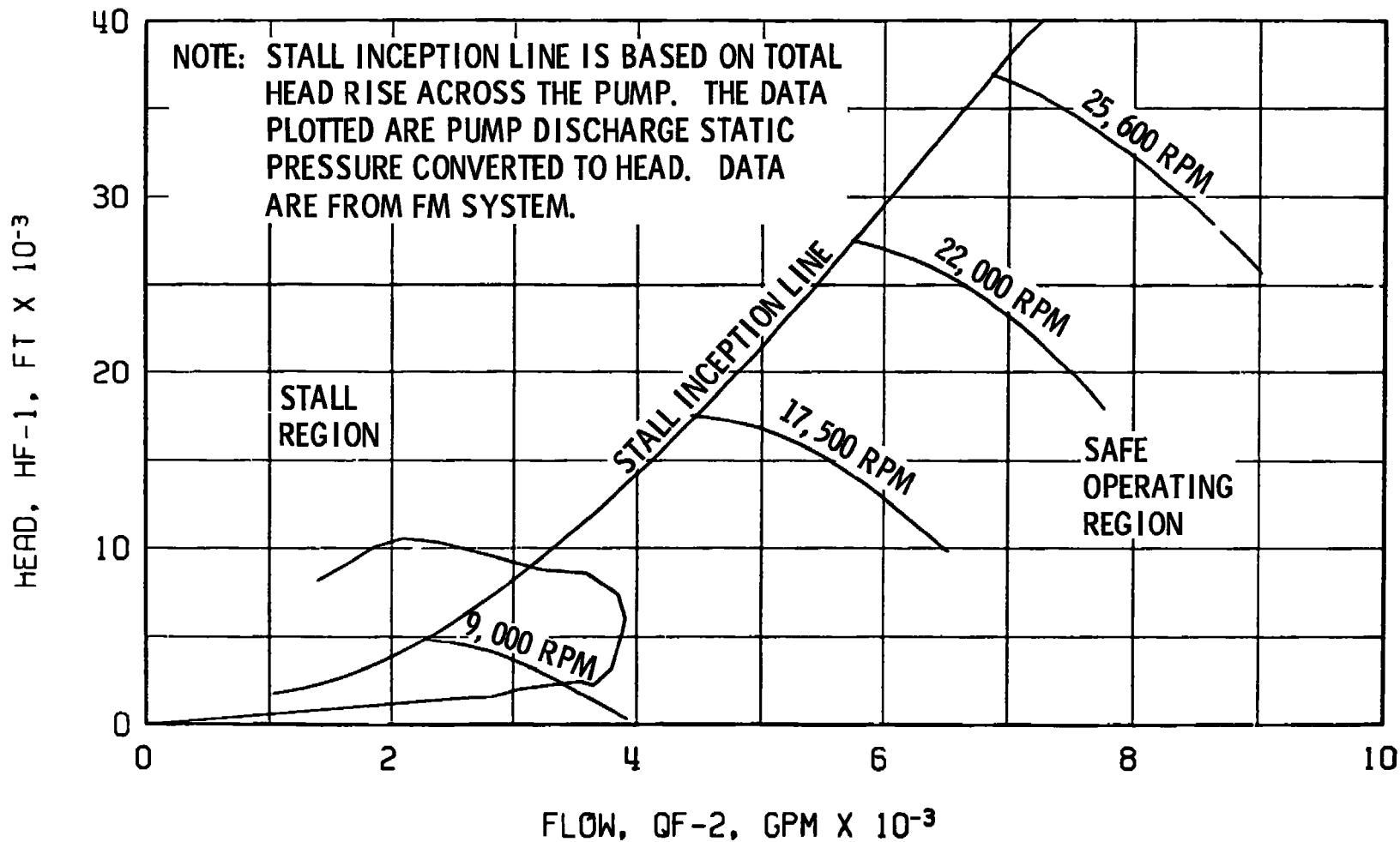
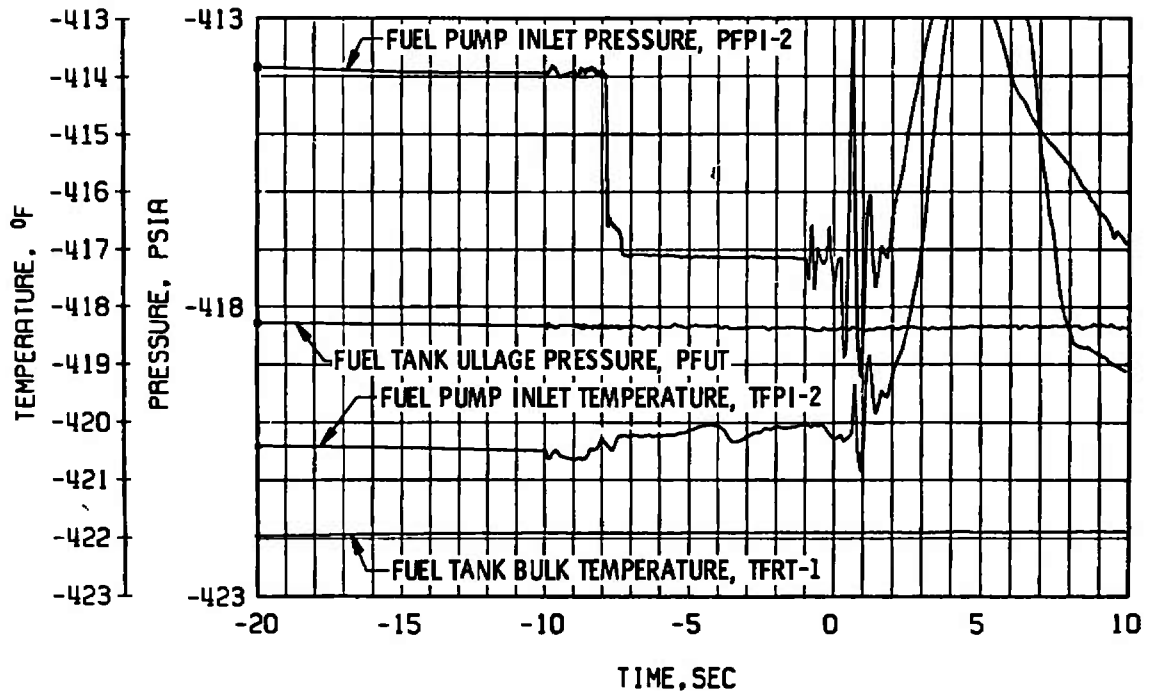
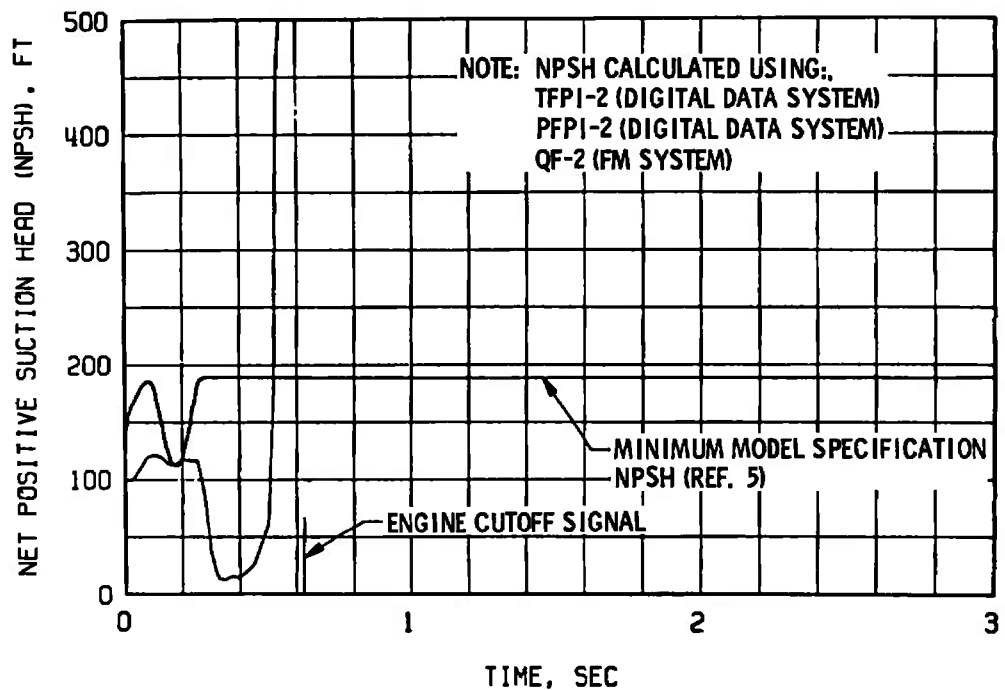


Fig. 63 Fuel Pump Start Transient Performance, Firing 31C

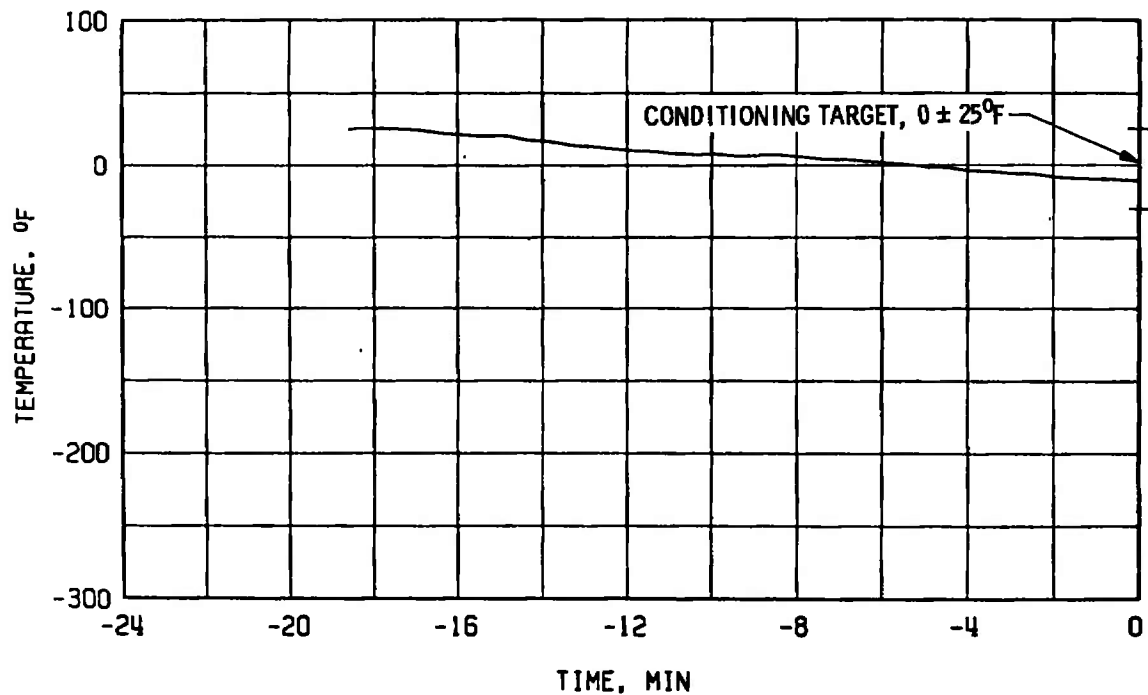


a. Duct Pressure and Temperature Transients

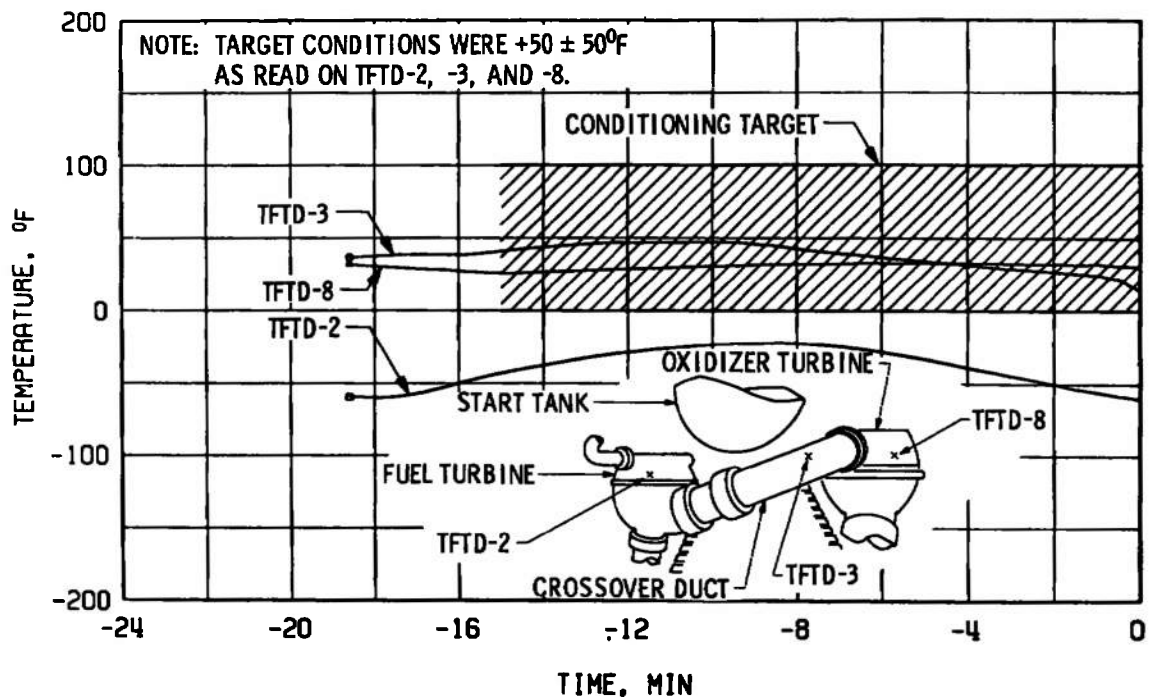


b. Fuel Pump NPSH during Start Transients, Firing 31C  
 Fig. 64 Fuel Low Pressure Duct Performance, Firing 31C



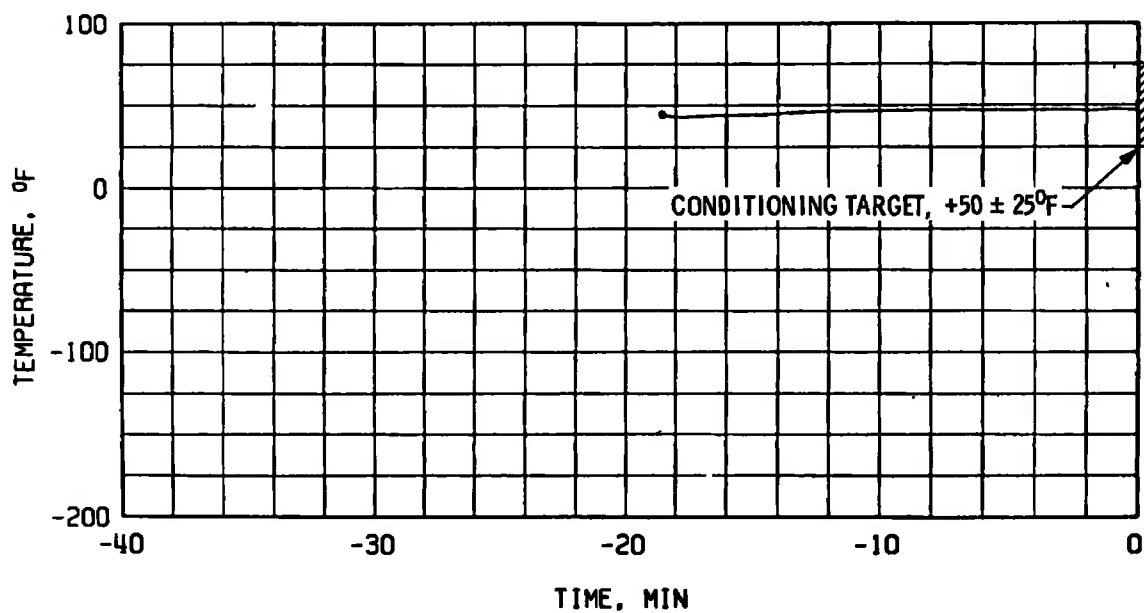


a. Thrust Chamber Throat, TTC-1P

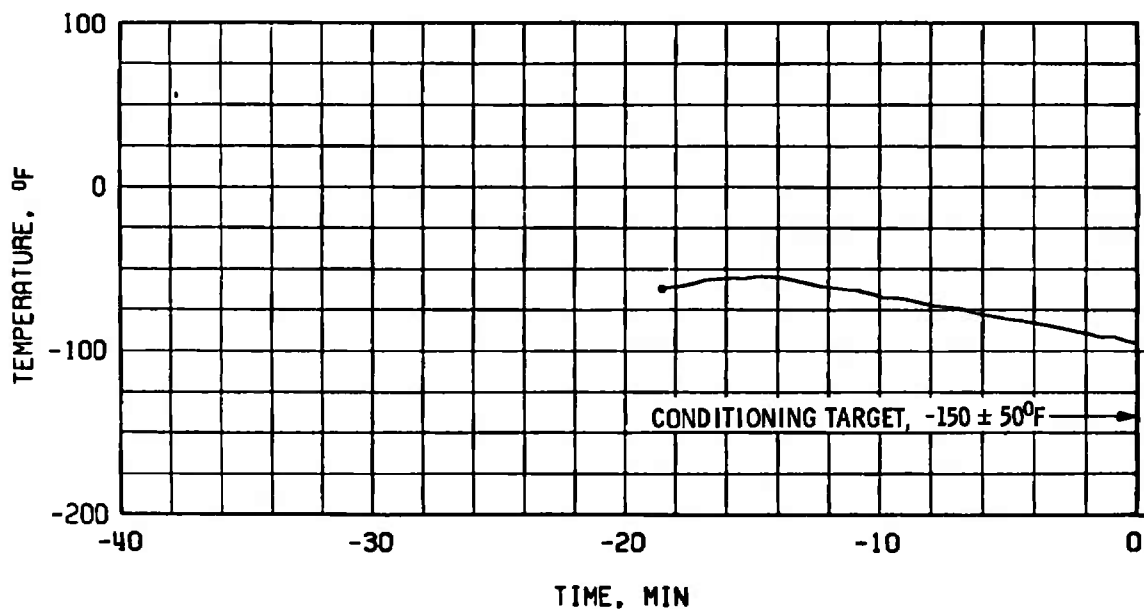


b. Crossover Duct, TFTD

Fig. 65 Thermal Conditioning History of Engine Components, Firing 31D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 65 Concluded

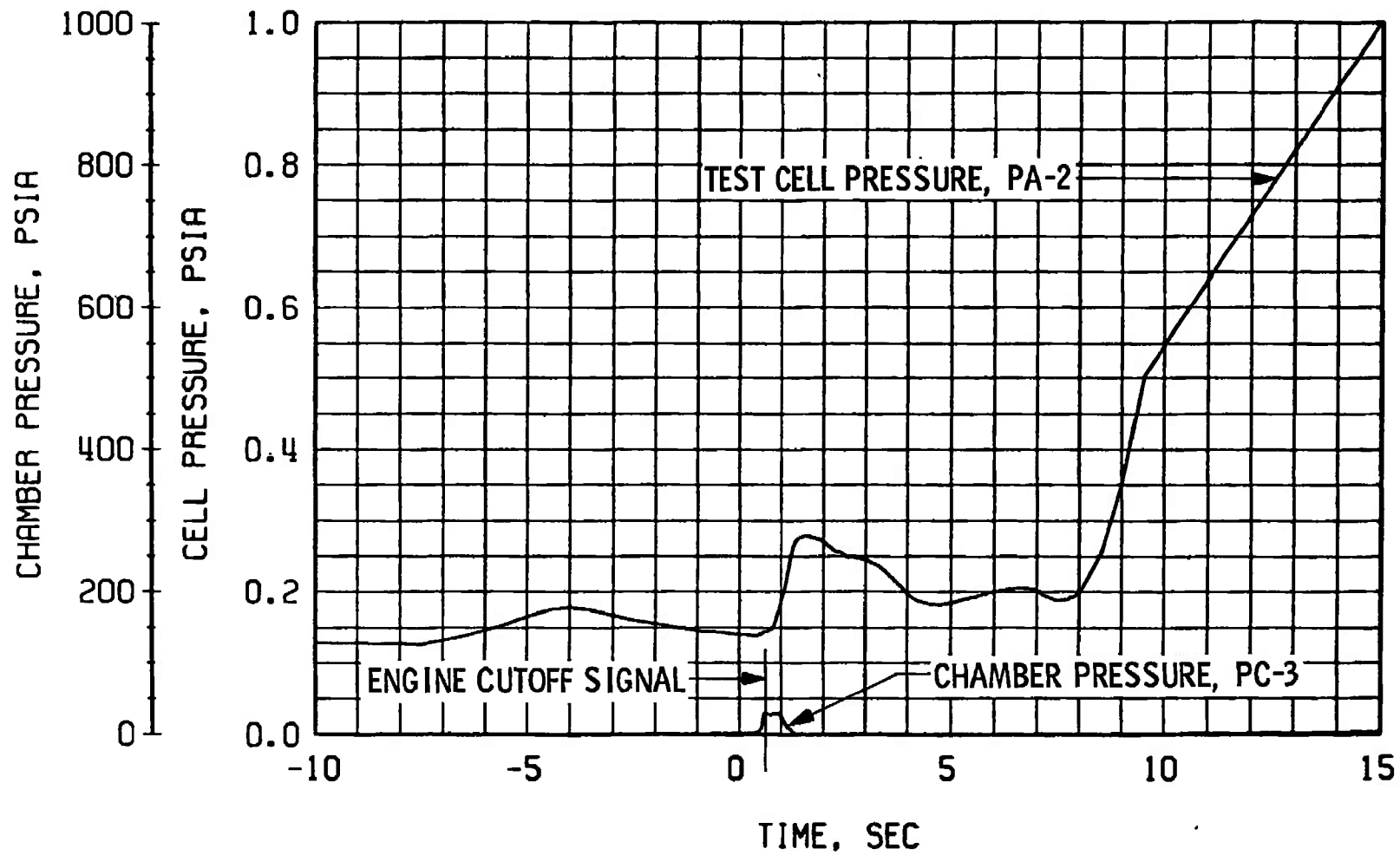
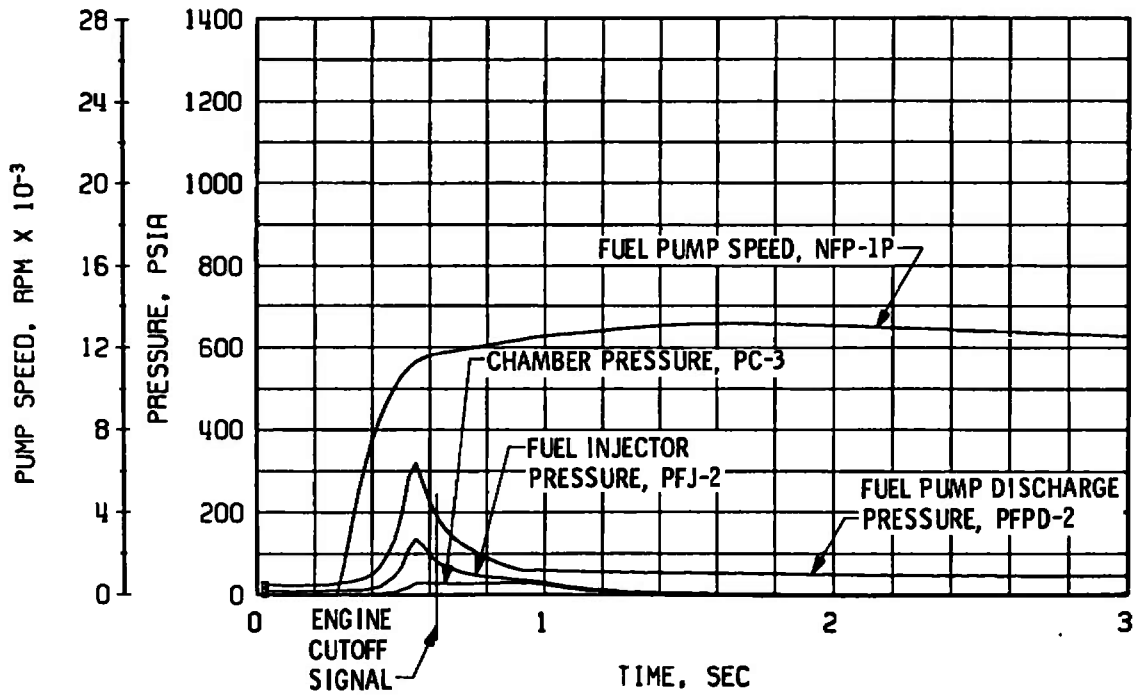
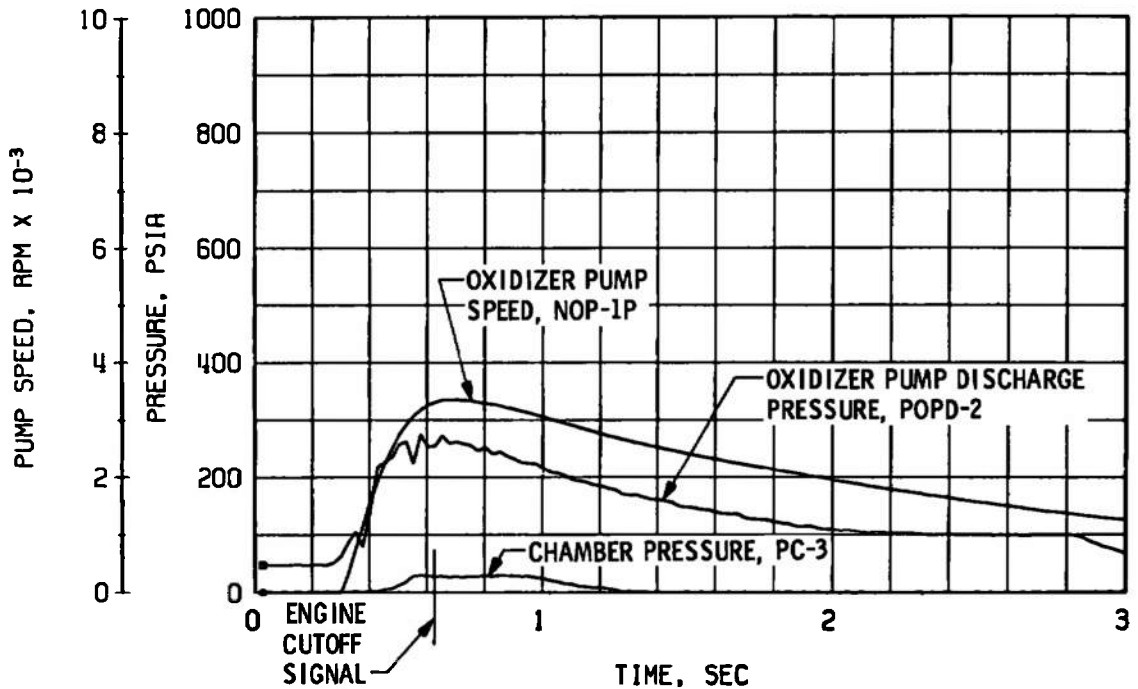


Fig. 66 Engine Ambient and Combustion Chamber Pressures, Firing 31D

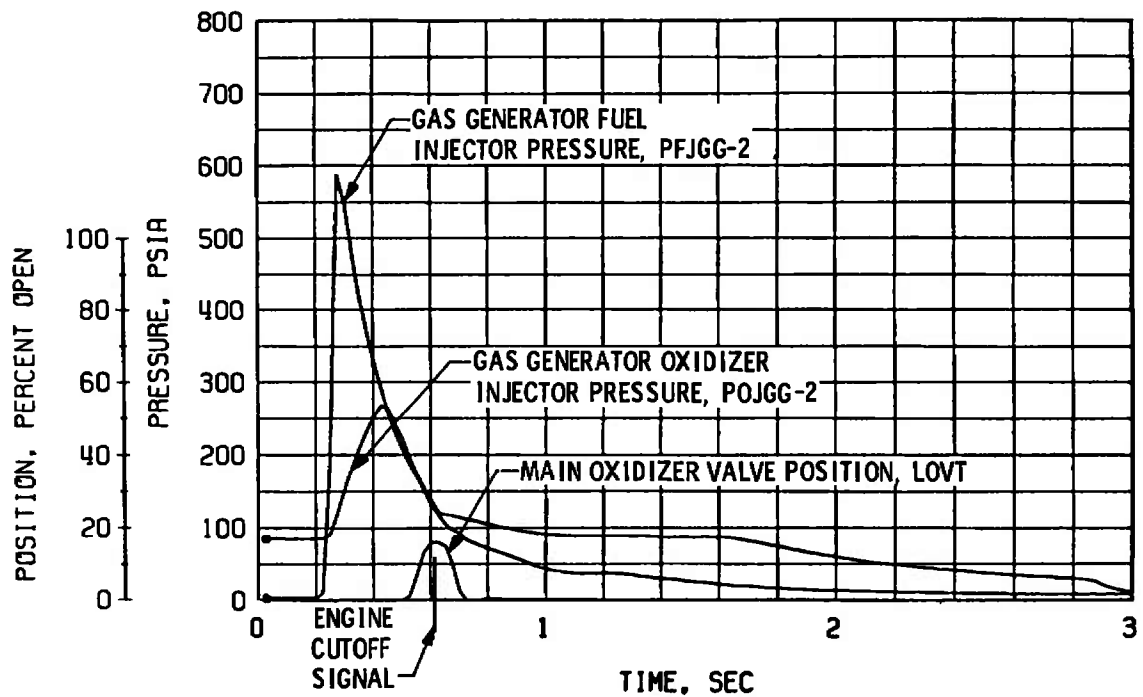


a. Thrust Chamber Fuel System, Start and Shutdown

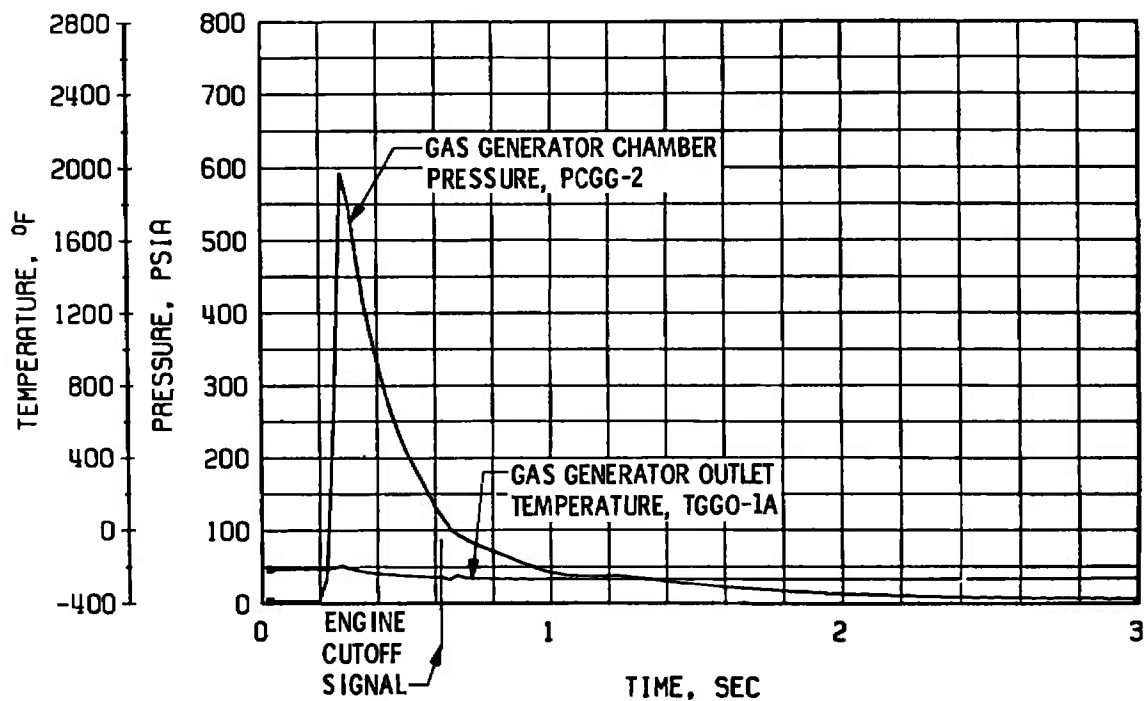


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 67 Engine Transient Operation, Firing 31D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 67 Concluded

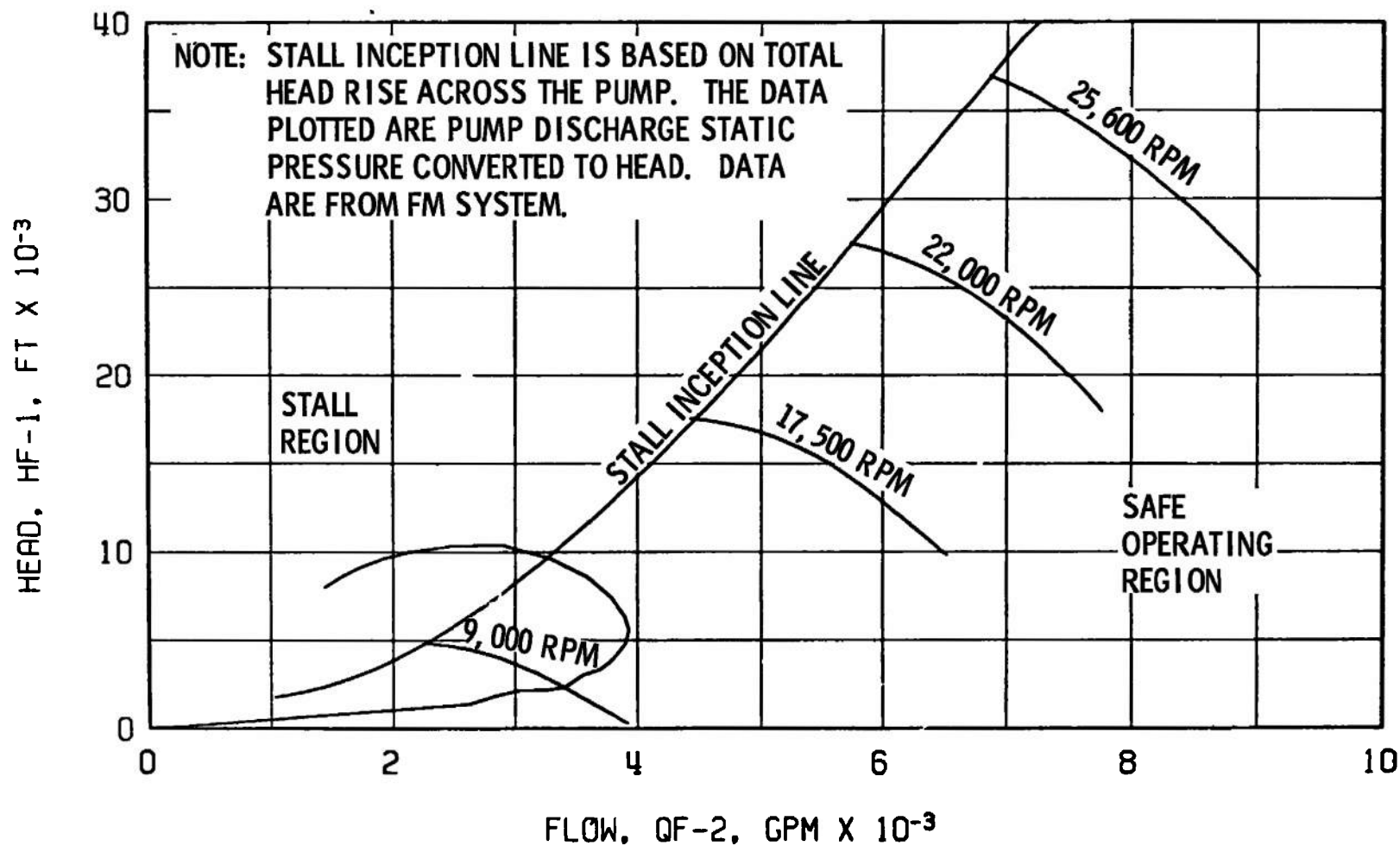
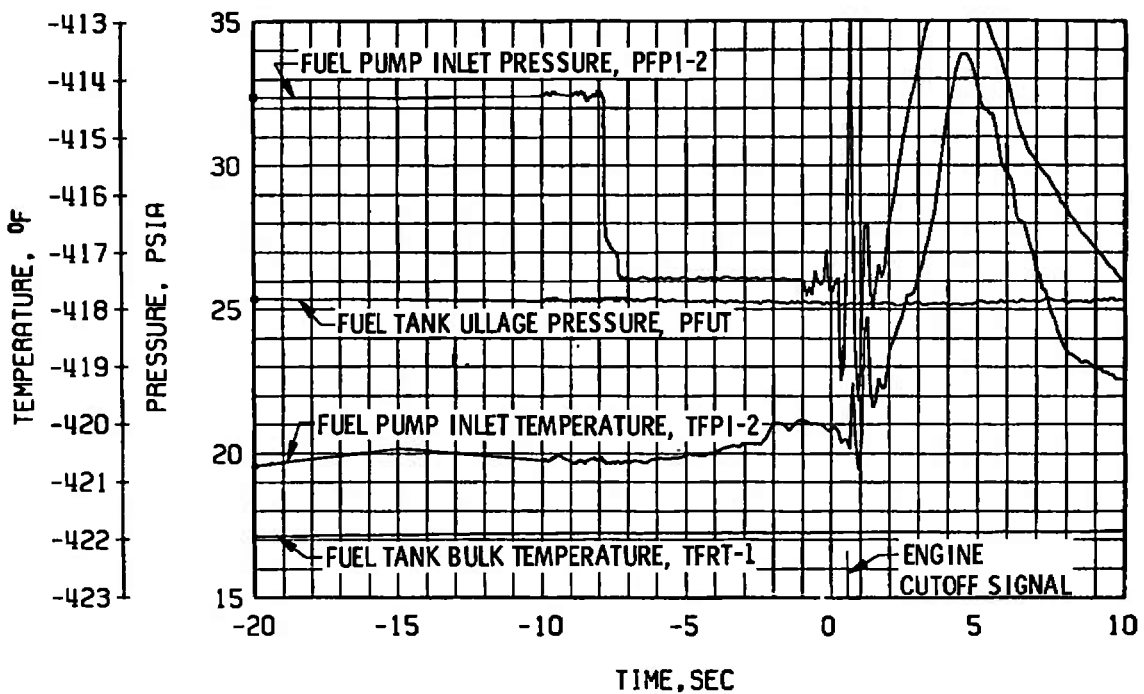
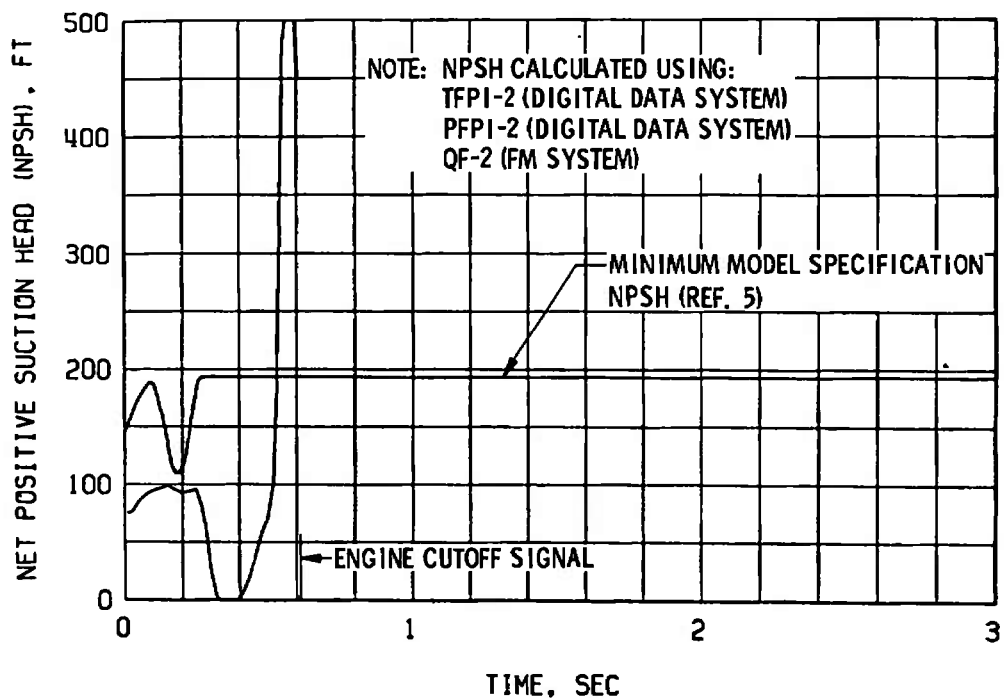


Fig. 68 Fuel Pump Start Transient Performance, Firing 31D

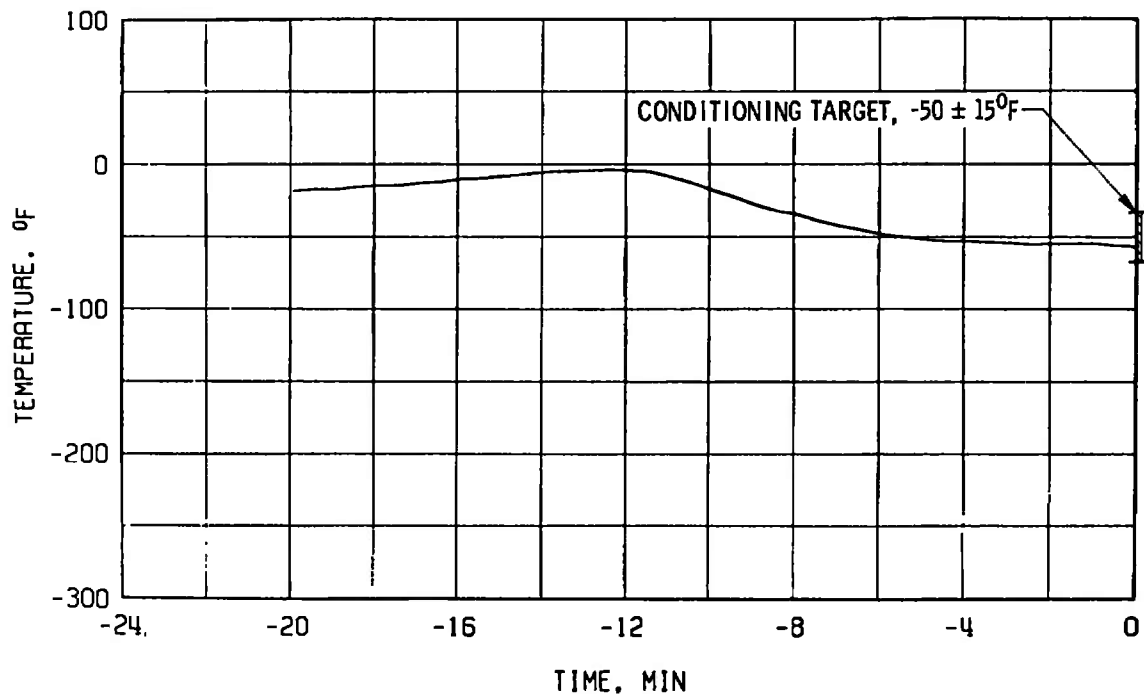


a. Duct Pressure and Temperature Transients

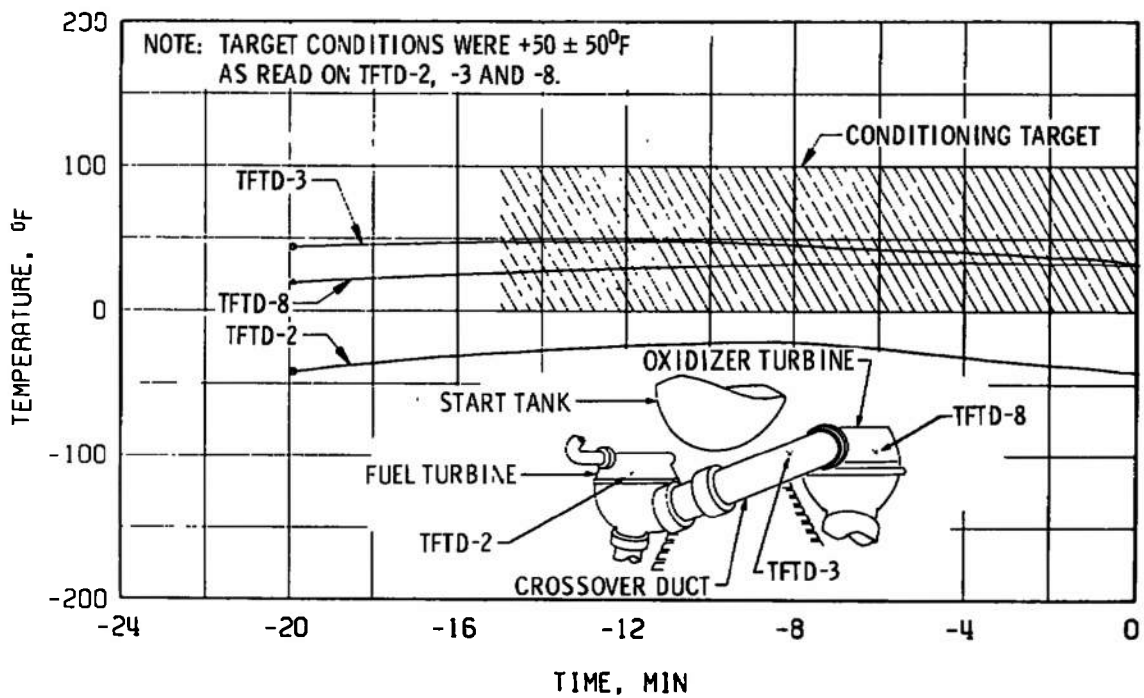


b. Fuel Pump NPSH during Start Transient, Firing 31D

Fig. 69 Fuel Low Pressure Duct Performance, Firing 31D



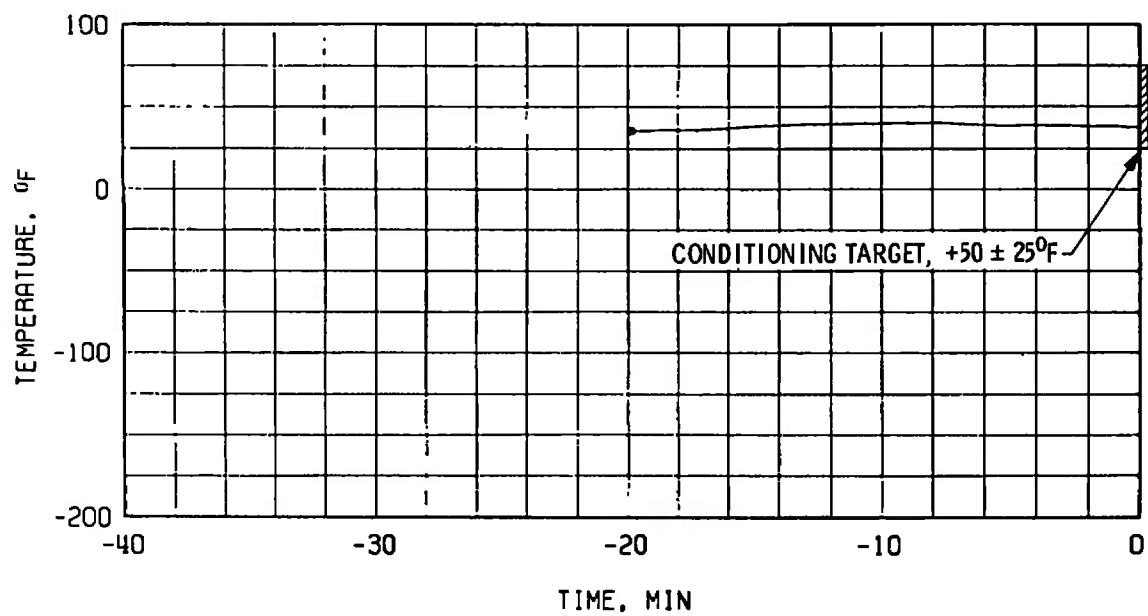
a. Thrust Chamber Throat, TTC-1P



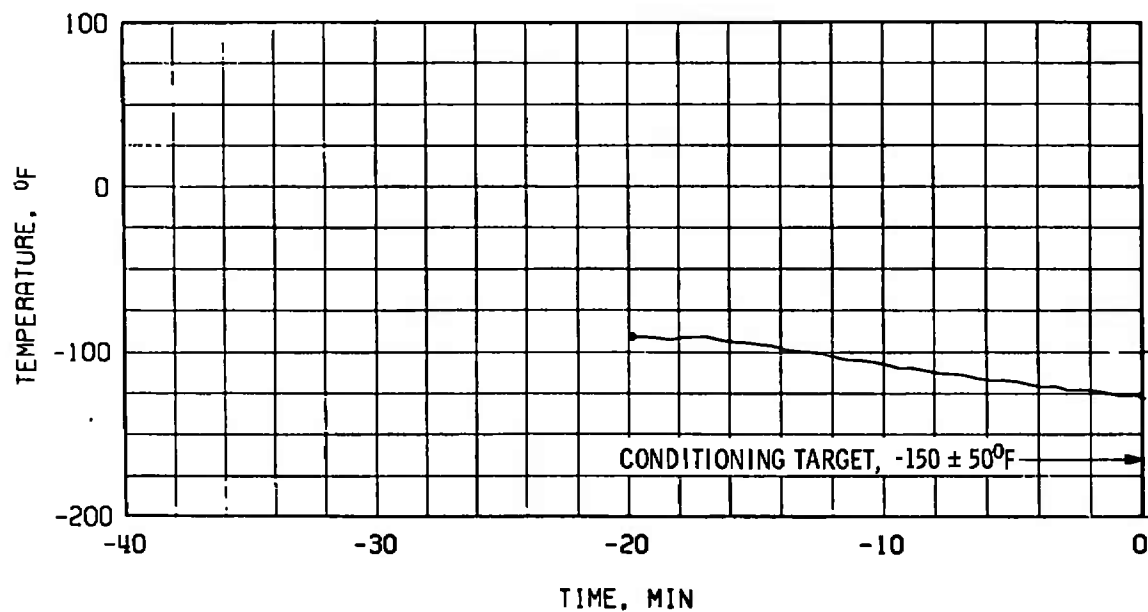
b. Crossover Duct, TFTD

Fig. 70 Thermal Conditioning History of Engine Components, Firing 31E





c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 70 Concluded

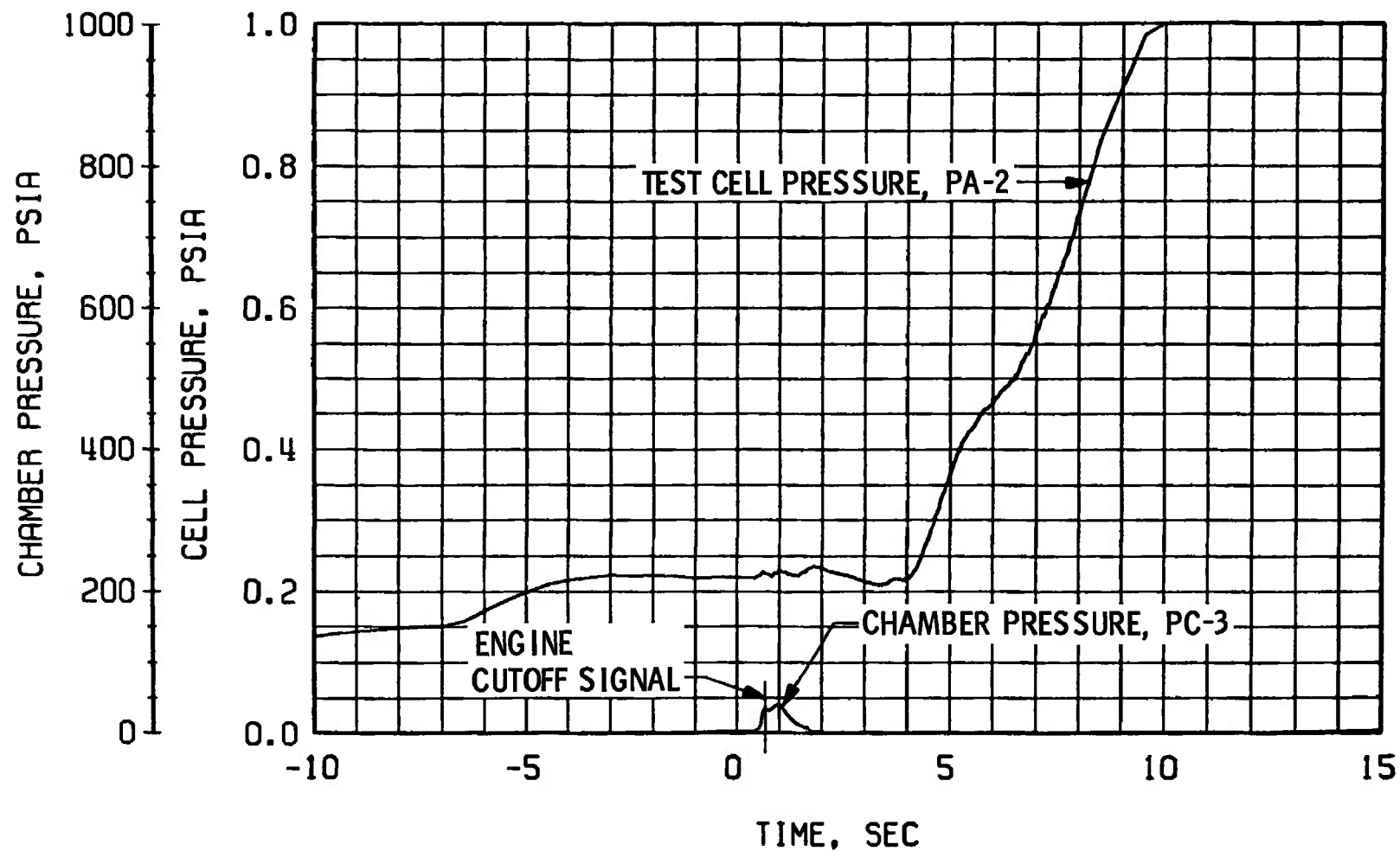
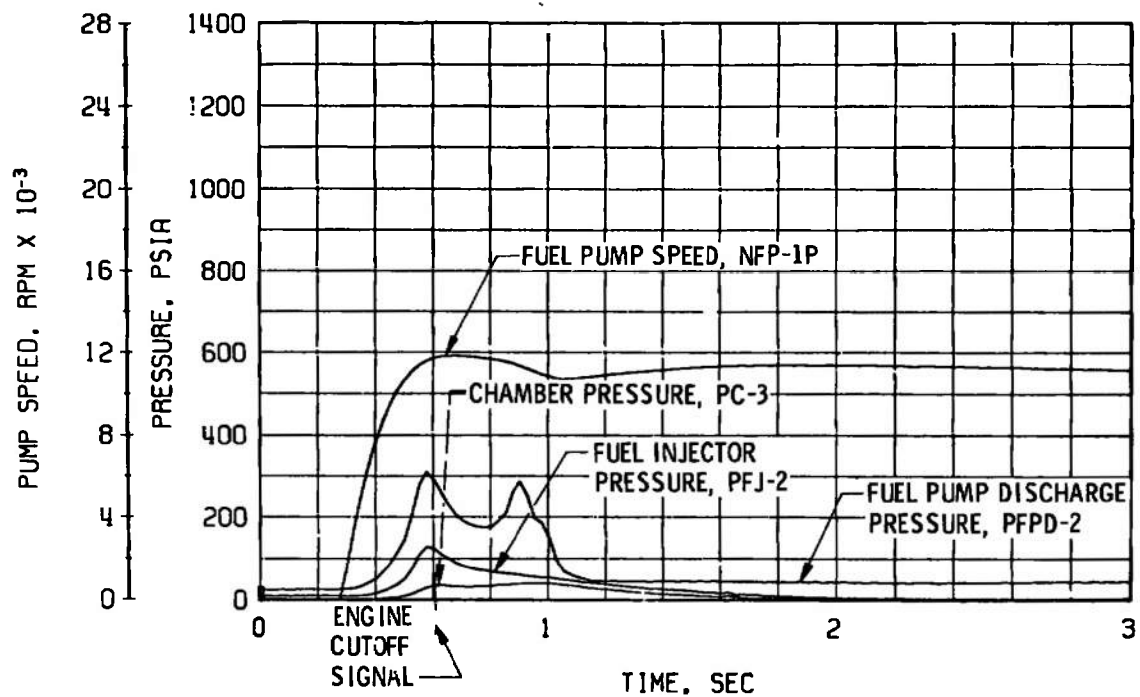
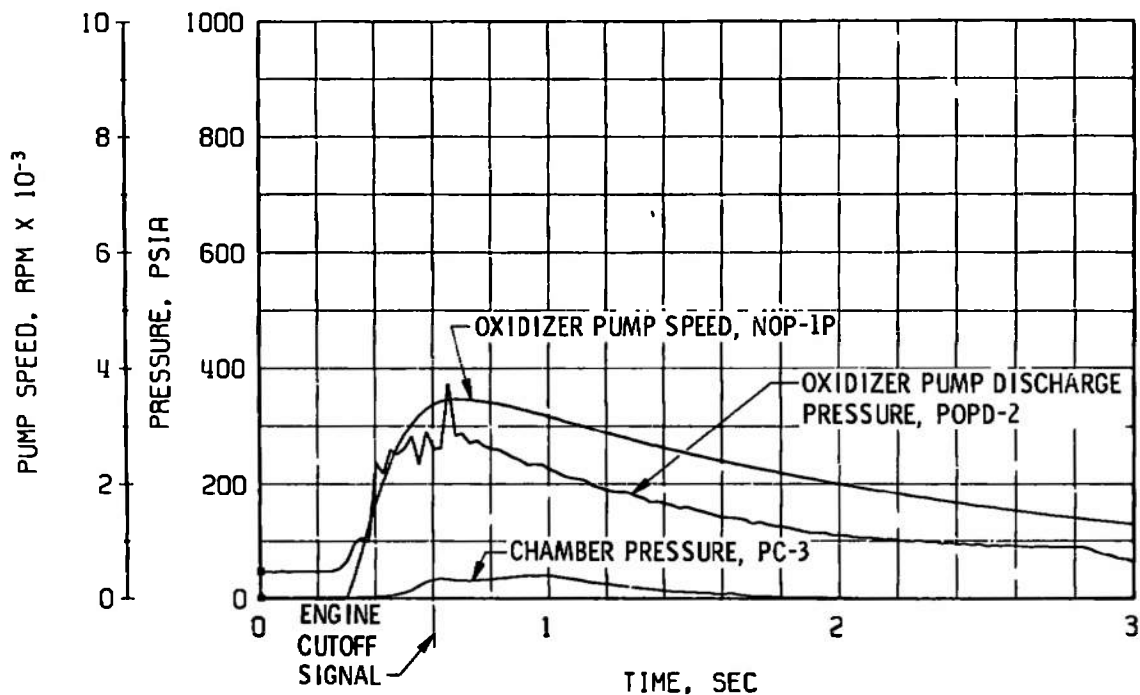
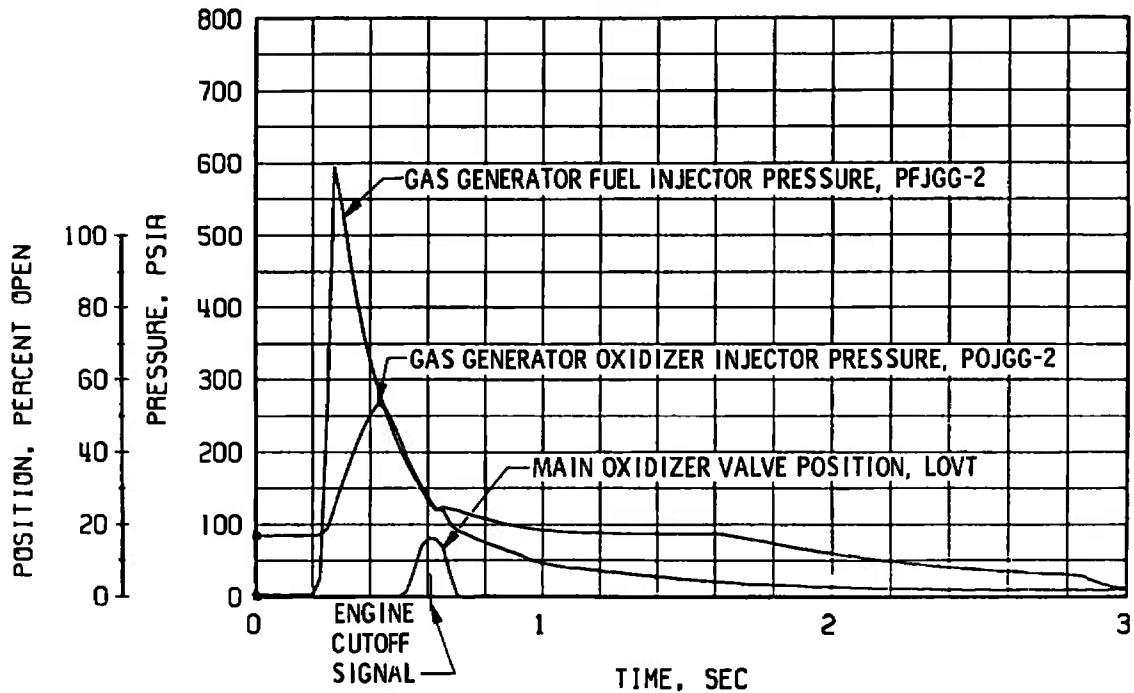


Fig. 71 Engine Ambient and Combustion Chamber Pressures, Firing 31E

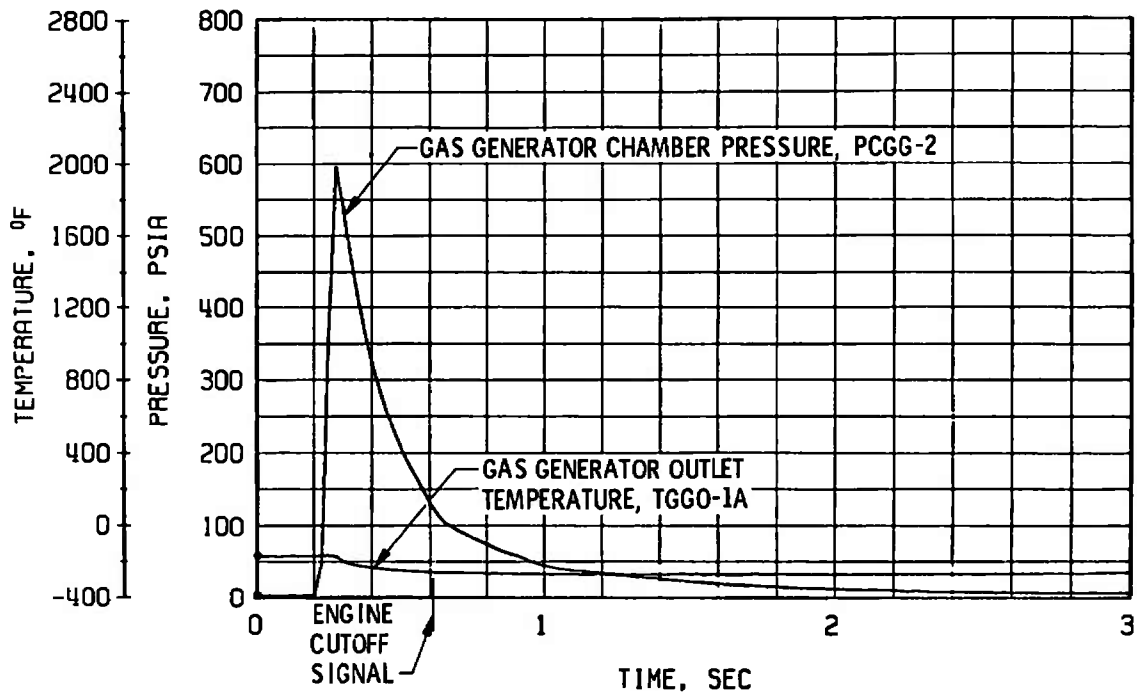


a. Thrust Chamber Fuel System, Start and Shutdown

b. Thrust Chamber Oxidizer System, Start and Shutdown  
Fig. 72 Engine Transient Operation, Firing 31E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 72 Concluded

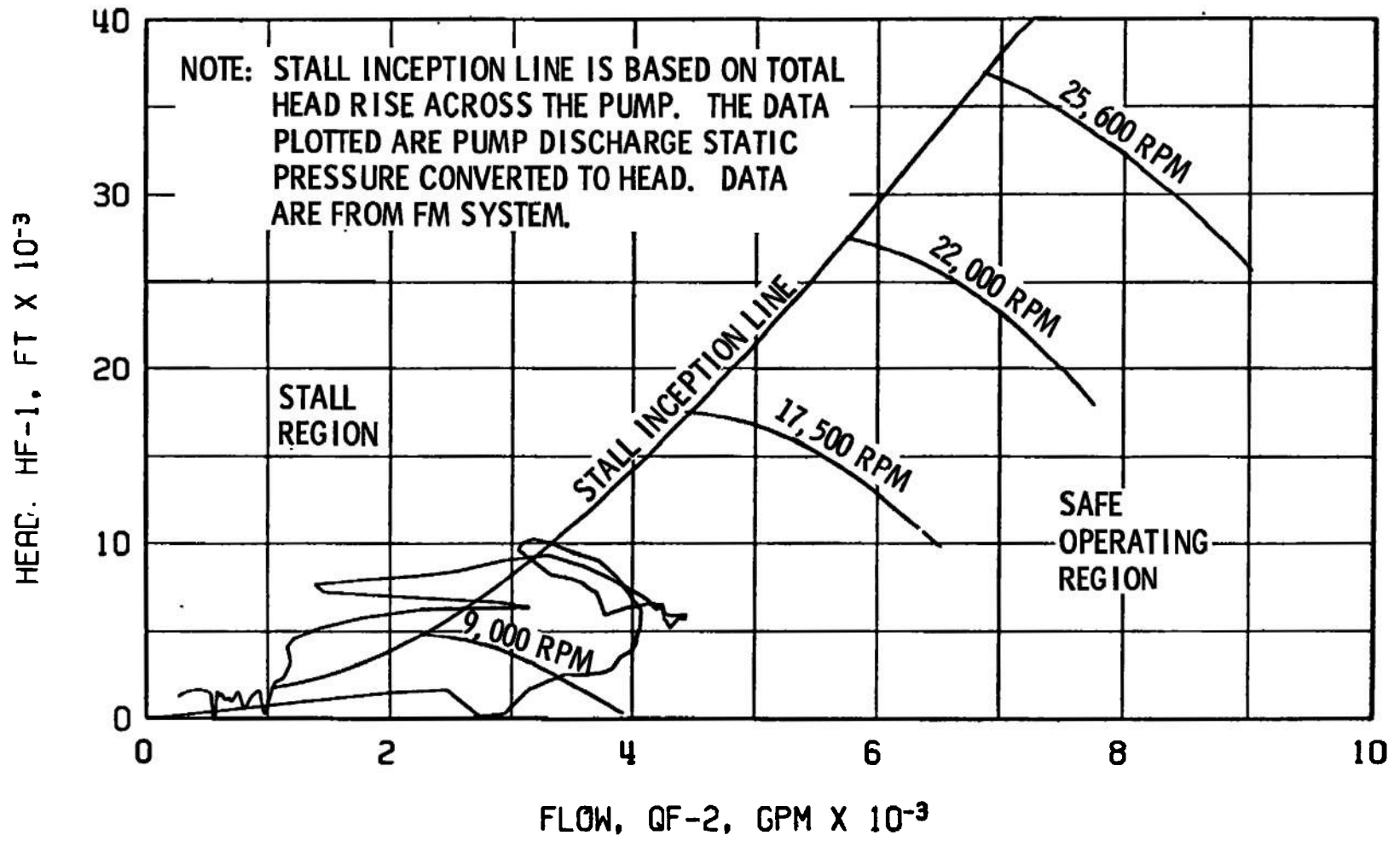
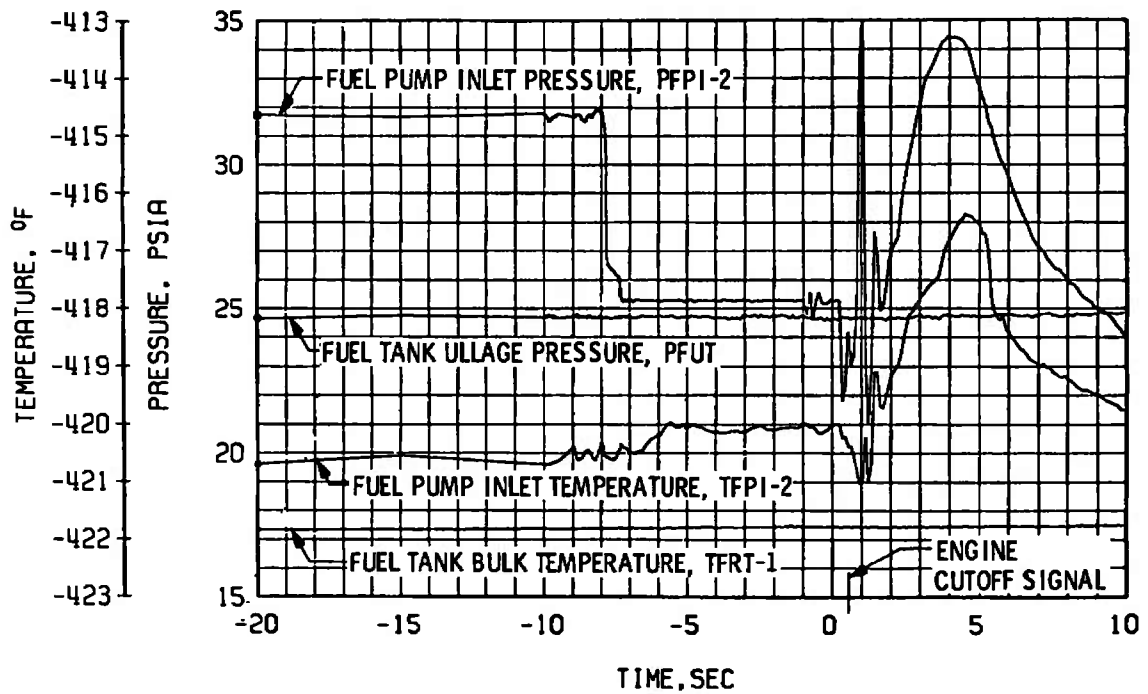
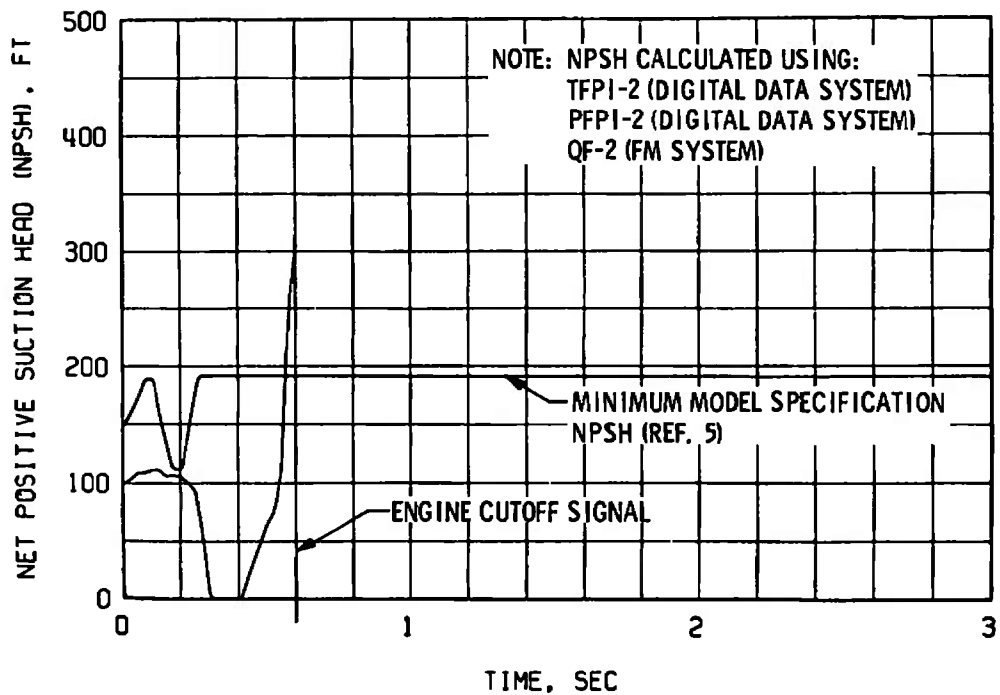


Fig. 73 Fuel Pump Start Transient Performance, Firing 31E

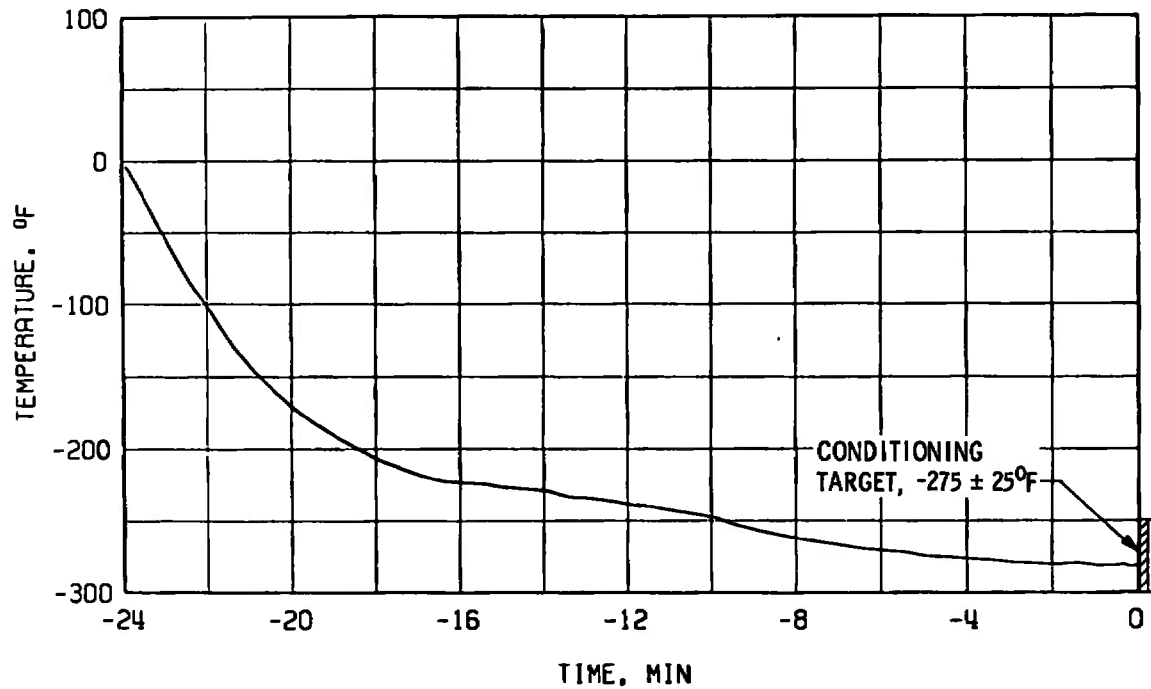


a. Duct Pressure and Temperature Transients

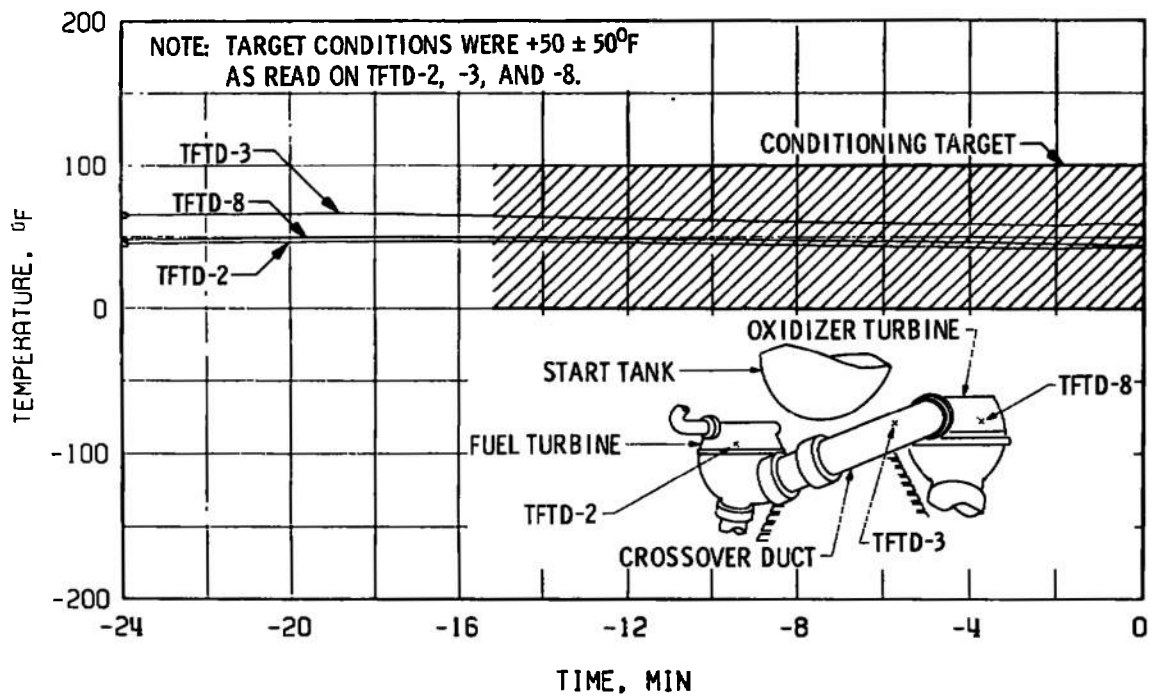


b. Fuel Pump NPSH during Start Transient, Firing 31E

Fig. 74 Fuel Low Pressure Duct Performance, Firing 31E

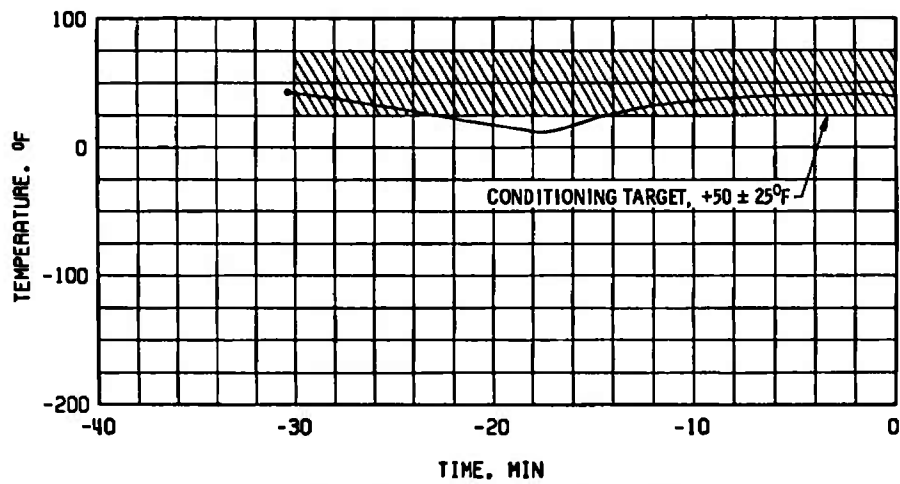


a. Thrust Chamber Throat, TTC-1P

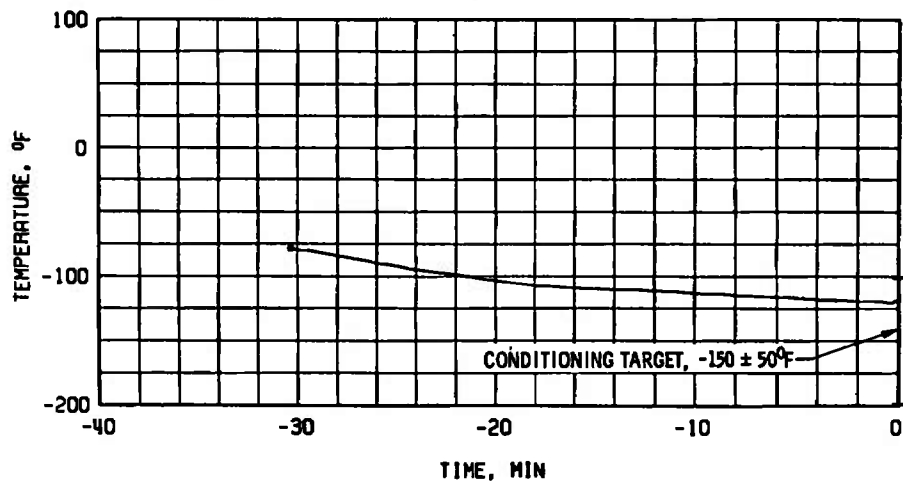


b. Crossover Duct, TFTD

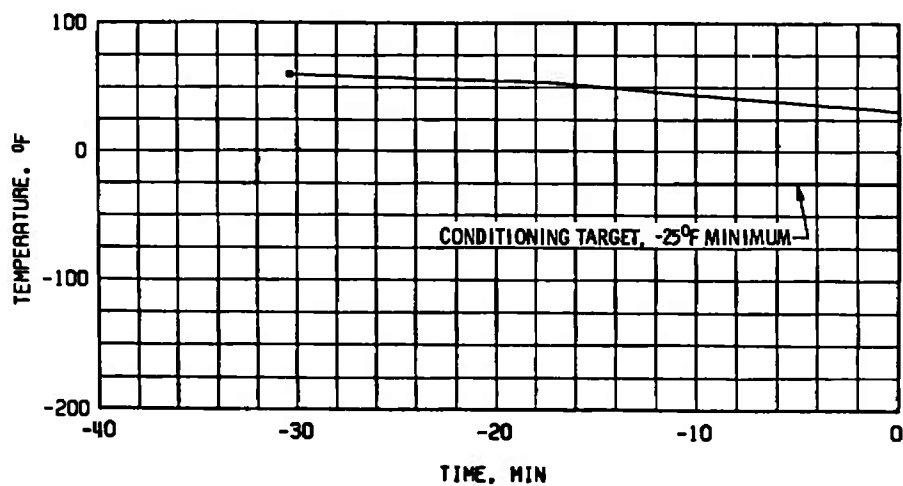
Fig. 75 Thermal Conditioning History of Engine Components, Firing 32A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 75 Concluded



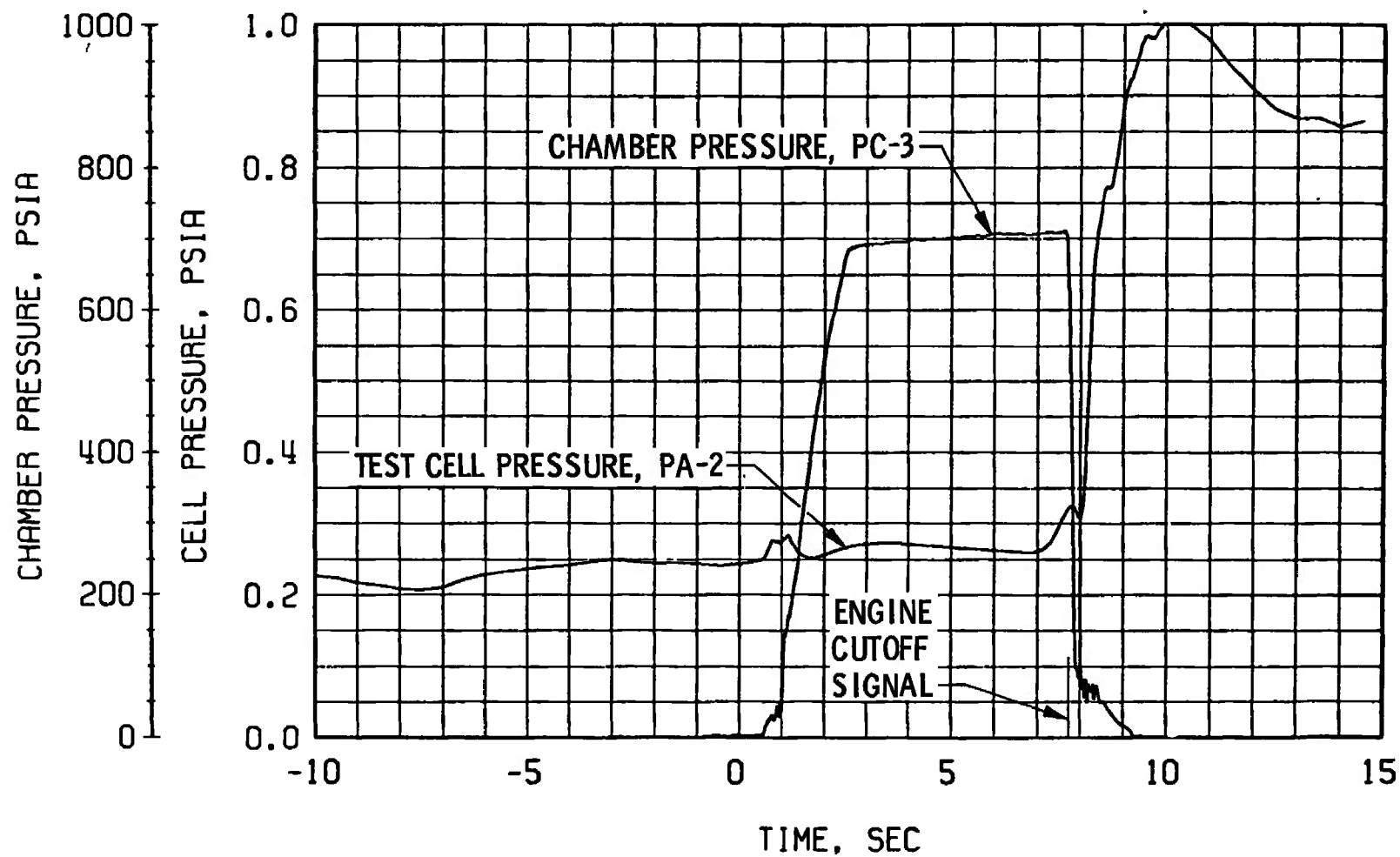
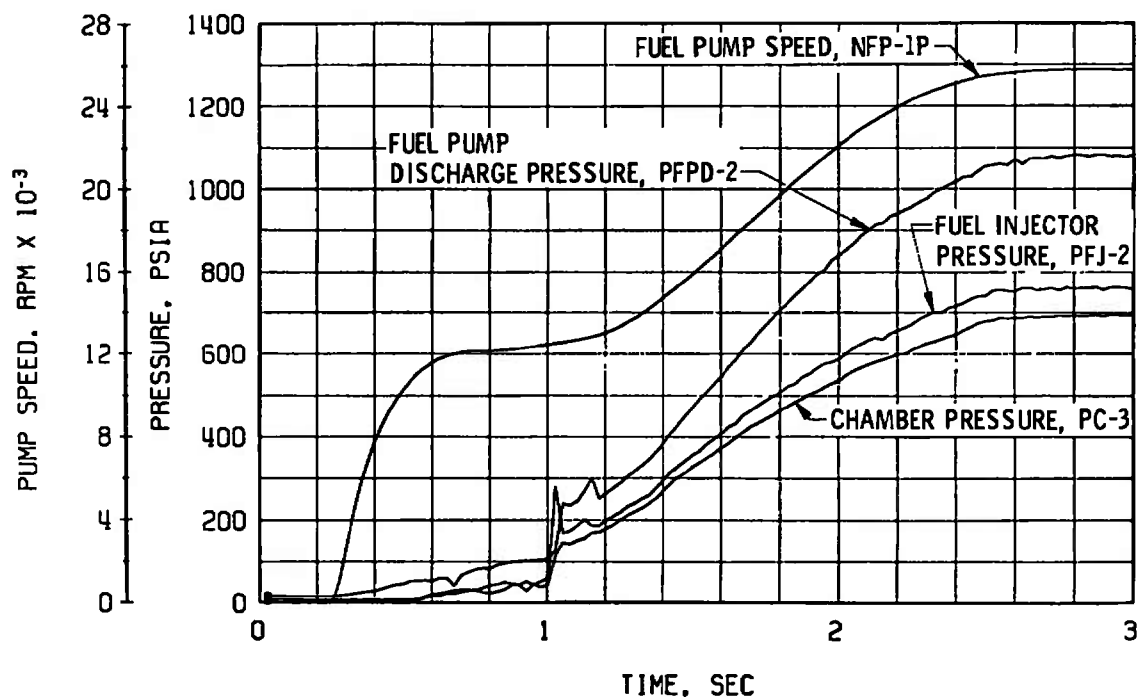
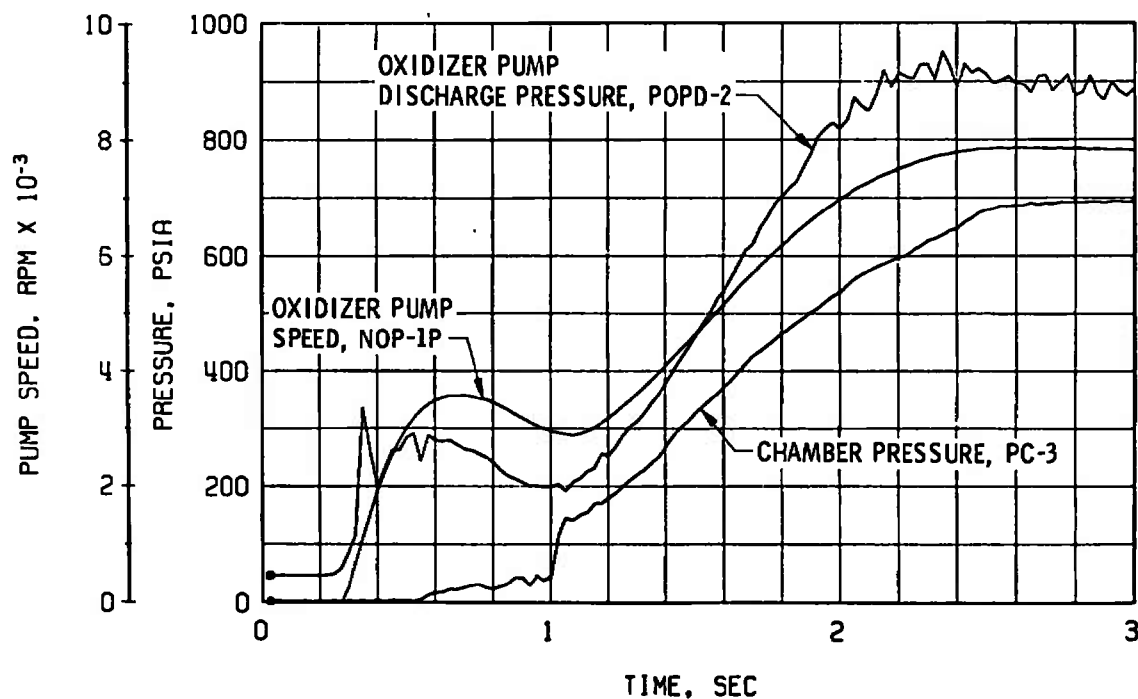


Fig. 76 Engine Ambient and Combustion Chamber Pressures, Firing 32A

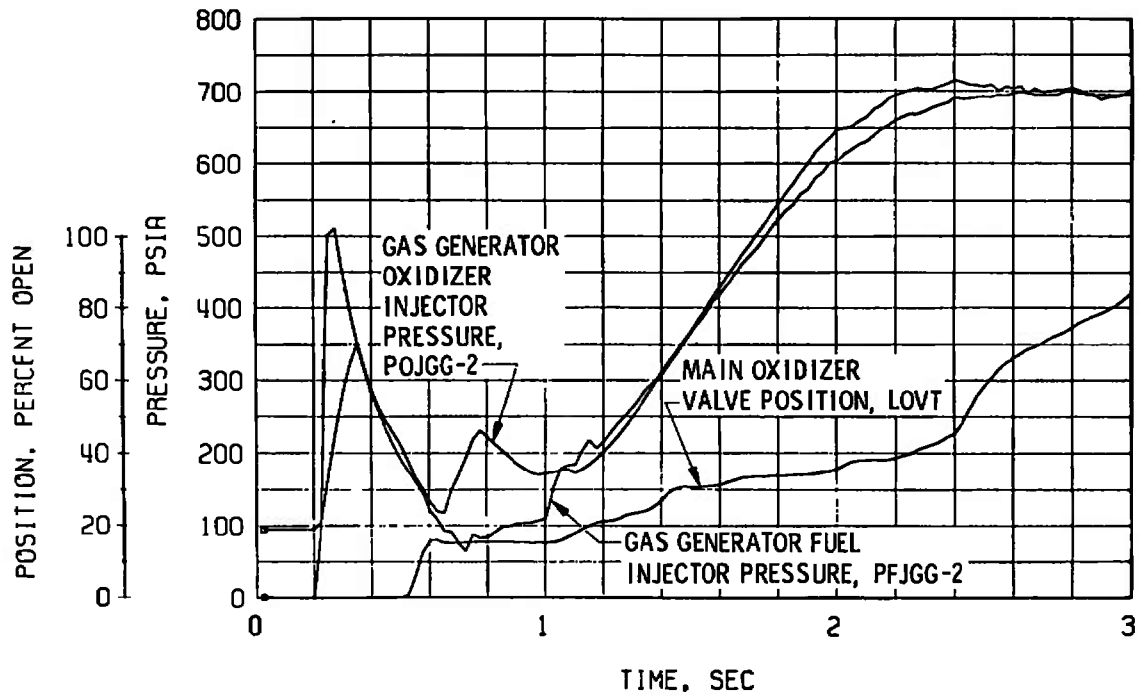


a. Thrust Chamber Fuel System, Start

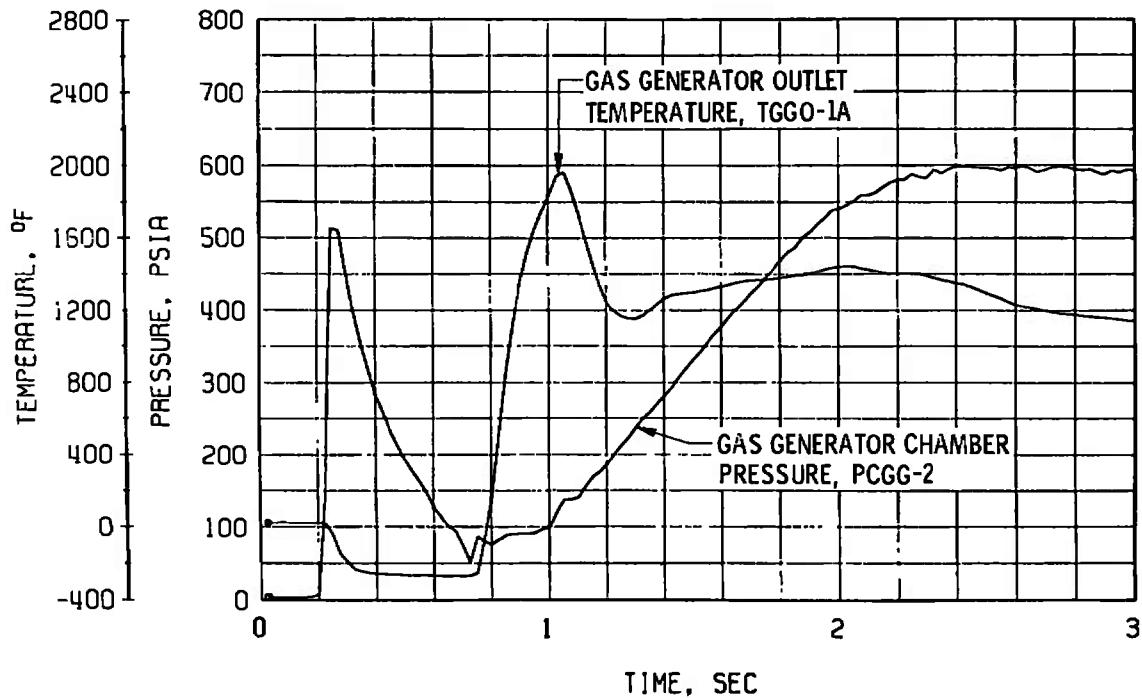


b. Thrust Chamber Oxidizer System, Start

Fig. 77 Engine Transient Operation, Firing 32A

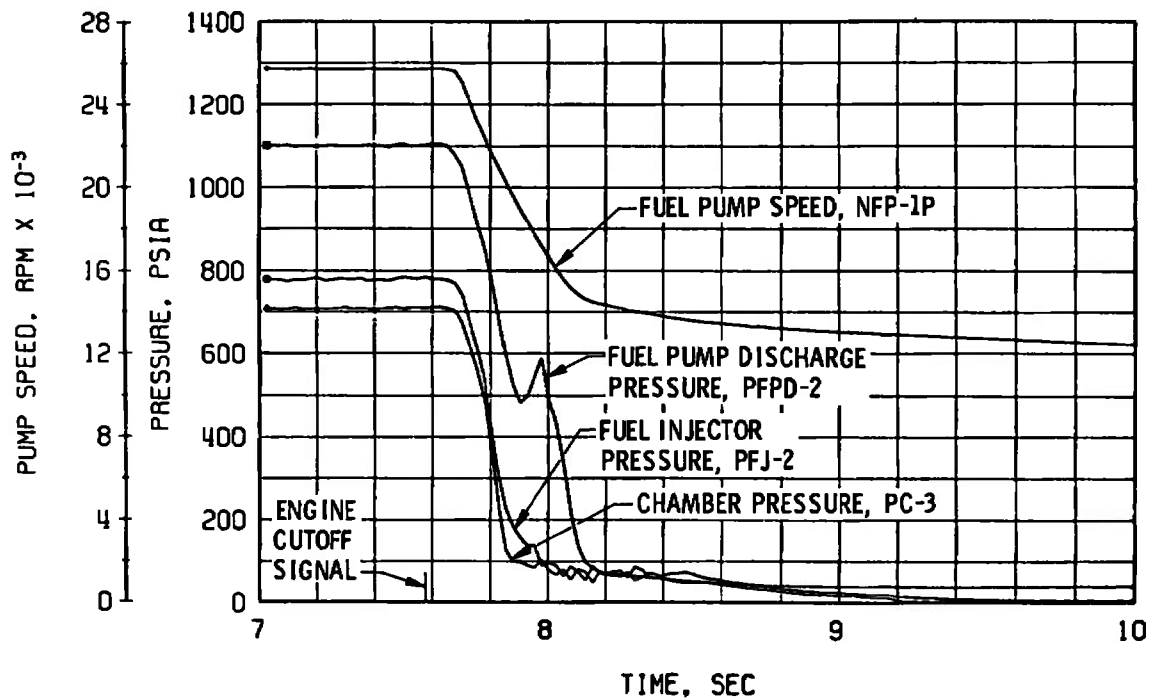


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

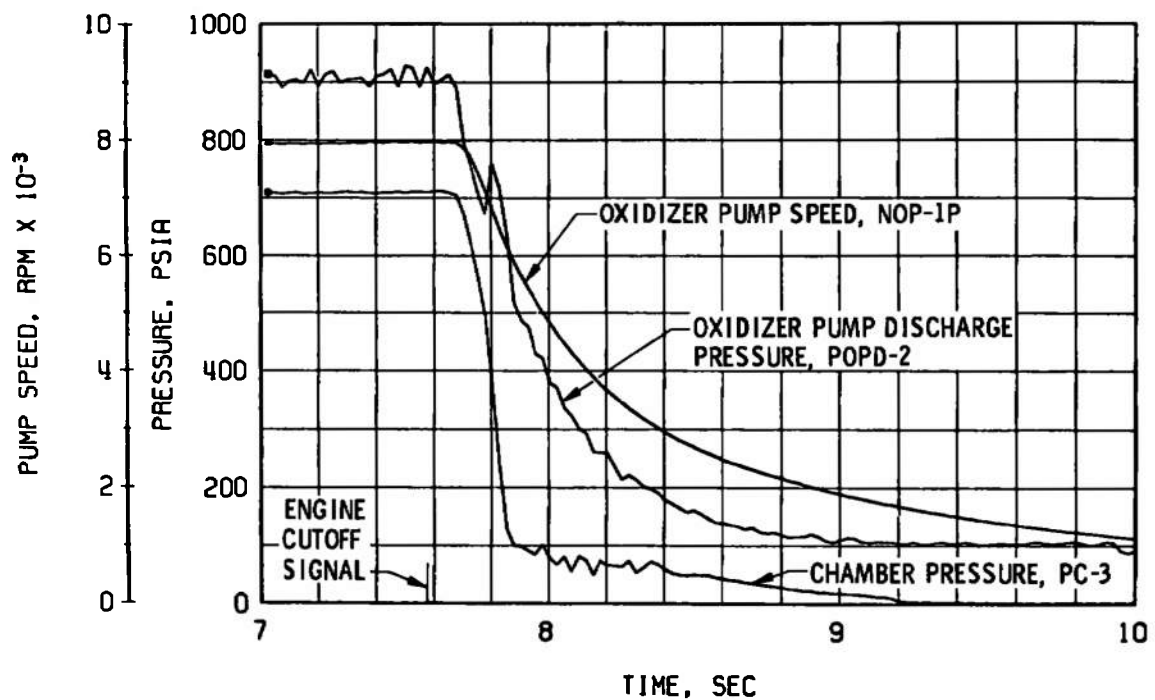


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 77 Continued

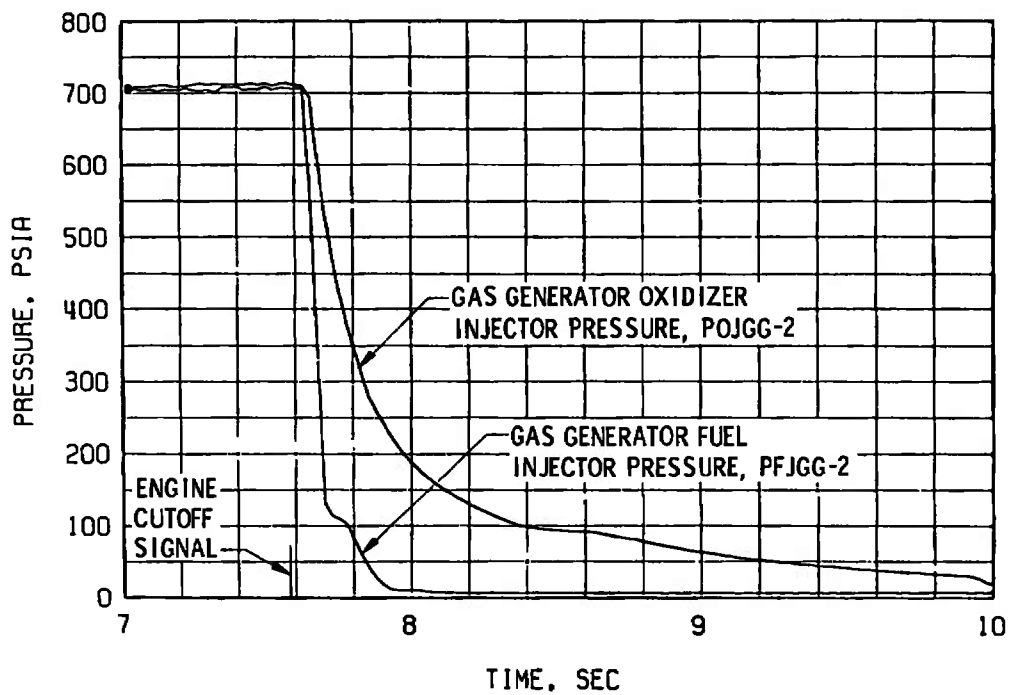


e. Thrust Chamber Fuel System, Shutdown

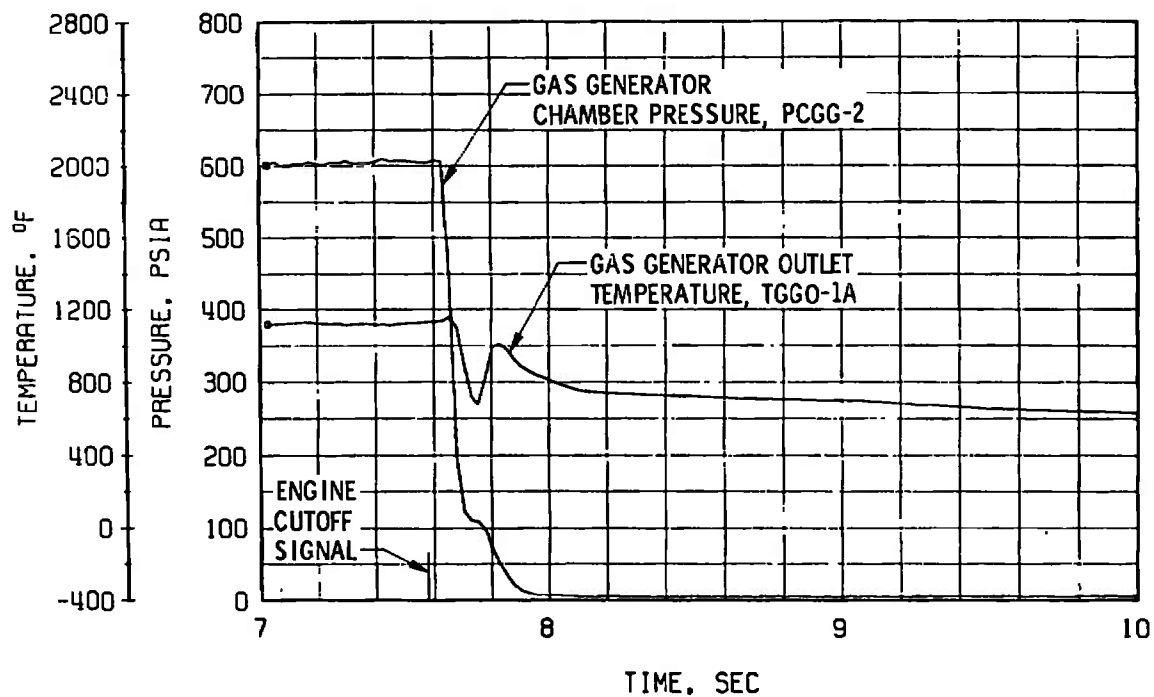


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 77 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 77 Concluded

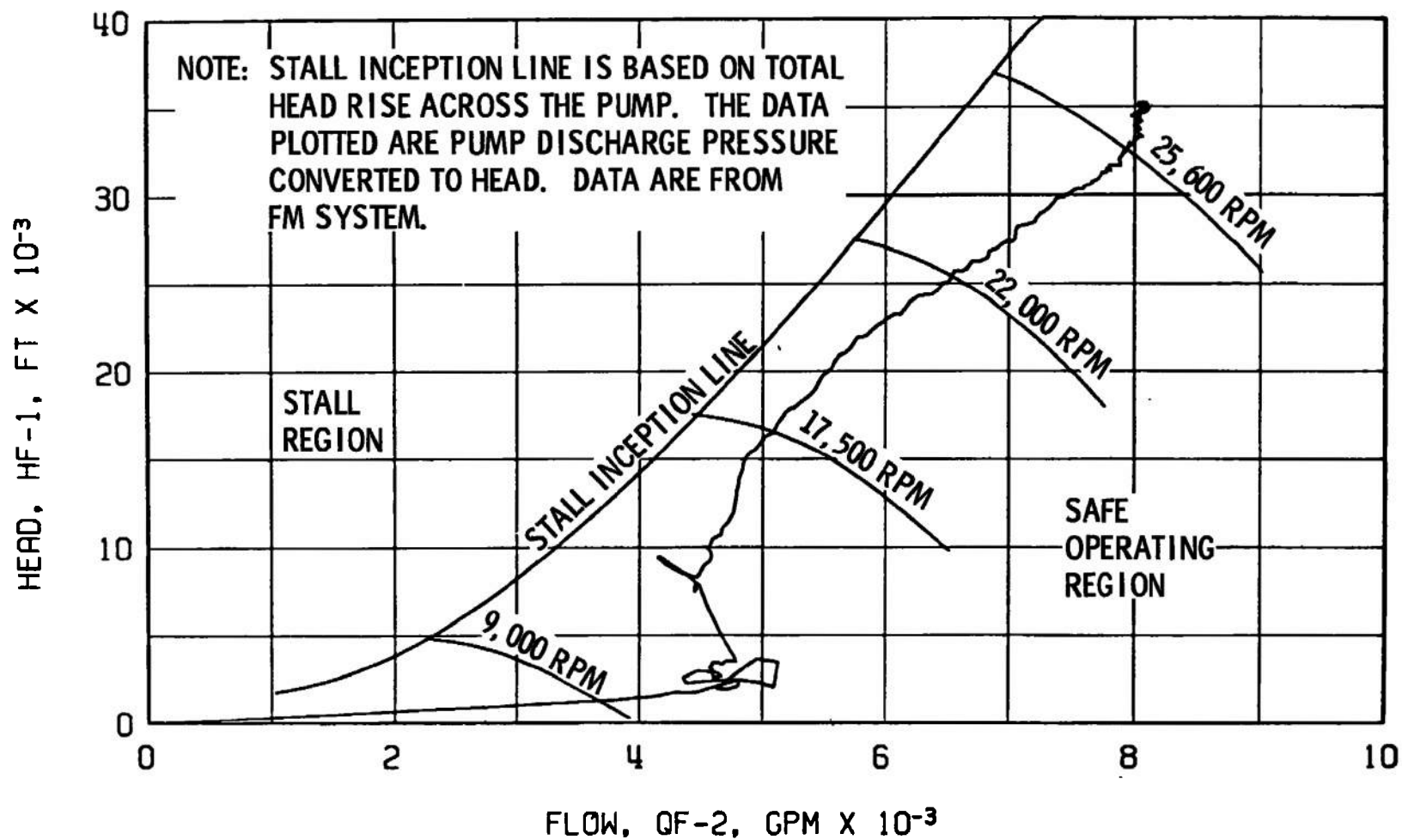
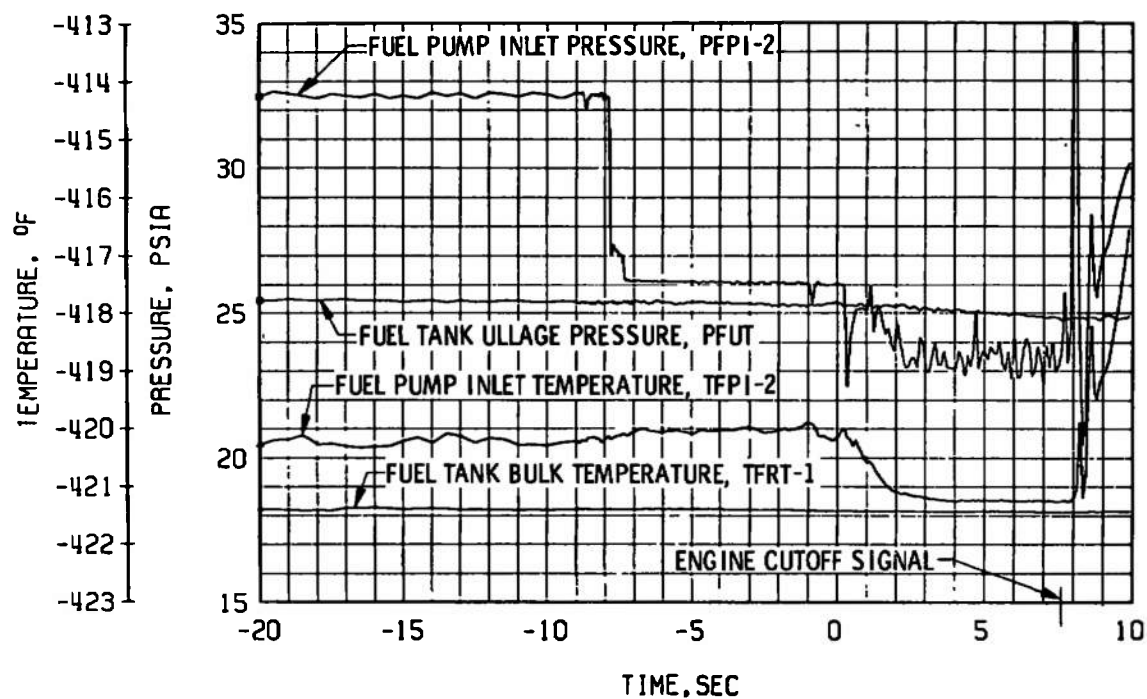
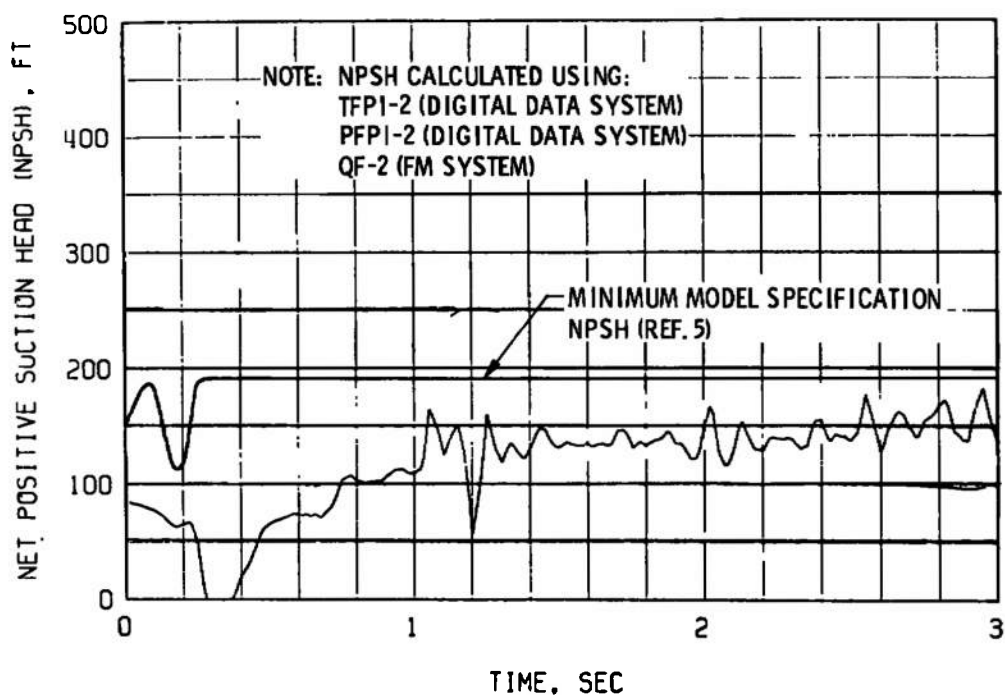


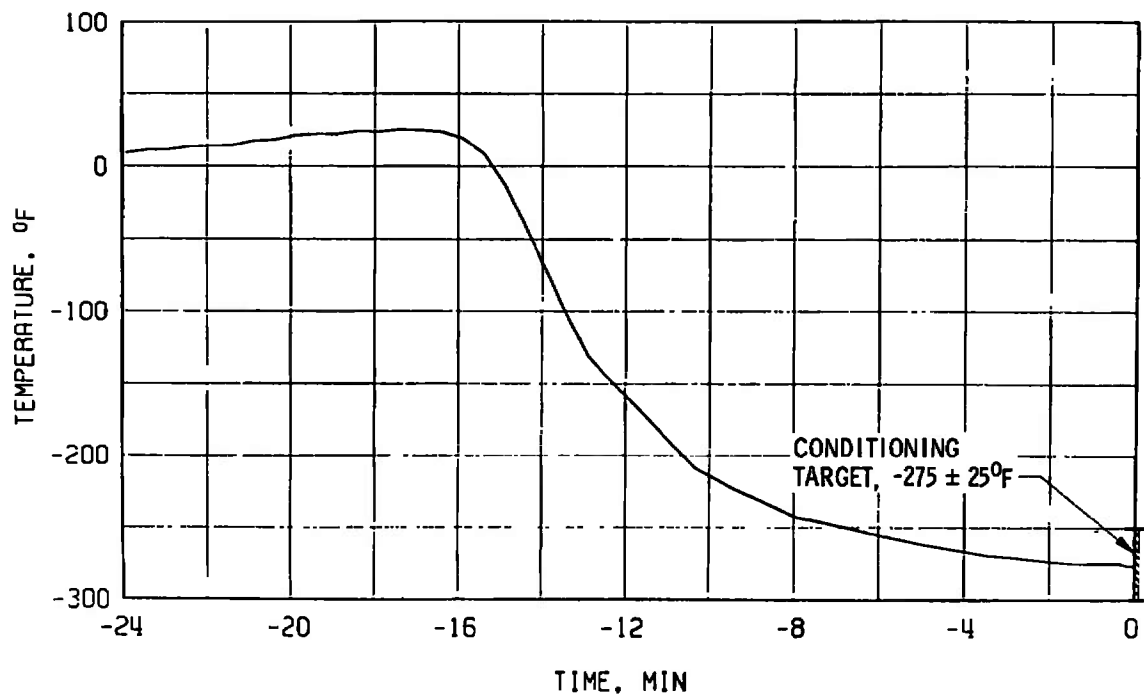
Fig. 78 Fuel Pump Start Transient Performance, Firing 32A



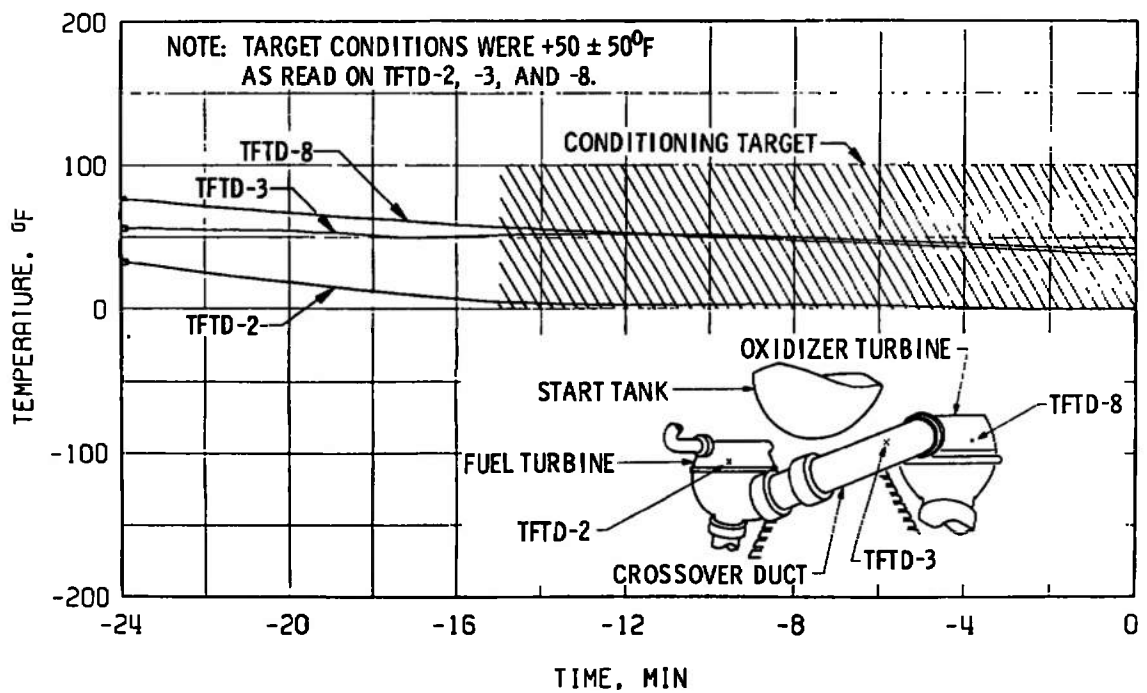
a. Duct Pressure and Temperature Transients



b. Fuel Pump NPSH during Start Transient, Firing 32A  
 Fig. 79 Fuel Low Pressure Duct Performance, Firing 32A



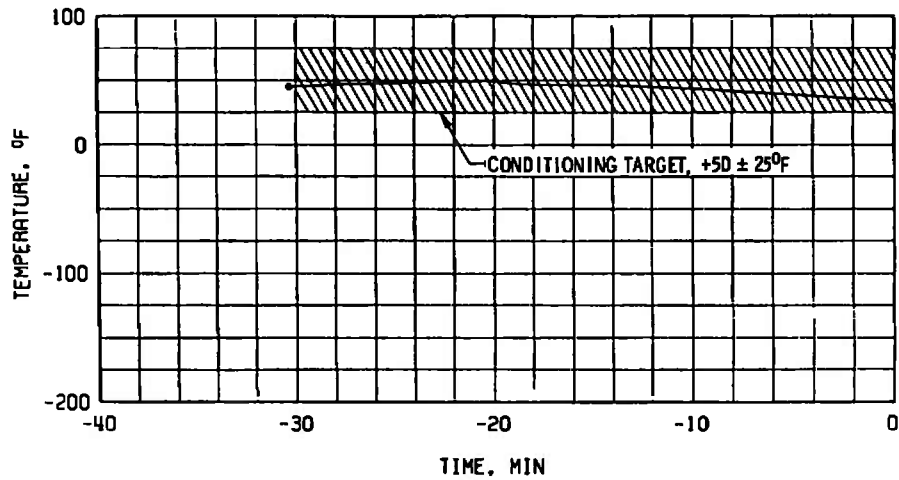
a. Thrust Chamber Throat, TTC-1P



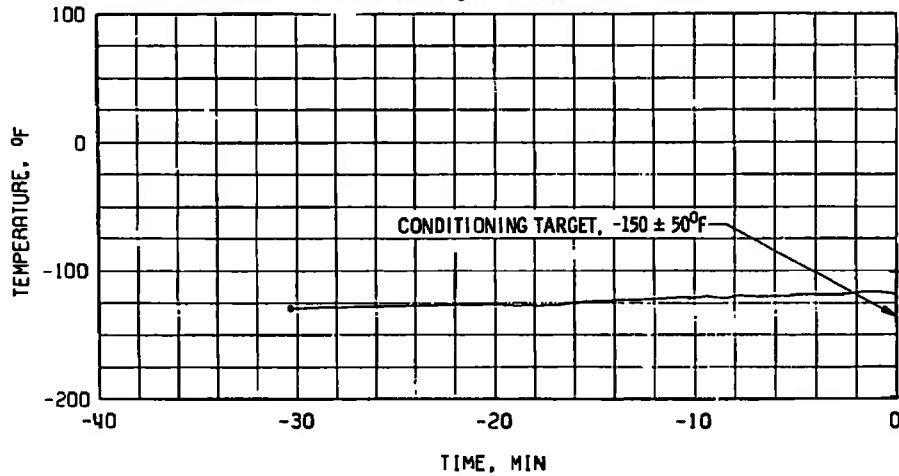
b. Crossover Duct, TFTD

Fig. 80 Thermal Conditioning History of Engine Components, Firing 32B

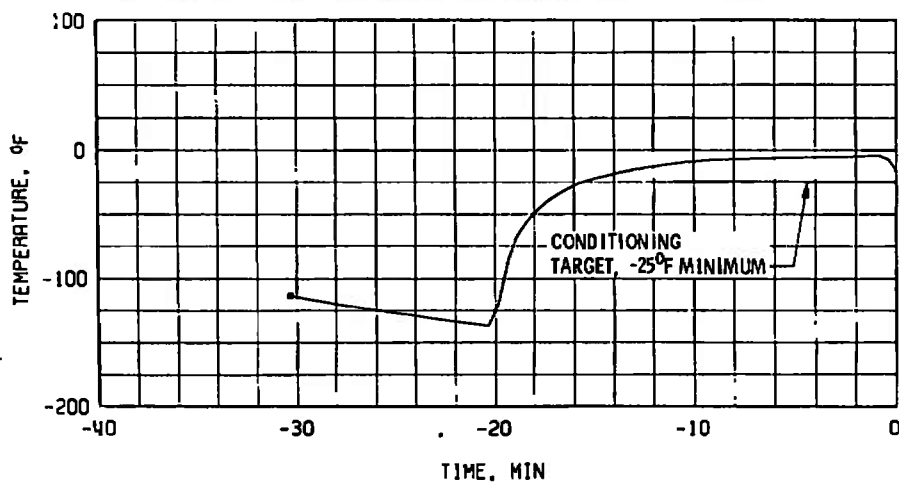




c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Valve Body, TGGVRS

Fig. 80 Concluded

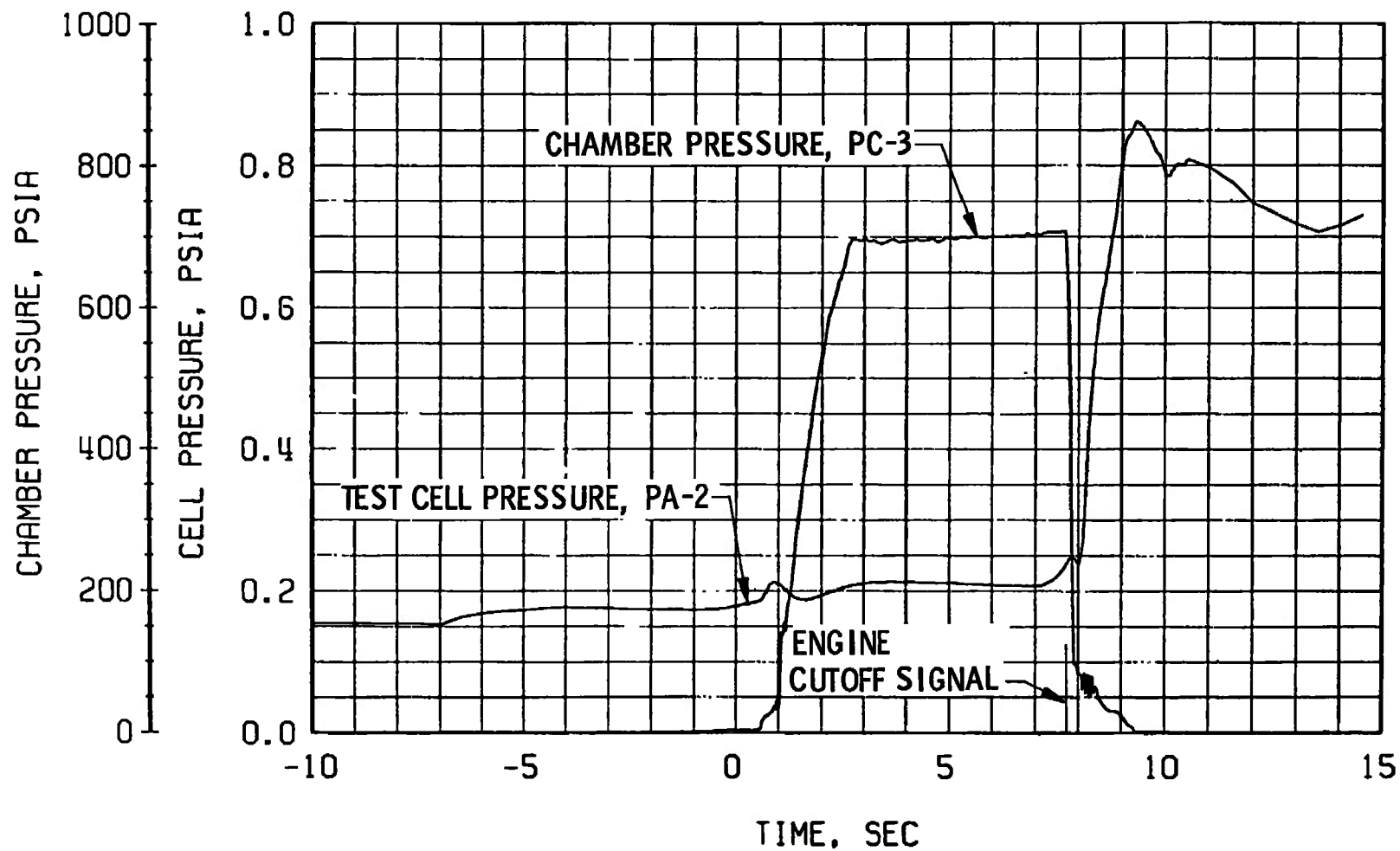
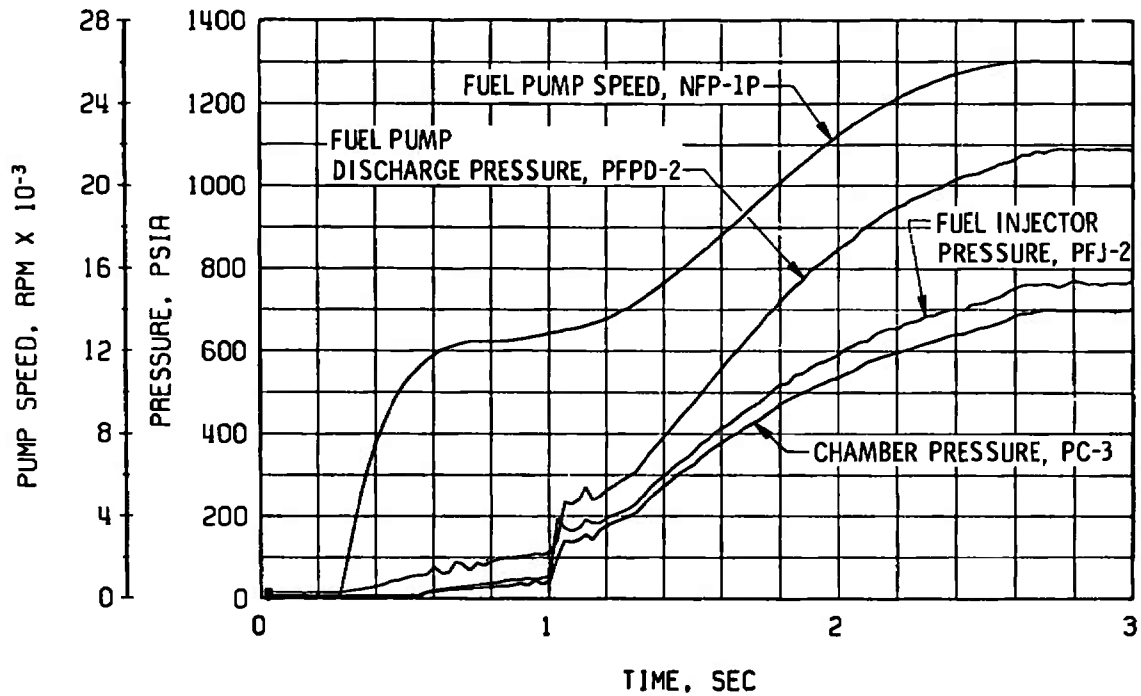
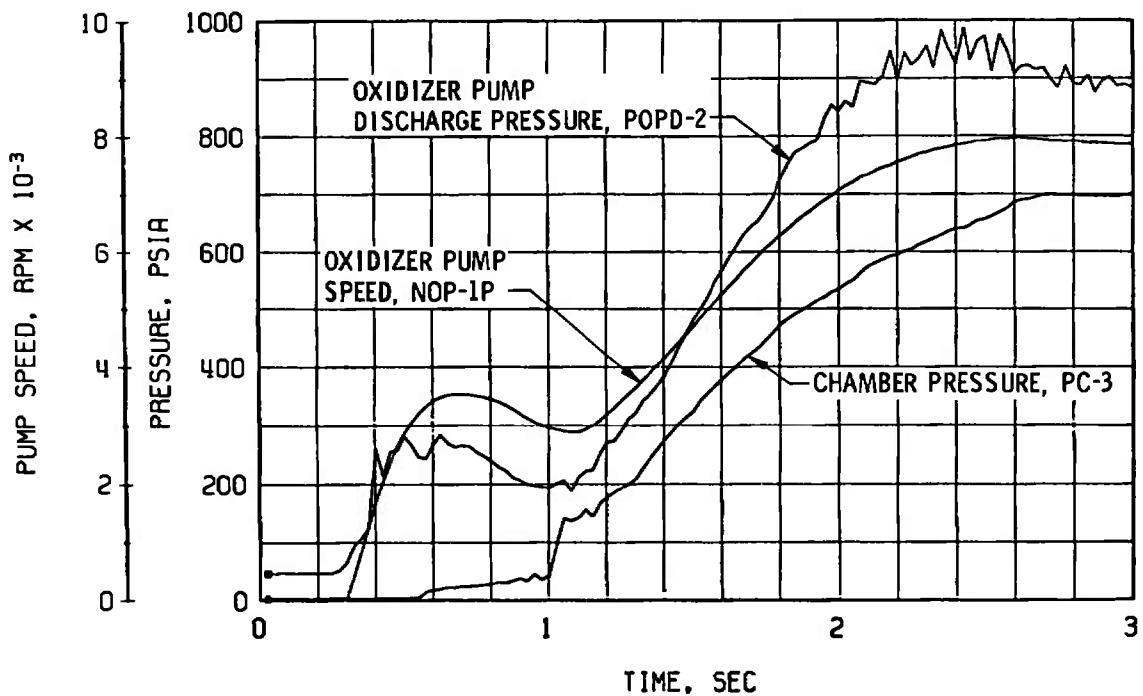


Fig. 81 Engine Ambient and Combustion Chamber Pressures, Firing 32B

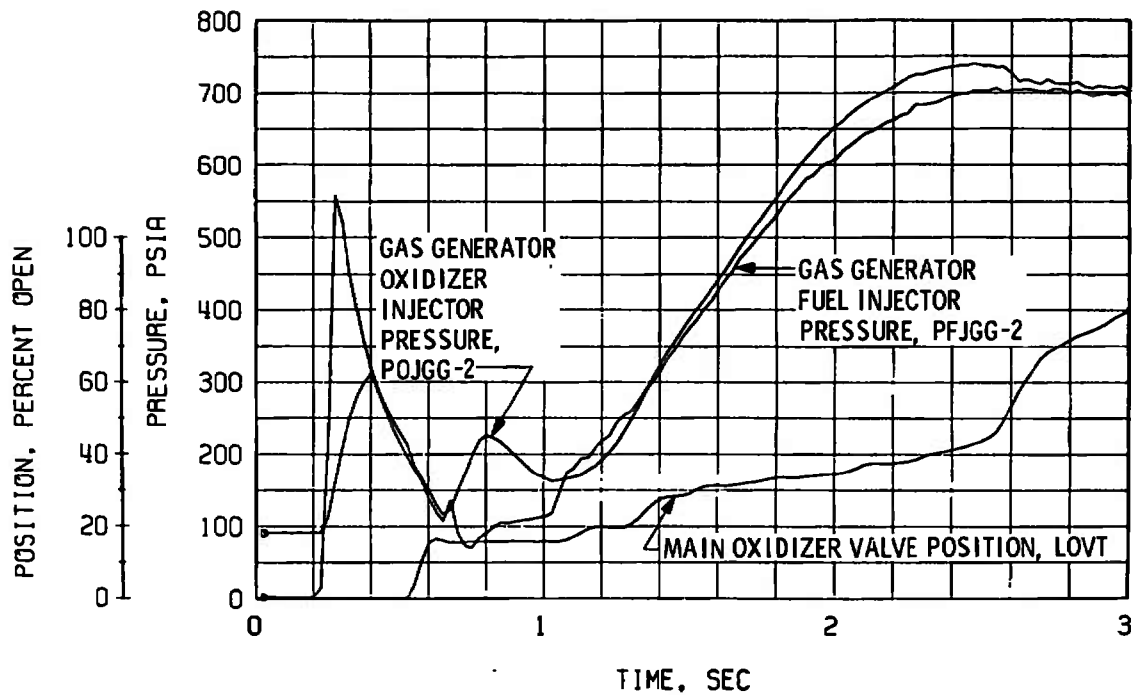


a. Thrust Chamber Fuel System, Start

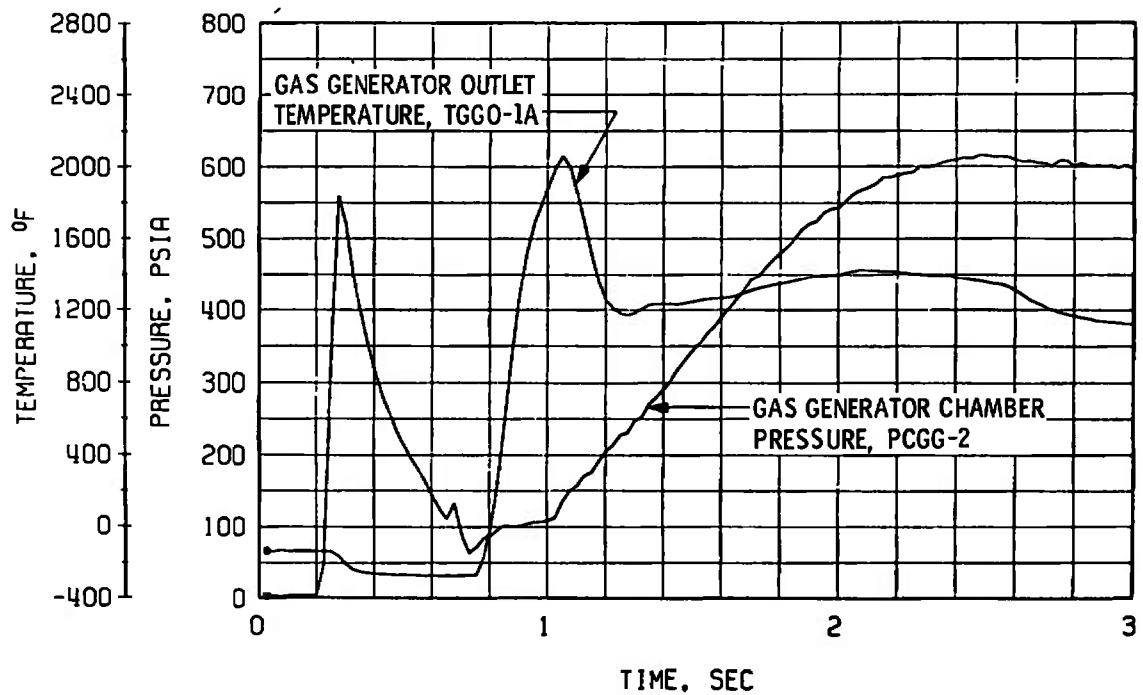


b. Thrust Chamber Oxidizer System, Start

Fig. 82 Engine Transient Operation, Firing 32B

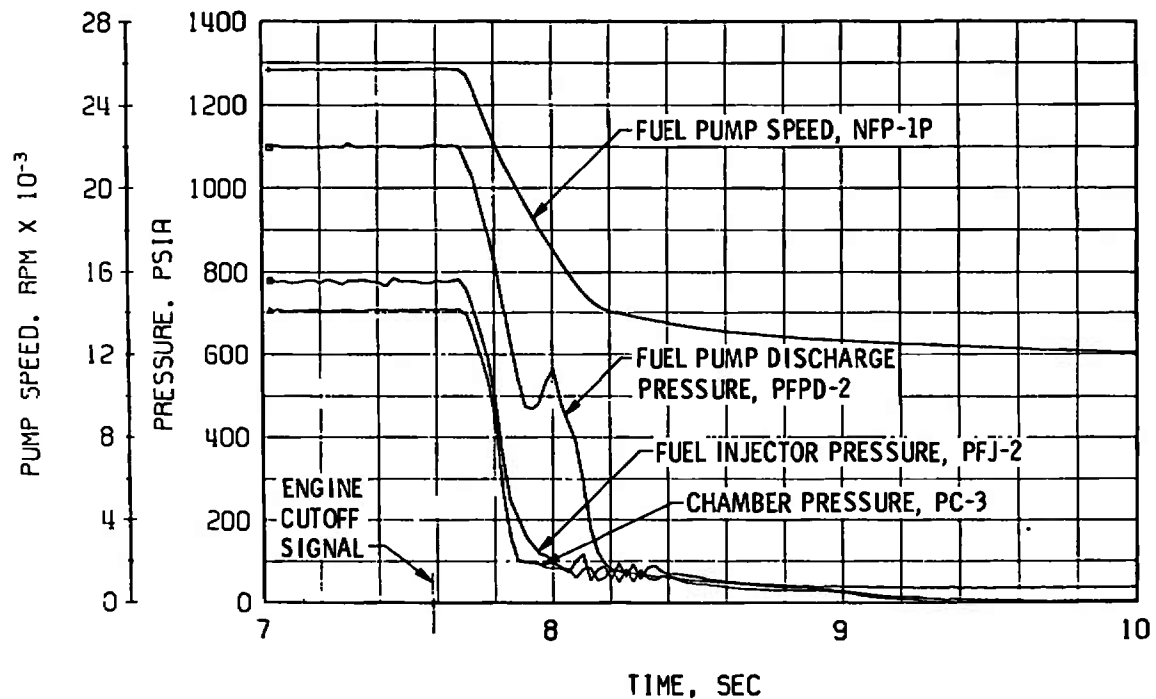


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

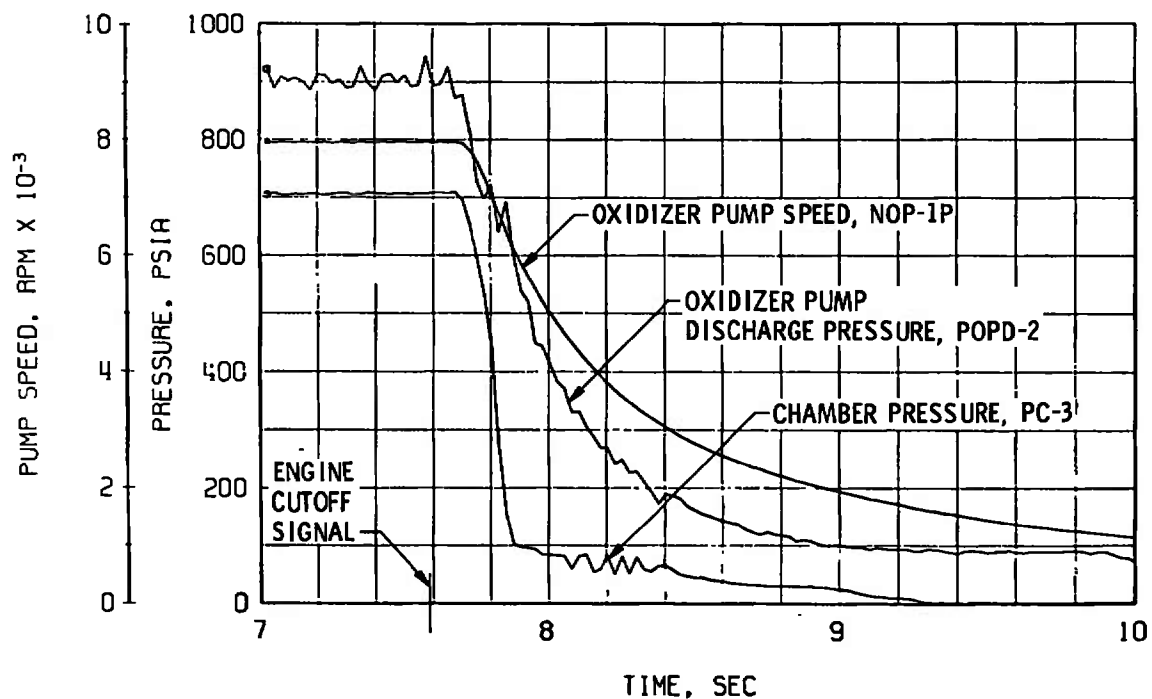


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 82 Continued

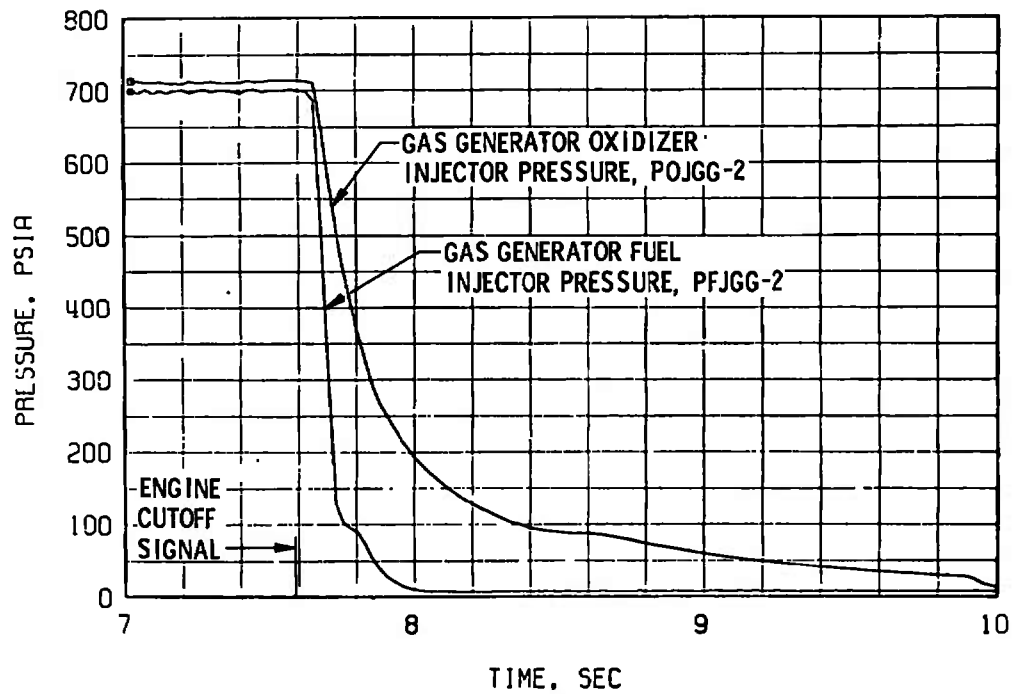


e. Thrust Chamber Fuel System, Shutdown

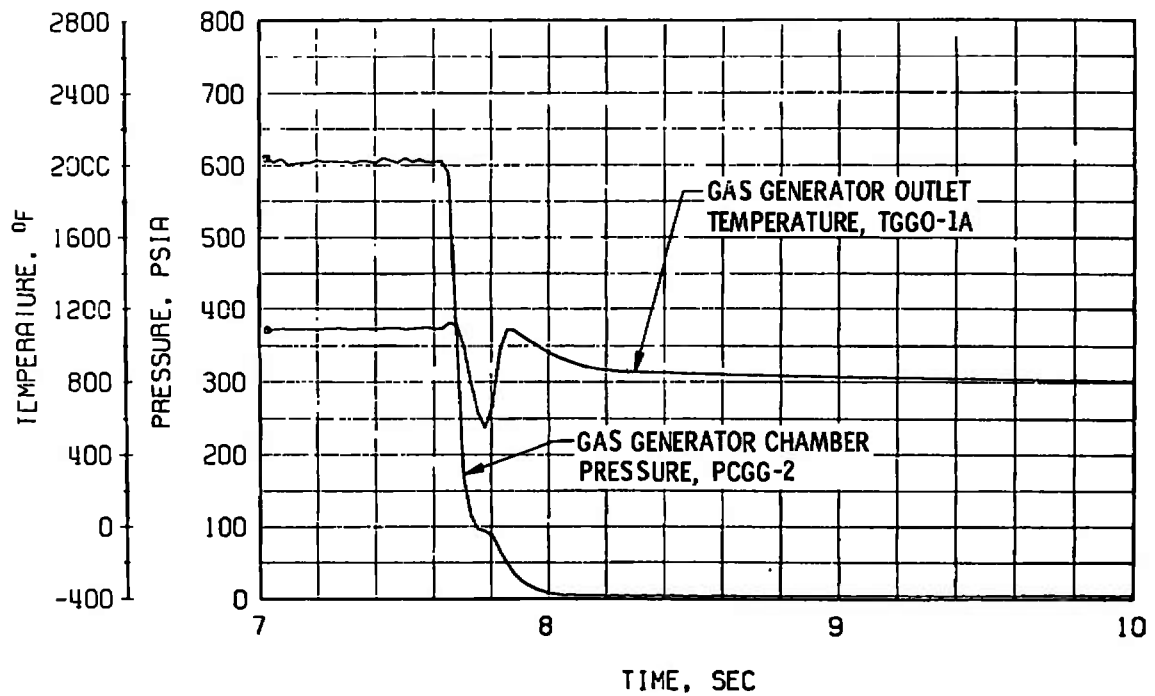


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 82 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 82 Concluded

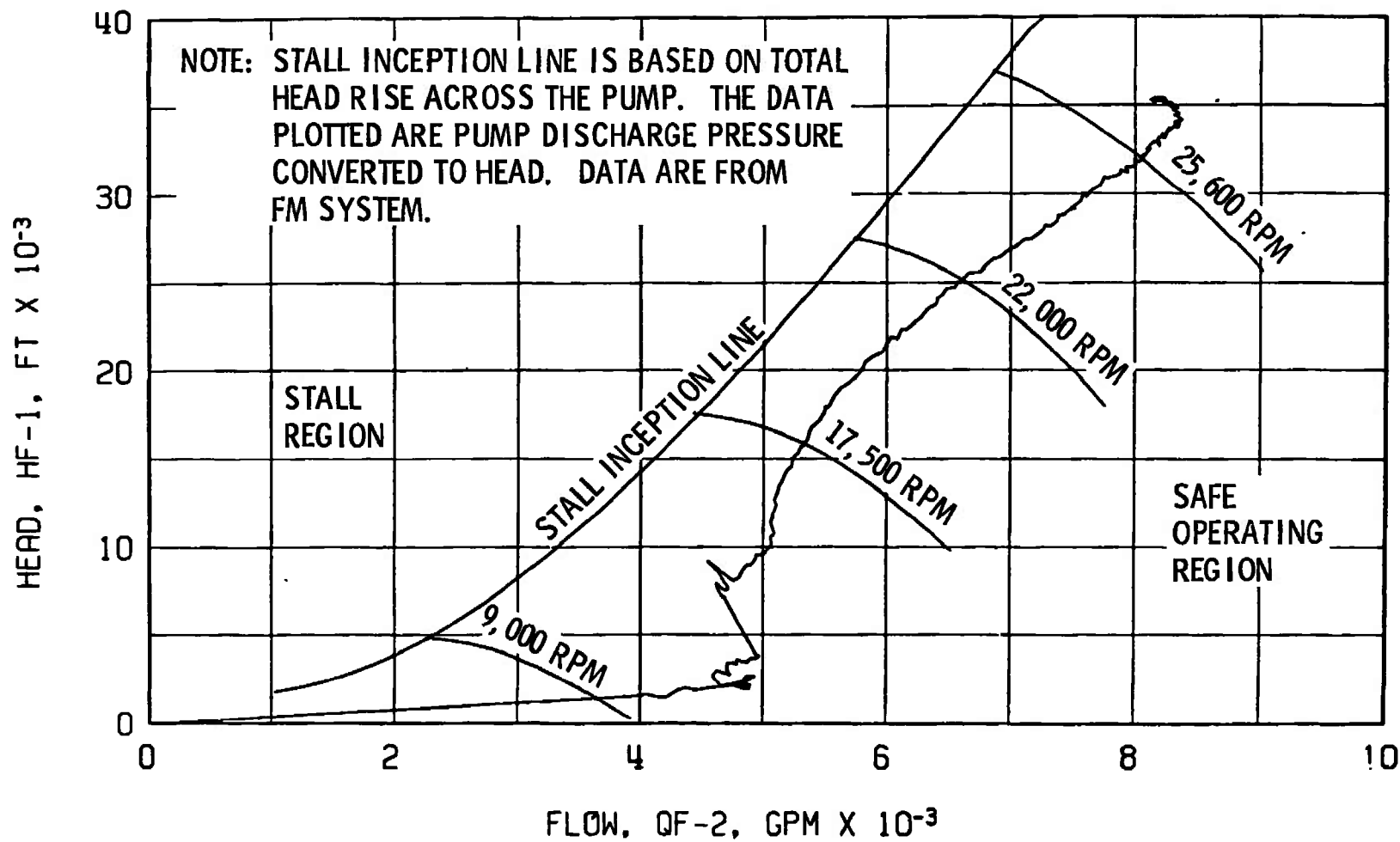
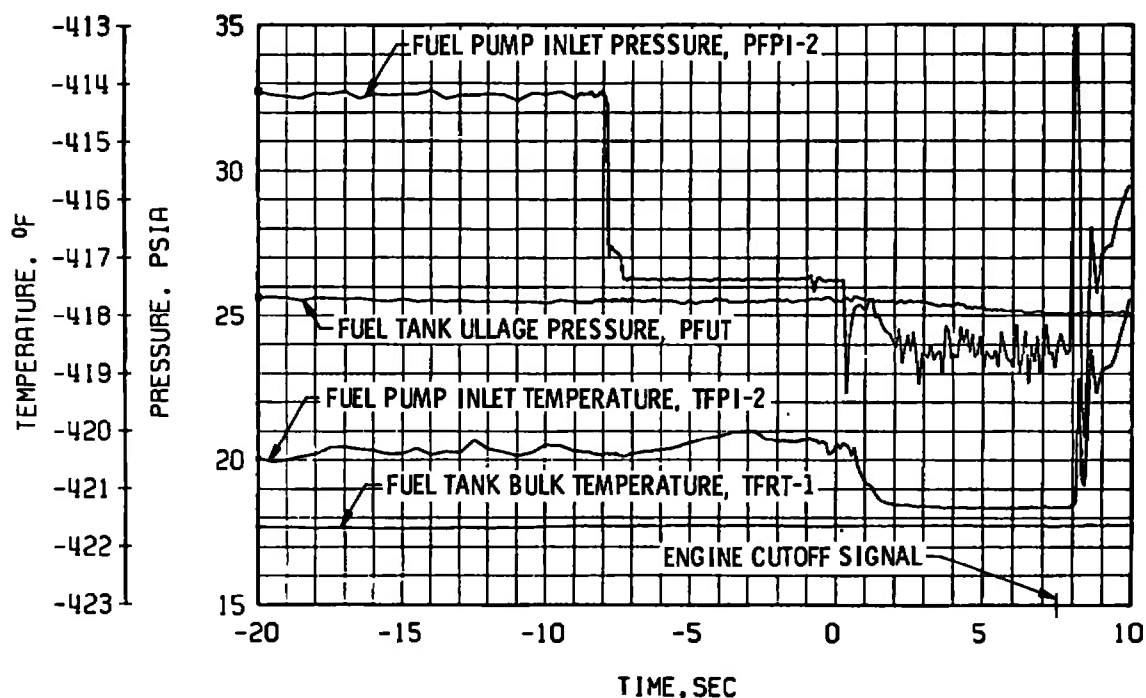
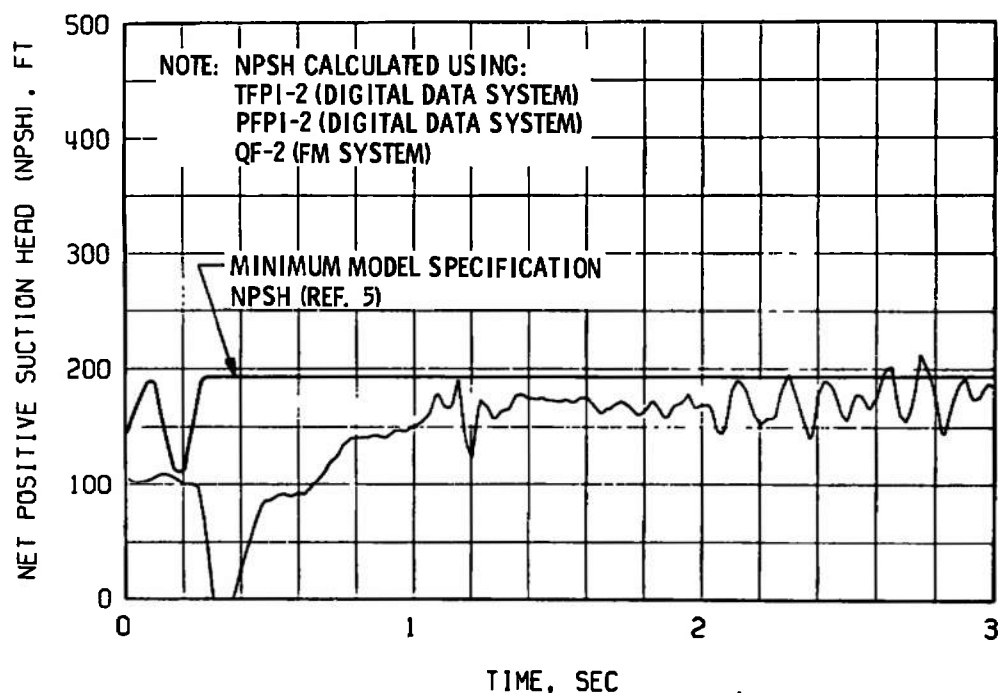


Fig. 83 Fuel Pump Start Transient Performance, Firing 32B



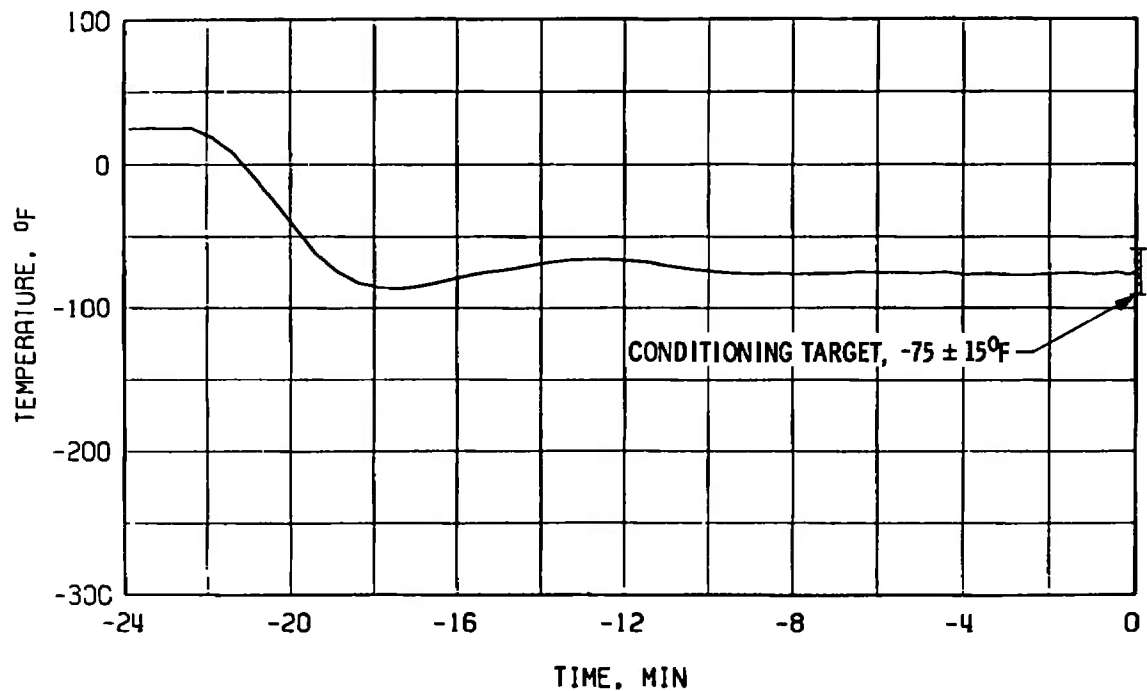
a. Duct Pressure and Temperature Transients



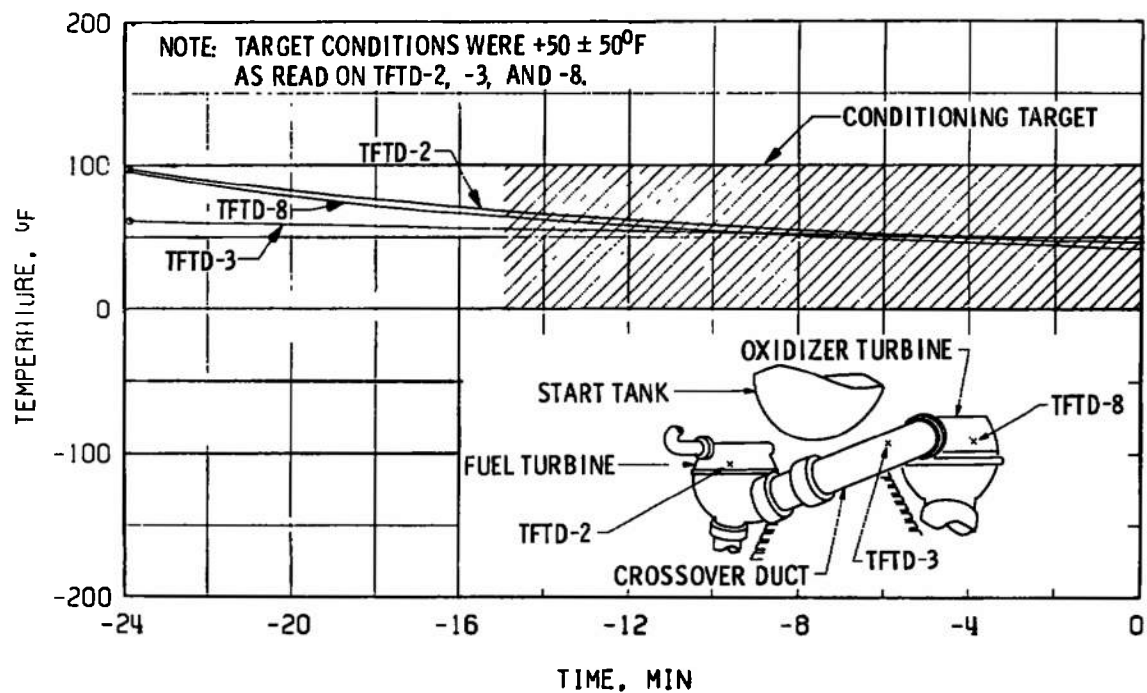
b. Fuel Pump NPSH during Start Transient, Firing 32B

Fig. 84 Fuel Low Pressure Duct Performance, Firing 32B



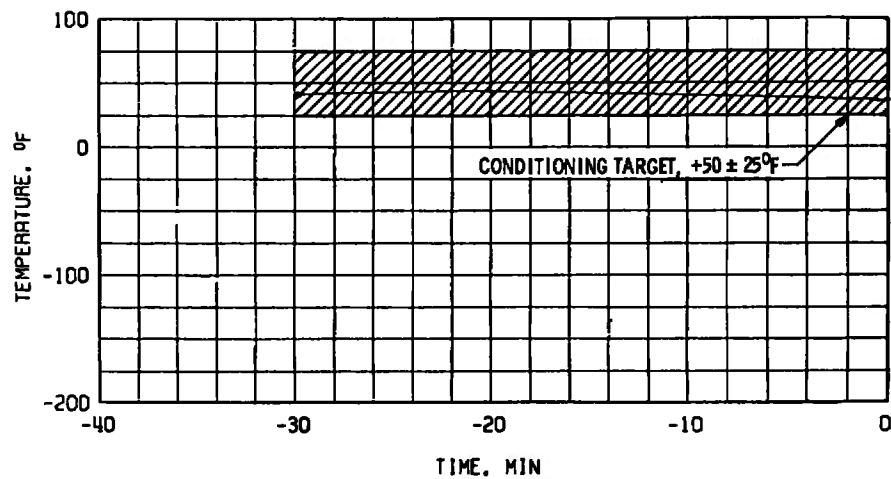


a. Thrust Chamber Throat, TTC-1P

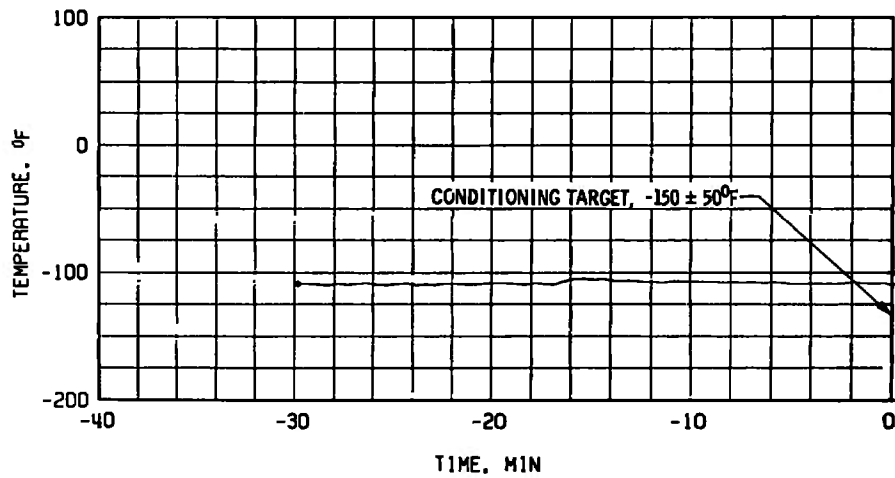


b. Crossover Duct, TTFD

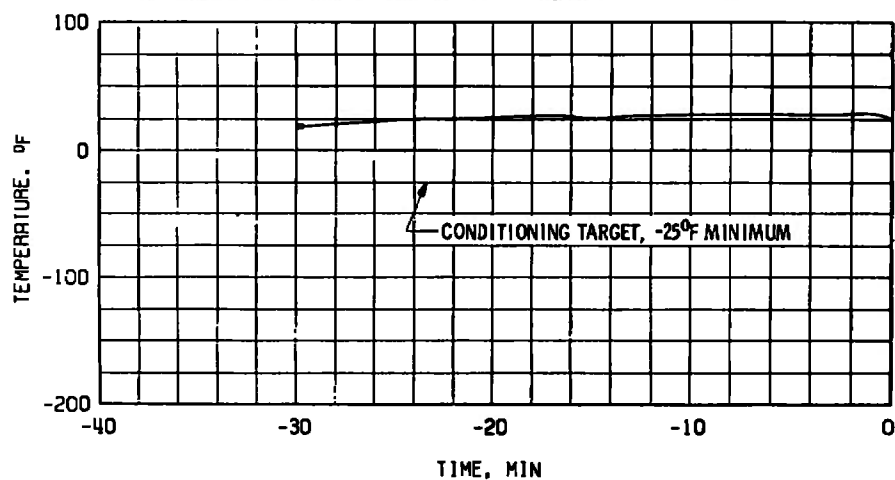
Fig. 85 Thermal Conditioning History of Engine Components, Firing 32C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 85 Concluded

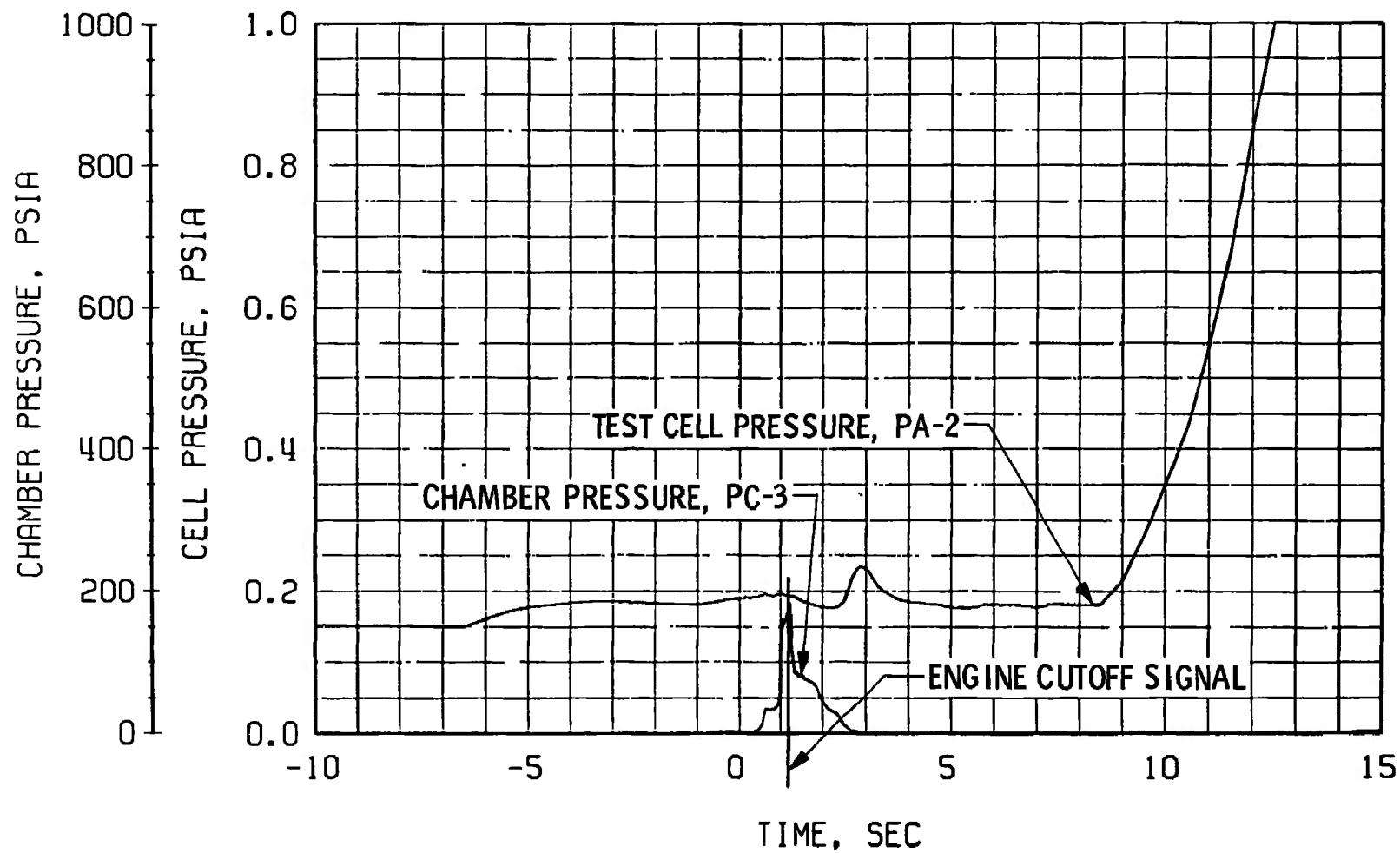
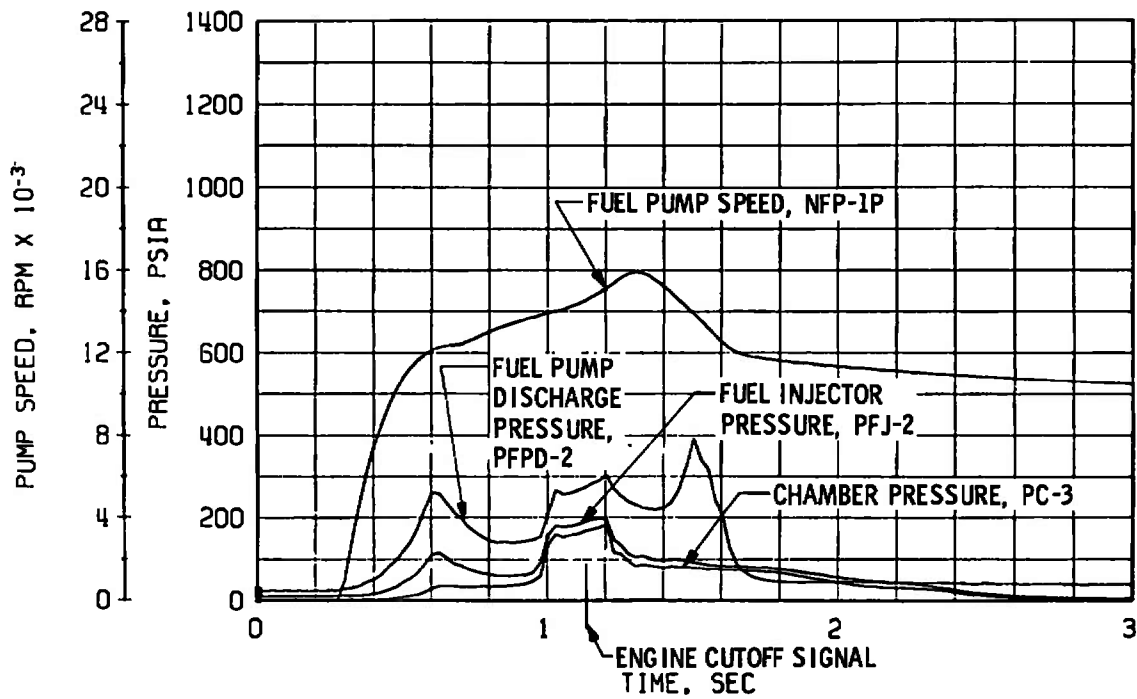
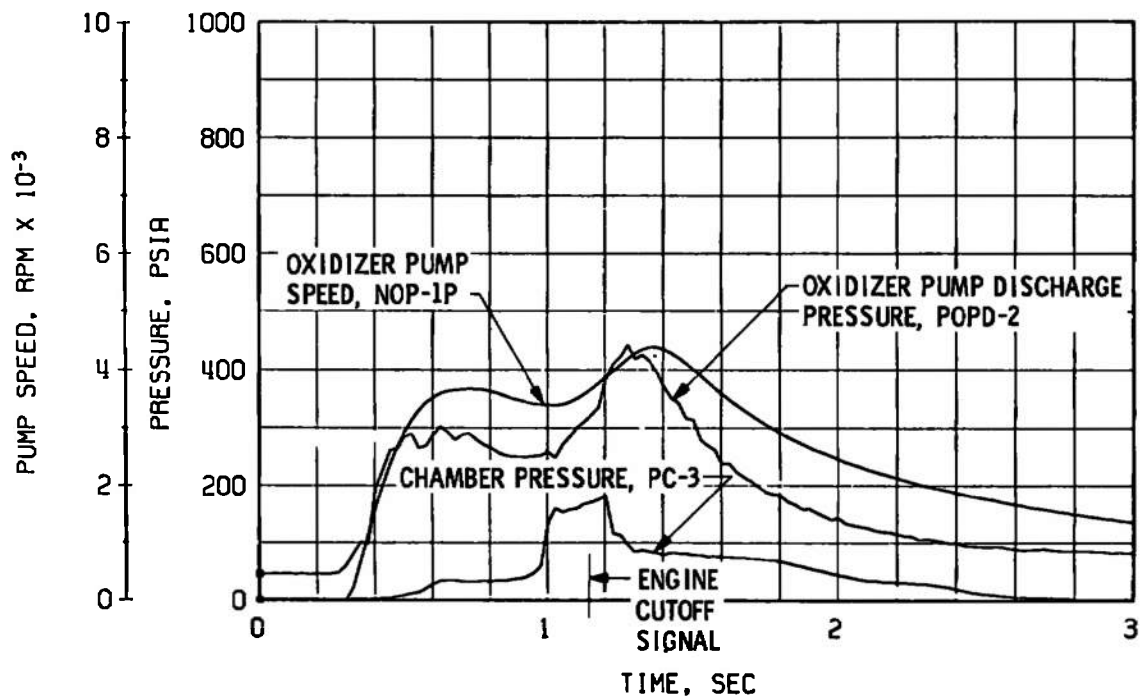


Fig. 86 Engine Ambient and Combustion Chamber Pressures, Firing 32C

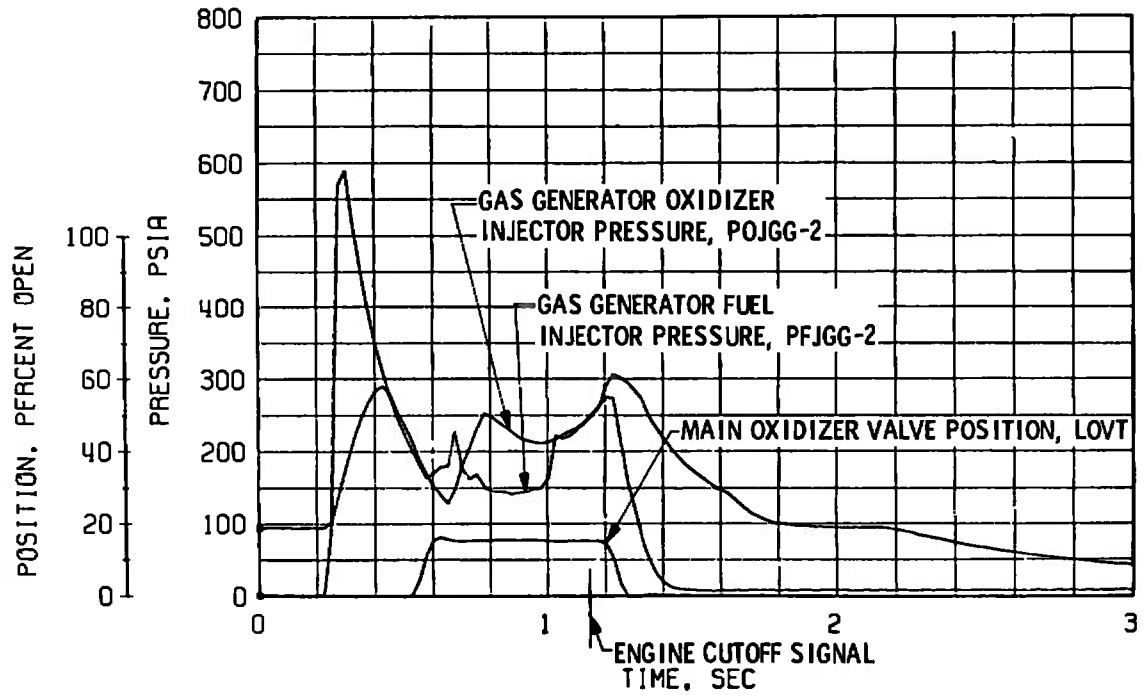


a. Thrust Chamber Fuel System, Start and Shutdown

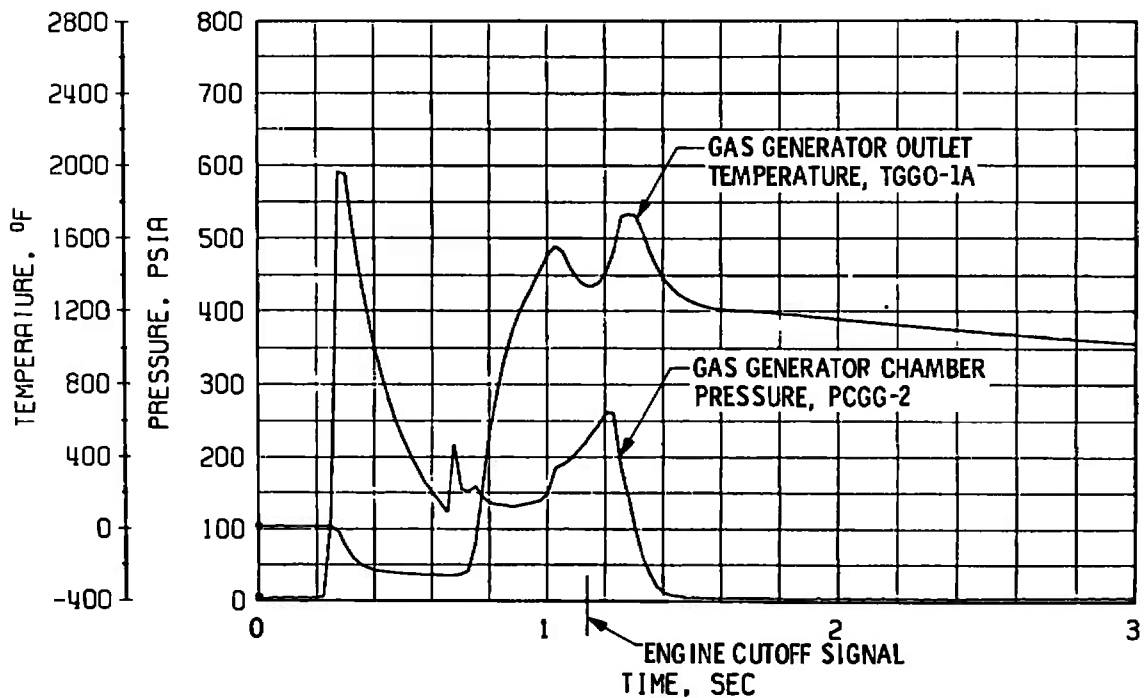


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 87 Engine Transient Operation, Firing 32C



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 87 Concluded

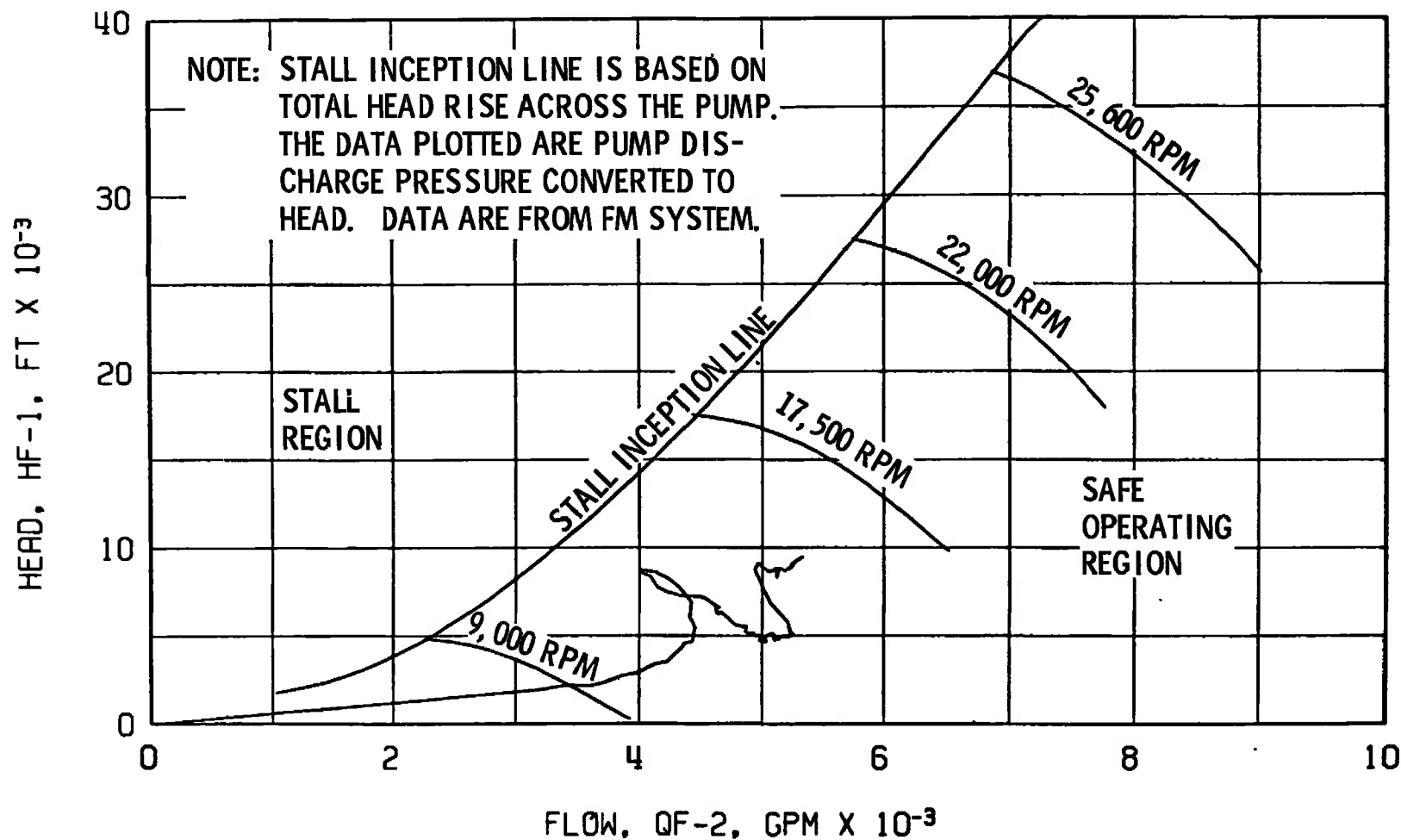
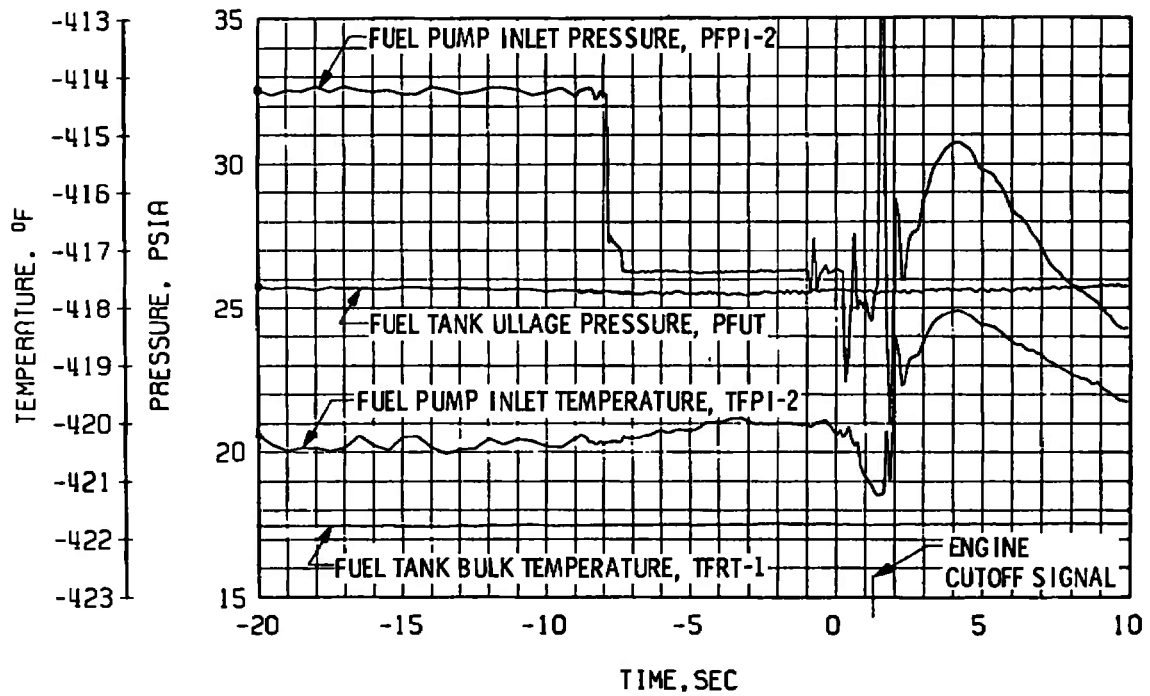
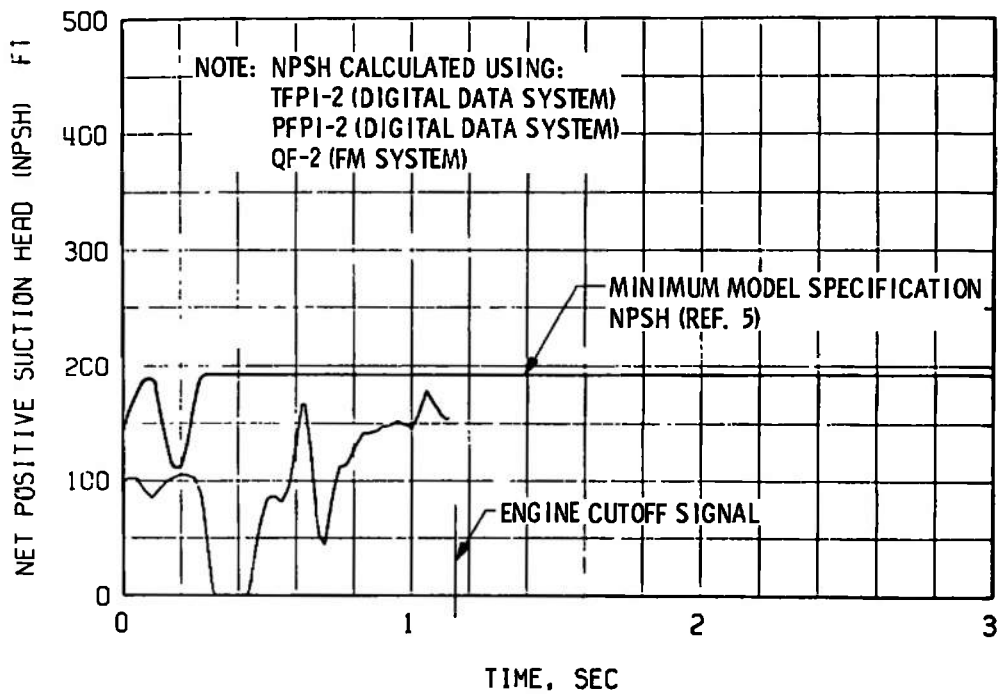


Fig. 88 Fuel Pump Start Transient Performance, Firing 32C

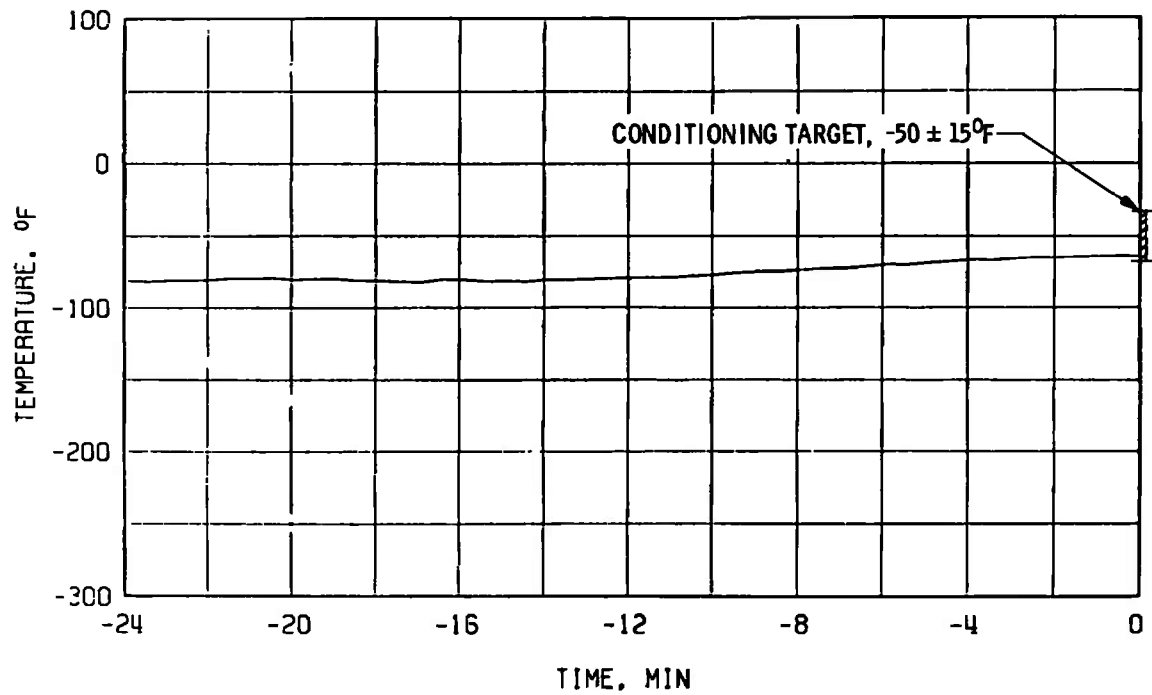


a. Duct Pressure and Temperature Transients

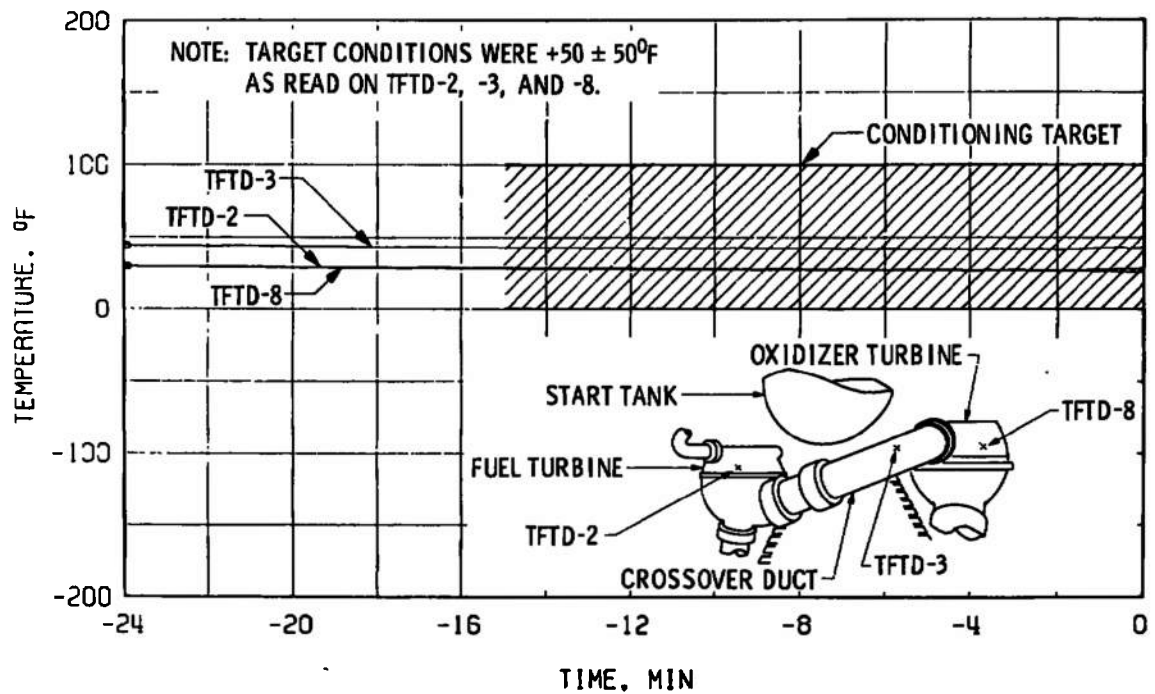


b. Fuel Pump NPSH during Start Transient, Firing 32C

Fig. 89 Fuel Low Pressure Duct Performance, Firing 32C



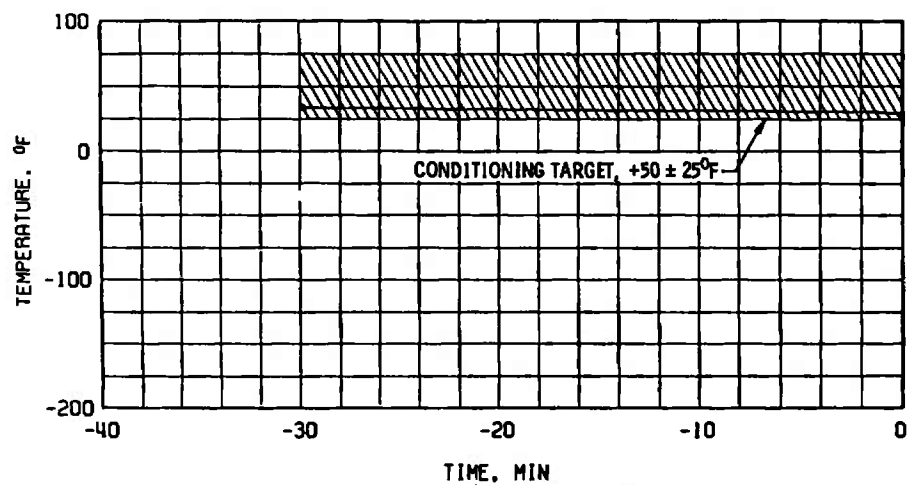
a. Thrust Chamber Throat, TTC-1P



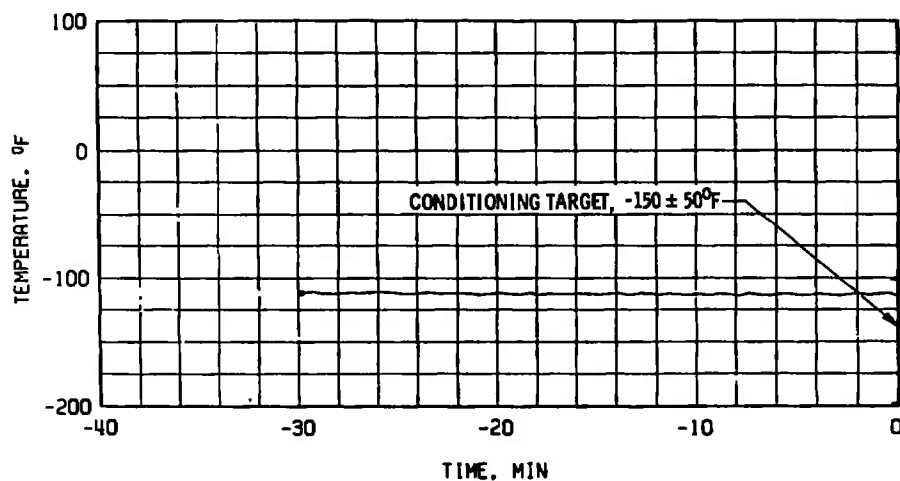
b. Crossover Duct, TFTD

Fig. 90 Thermal Conditioning History of Engine Components, Firing 32D

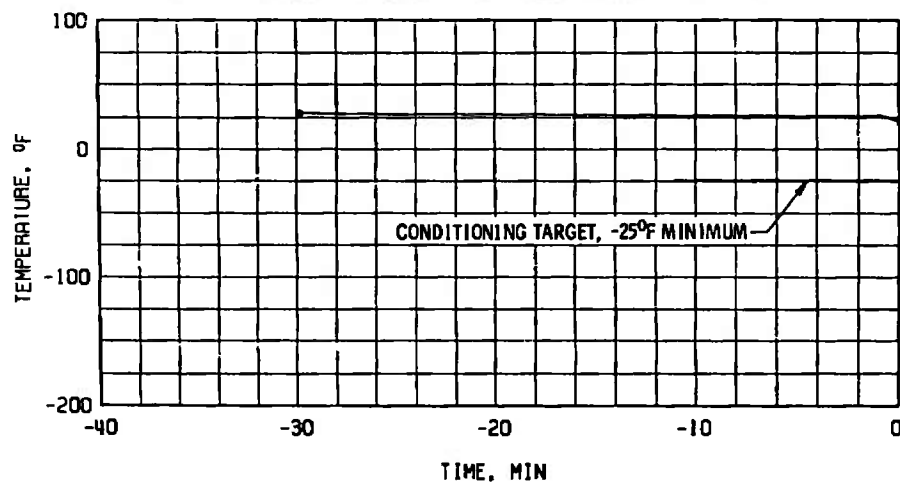




c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 90 Concluded

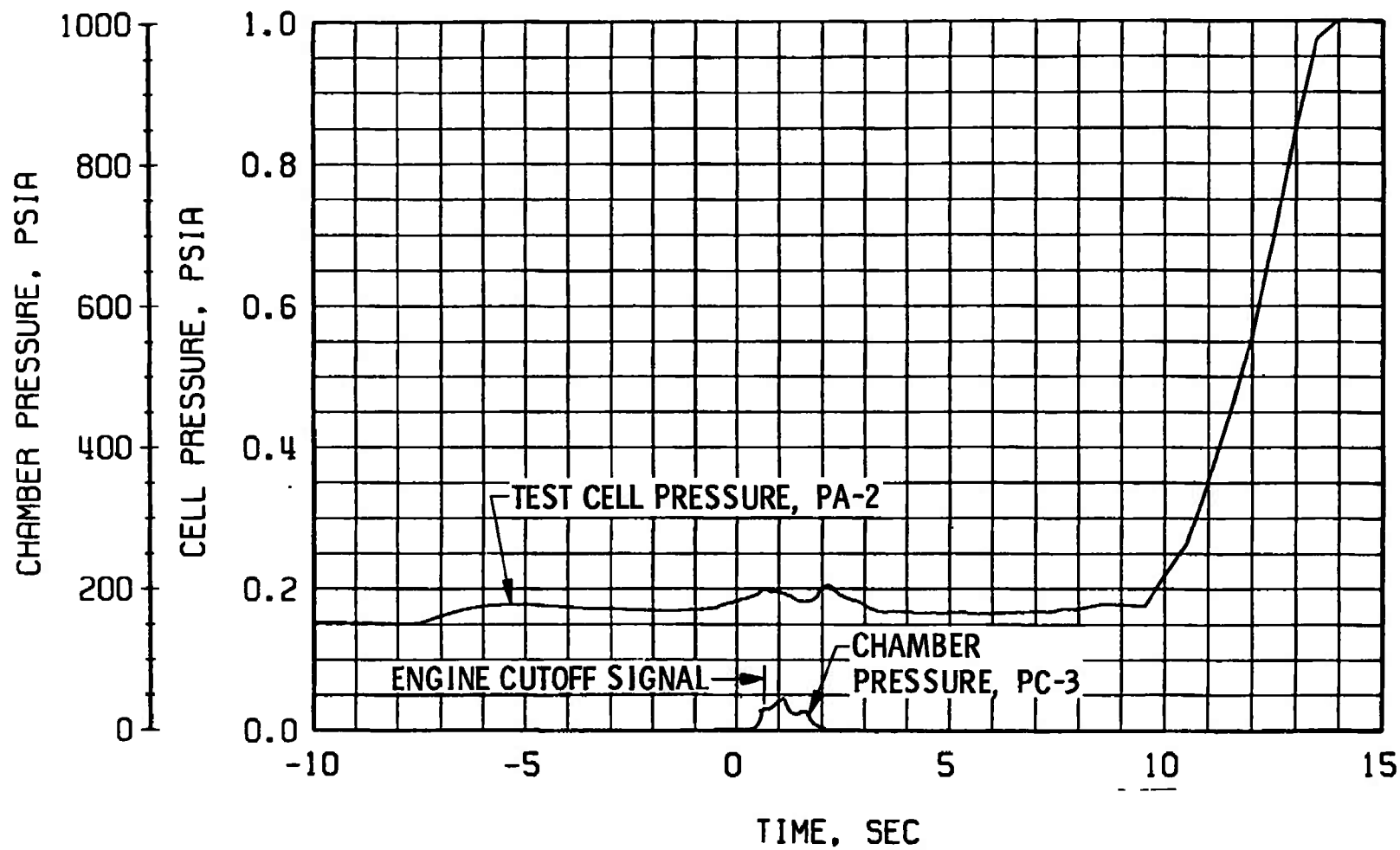
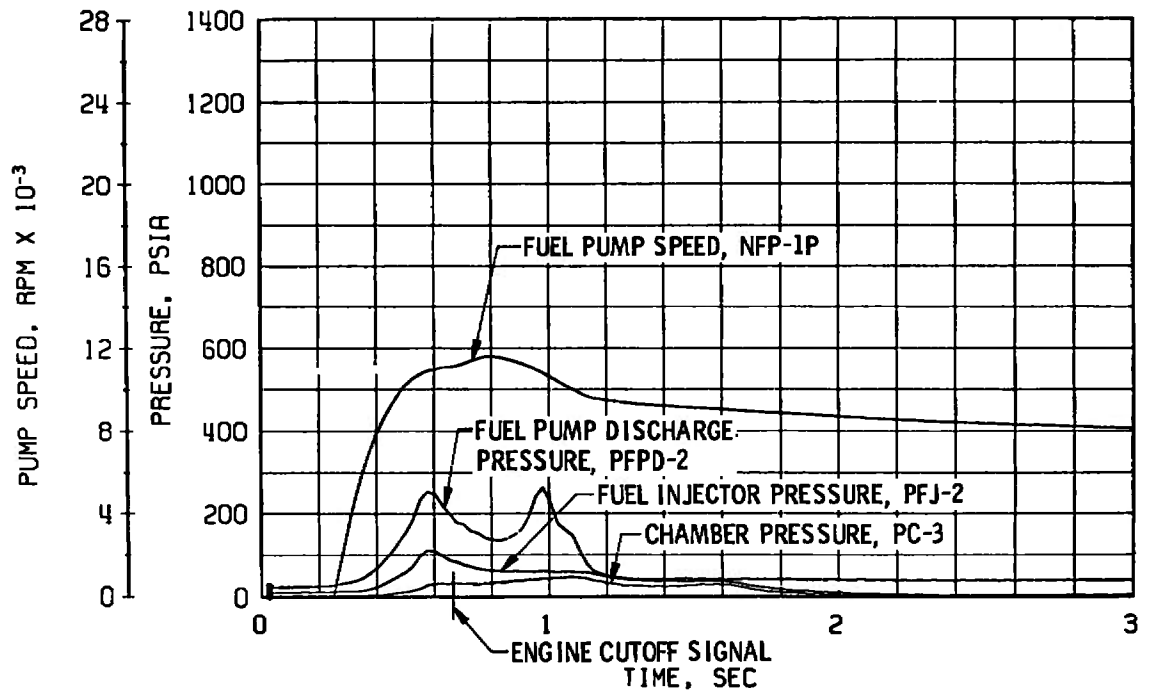
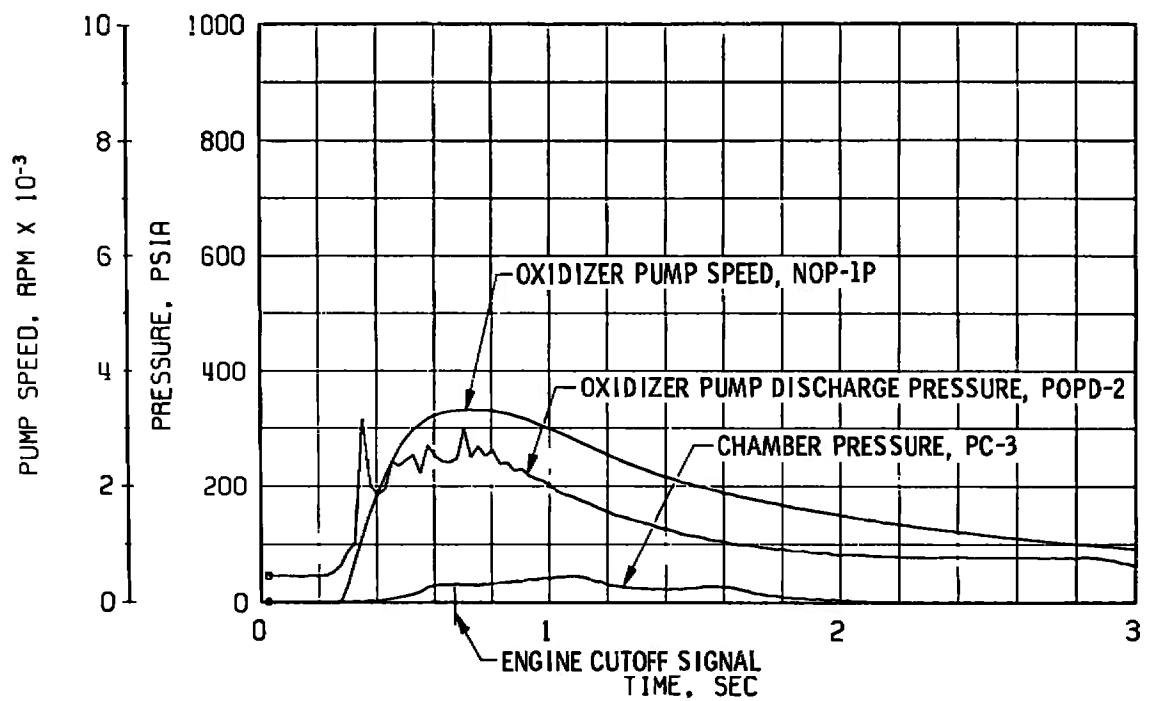


Fig. 91 Engine Ambient and Combustion Chamber Pressures, Firing 32D

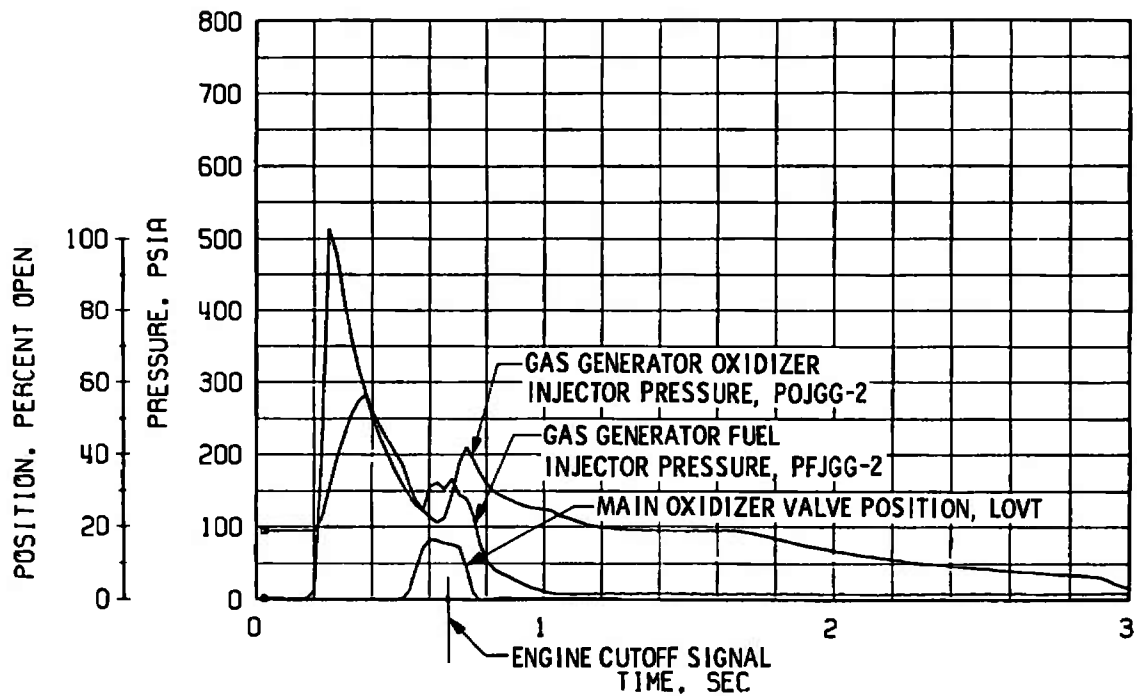


a. Thrust Chamber Fuel System, Start and Shutdown

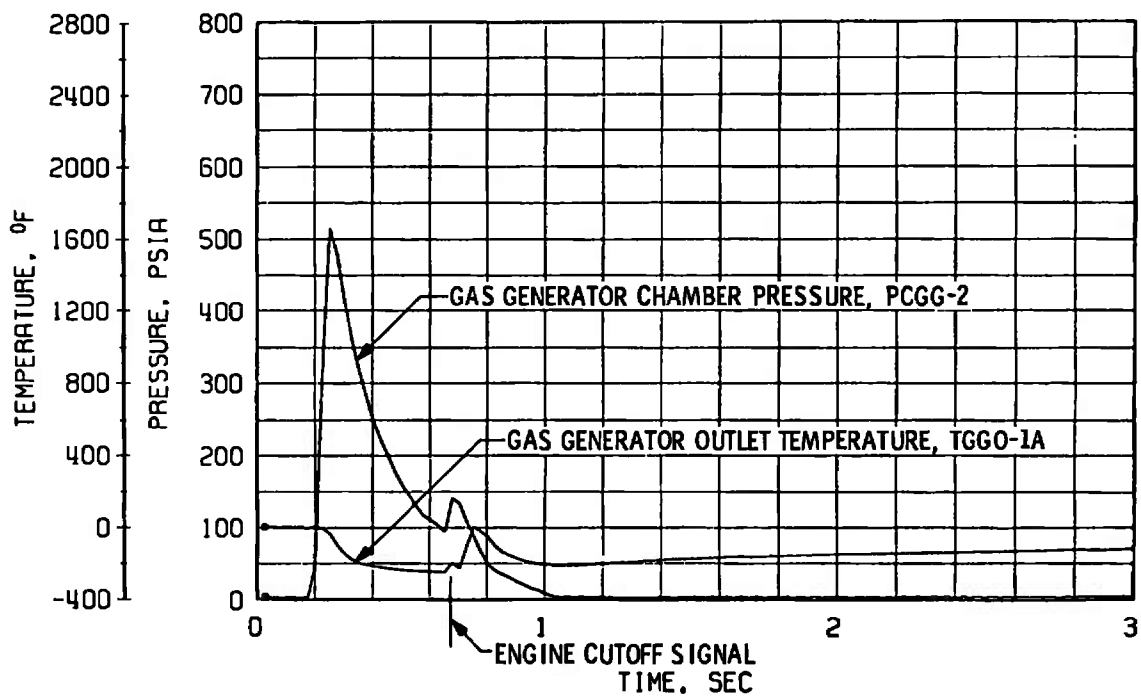


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 92 Engine Transient Operation, Firing 32D



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 92 Concluded

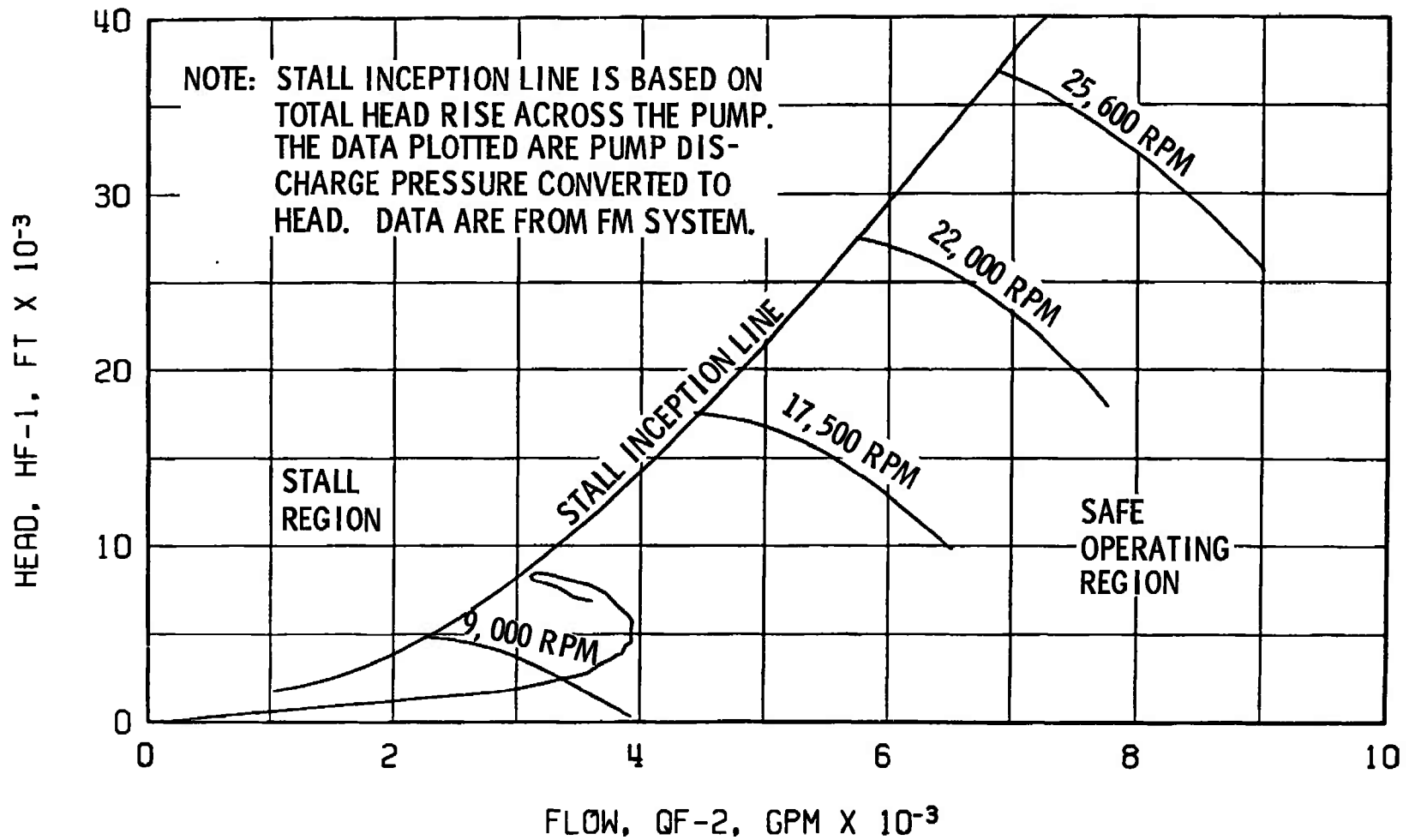
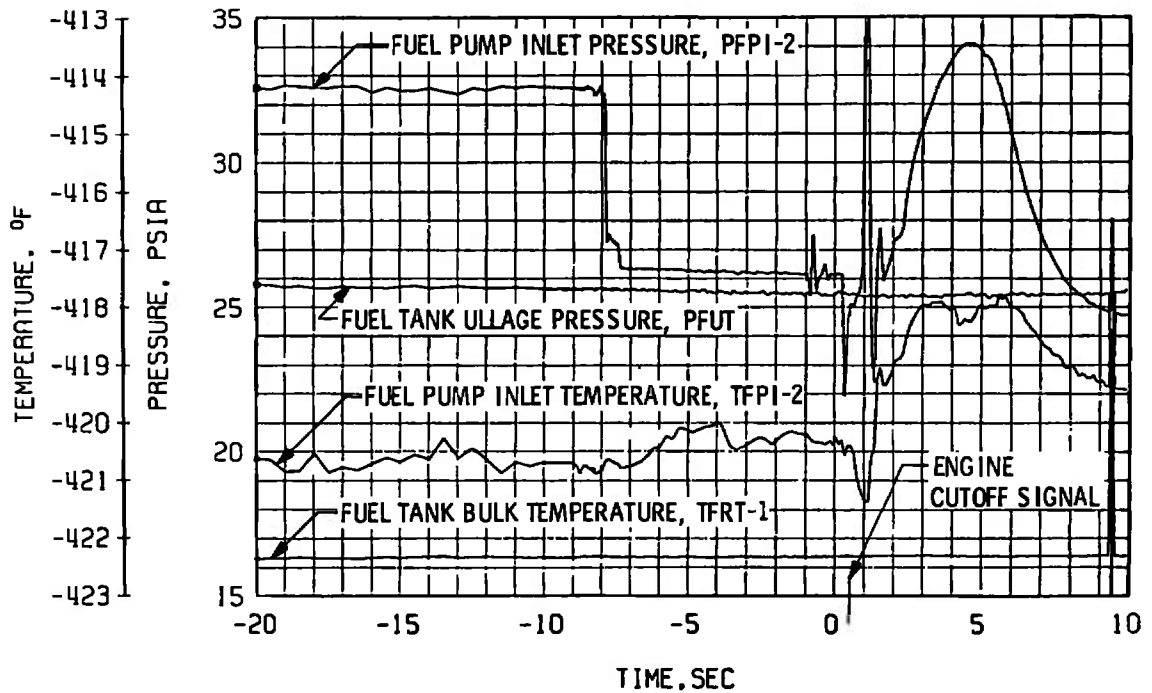
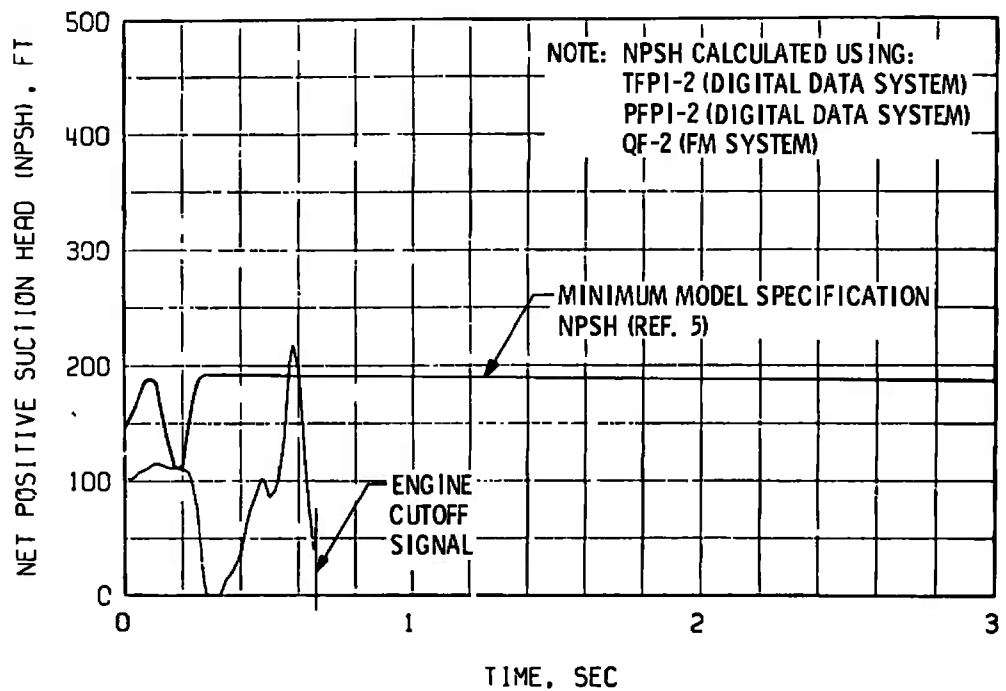


Fig. 93 Fuel Pump Start Transient Performance, Firing 32D

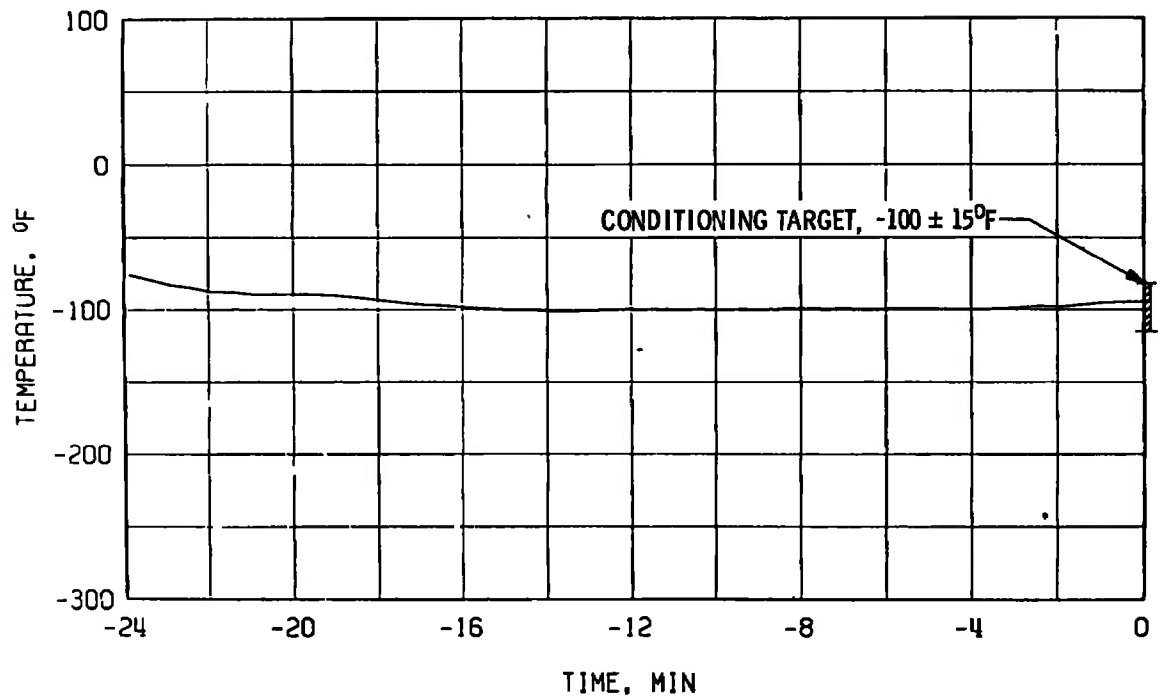


a. Duct Pressure and Temperature Transients

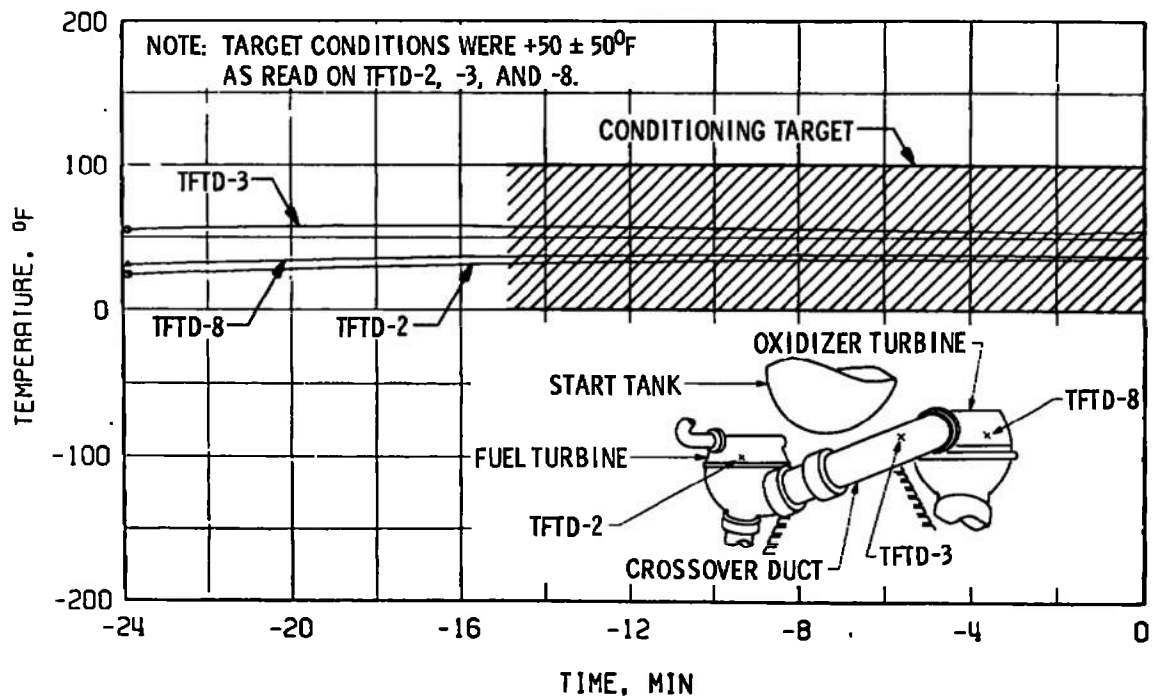


b. Fuel Pump NPSH during Start Transient, Firing 32D

Fig. 94 Fuel Low Pressure Duct Performance, Firing 32D

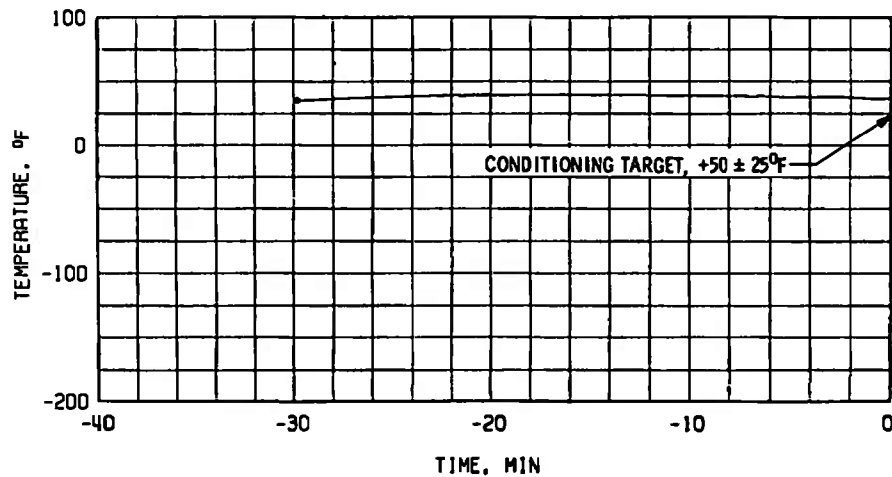
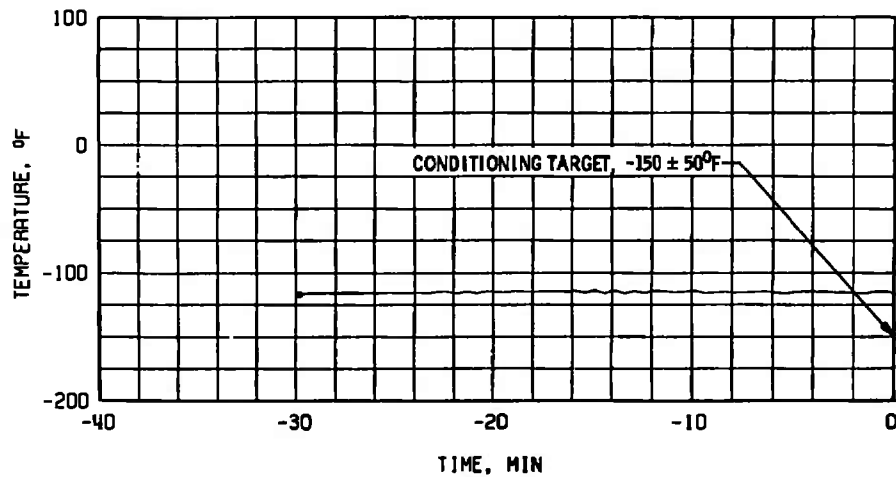
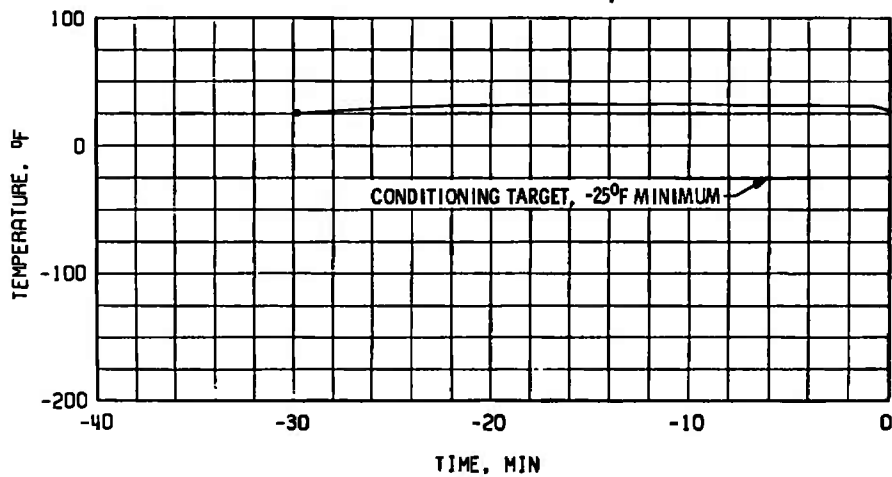


a. Thrust Chamber Throat, TTC-1P



b. Crossover Duct, TFTD

Fig. 95 Thermal Conditioning History of Engine Components, Firing 32E

**c. Start Tank Discharge Valve, TSTDVOC****d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1****e. Gas Generator Valve Body, TGGVRS****Fig. 95 Concluded**



184

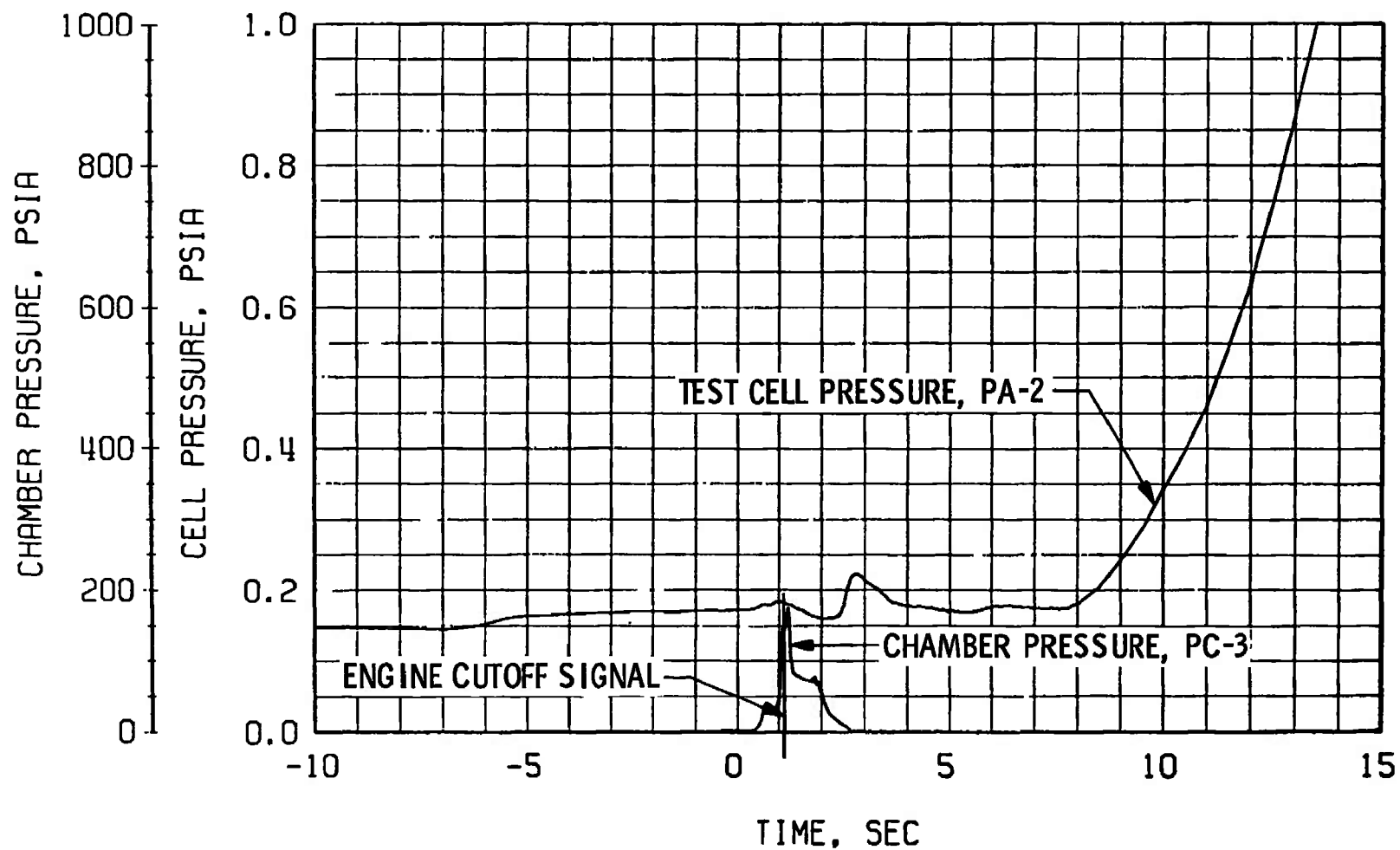
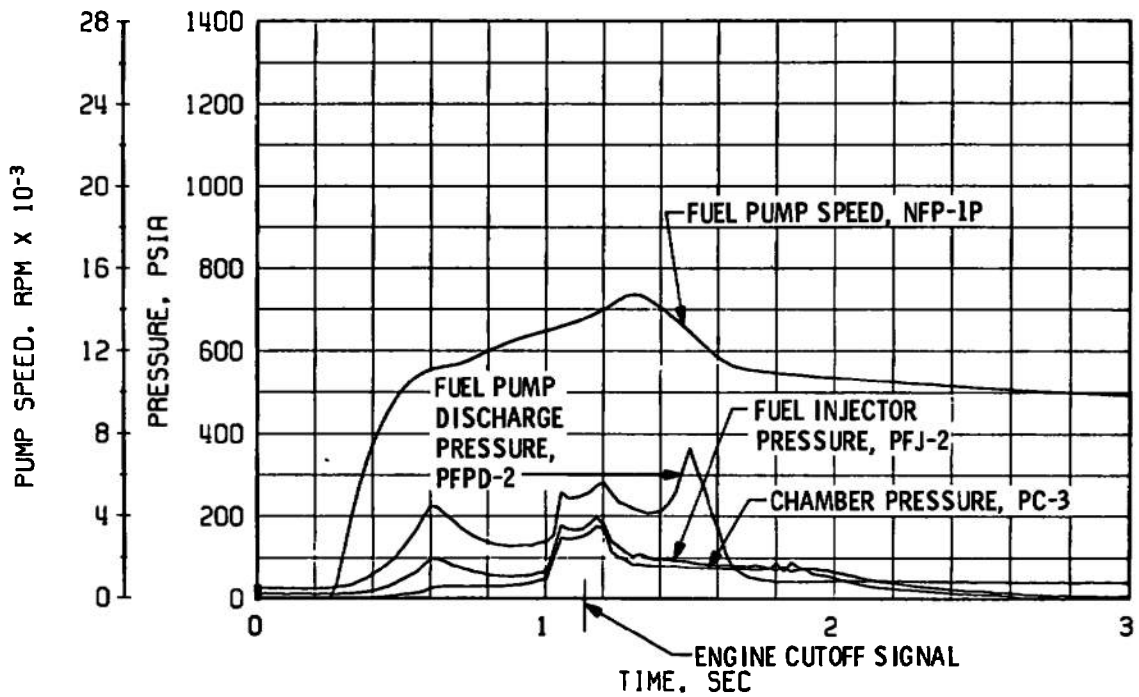
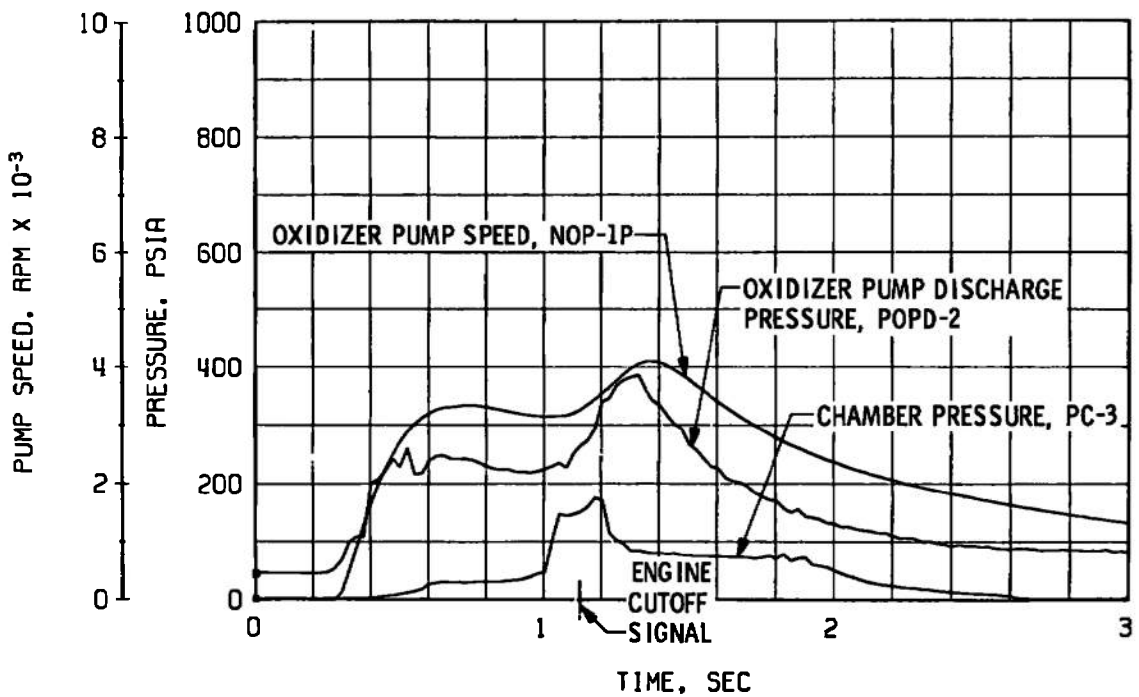


Fig. 96 Engine Ambient and Combustion Chamber Pressures, Firing 32E

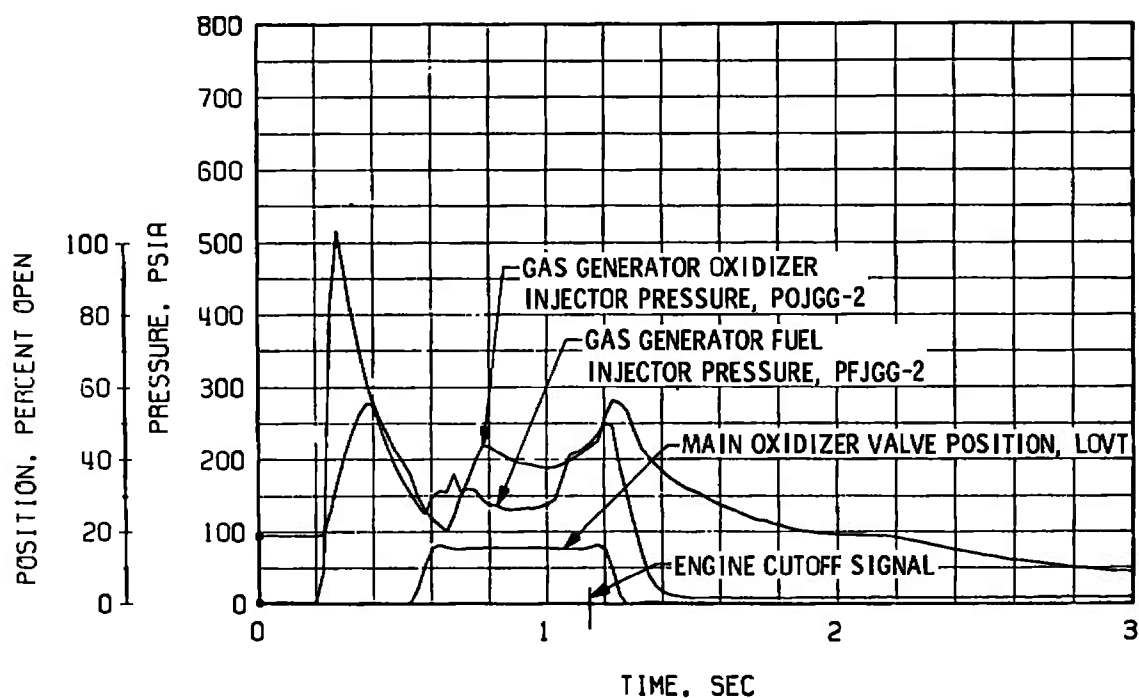


a. Thrust Chamber Fuel System, Start and Shutdown

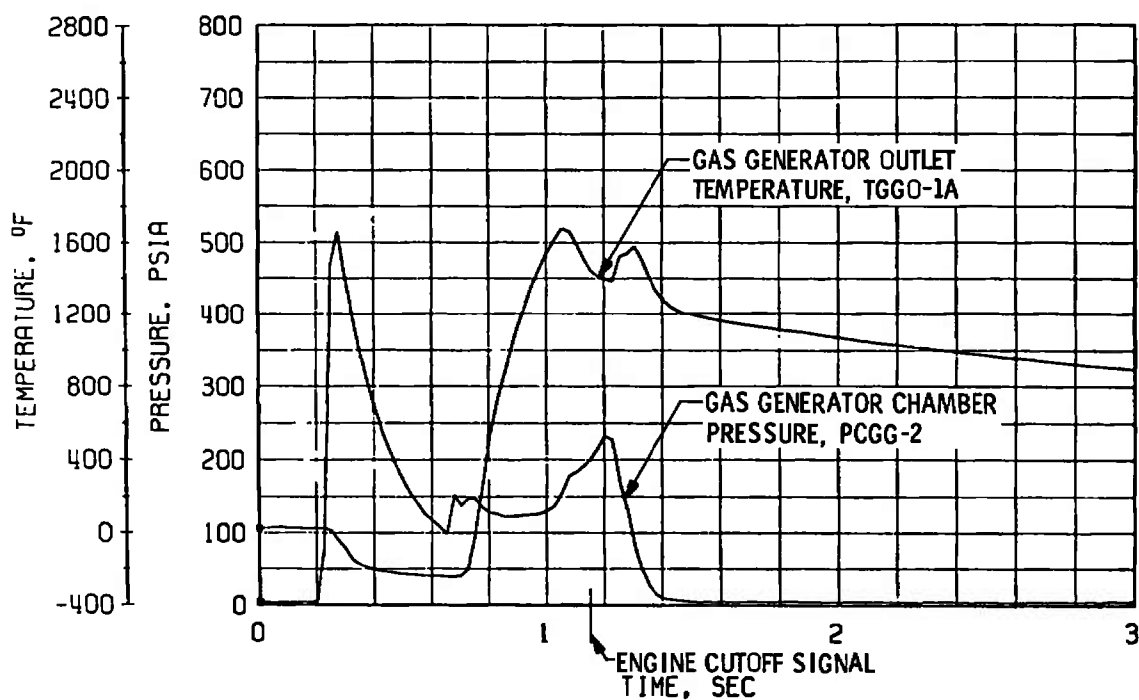


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 97 Engine Transient Operation, Firing 32E



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 97 Concluded

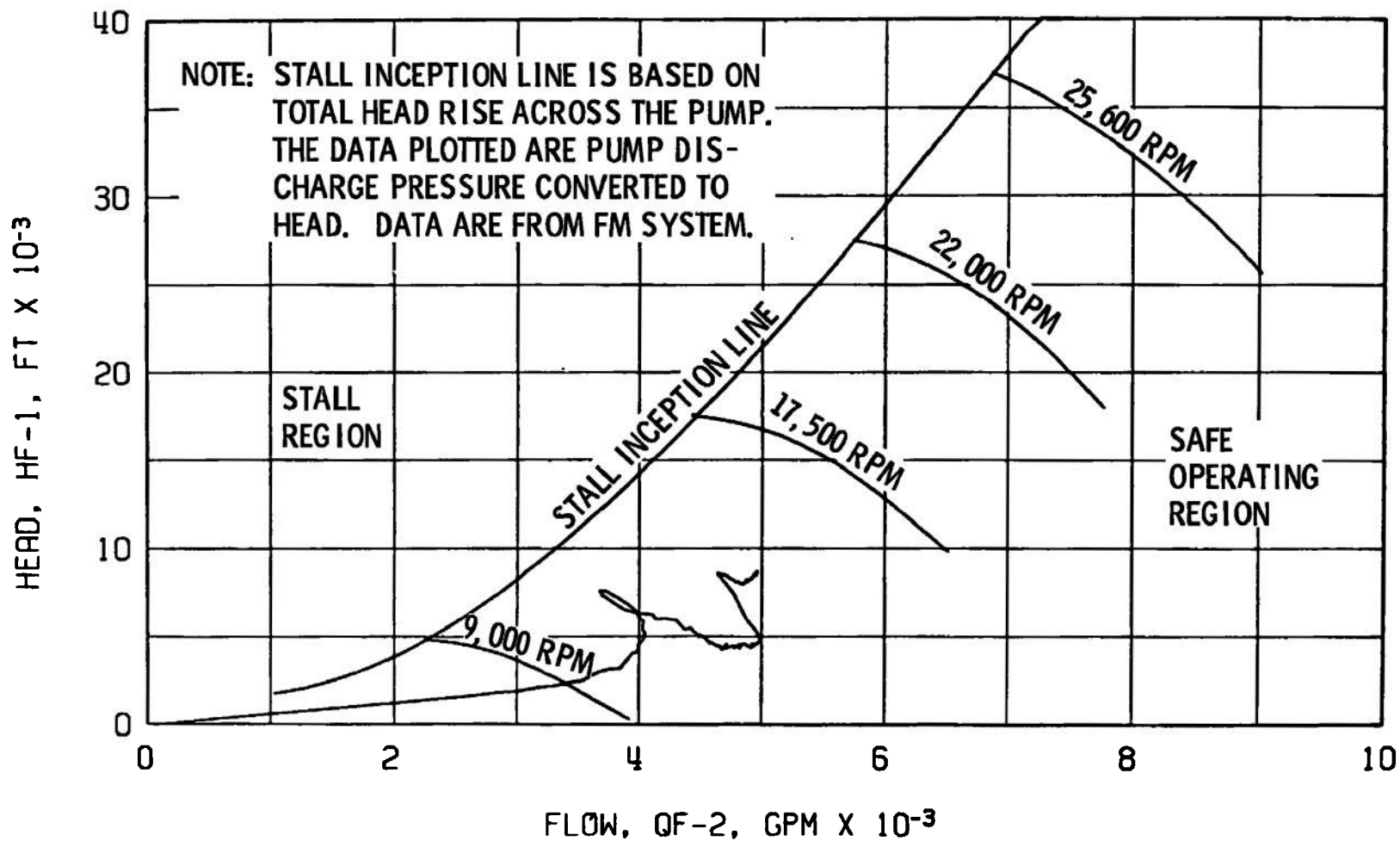
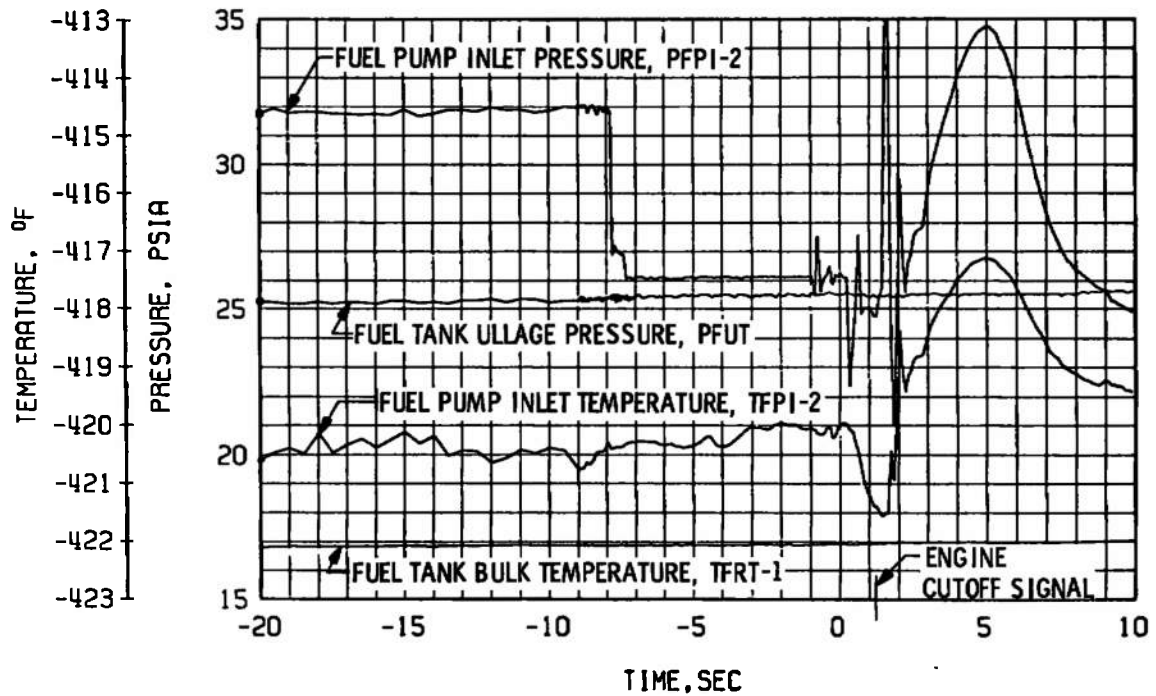
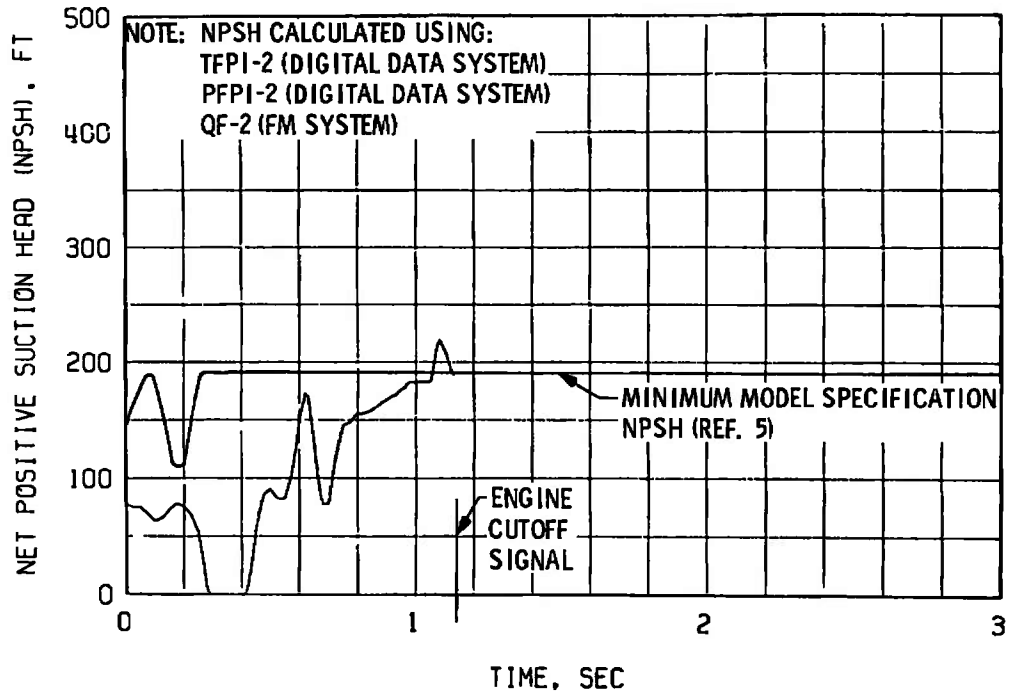


Fig. 98 Fuel Pump Start Transient Performance, Firing 32E

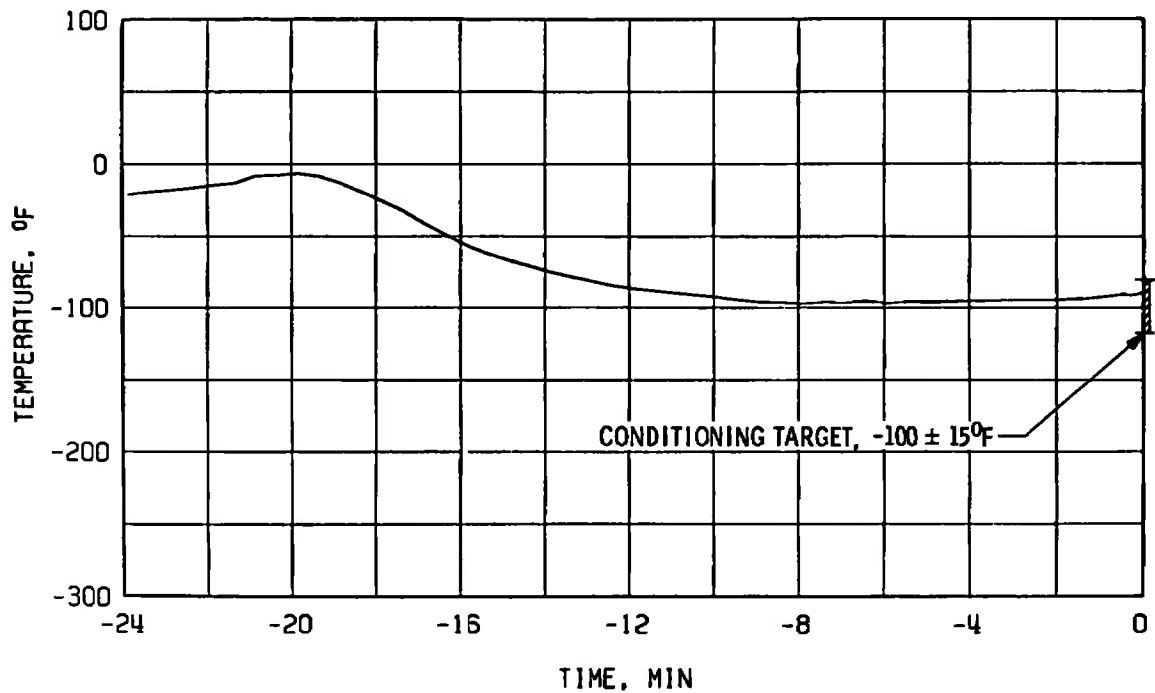


a. Duct Pressure and Temperature Transients

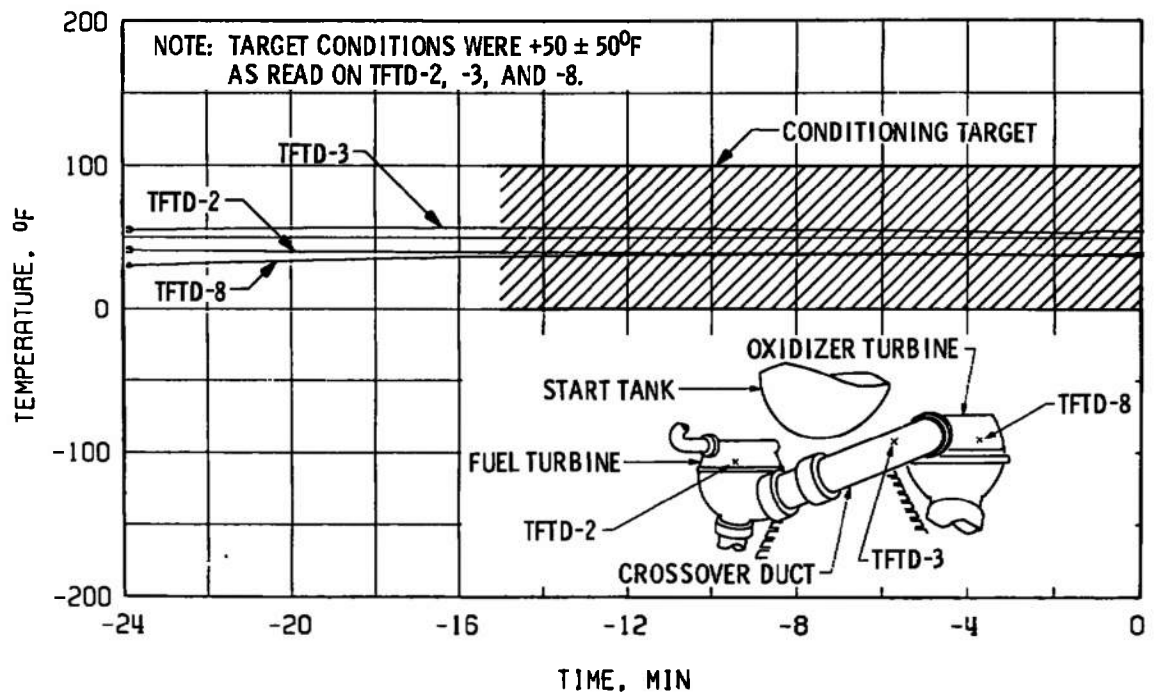


b. Fuel Pump NPSH during Start Transient, Firing 32E

Fig. 99 Fuel Low Pressure Duct Performance, Firing 32E

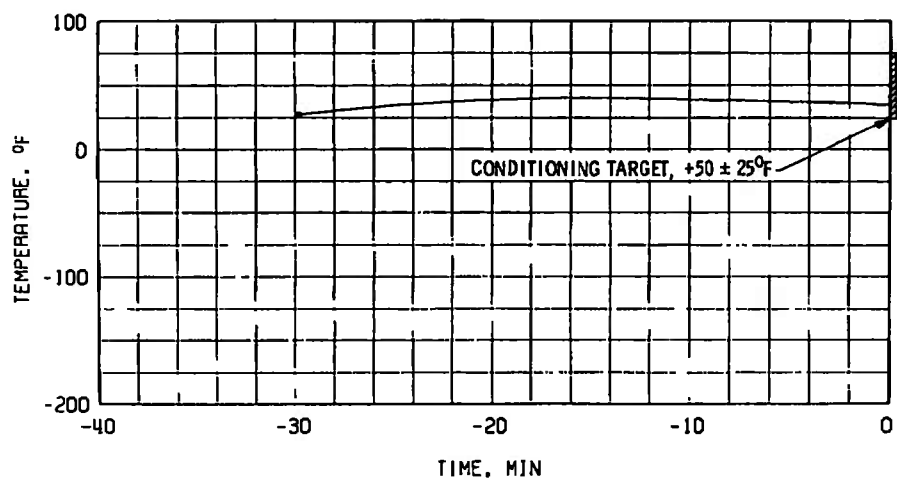
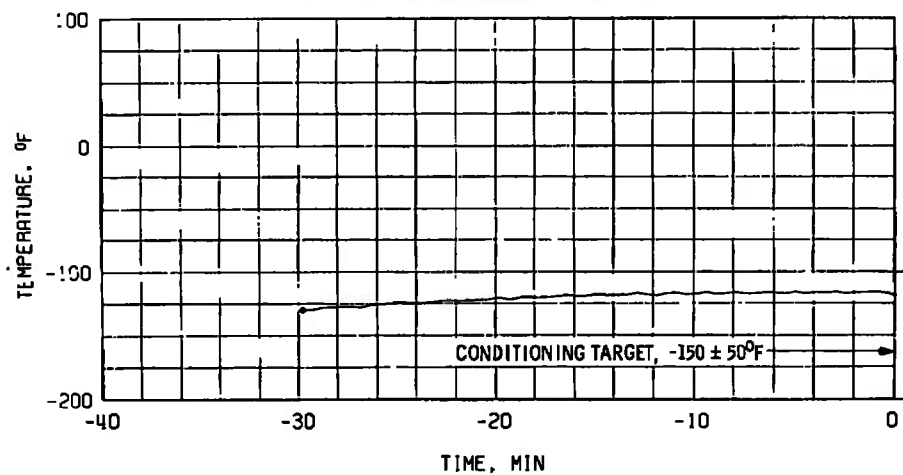
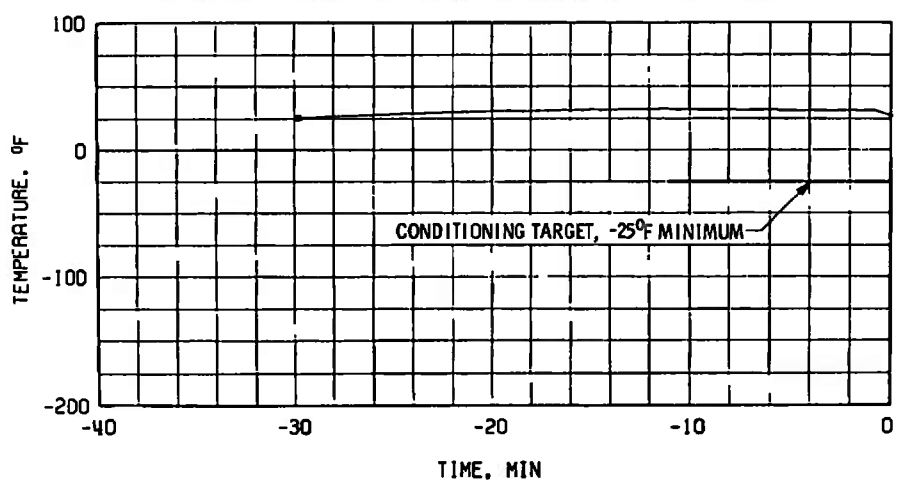


a. Thrust Chamber Throat, TTC-1P



b. Crossover Duct, TFTD

Fig. 100 Thermal Conditioning History of Engine Components, Firing 32F

**c. Start Tank Discharge Valve, TSTDVOC****d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1****e. Gas Generator Body Temperature, TGGVRS****Fig. 100 Concluded**

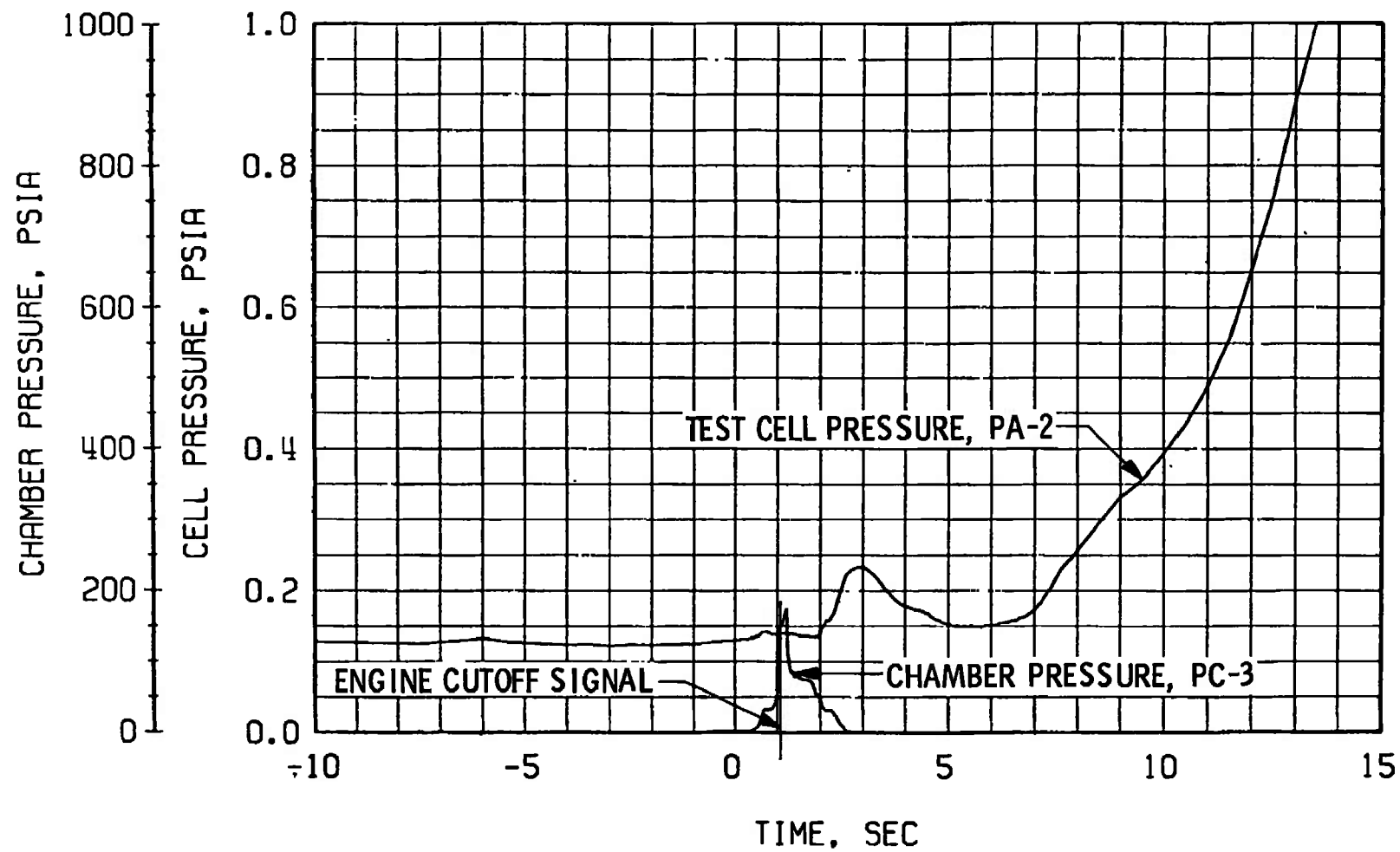
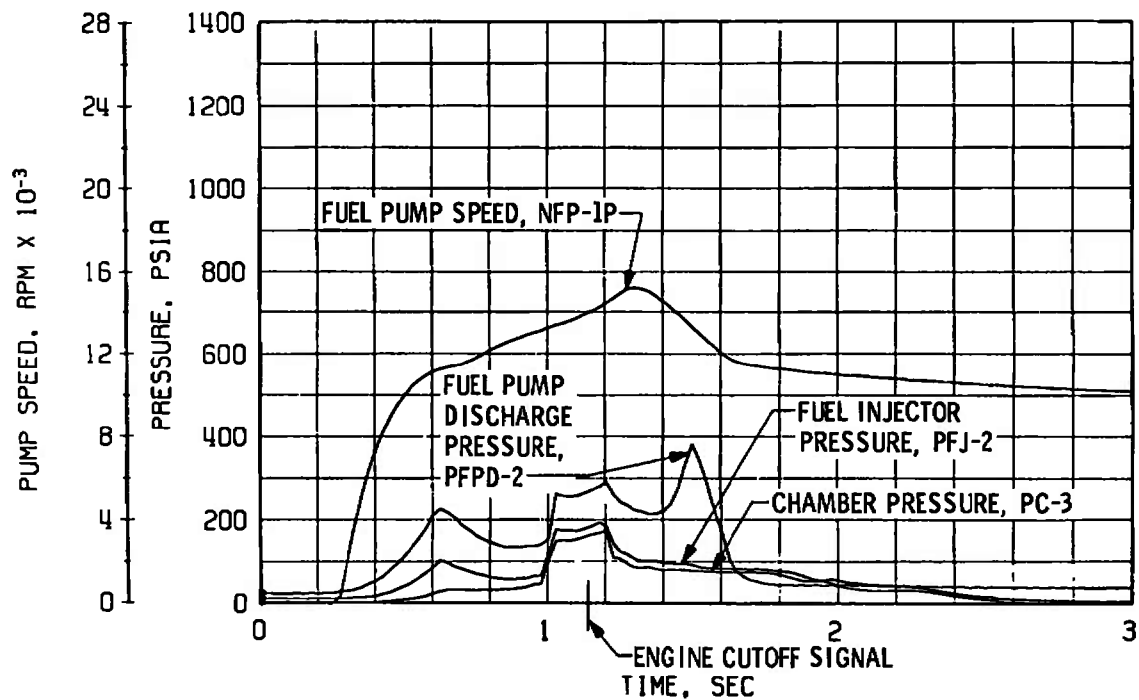
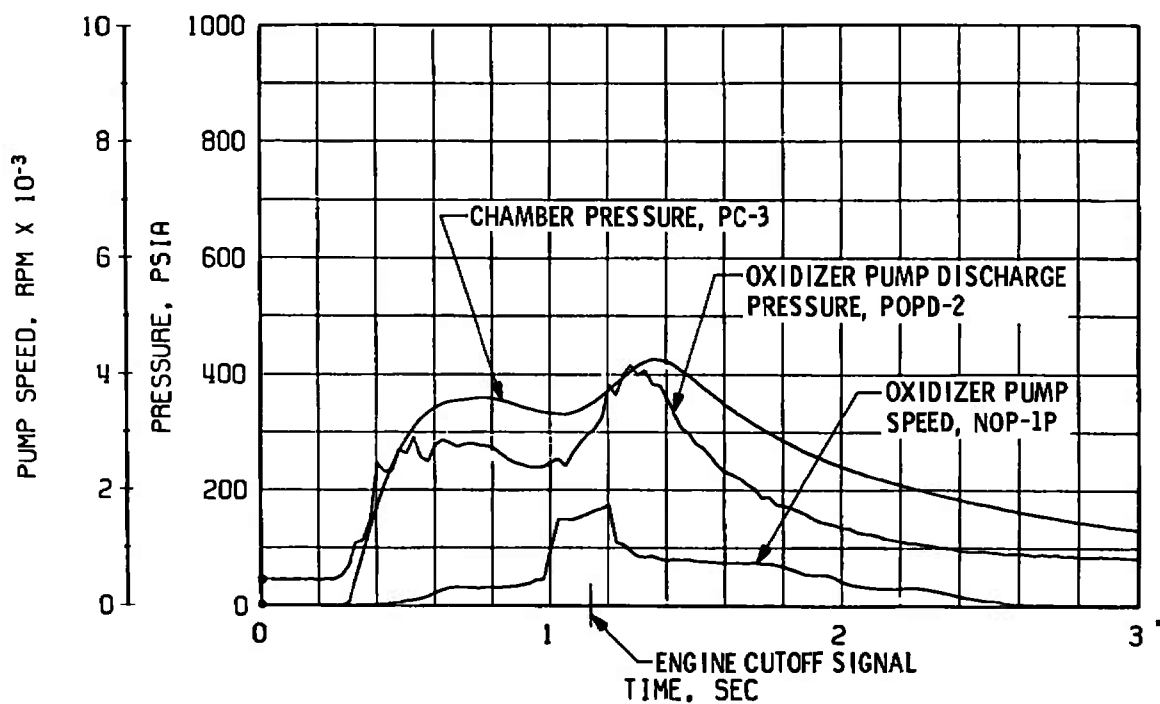


Fig. 101 Engine Ambient and Combustion Chamber Pressures, Firing 32F



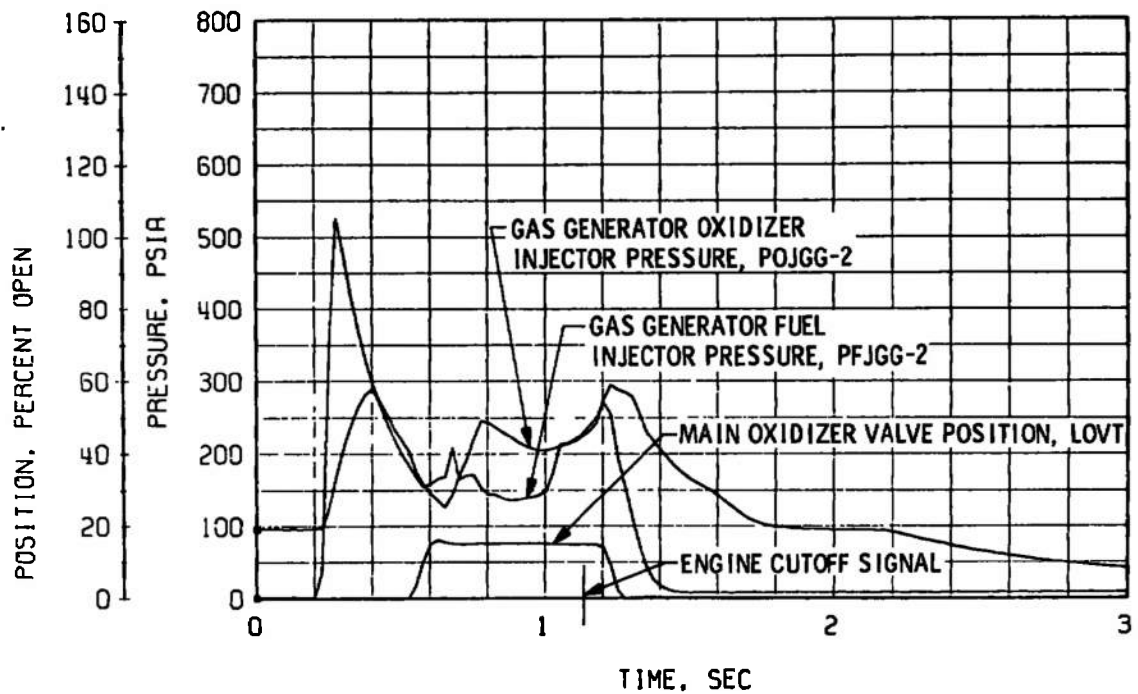


a. Thrust Chamber Fuel System, Start and Shutdown

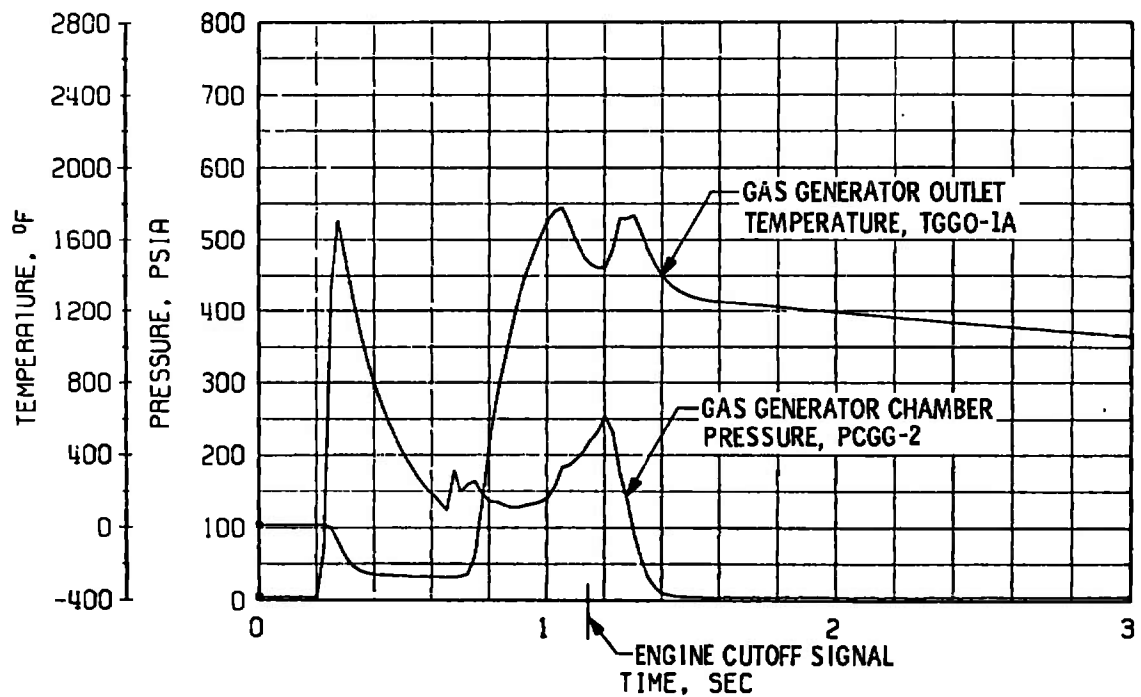


b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 102 Engine Transient Operation, Firing 32F



c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 102 Concluded

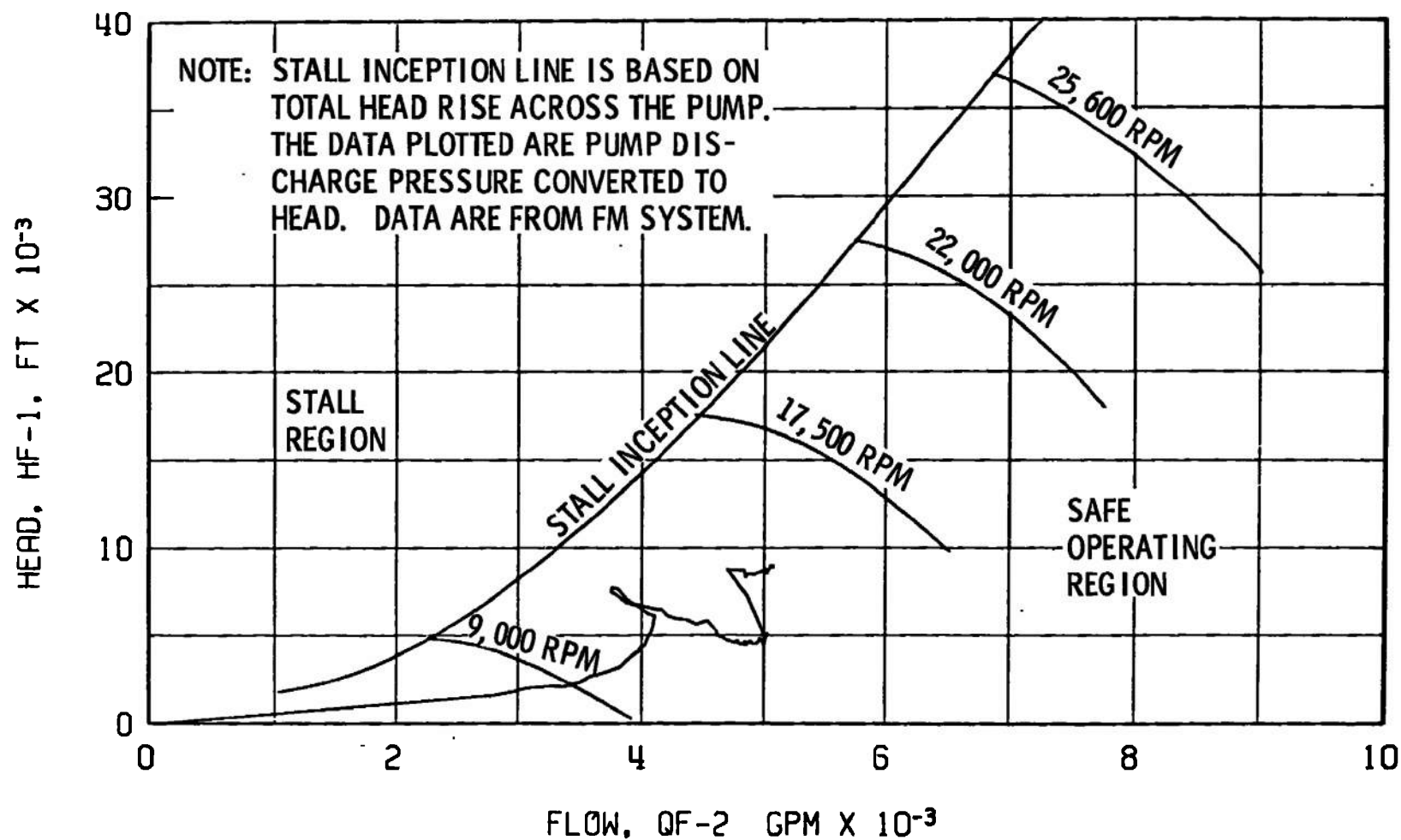
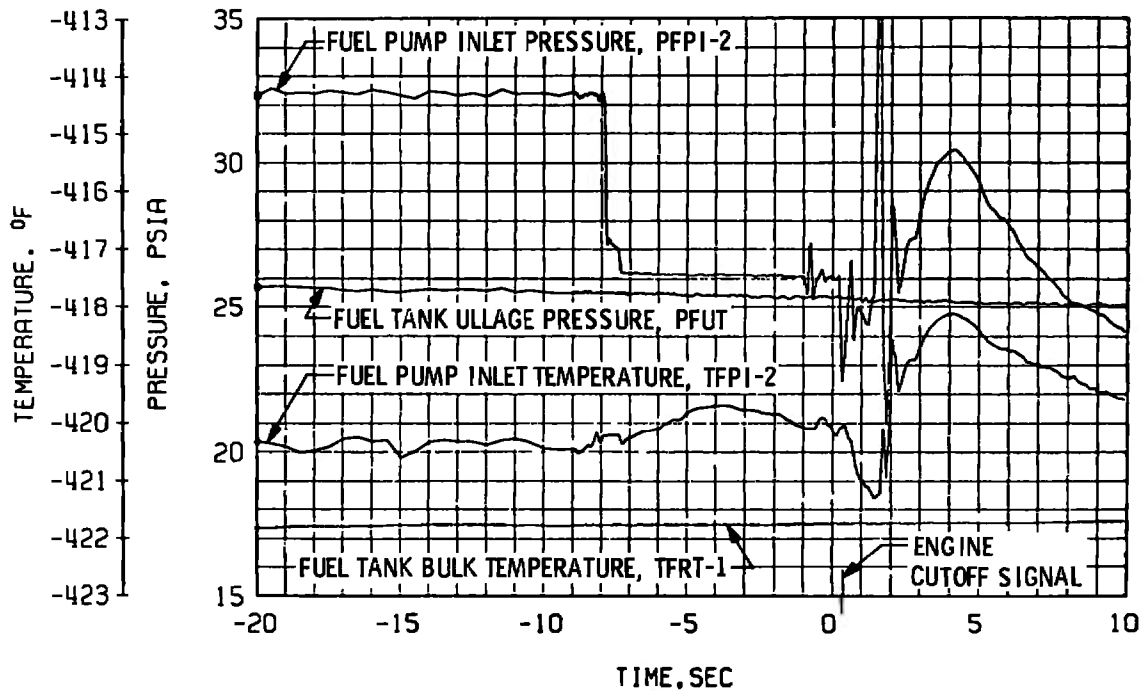
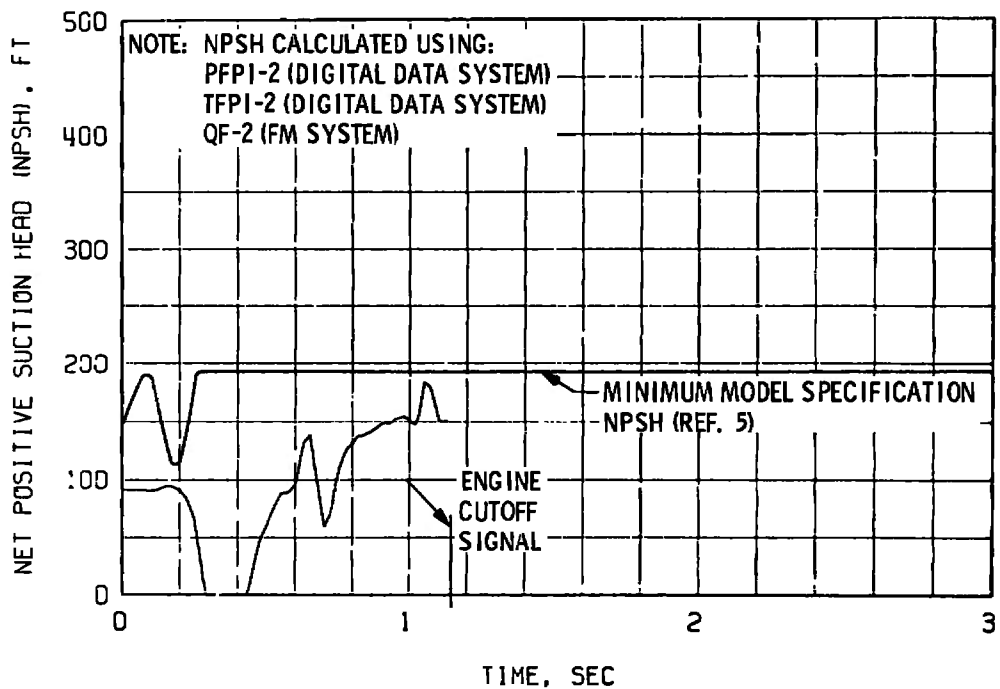


Fig. 103 Fuel Pump Start Transient Performance, Firing 32F

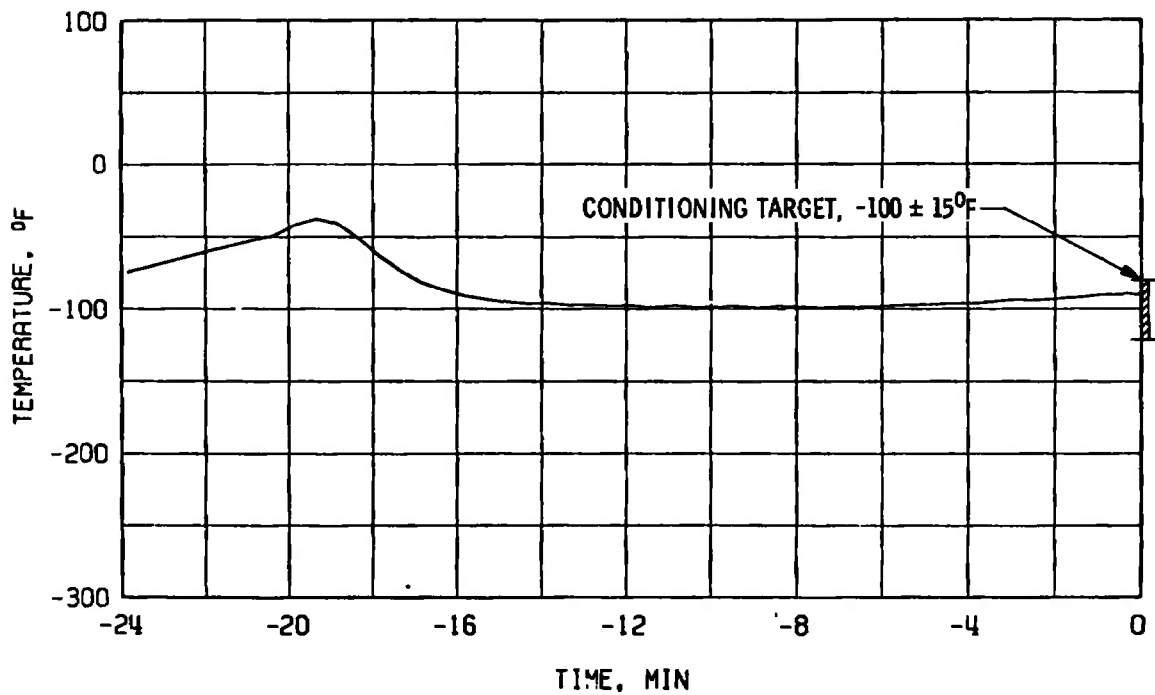


a. Duct Pressure and Temperature Transients

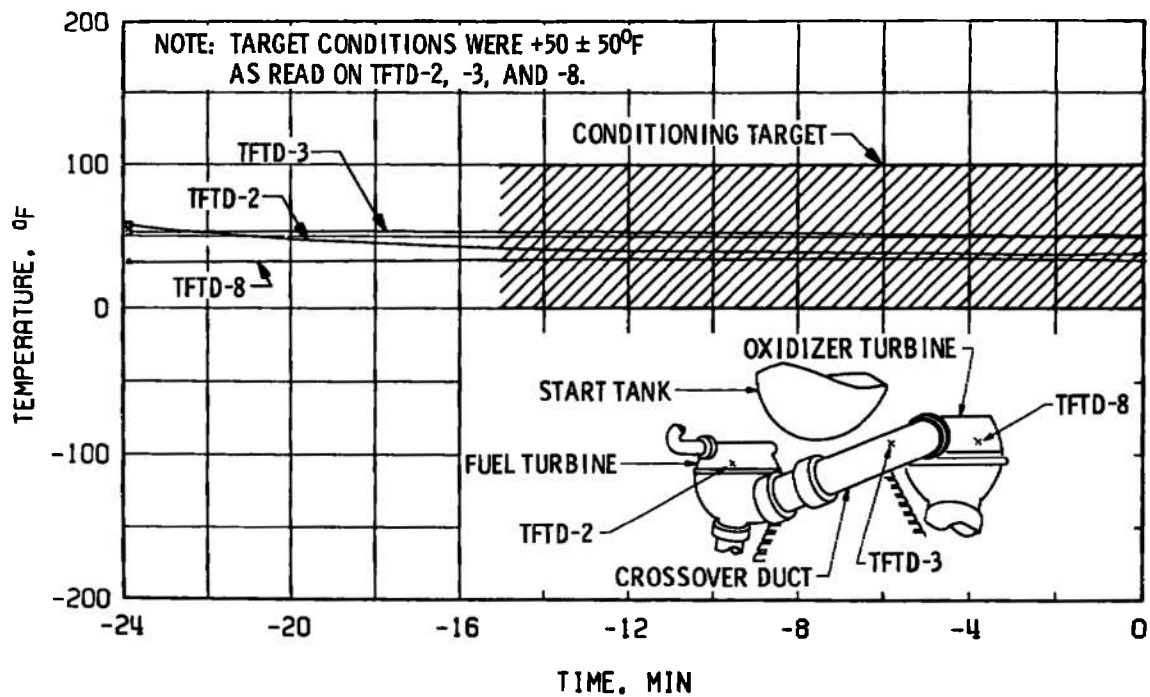


b. Fuel Pump NPSH during Start Transient, Firing 32F

Fig. 104 Fuel Low Pressure Duct Performance, Firing 32F

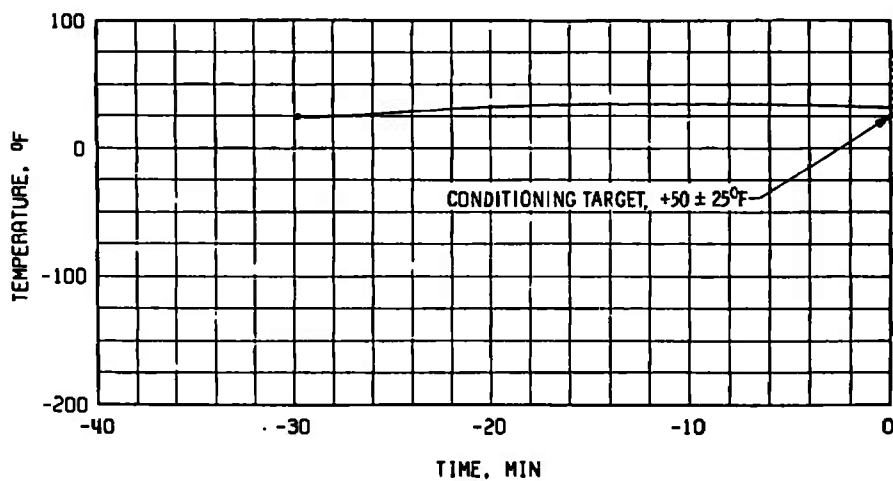


a. Thrust Chamber Throat, TTC-1P

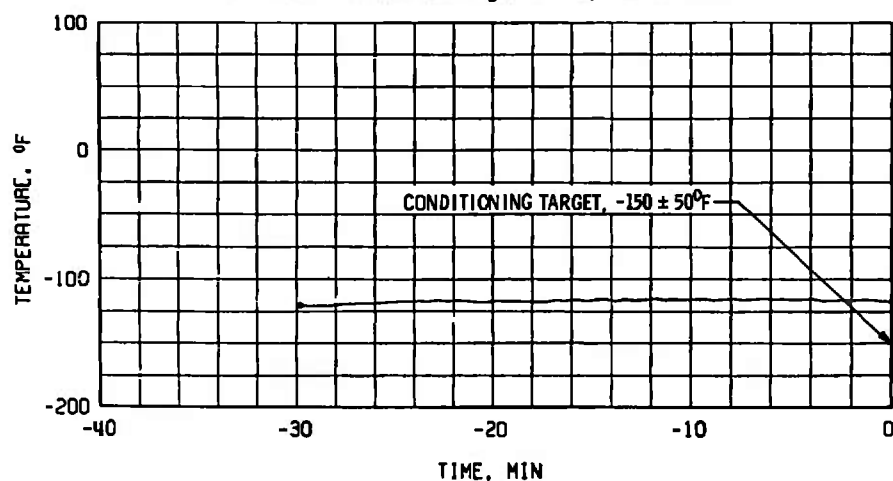


b. Crossover Duct, TFTD

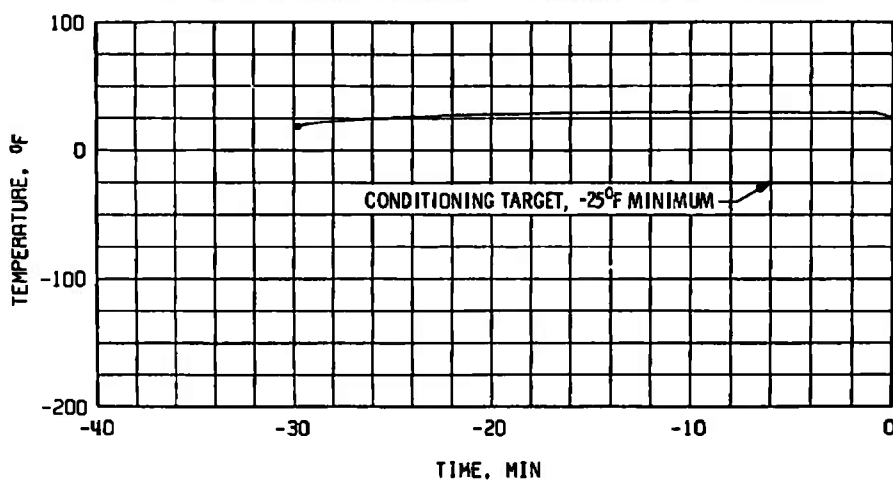
Fig. 105 Thermal Conditioning History of Engine Components, Firing 32G



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1



e. Gas Generator Body Temperature, TGGVRS

Fig. 105 Concluded

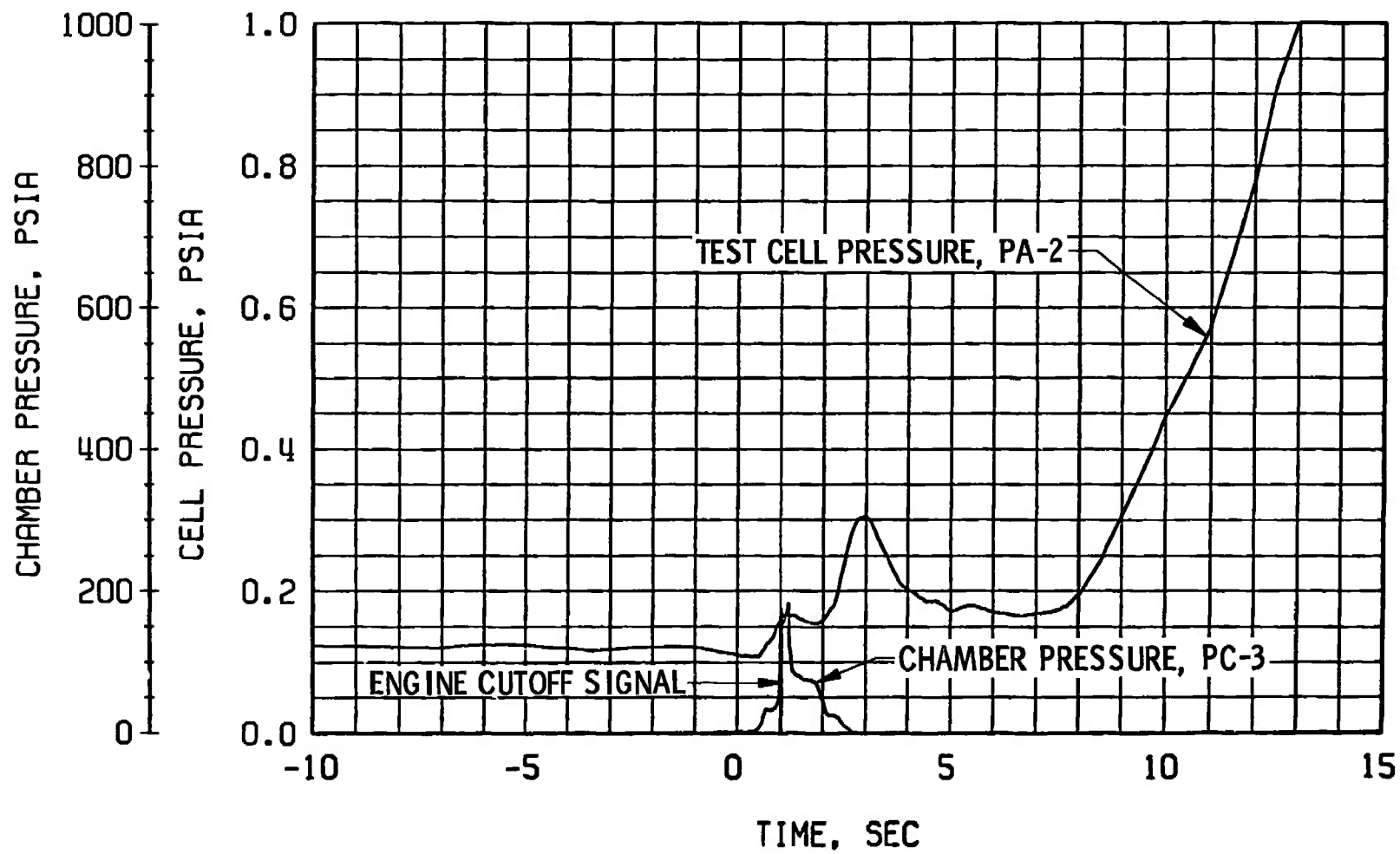
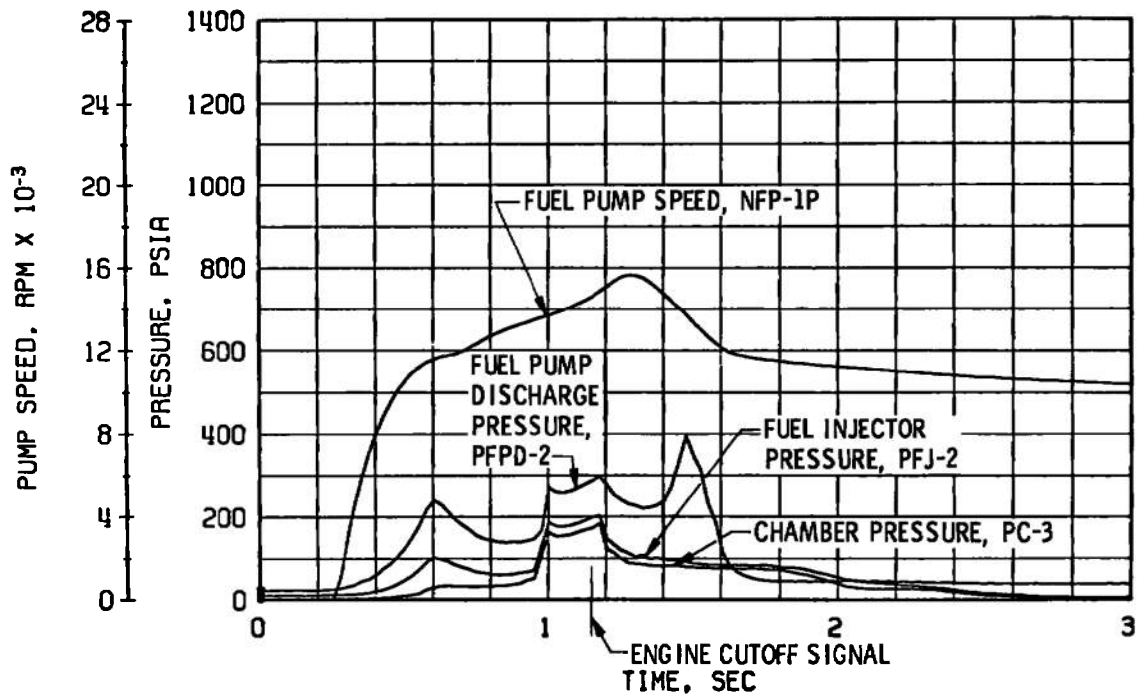
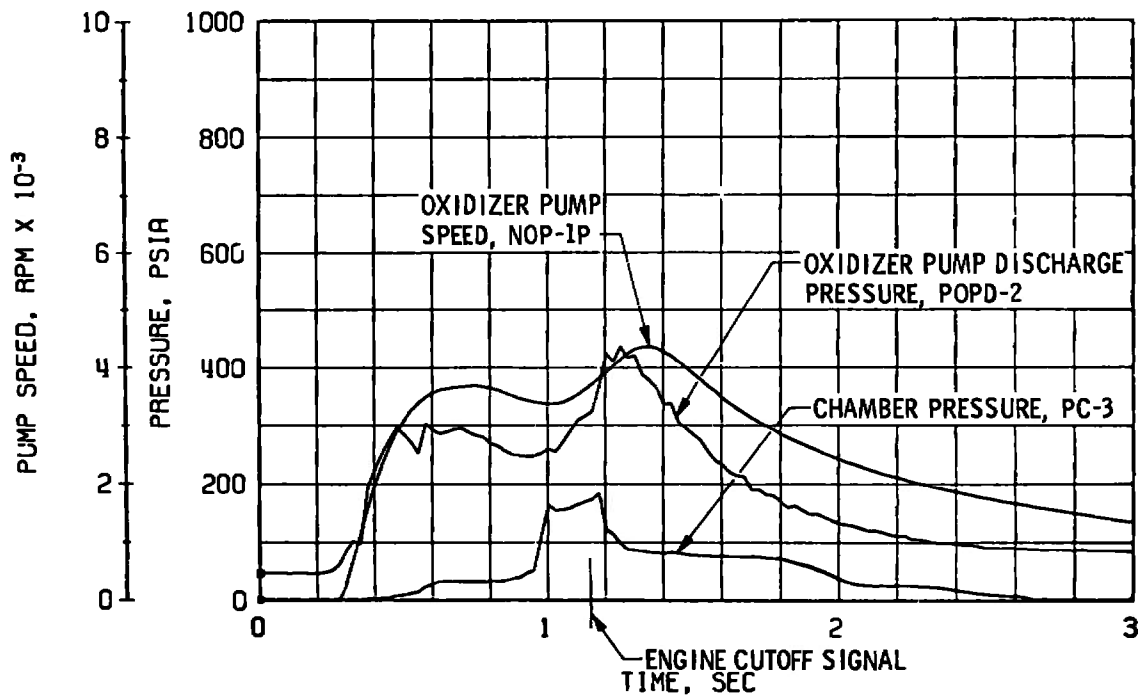


Fig. 106 Engine Ambient and Combustion Chamber Pressures, Firing 32G



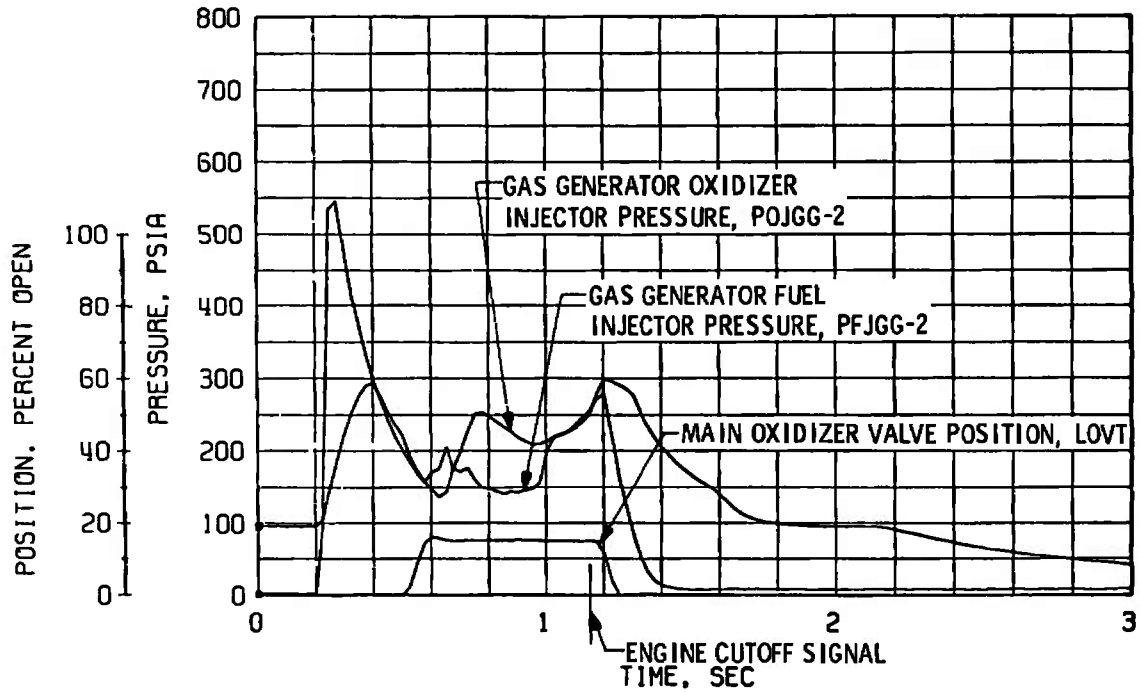
a. Thrust Chamber Fuel System, Start and Shutdown



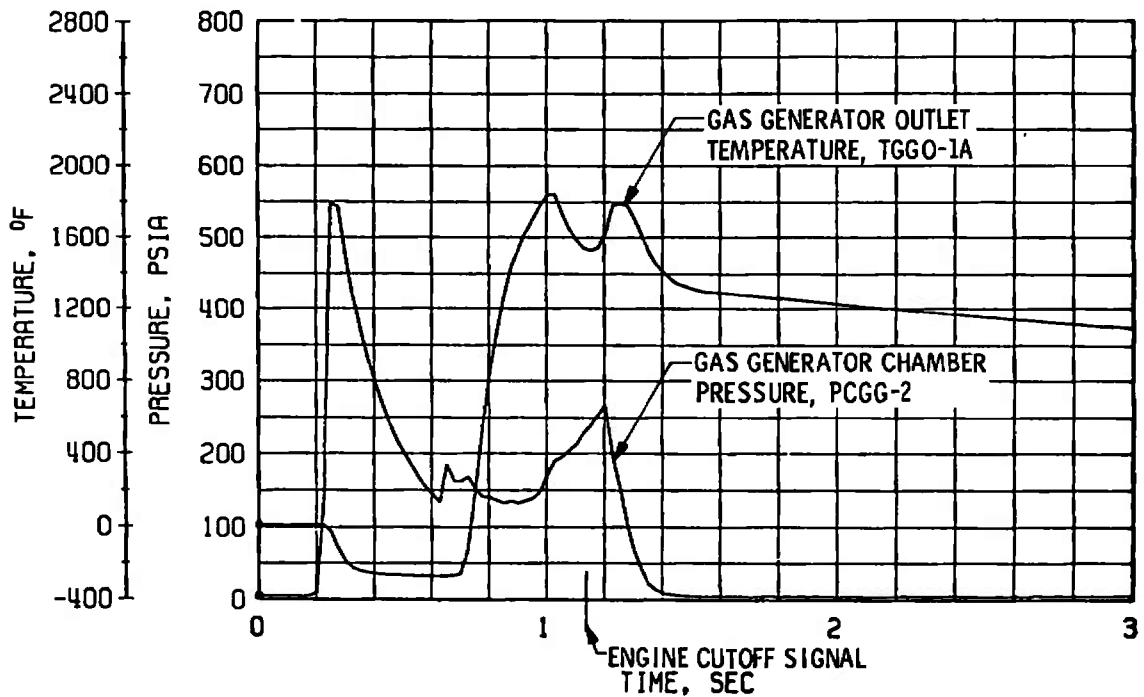
b. Thrust Chamber Oxidizer System, Start and Shutdown

Fig. 107 Engine Transient Operation, Firing 32G





c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start and Shutdown



d. Gas Generator Chamber Pressure and Temperature, Start and Shutdown

Fig. 107 Concluded

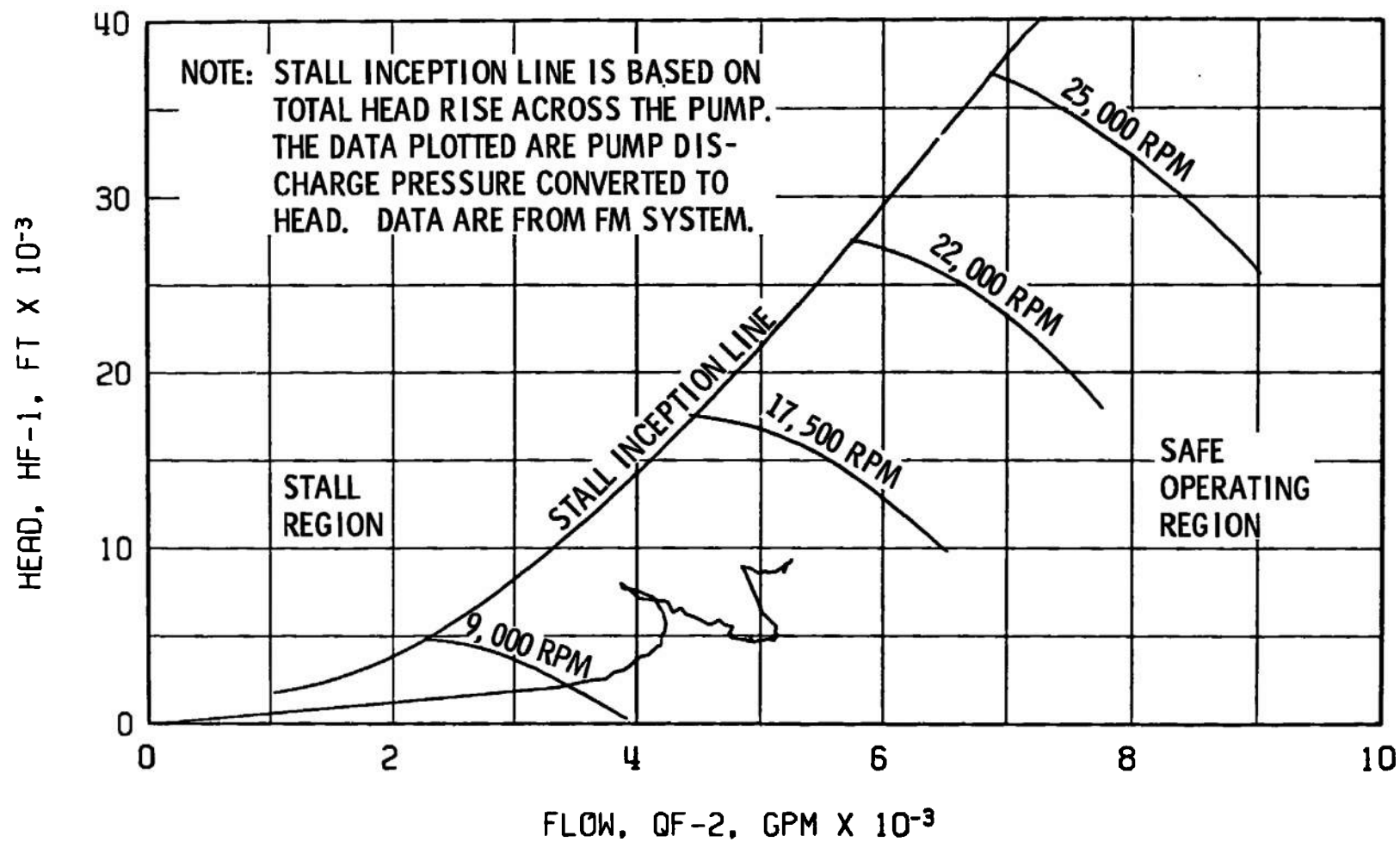
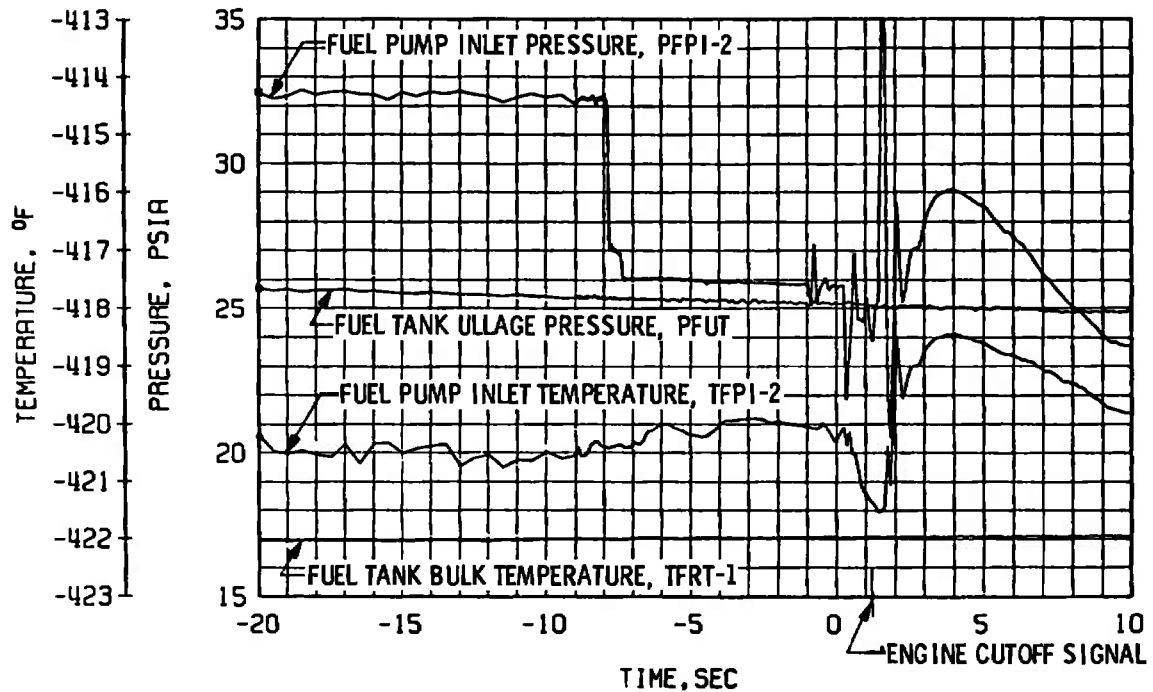
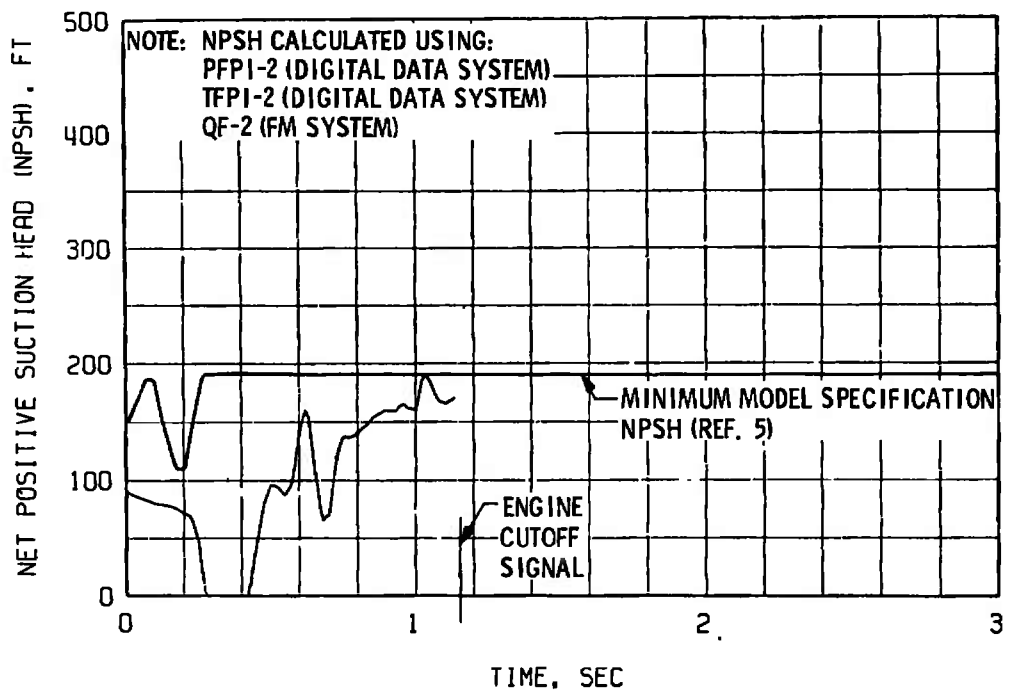


Fig. 108 Fuel Pump Start Transient Performance, Firing 32G

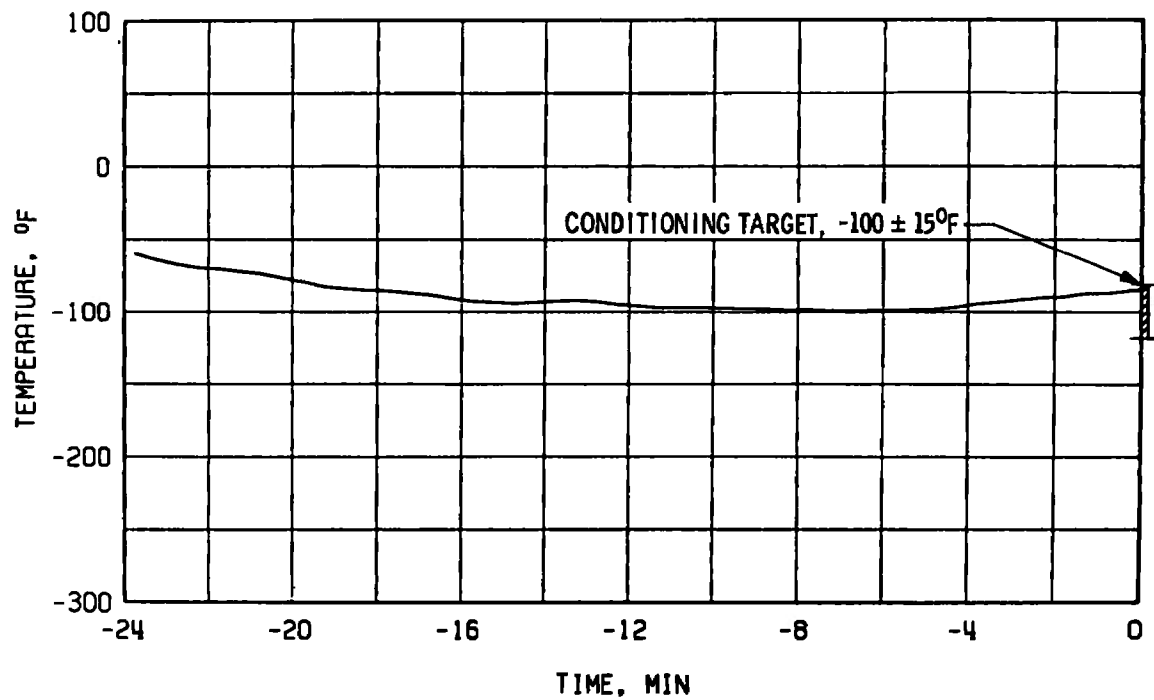


a. Duct Pressure and Temperature Transients

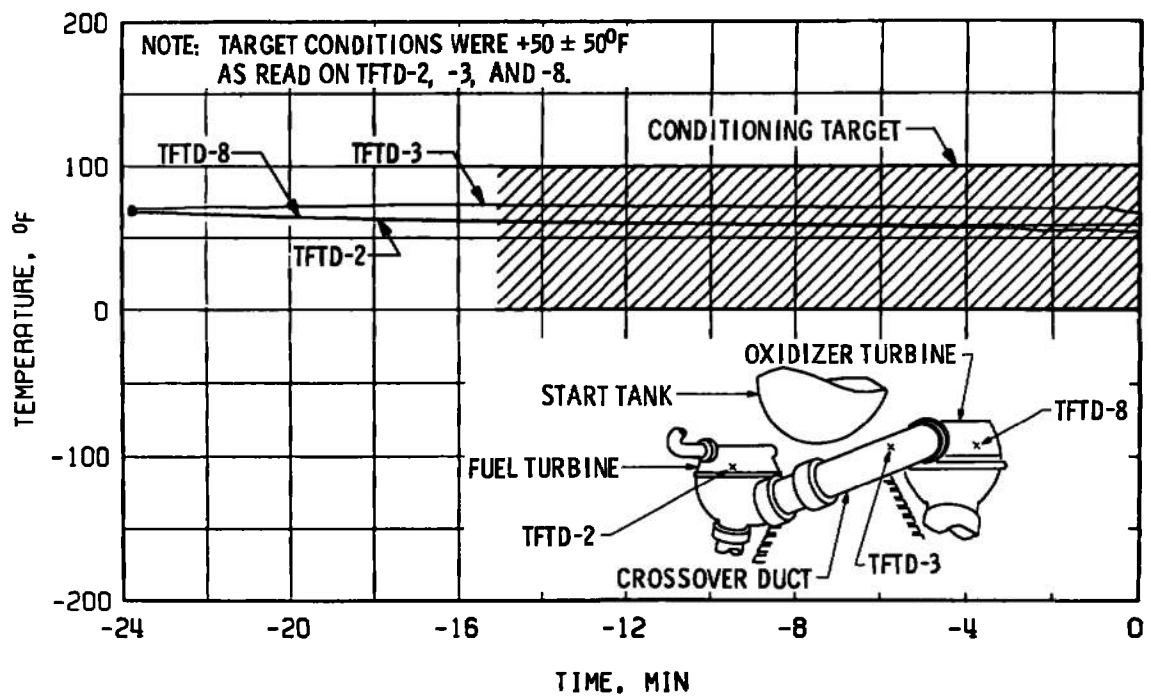


b. Fuel Pump NPSH during Start Transient, Firing 32G

Fig. 109 Fuel Low Pressure Duct Performance, Firing 32G

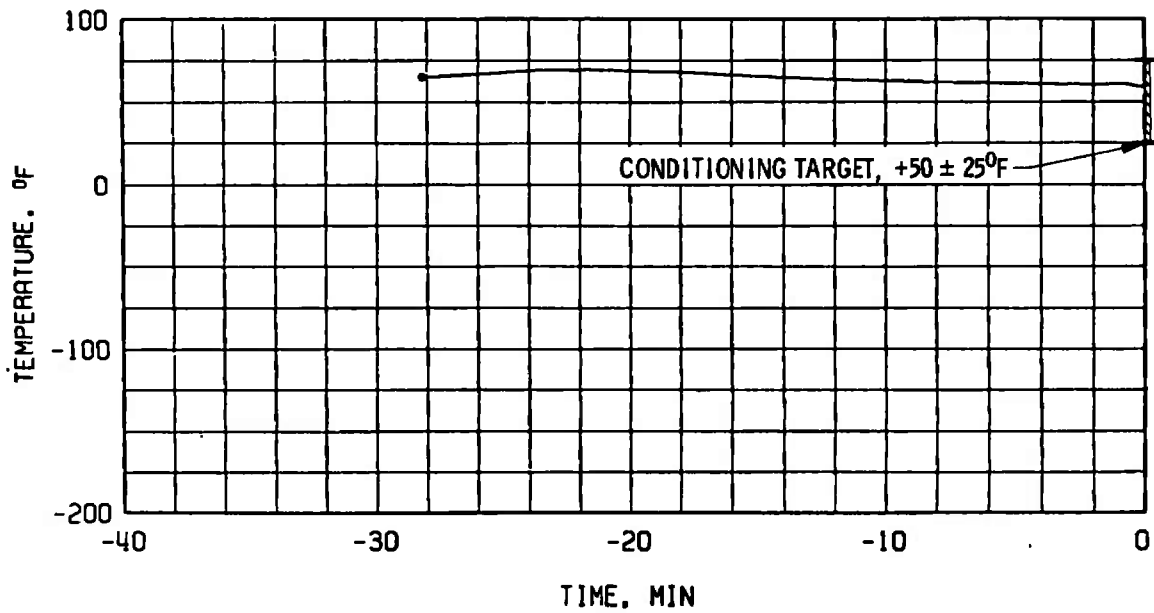


a. Thrust Chamber Throat, TTC-1P

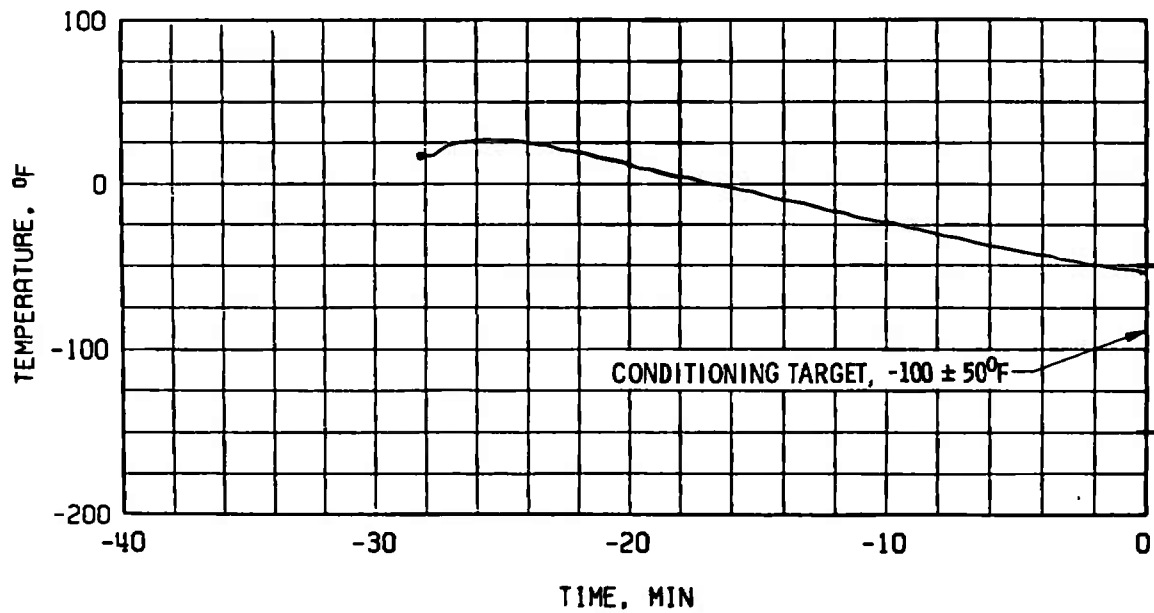


b. Crossover Duct, TFTD

Fig. 110 Thermal Conditioning History of Engine Components, Firing 33A



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 110 Concluded

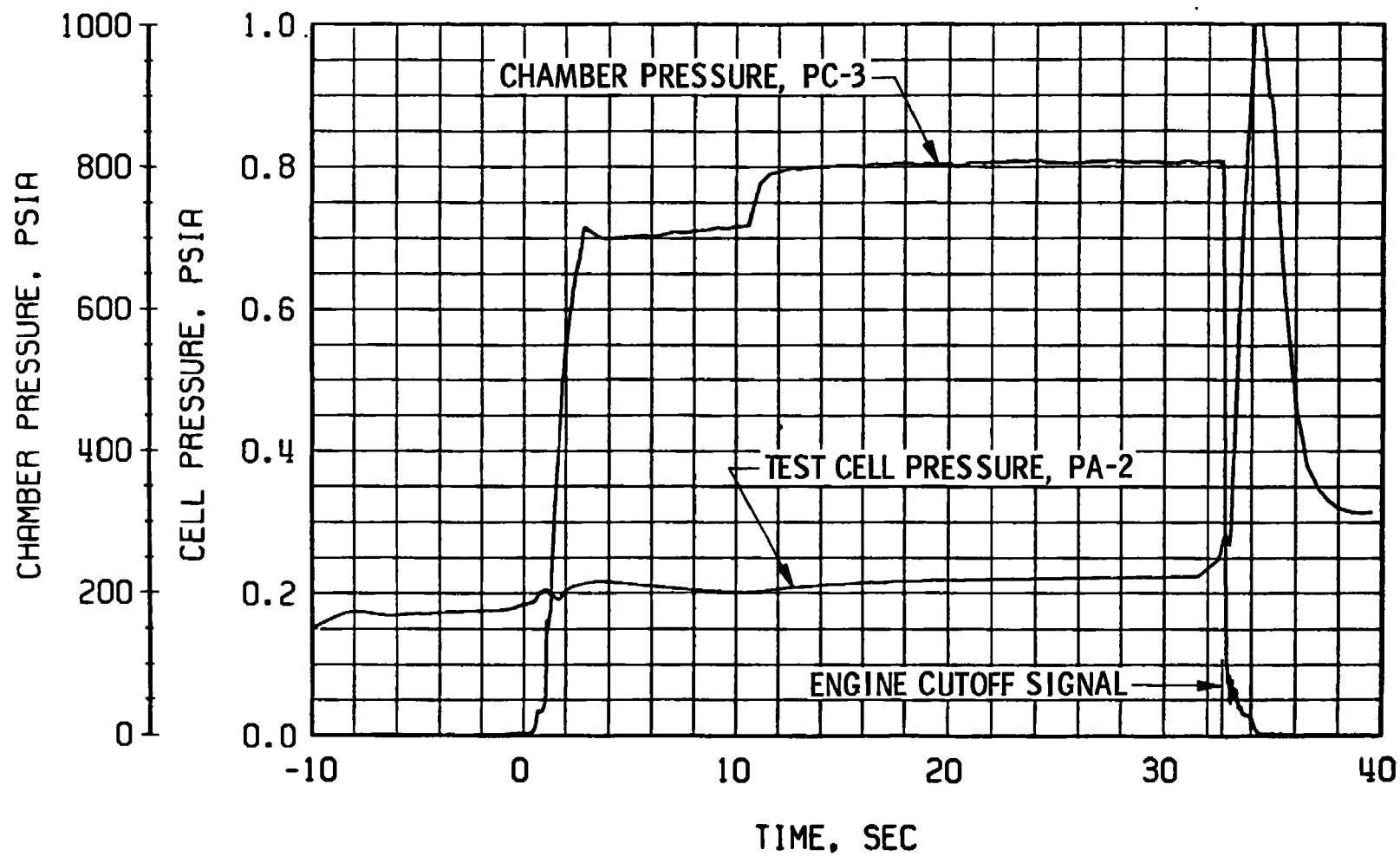
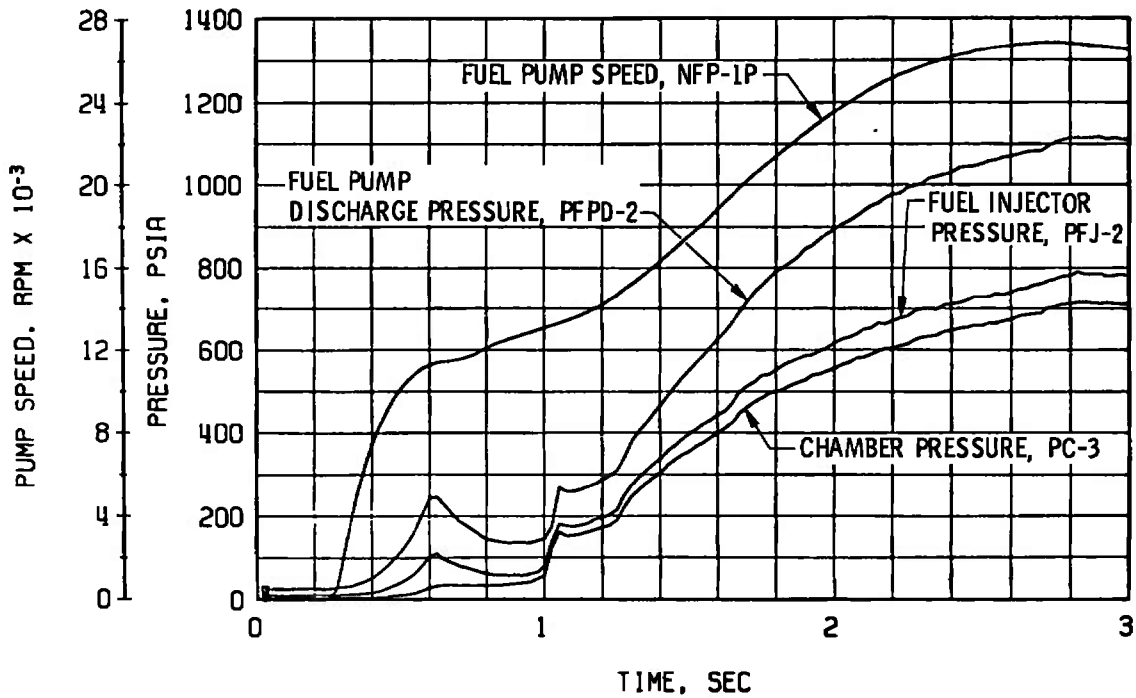
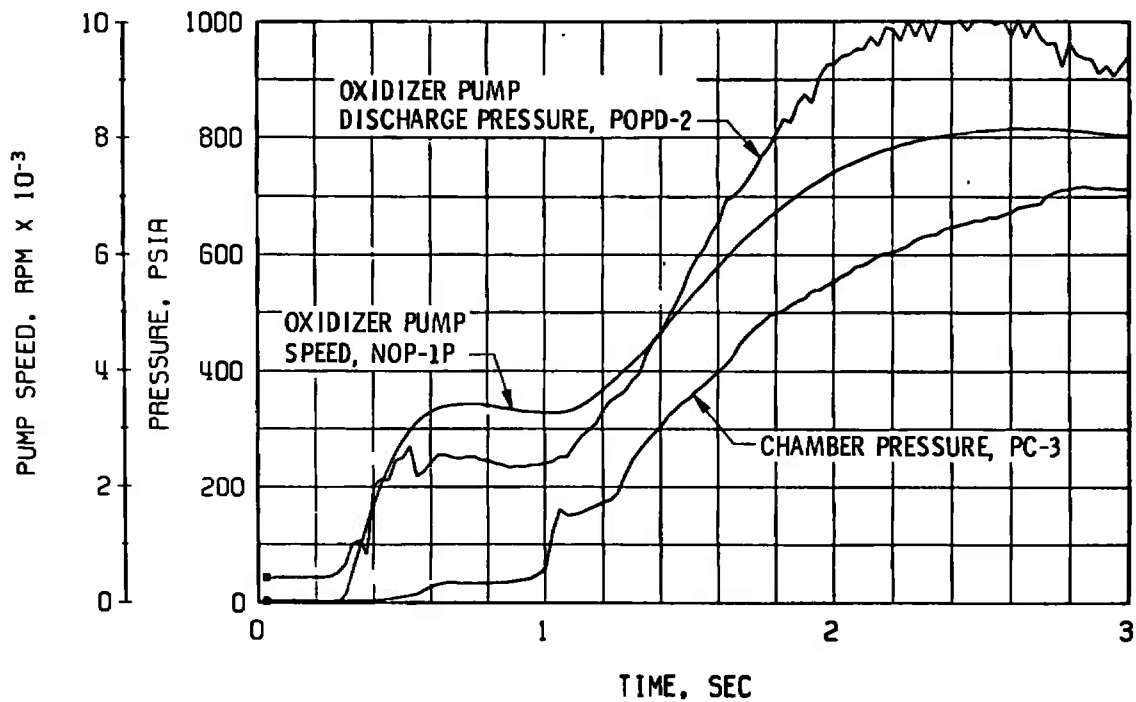


Fig. 111 Engine Ambient and Combustion Chamber Pressures, Firing 33A

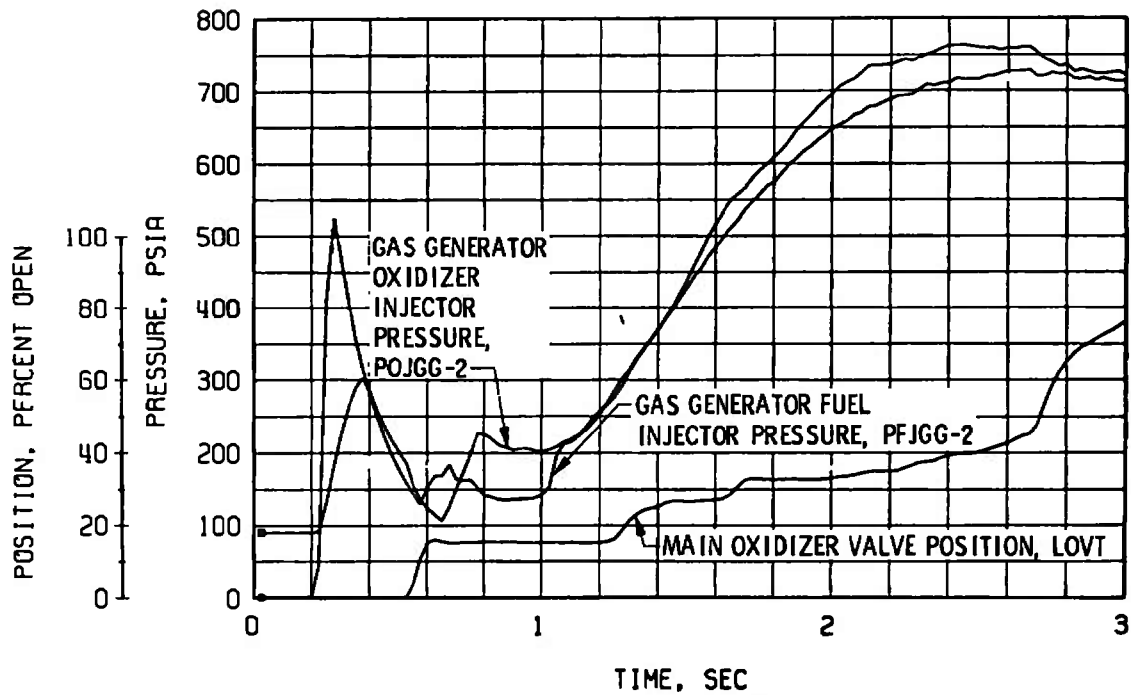


a. Thrust Chamber Fuel System, Start

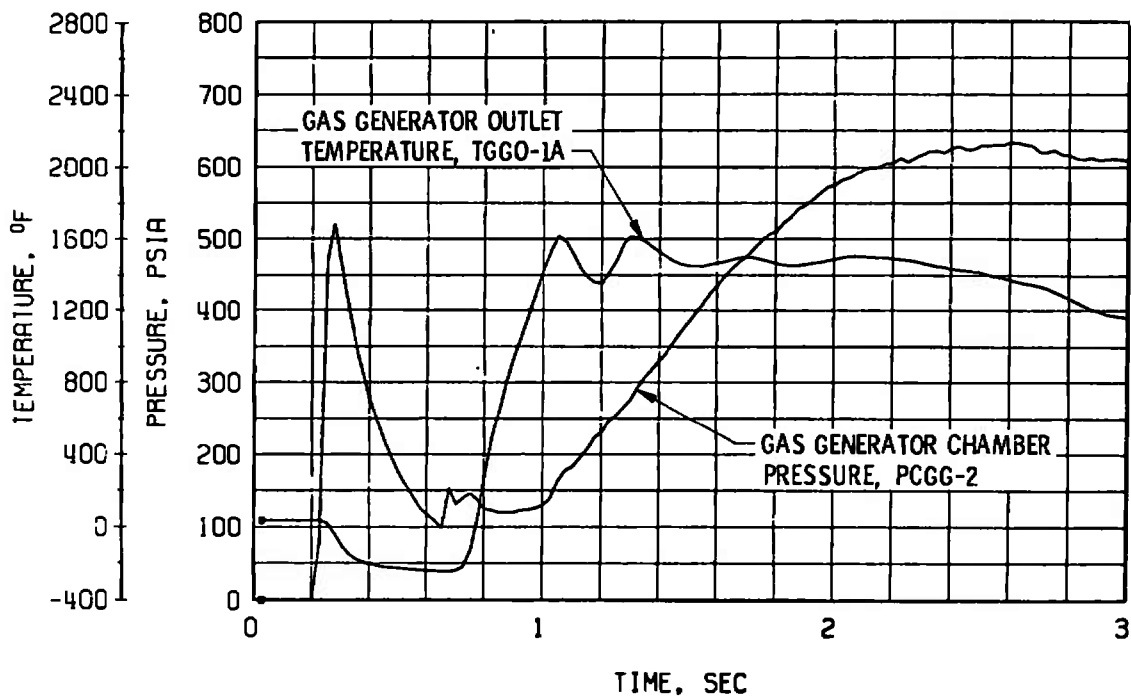


b. Thrust Chamber Oxidizer System, Start

Fig. 112 Engine Transient Operation, Firing 33A



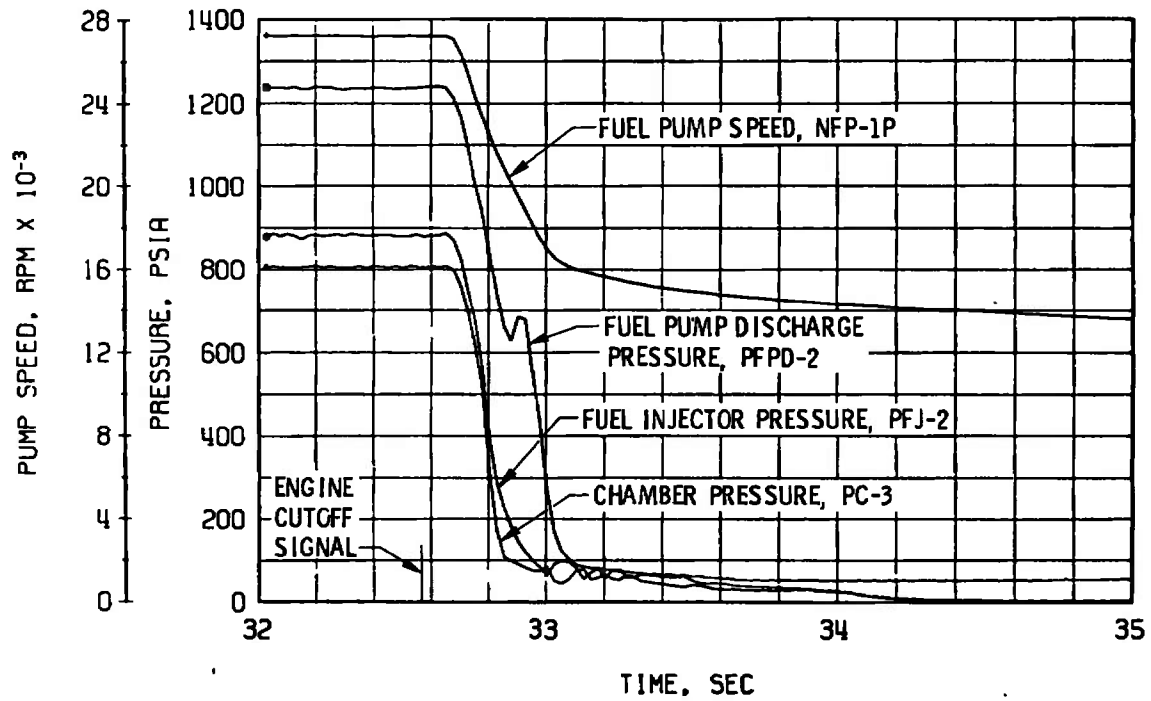
c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start



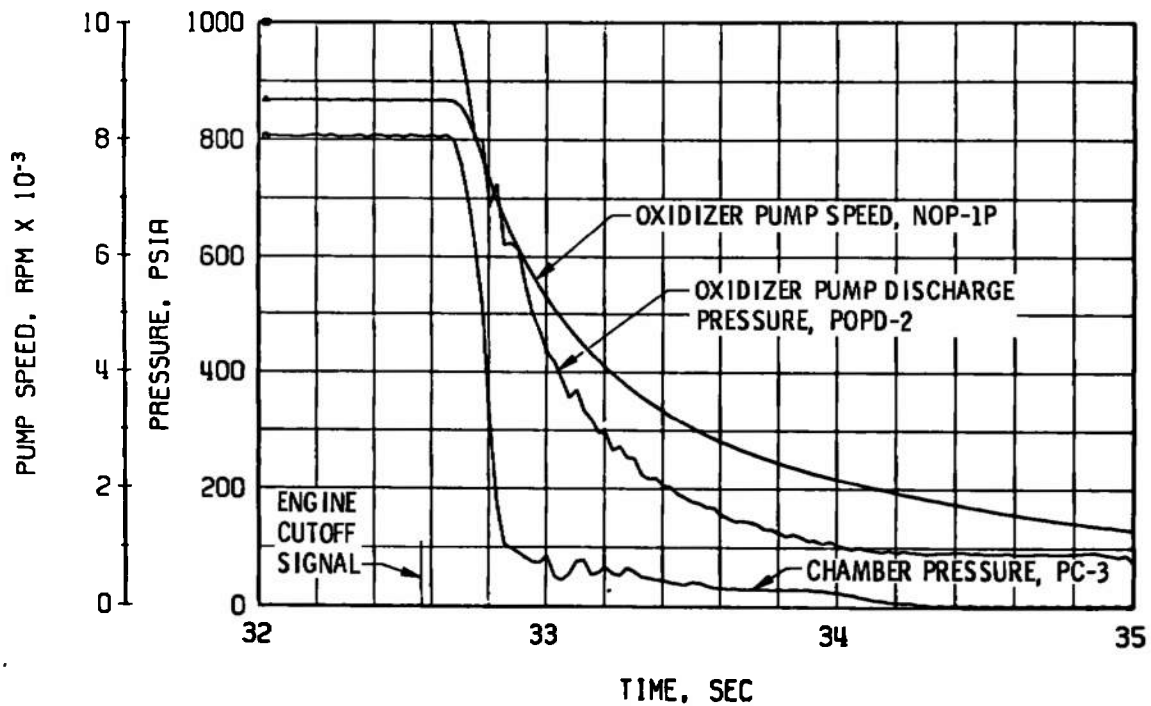
d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 112 Continued



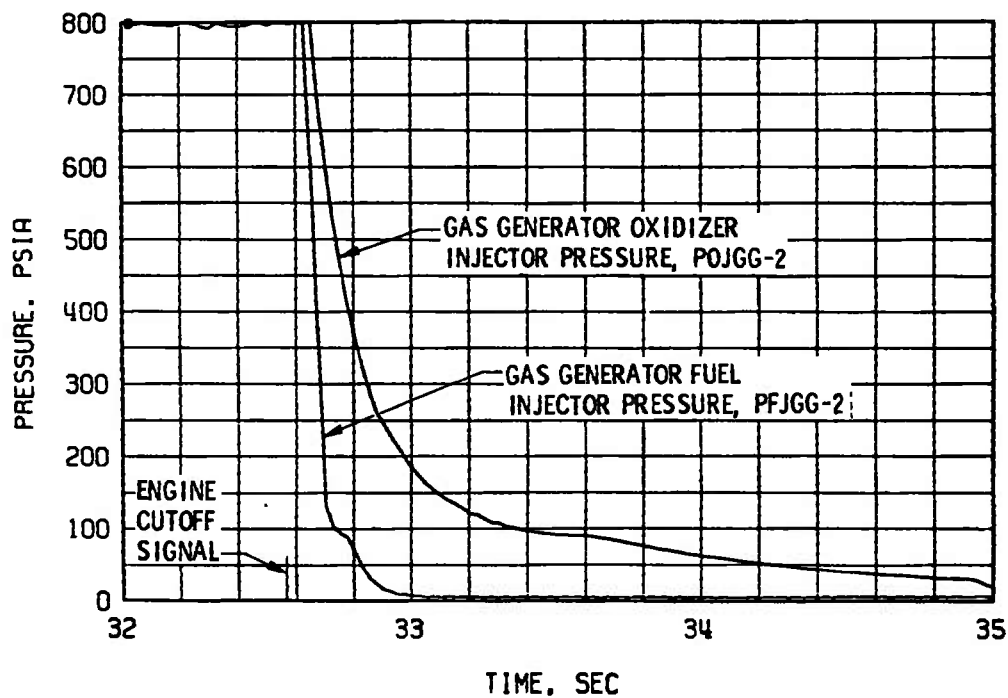


e. Thrust Chamber Fuel System, Shutdown

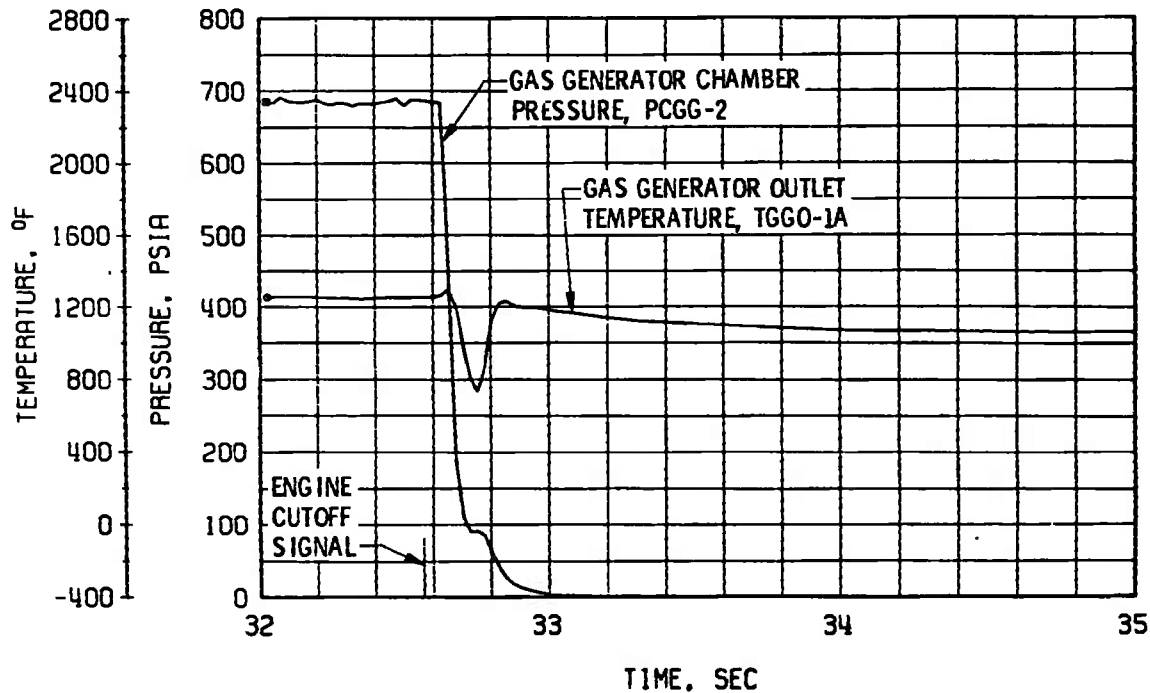


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 112 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 112 Concluded

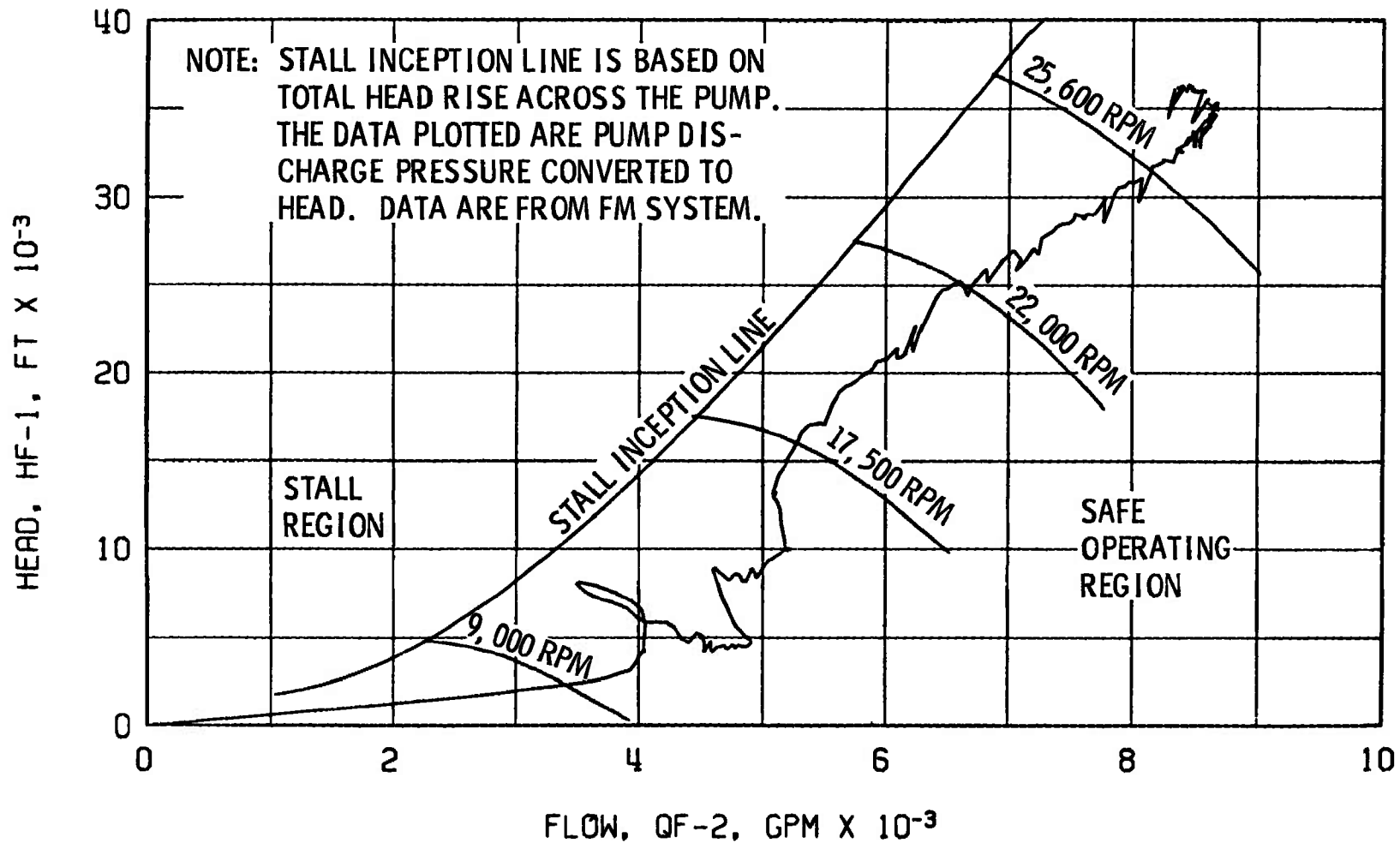
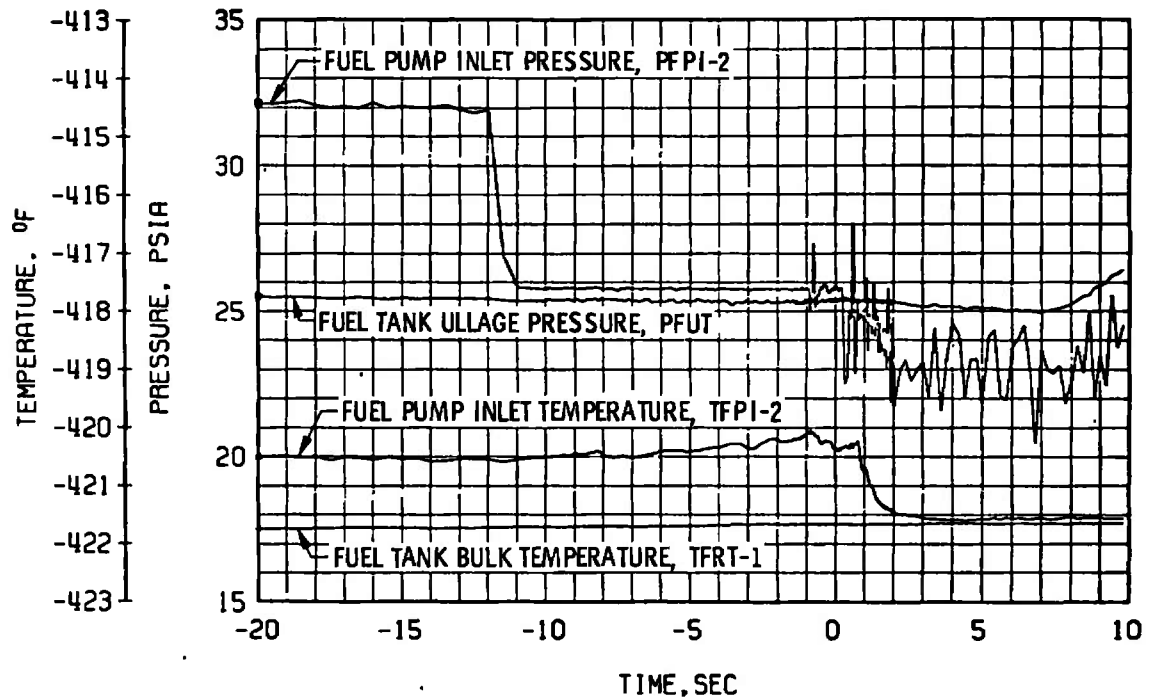
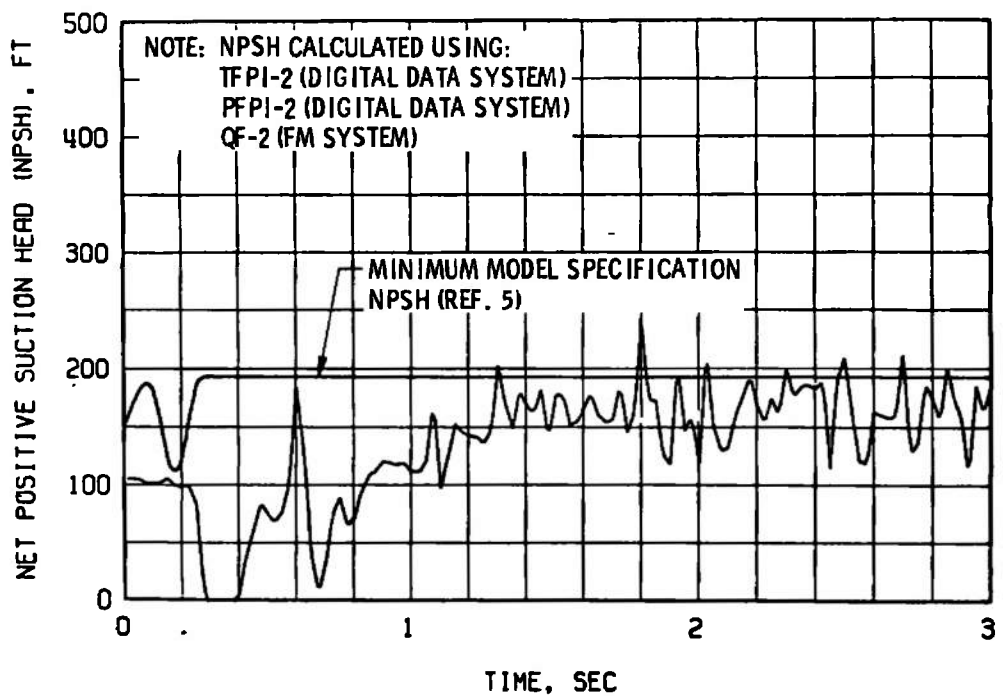


Fig. 113 Fuel Pump Start Transient Performance, Firing 33A

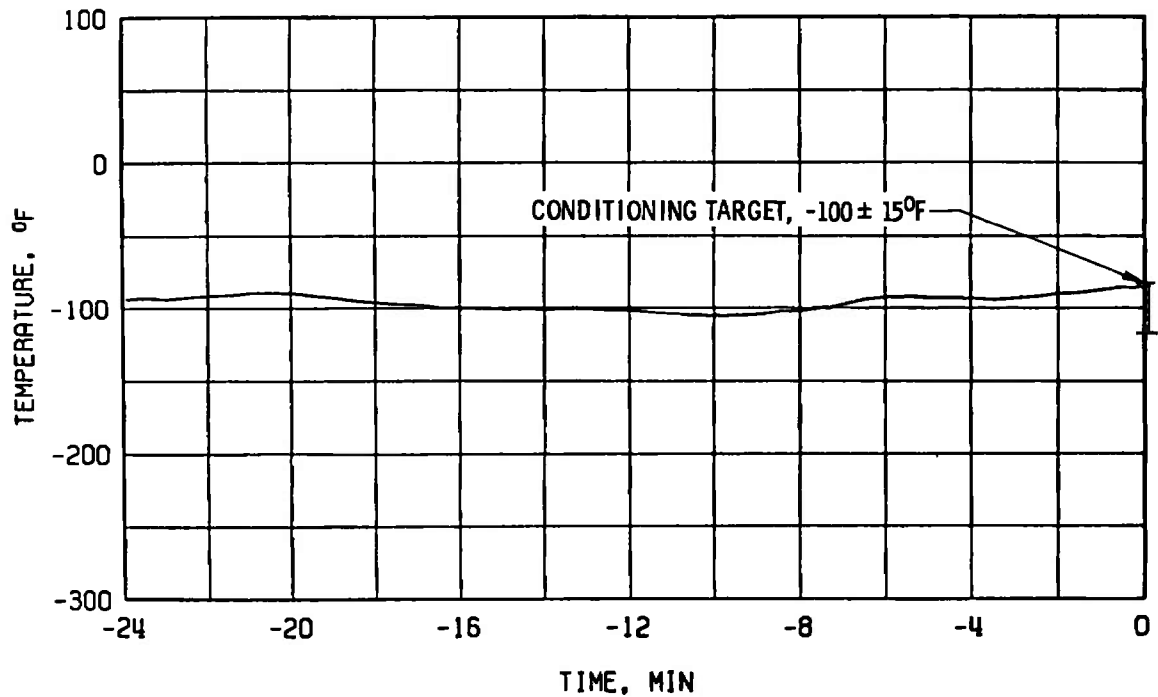


a. Duct Pressure and Temperature Transients

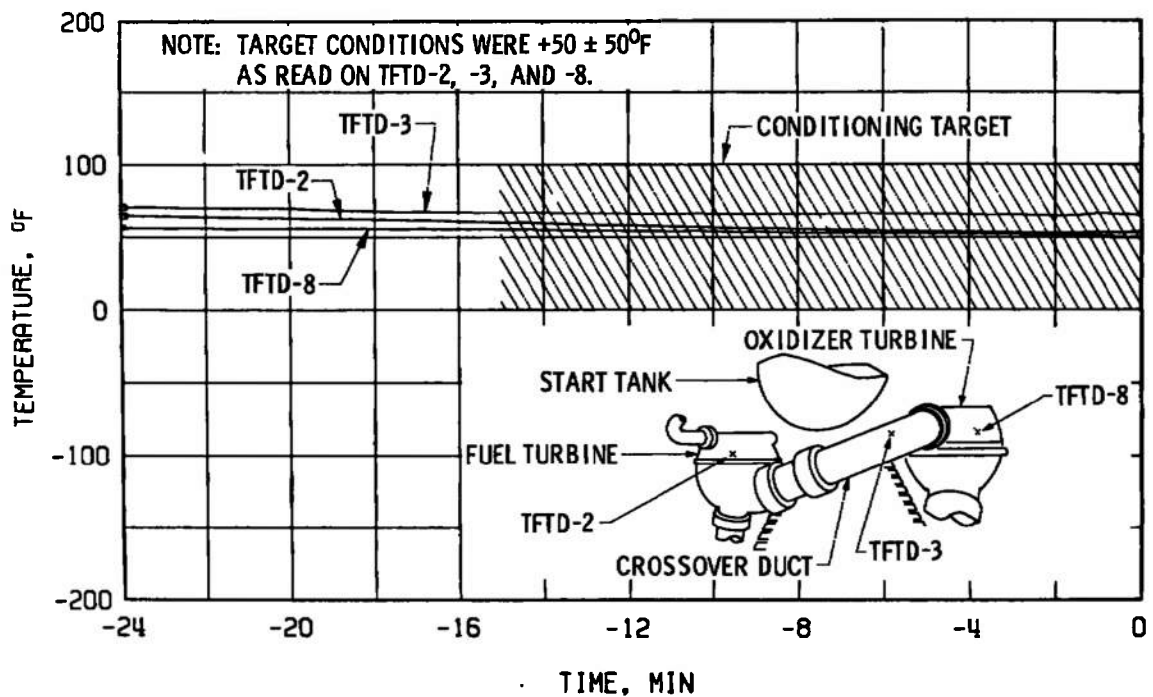


b. Fuel Pump NPSH during Start Transient, Firing 33A

Fig. 114 Fuel Low Pressure Duct Performance, Firing 33A

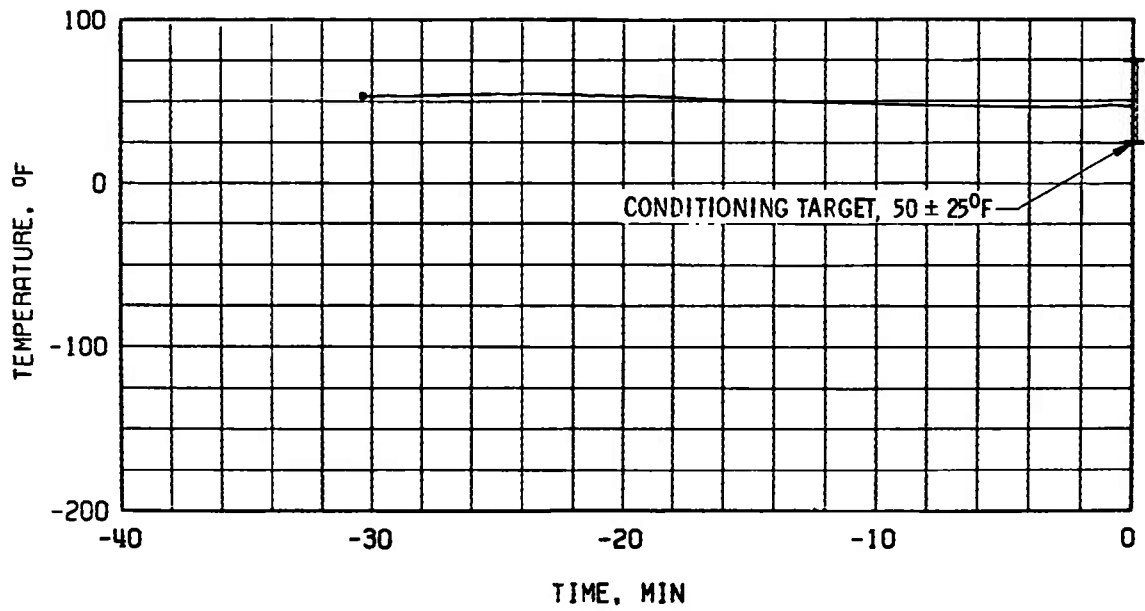


a. Thrust Chamber Throat, TTC-1P

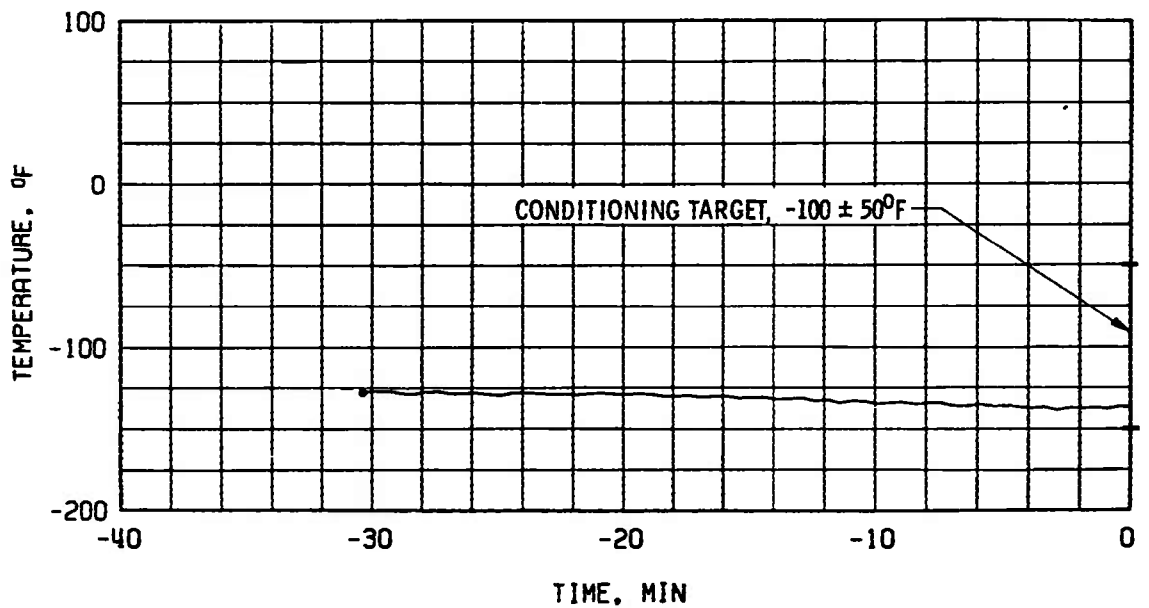


b. Crossover Duct, TFTD

Fig. 115 Thermal Conditioning History of Engine Components, Firing 33B



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 115 Concluded

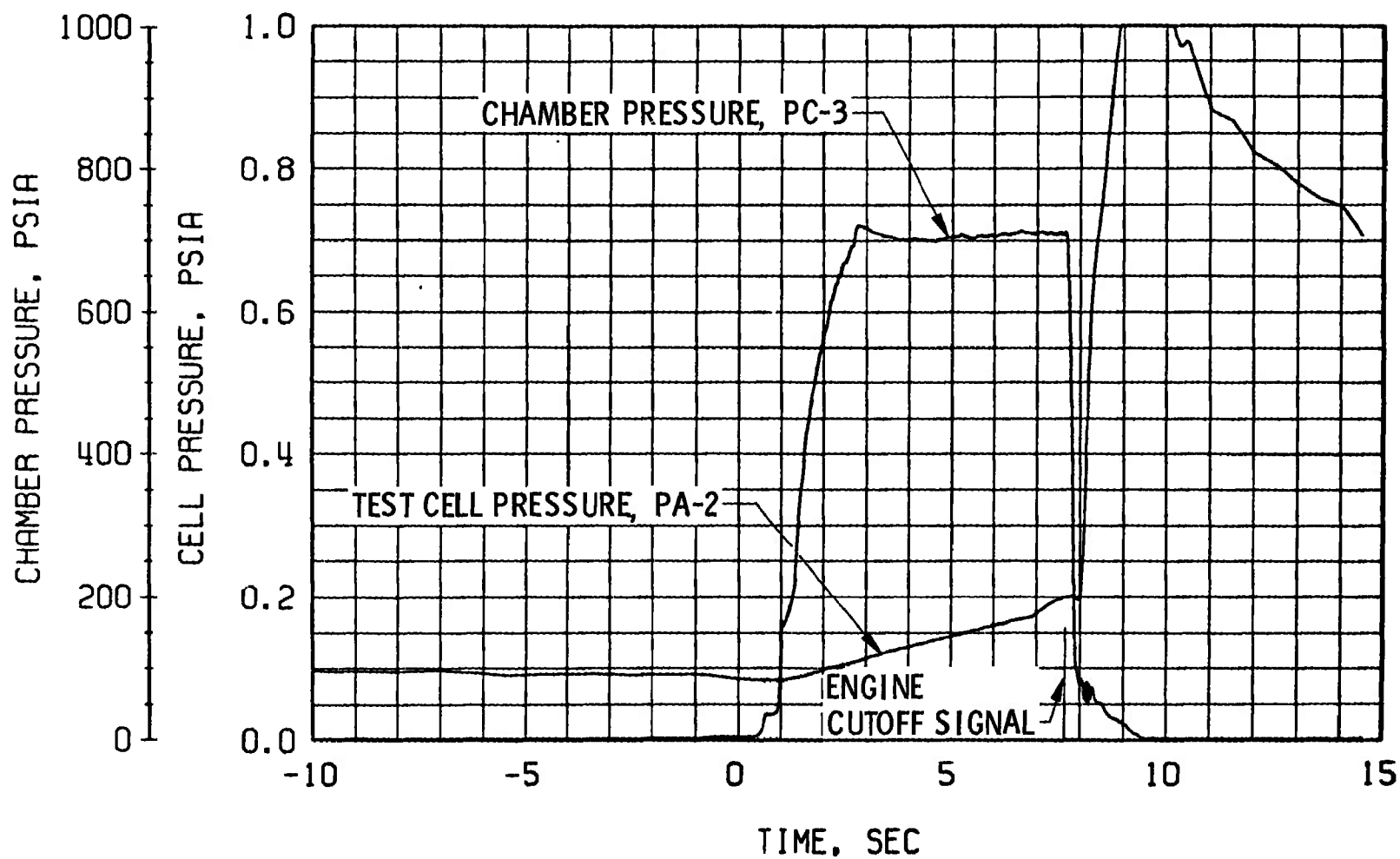
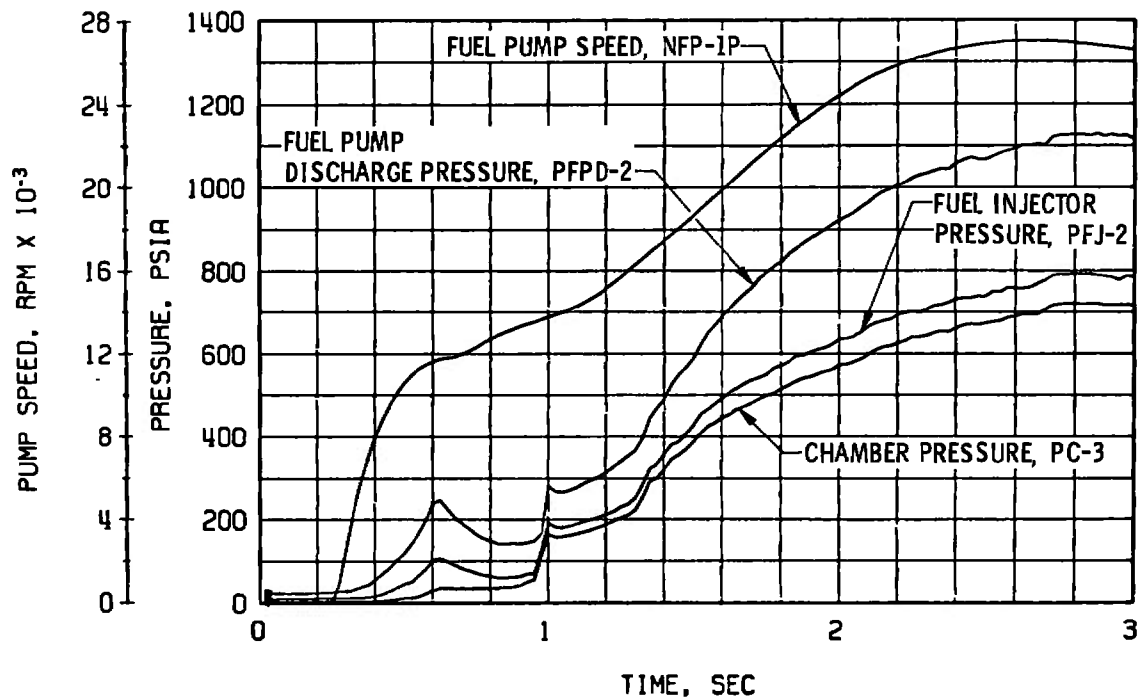
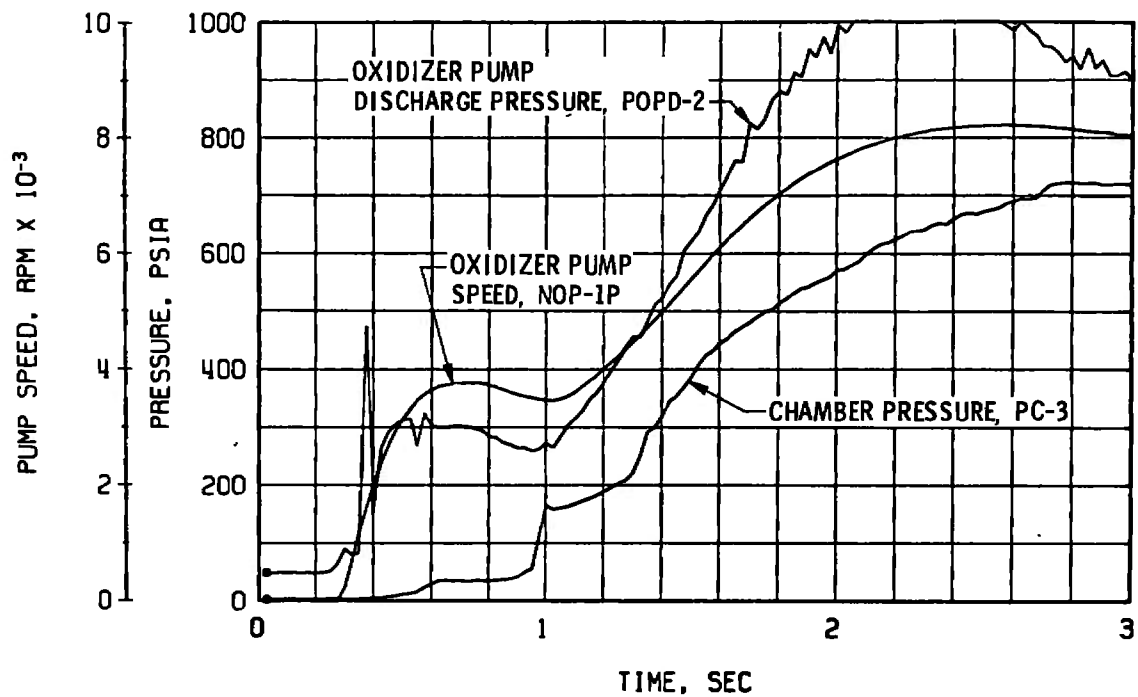


Fig. 116 Engine Ambient and Combustion Chamber Pressures, Firing 33B



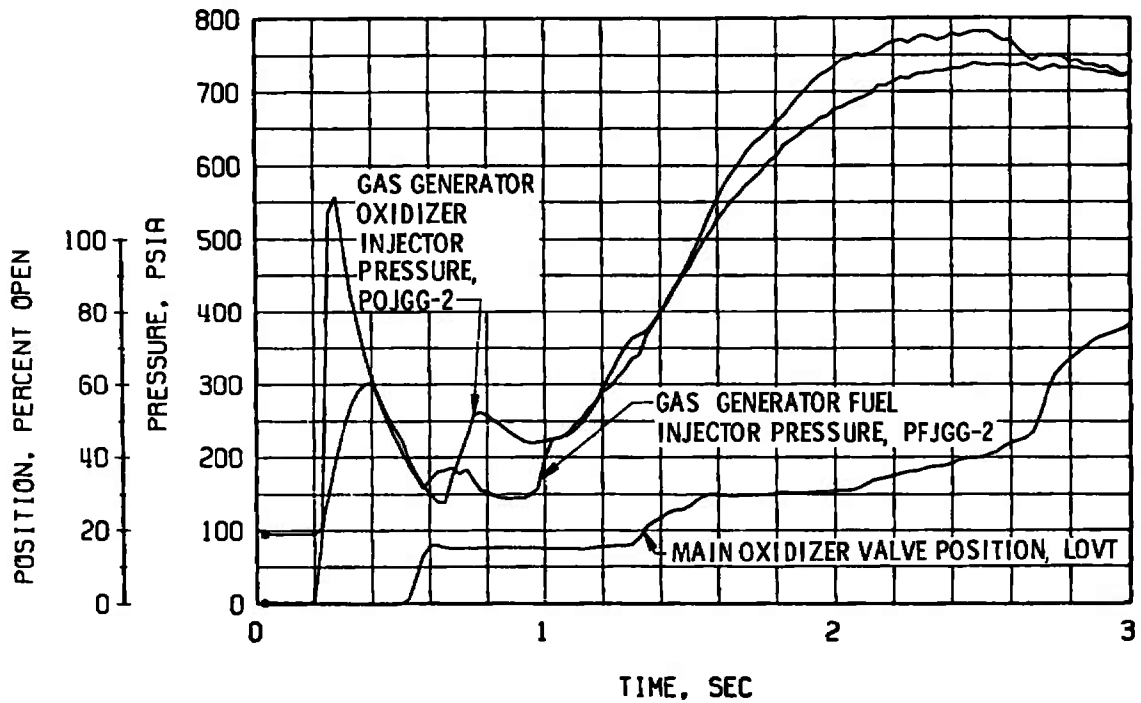
a. Thrust Chamber Fuel System, Start



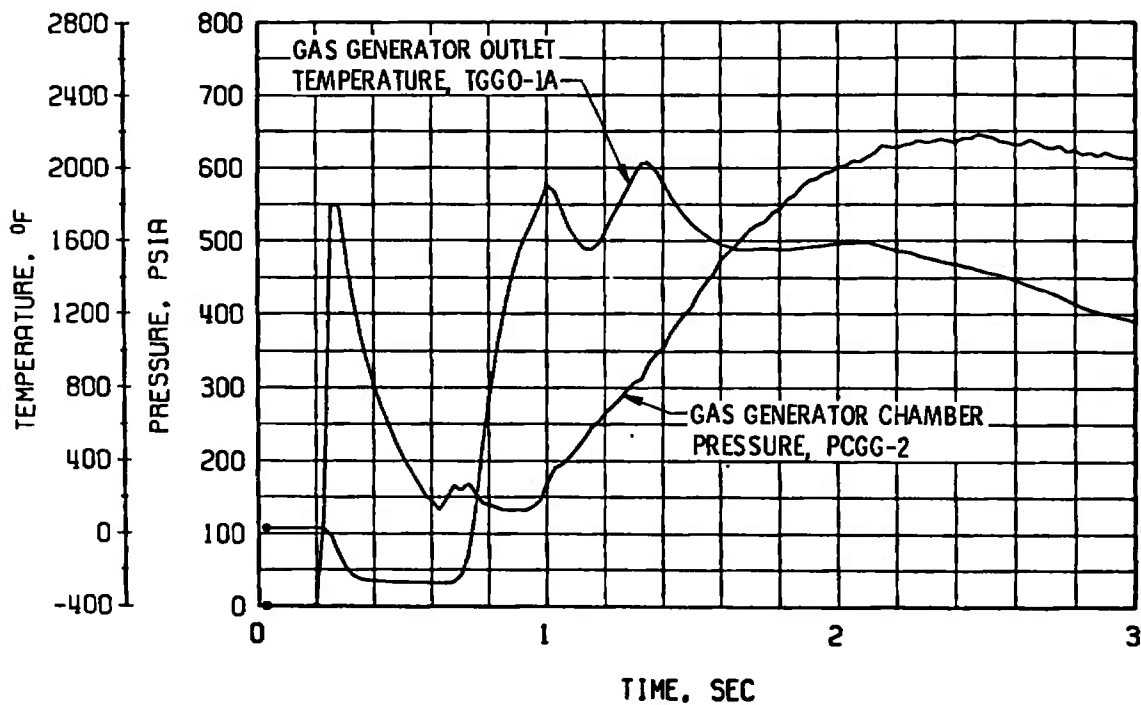
b. Thrust Chamber Oxidizer System, Start

Fig. 117 Engine Transient Operation, Firing 33B



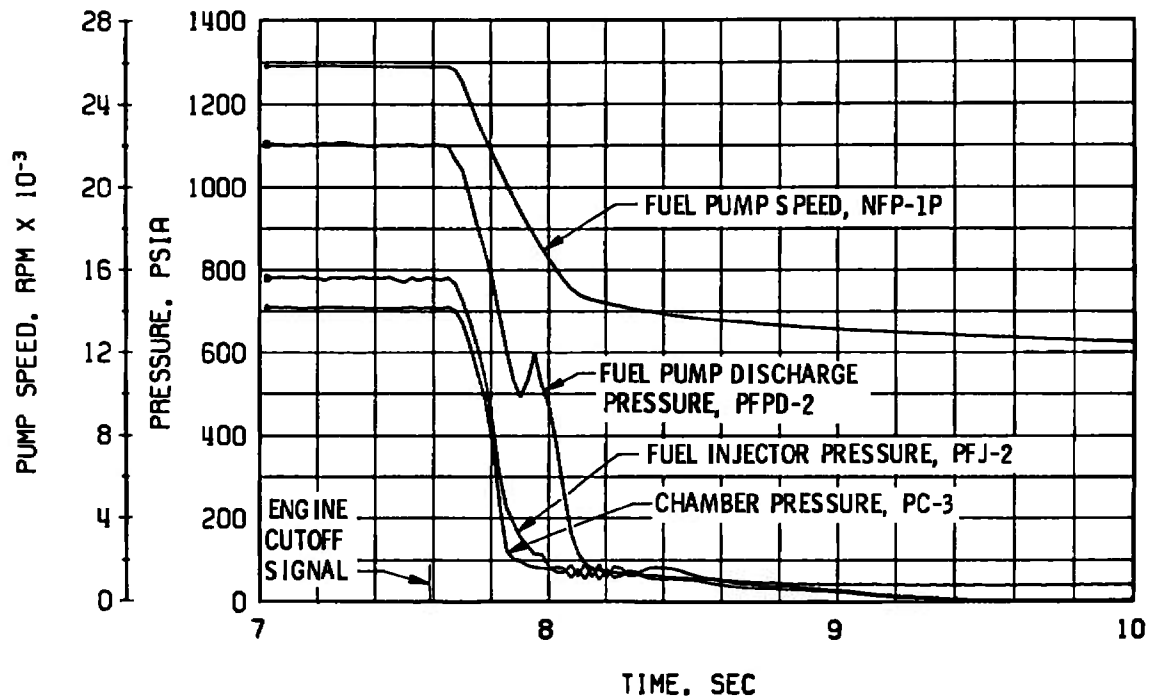


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

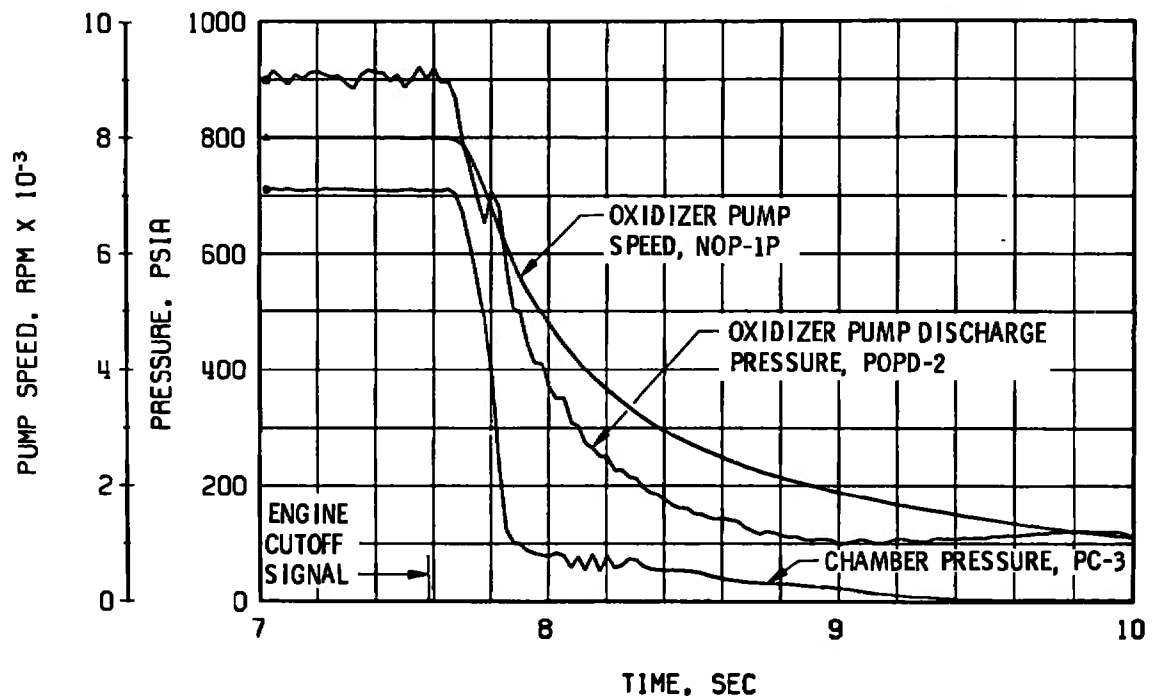


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 117 Continued

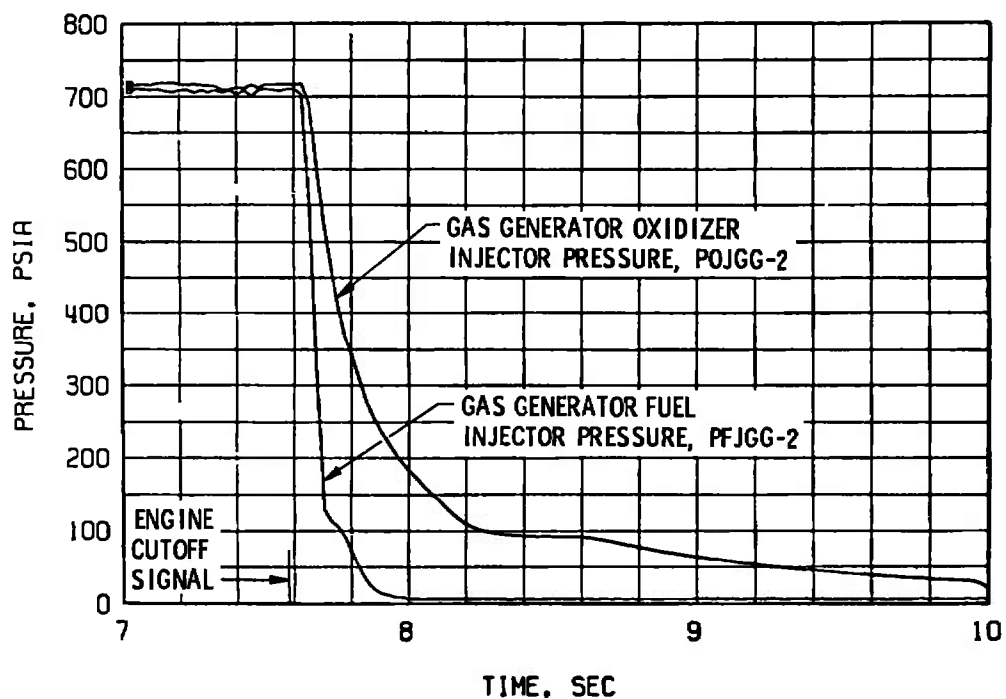


e. Thrust Chamber Fuel System, Shutdown

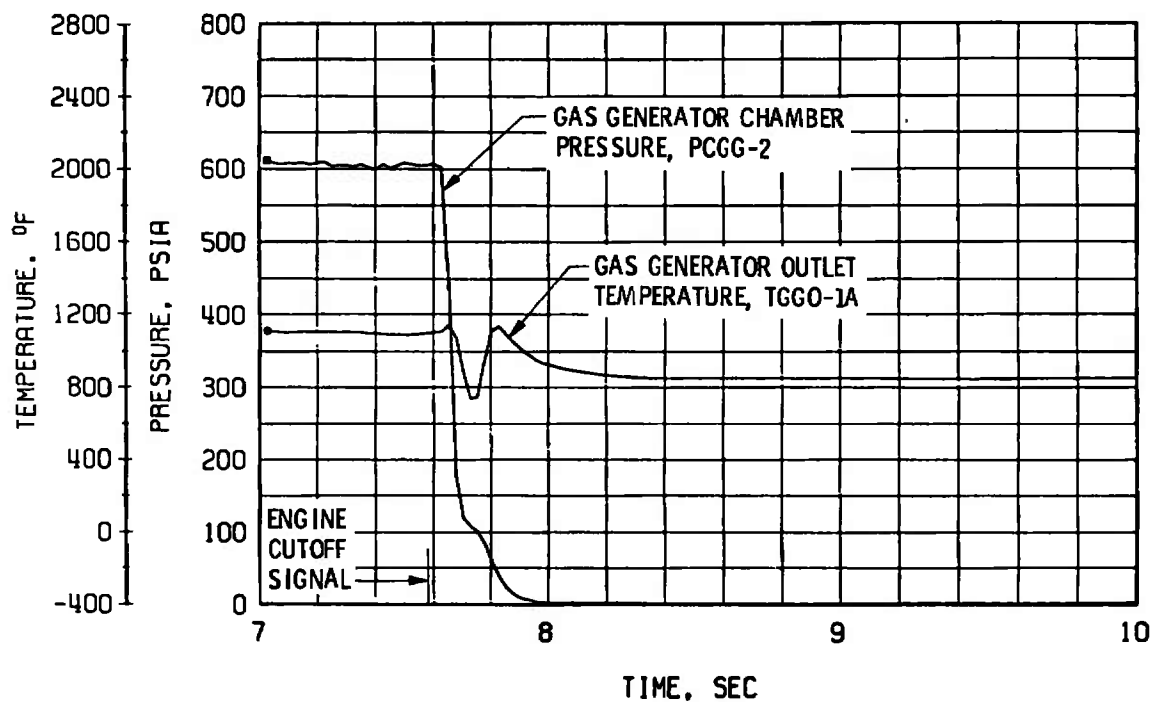


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 117 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 117 Concluded

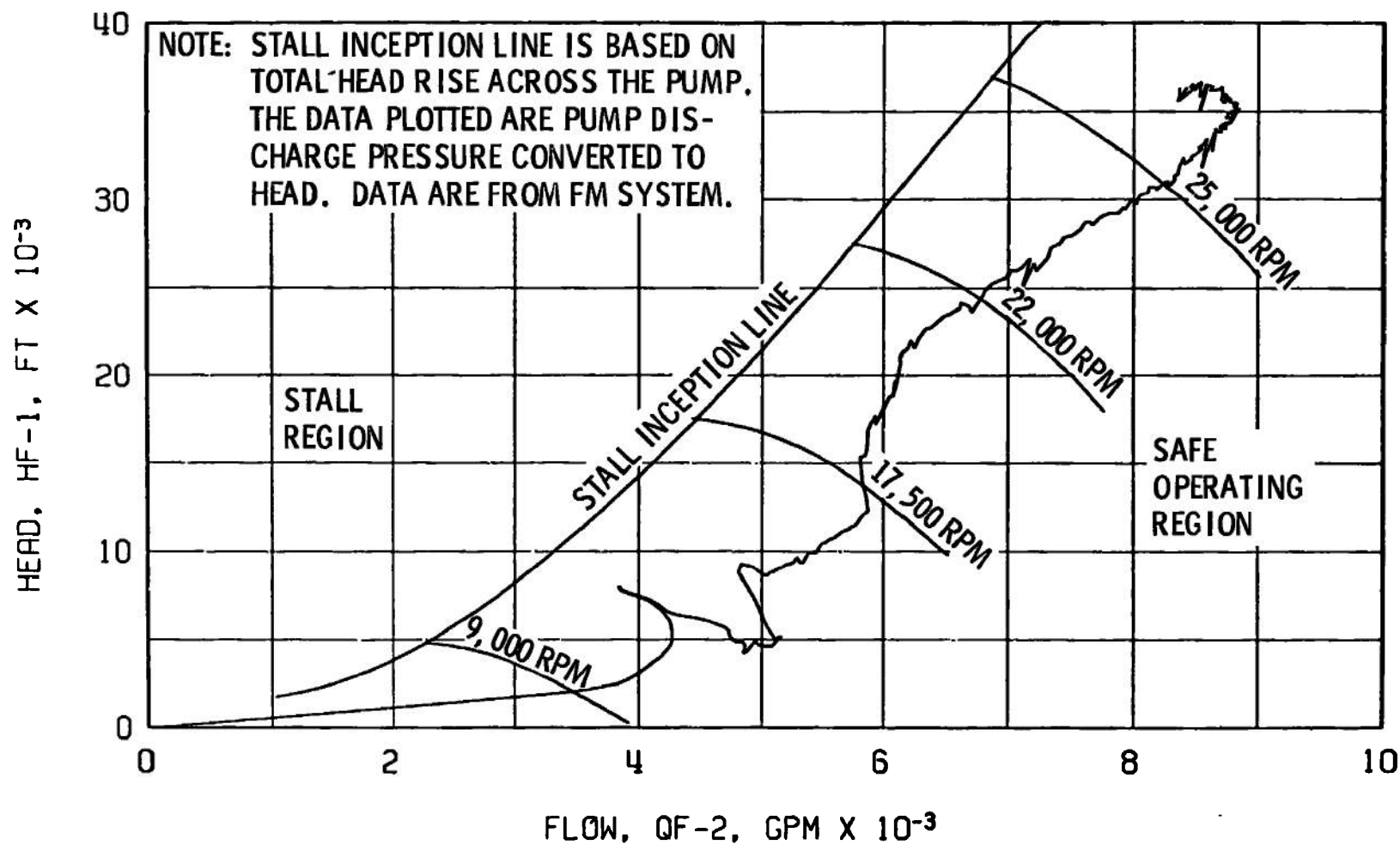
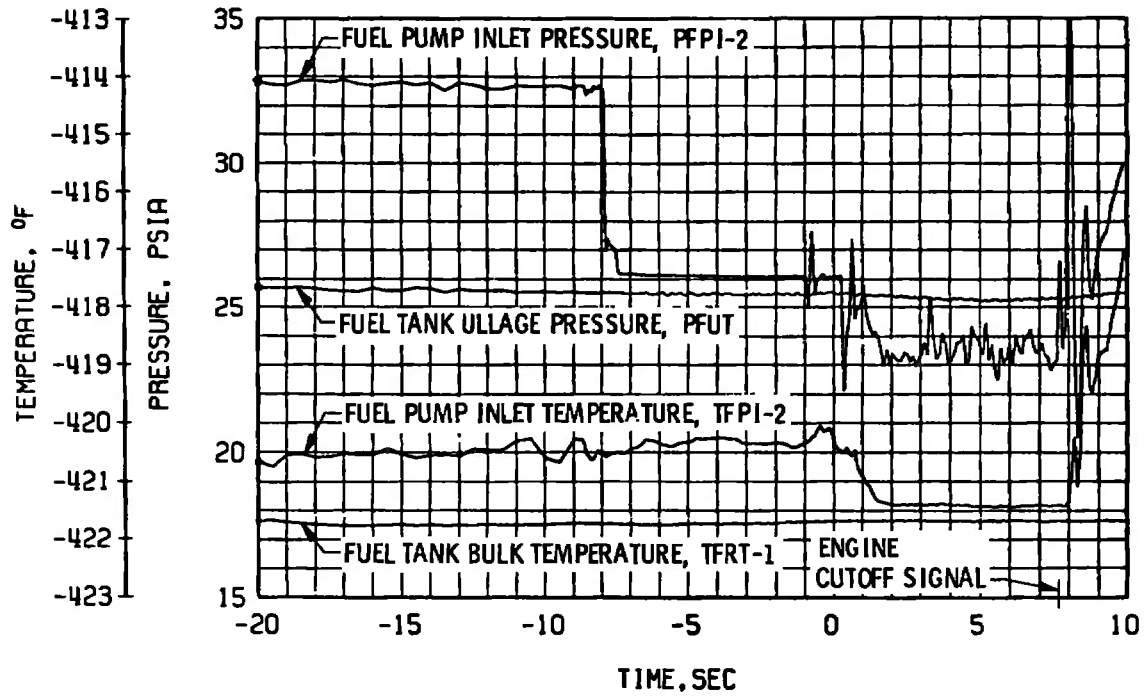
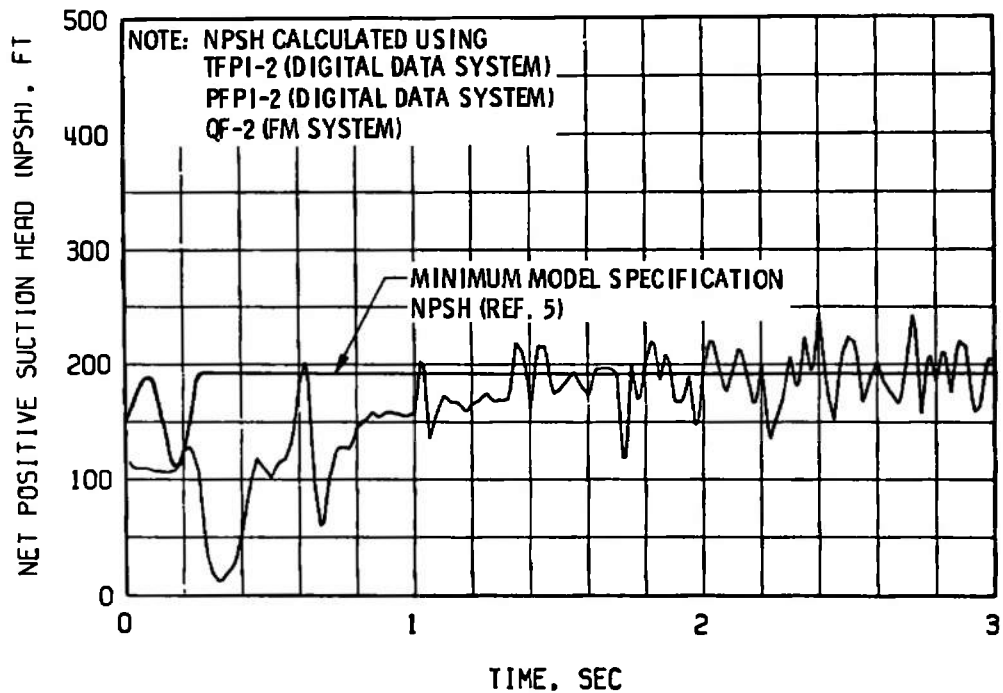


Fig. 118 Fuel Pump Start Transient Performance, Firing 33B

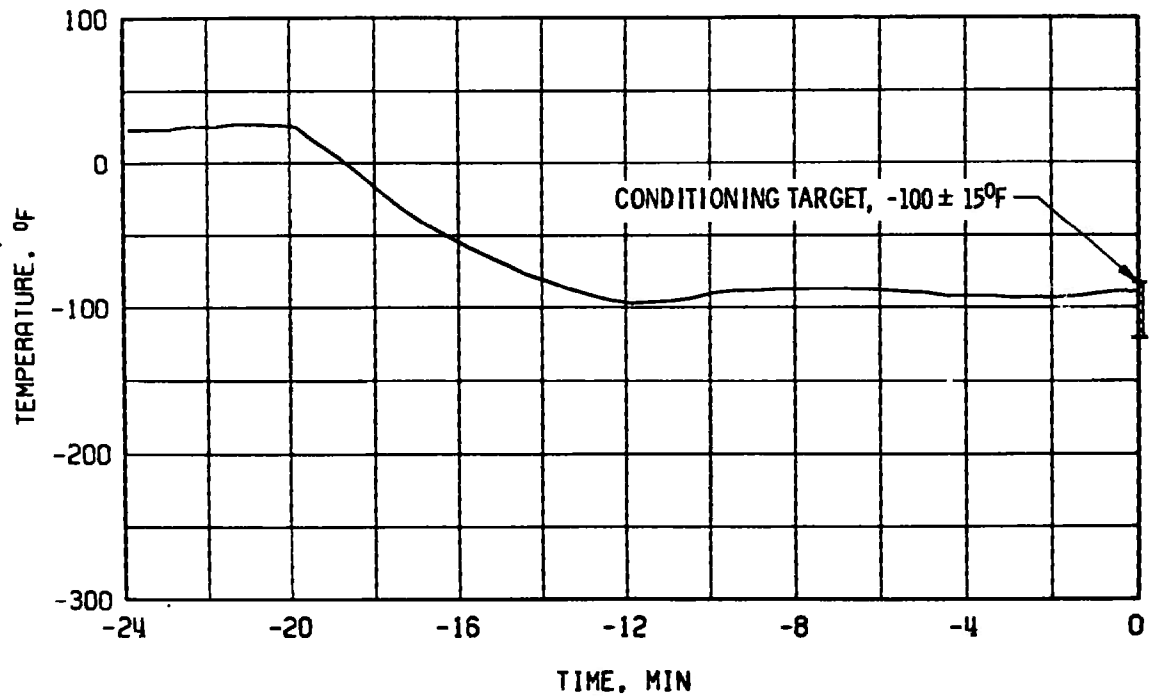


a. Duct Pressure and Temperature Transients

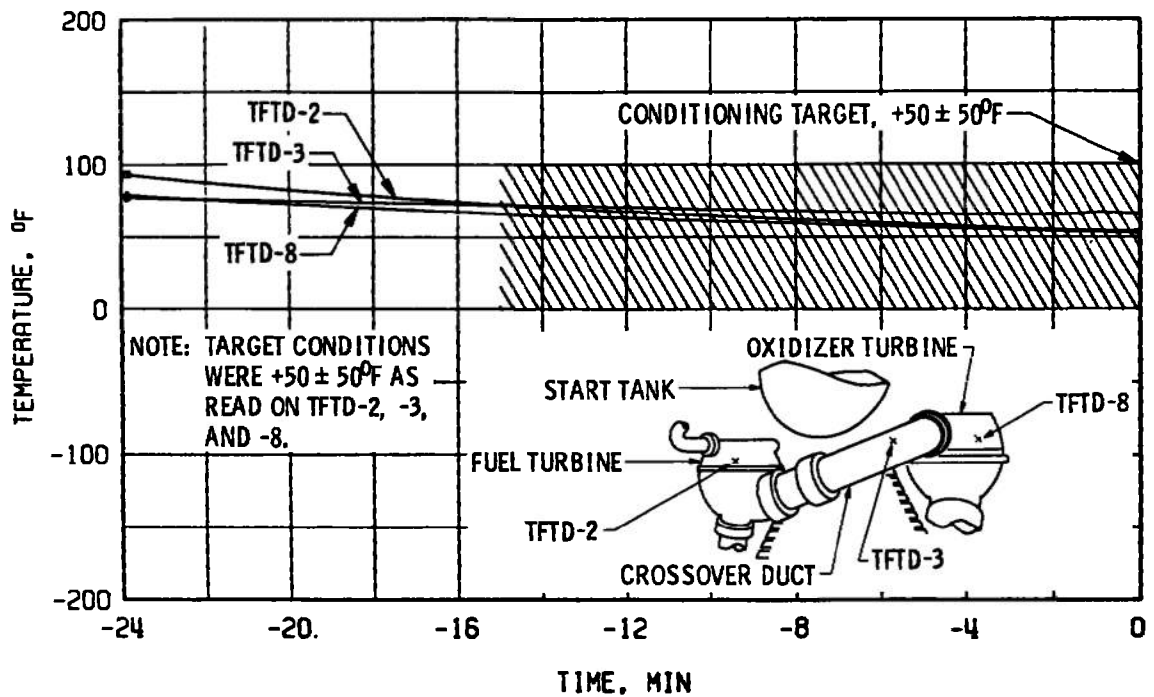


b. Fuel Pump NPSH during Start Transients

Fig. 119 Fuel Low Pressure Duct Performance, Firing 33B

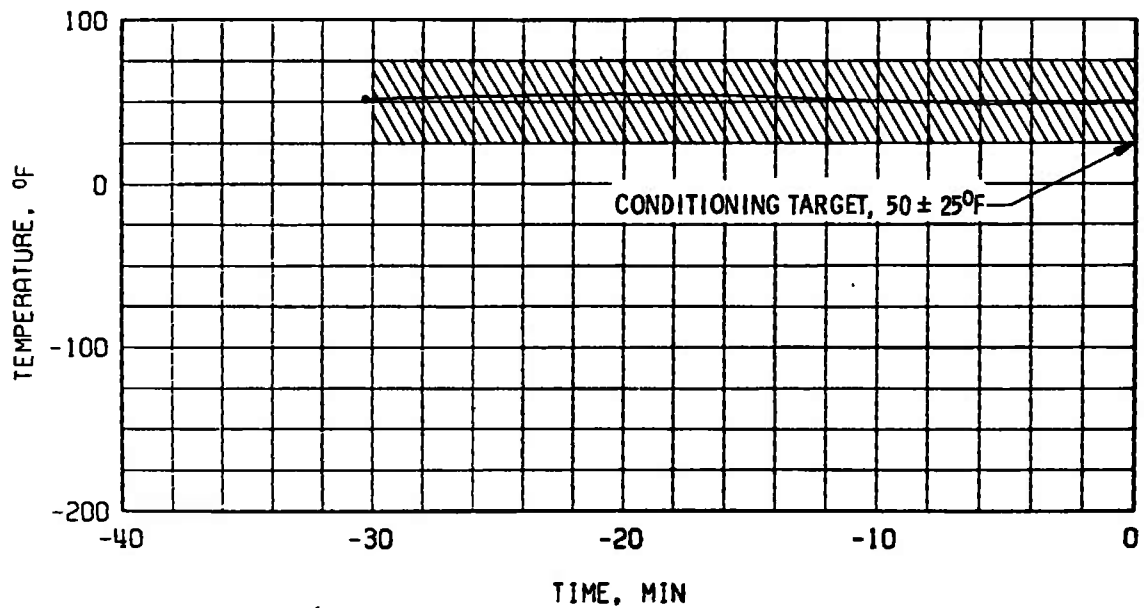


a. Thrust Chamber Throat, TTC-1P

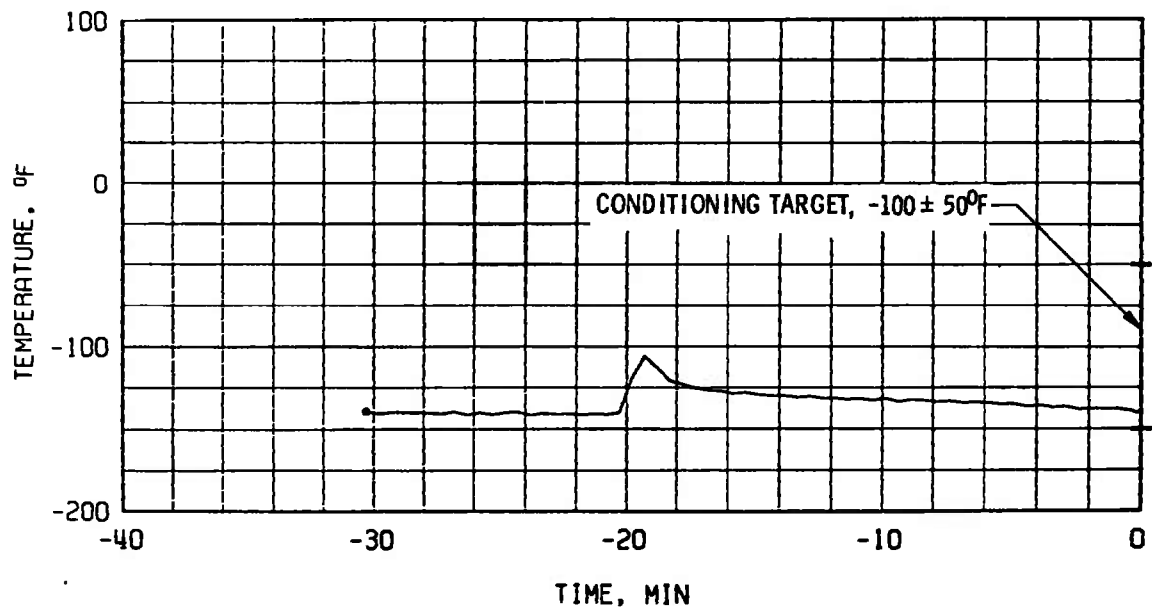


b. Crossover Duct, TFTD

Fig. 120 Thermal Conditioning History of Engine Components, Firing 33C



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 120 Concluded

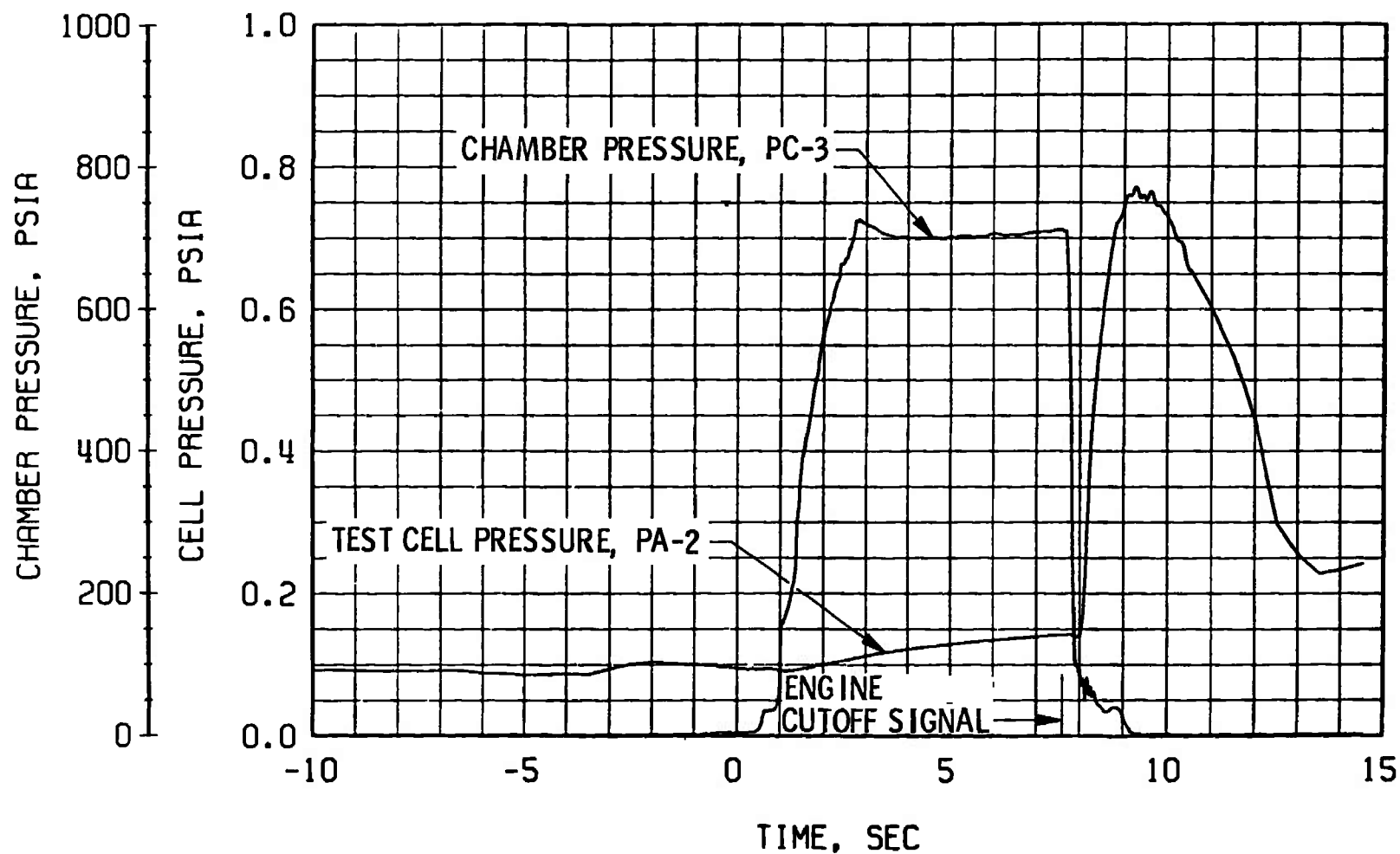
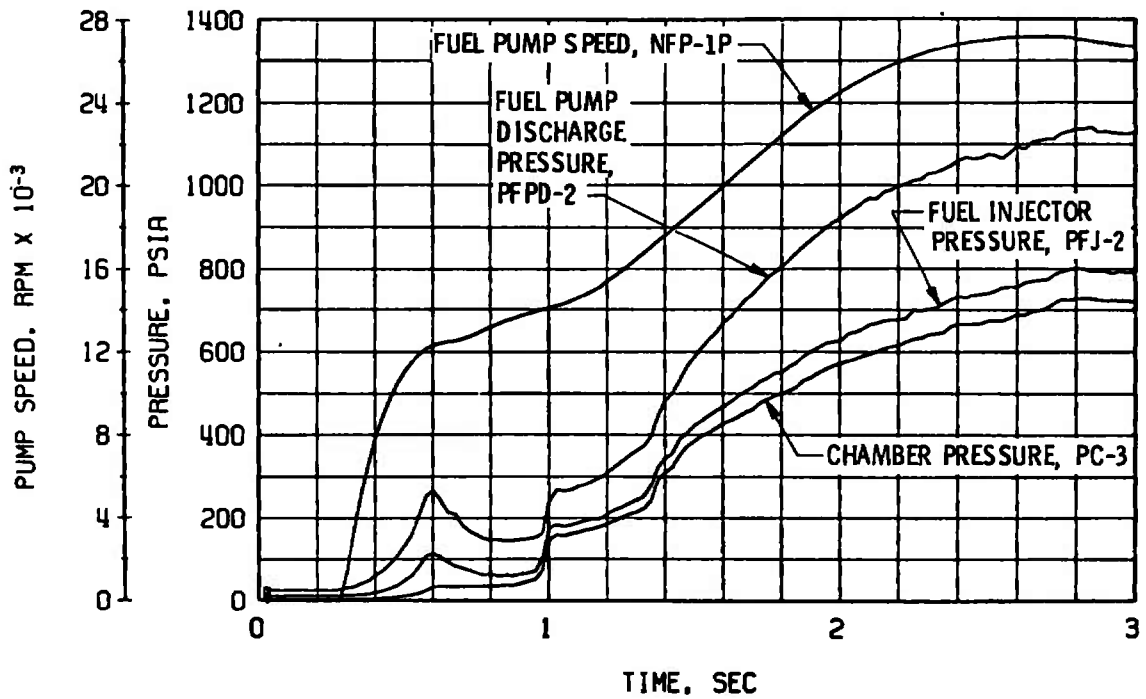
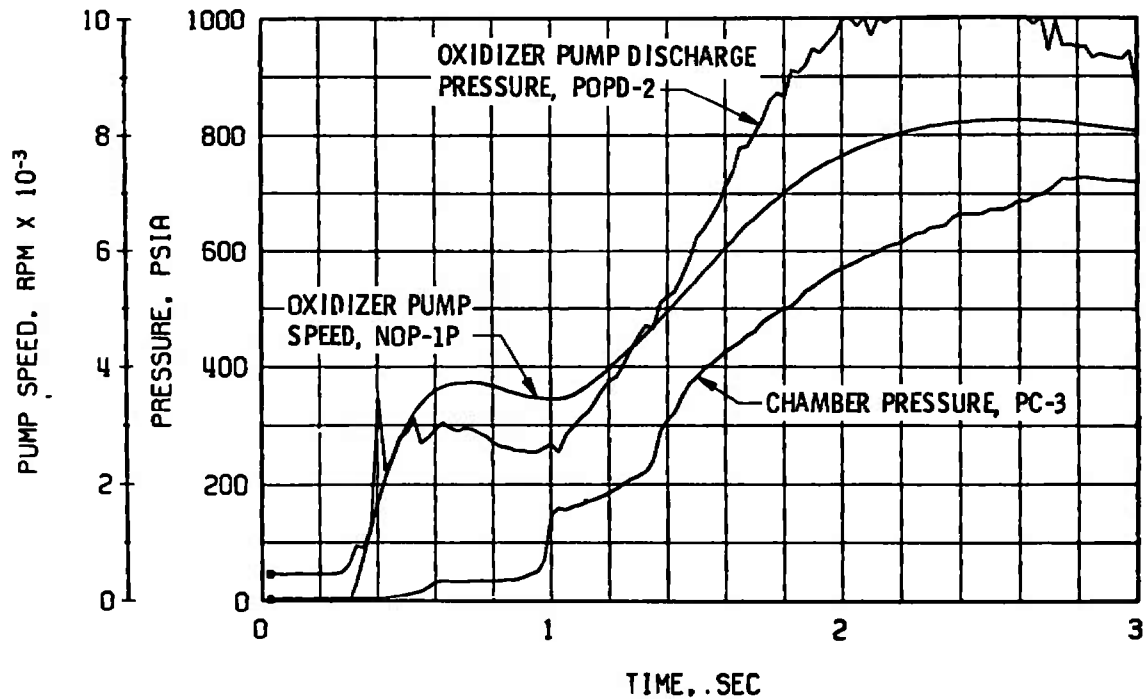


Fig. 121 Engine Ambient and Combustion Chamber Pressures, Firing 33C



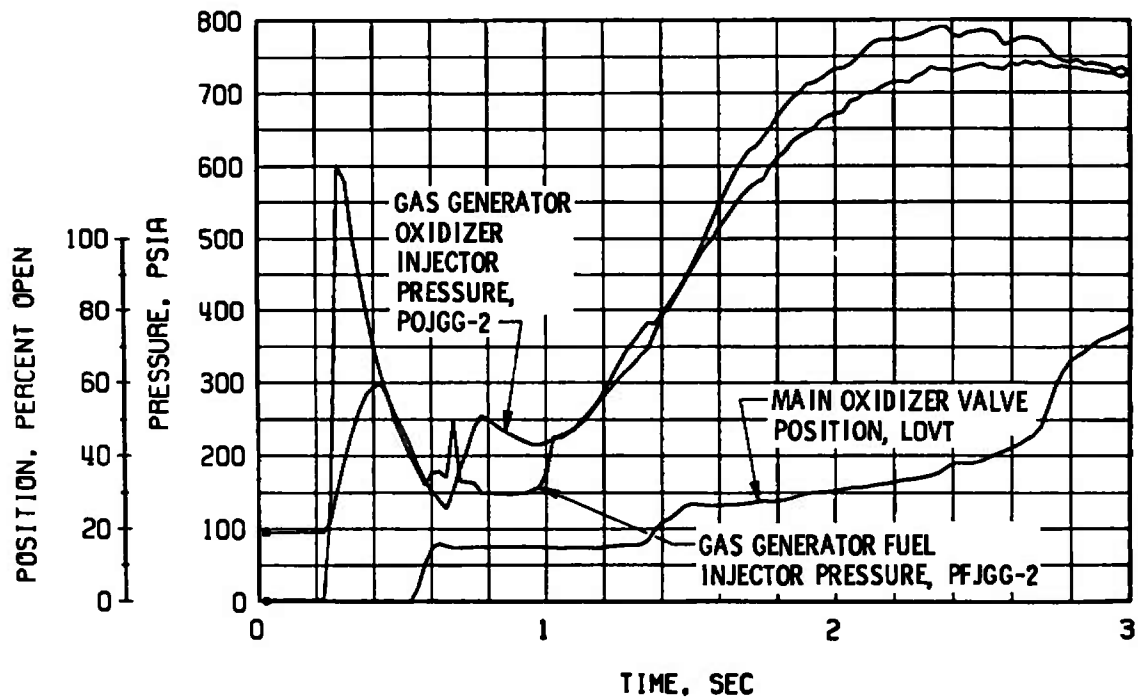


a. Thrust Chamber Fuel System, Start

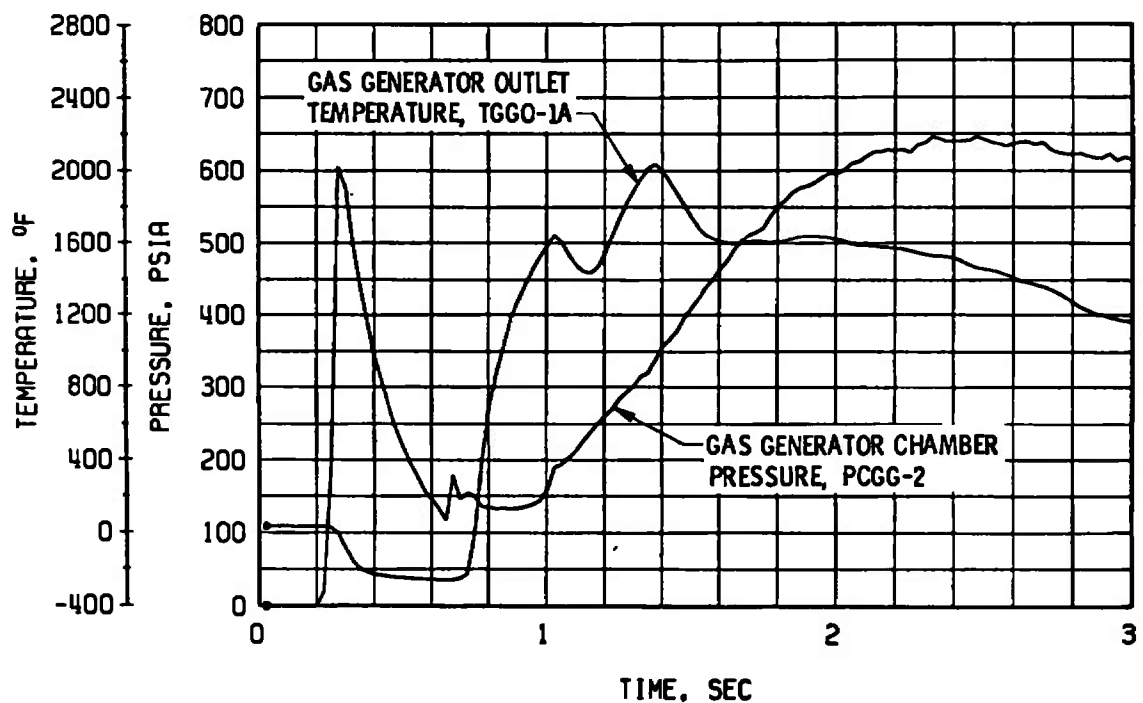


b. Thrust Chamber Oxidizer System, Start

Fig. 122 Engine Transient Operation, Firing 33C

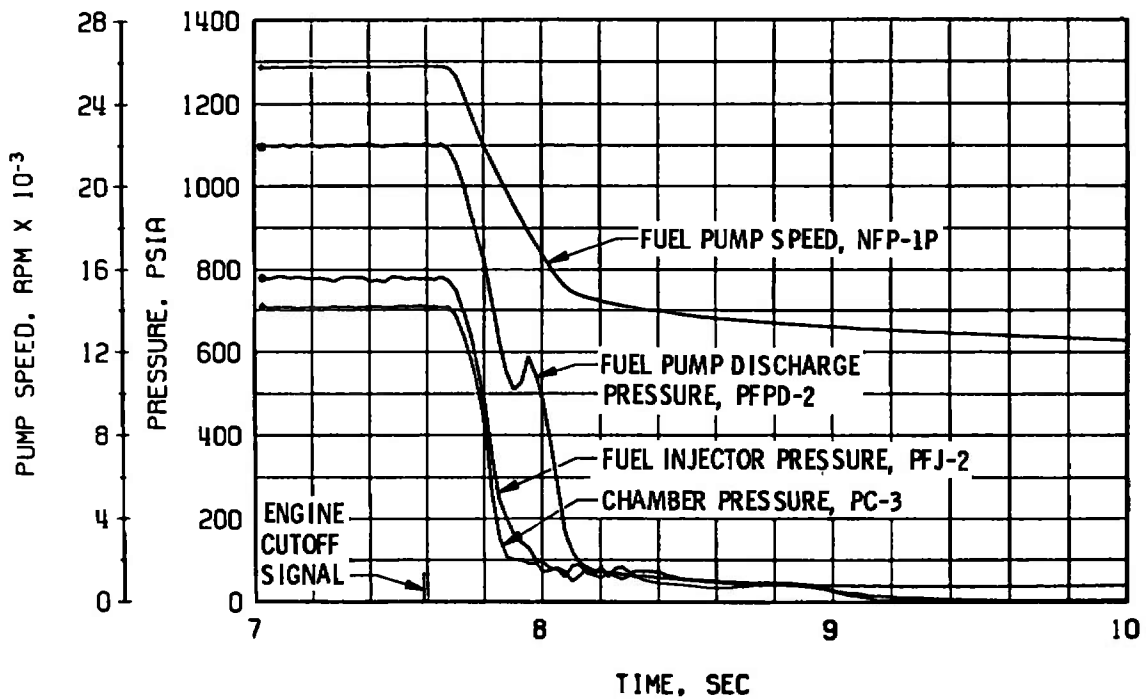


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

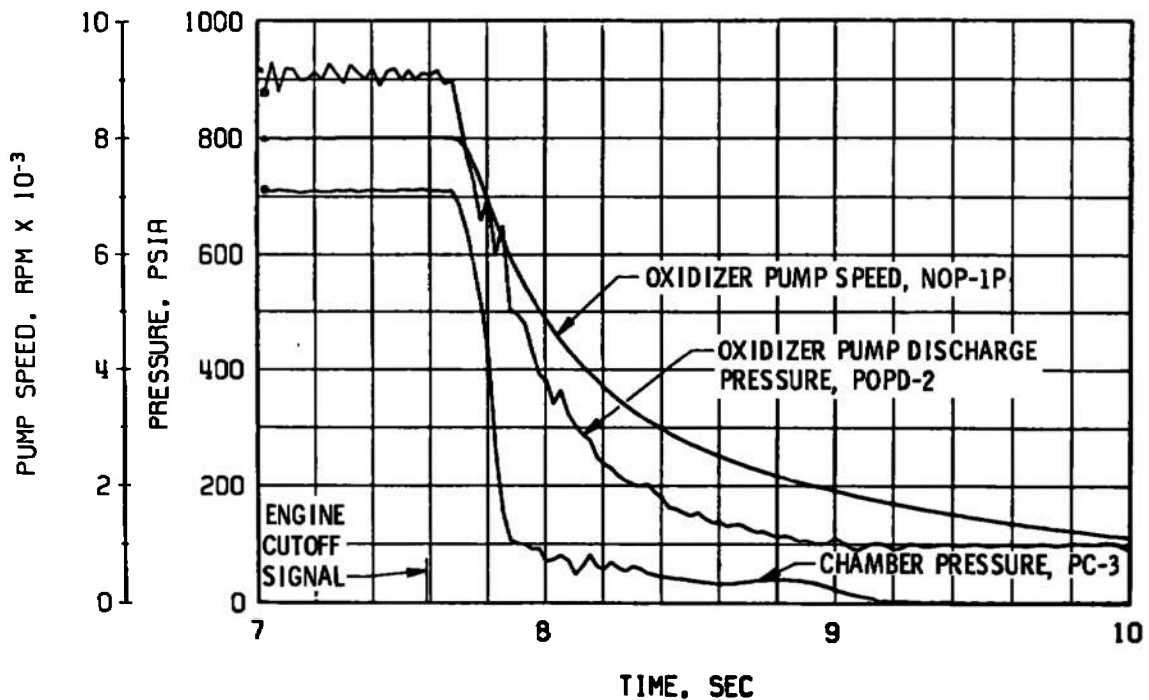


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 122 Continued

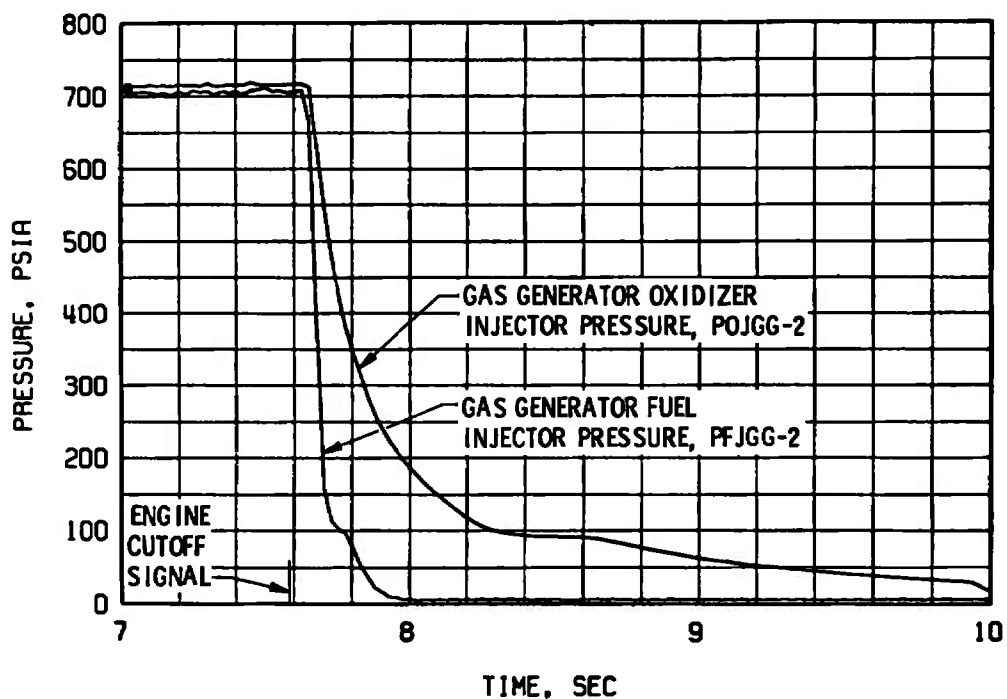


e. Thrust Chamber Fuel System, Shutdown

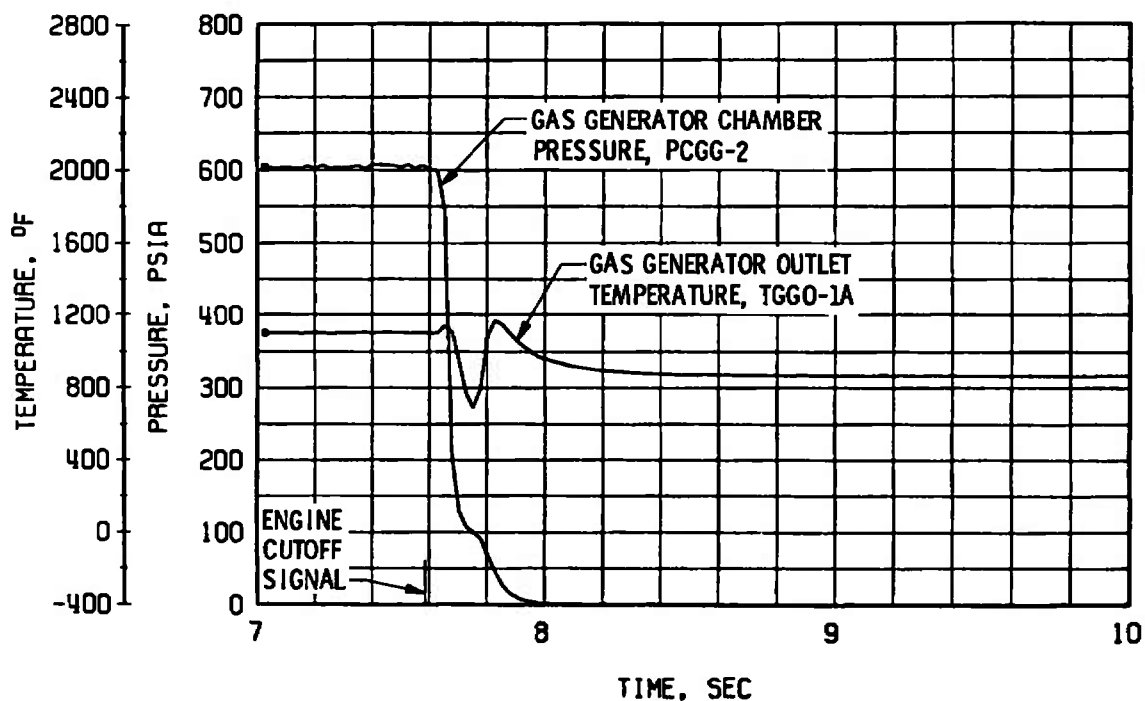


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 122 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 122 Concluded

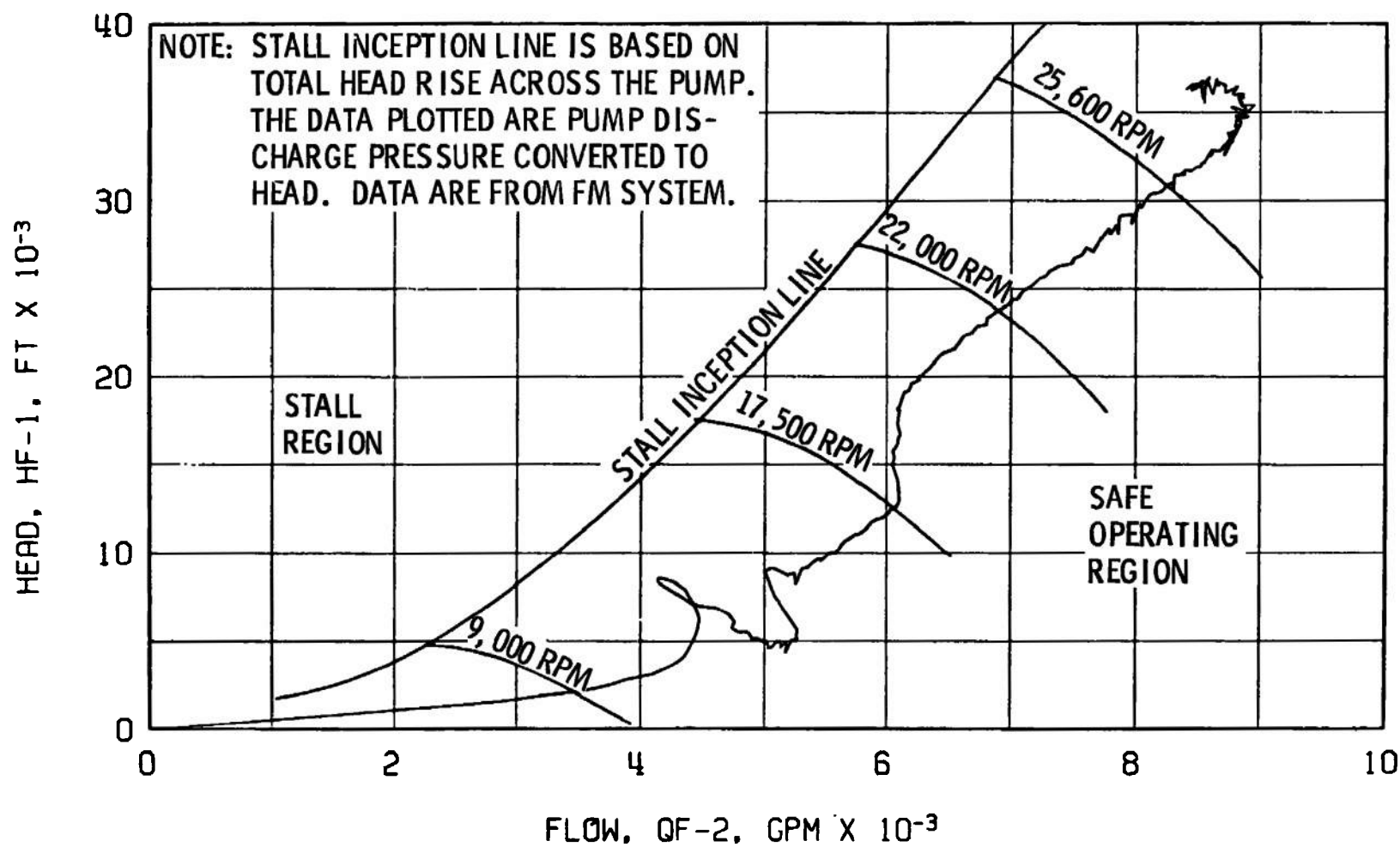
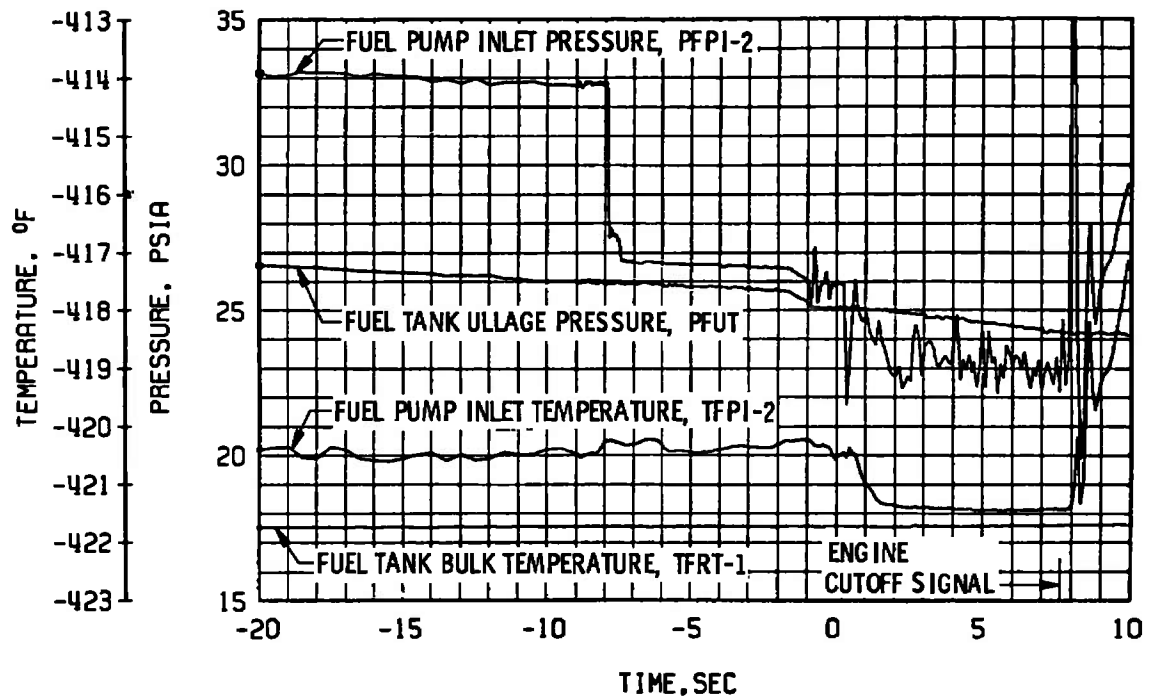
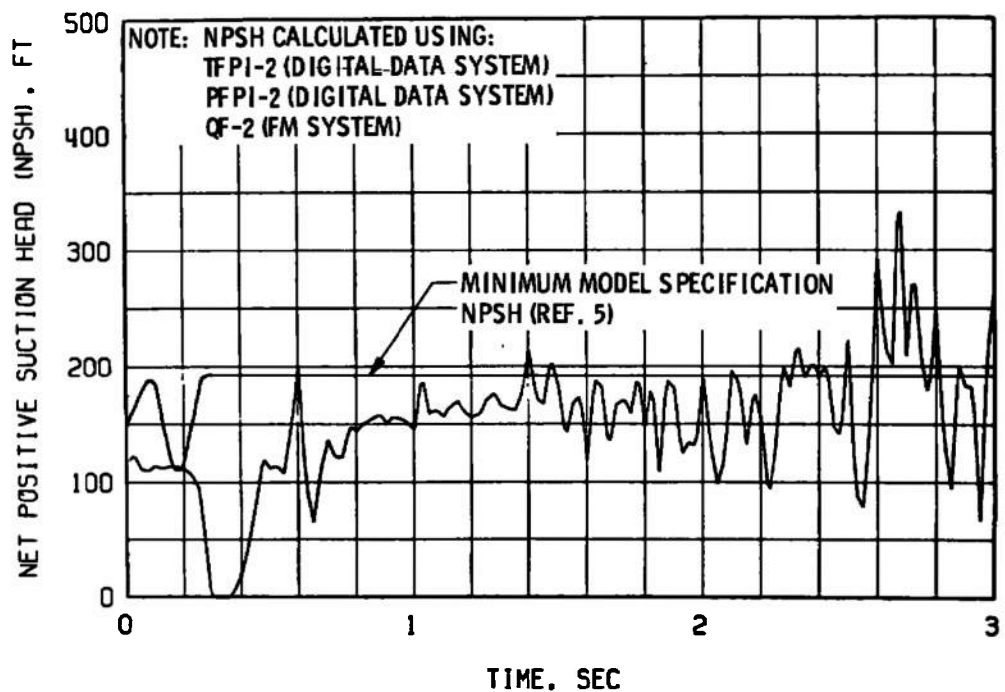


Fig. 123 Fuel Pump Start Transient Performance, Firing 33C

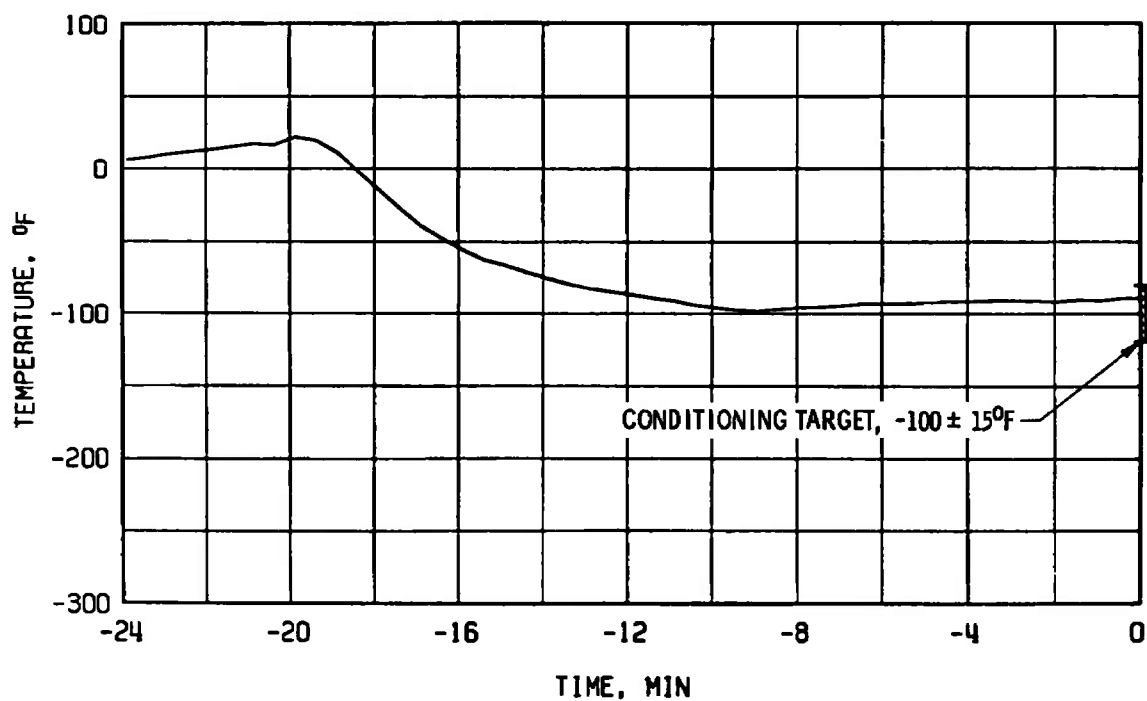


a. Duct Pressure and Temperature Transients

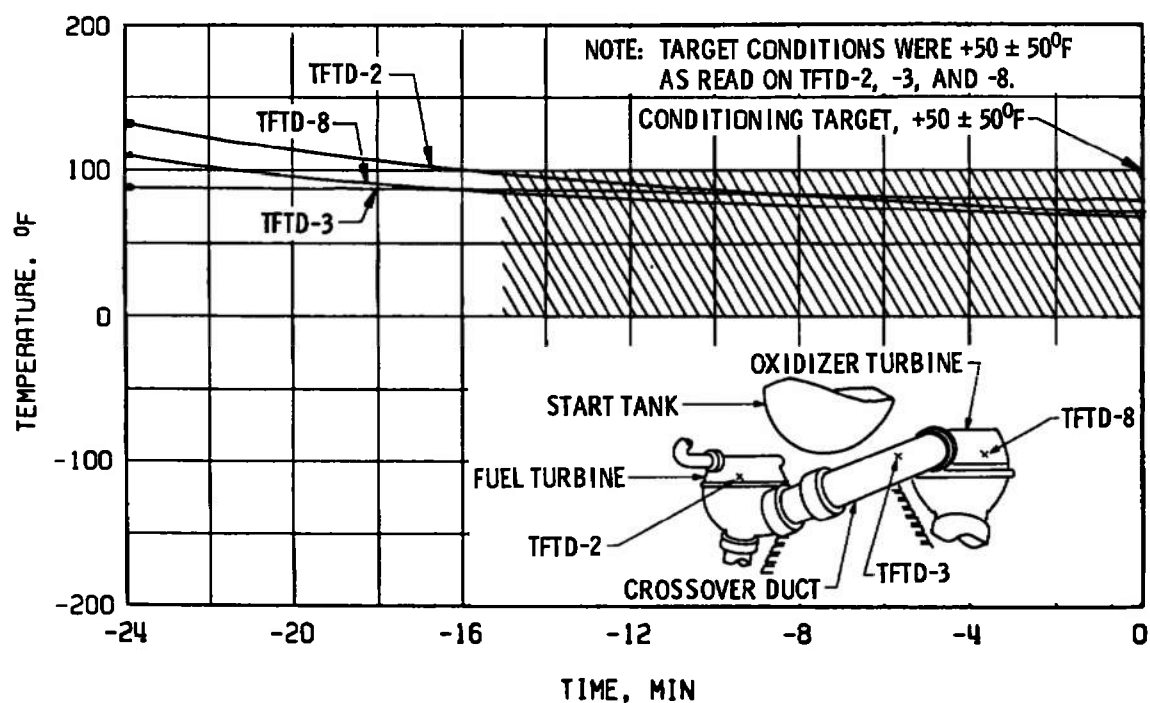


b. Fuel Pump NPSH during Start Transient, Firing 33C

Fig. 124 Fuel Low Pressure Duct Performance, Firing 33C

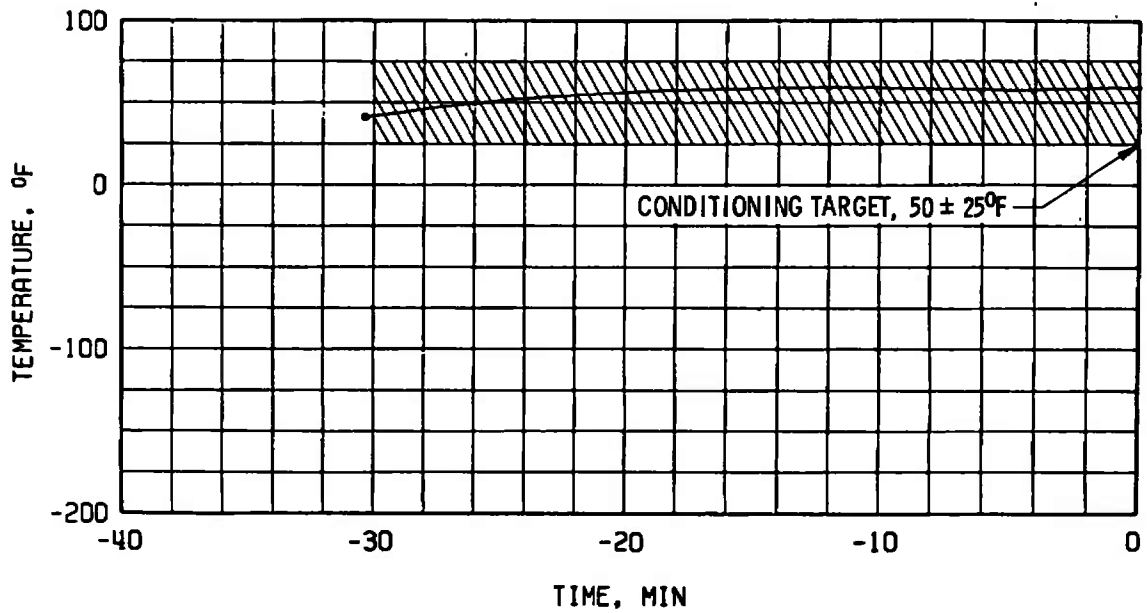


a. Thrust Chamber Throat, TTC-1P

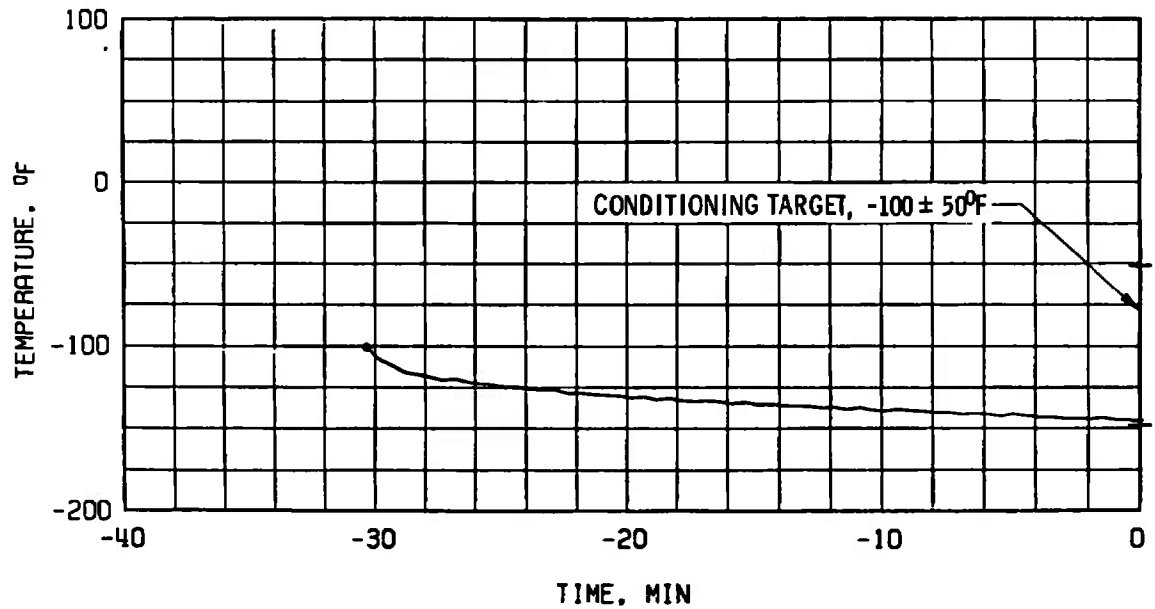


b. Crossover Duct, TFTD

Fig. 125 Thermal Conditioning History of Engine Components, Firing 33D



c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 125 Concluded



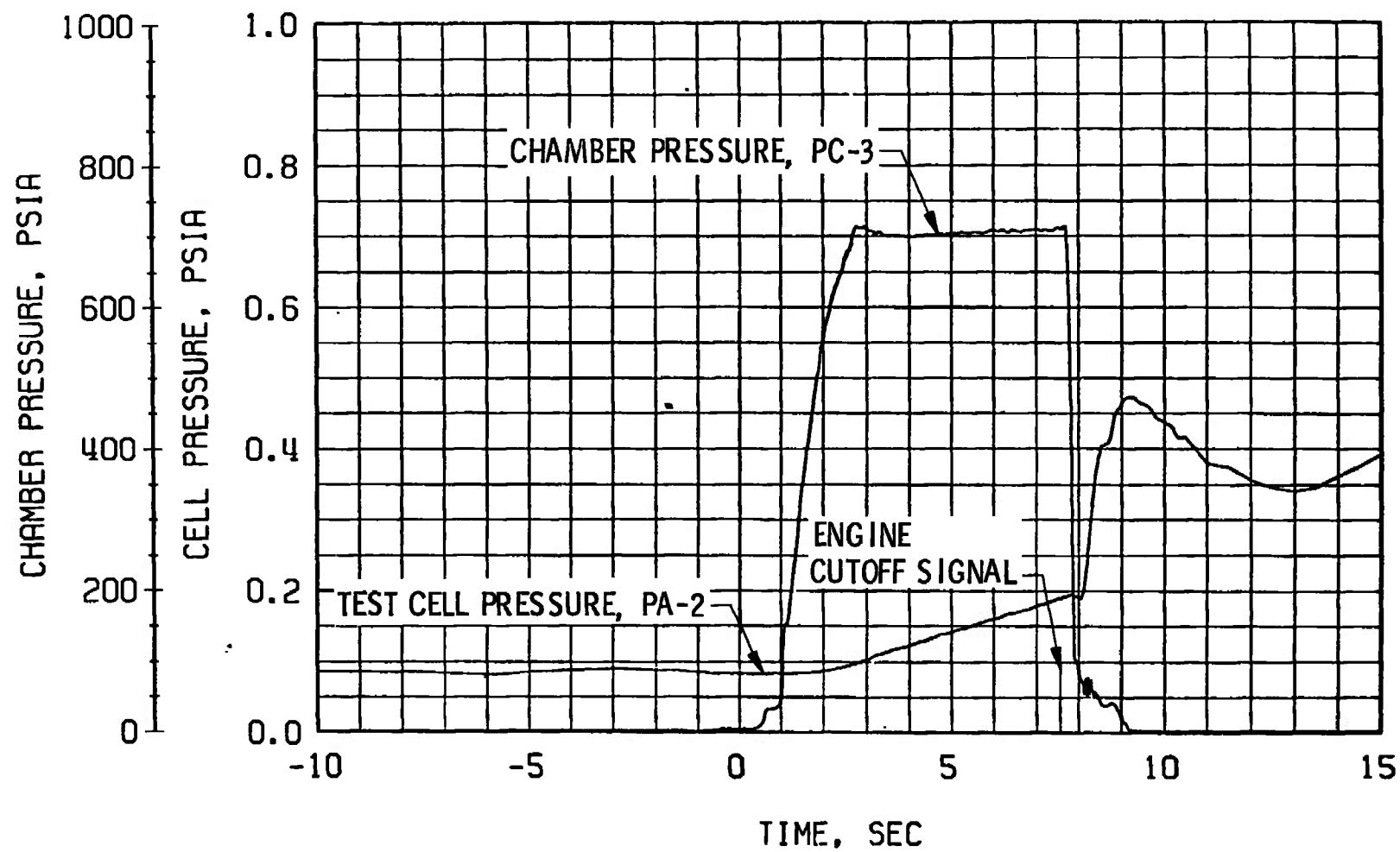
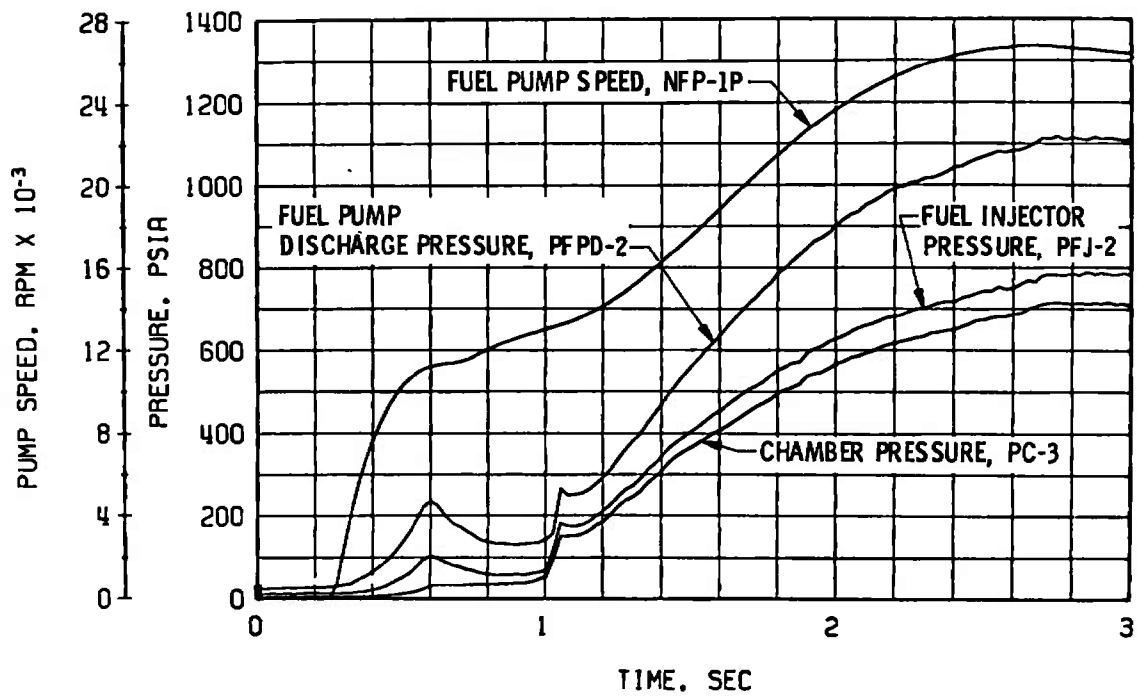
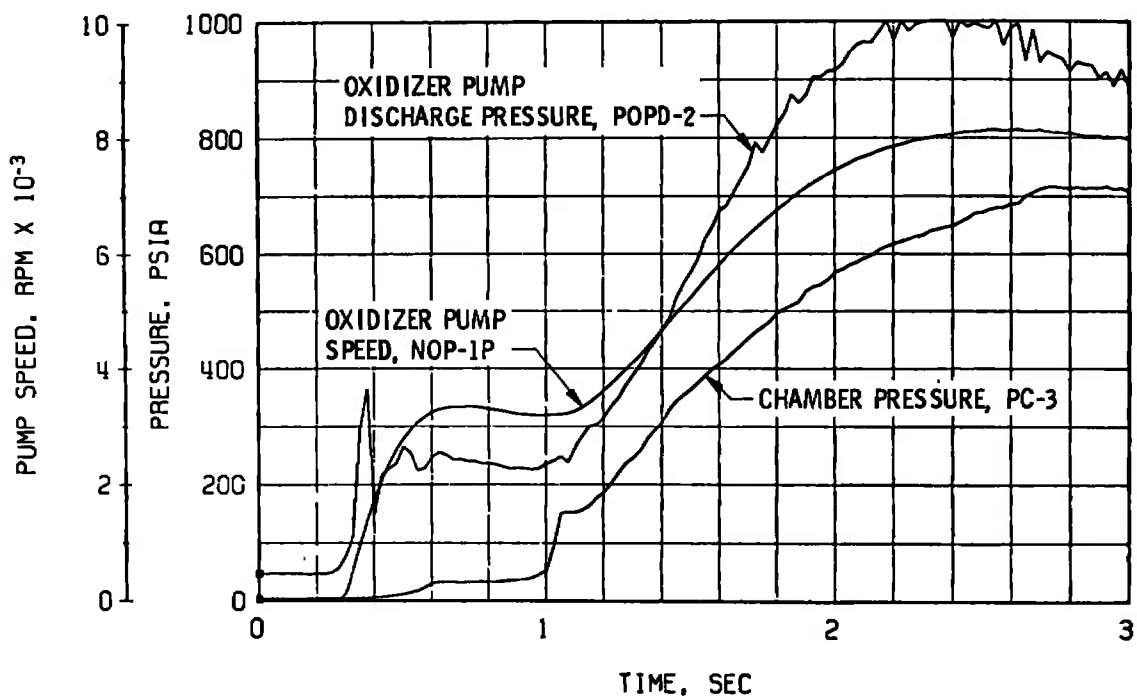


Fig. 126 Engine Ambient and Combustion Chamber Pressures, Firing 33D

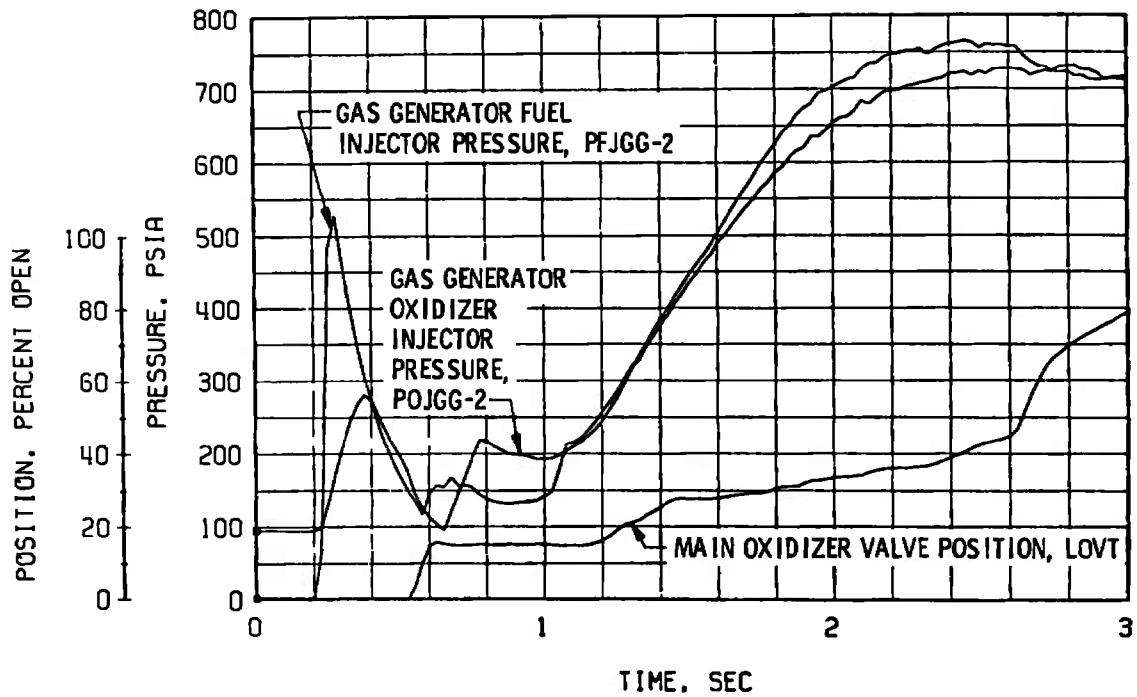


a. Thrust Chamber Fuel System, Start

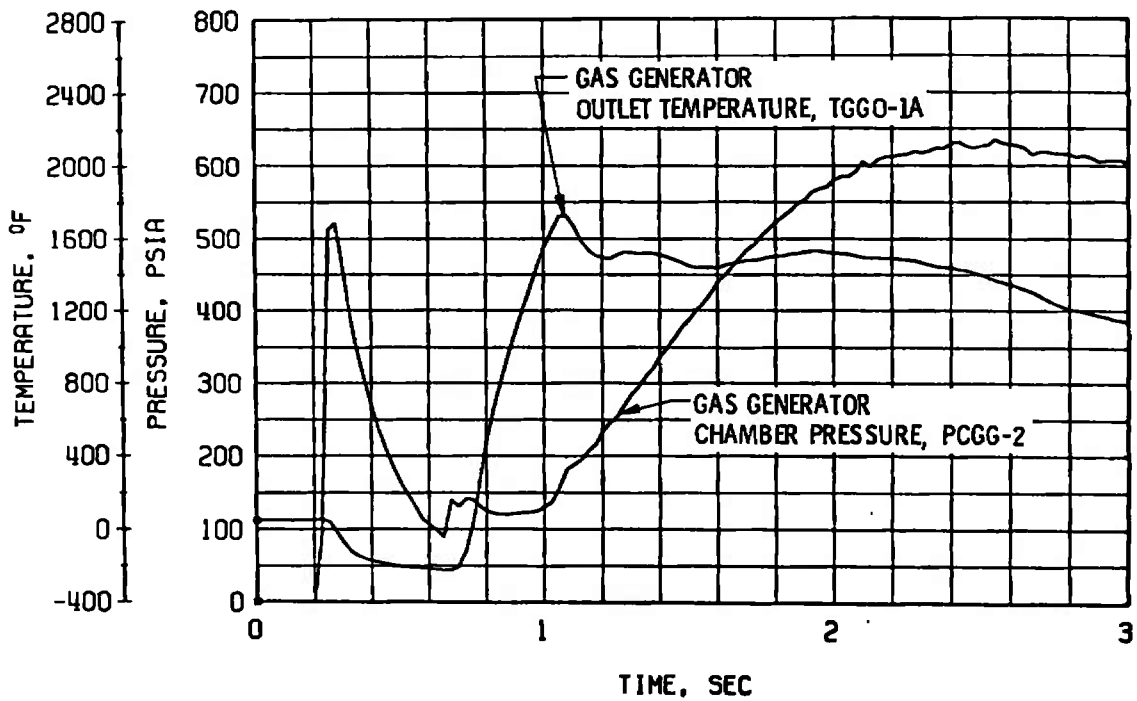


b. Thrust Chamber Oxidizer System, Start

Fig. 127 Engine Transient Operation, Firing 33D

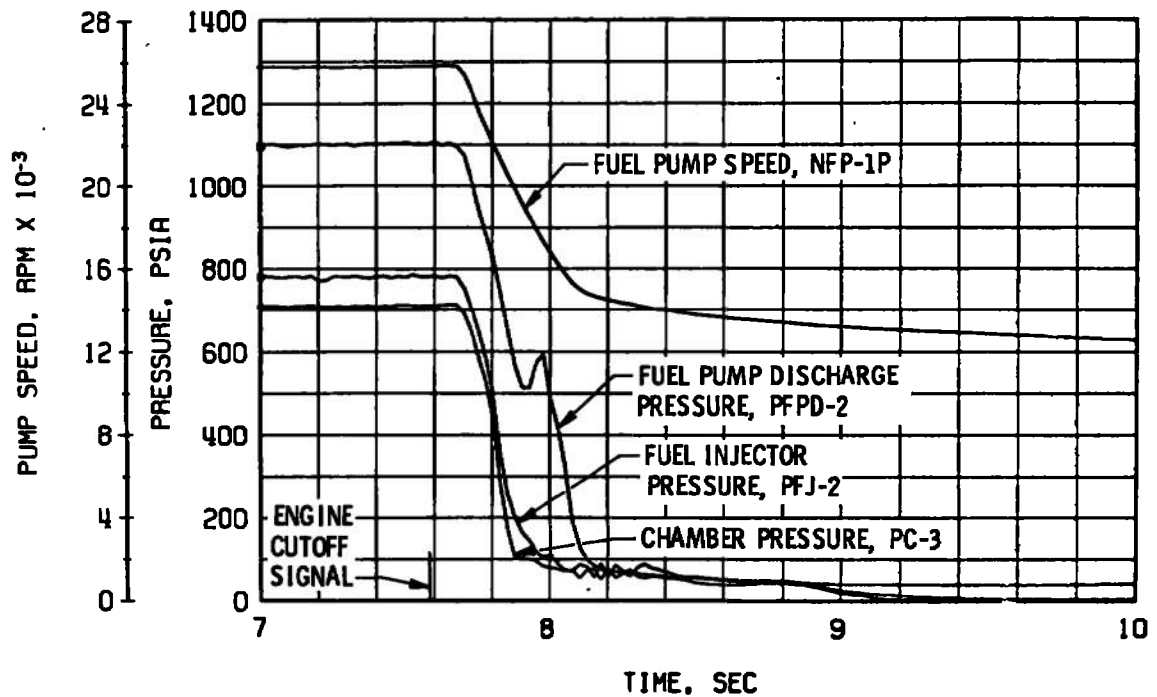


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

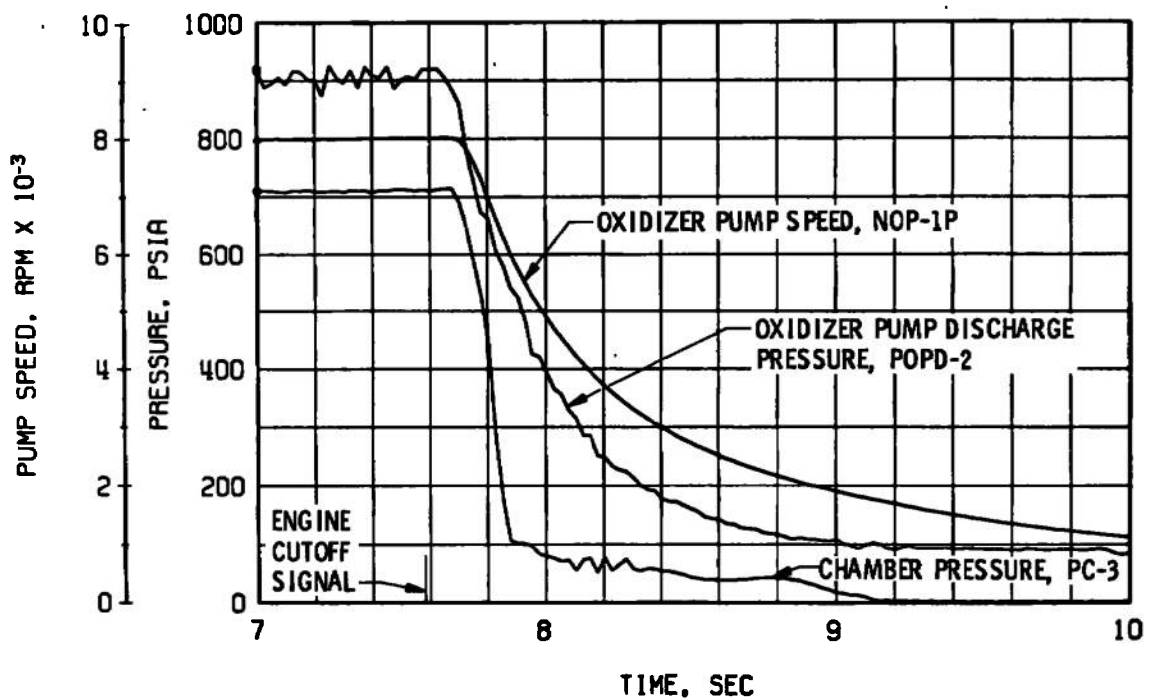


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 127 Continued

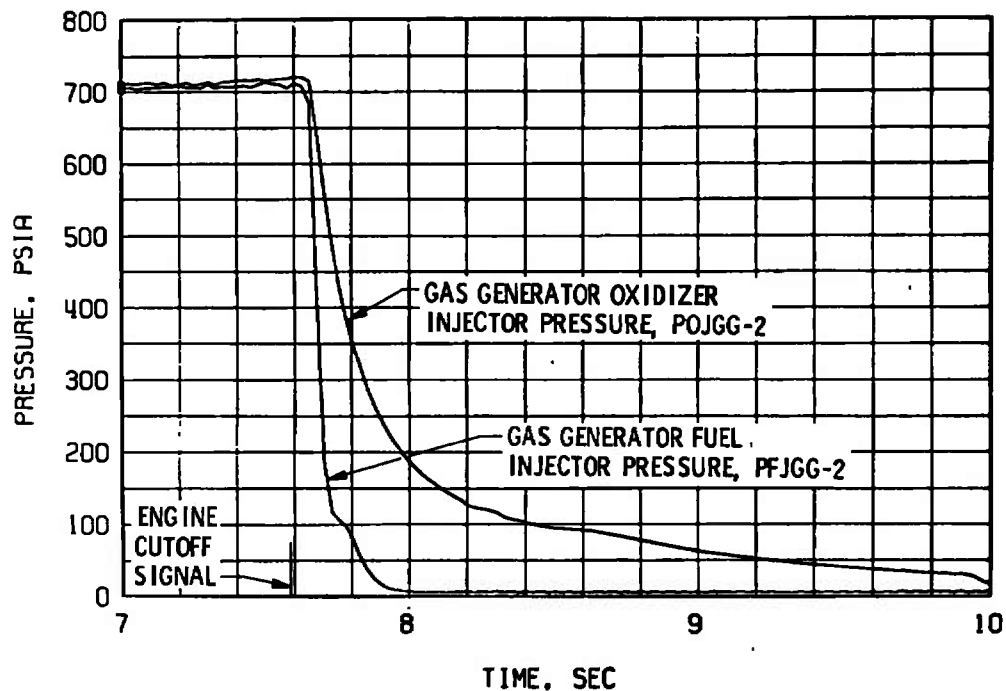


e. Thrust Chamber Fuel System, Shutdown

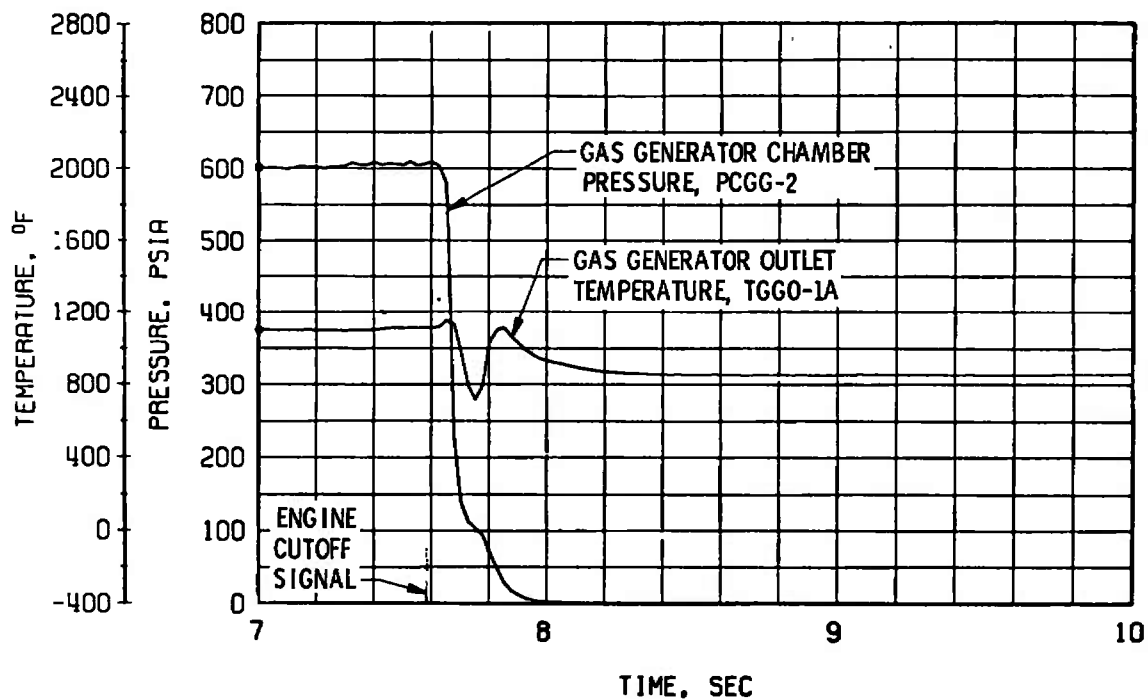


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 127 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 127 Concluded

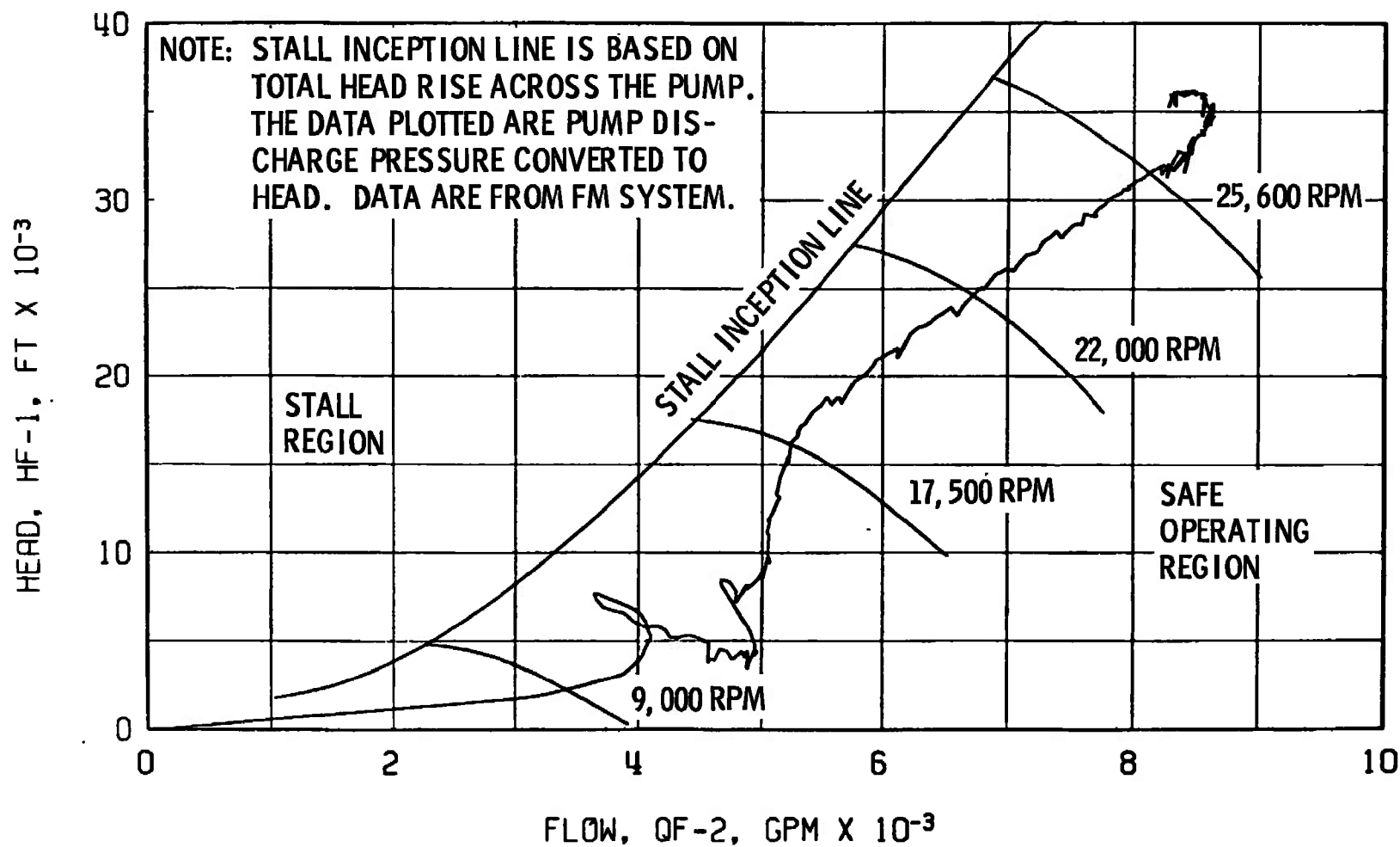
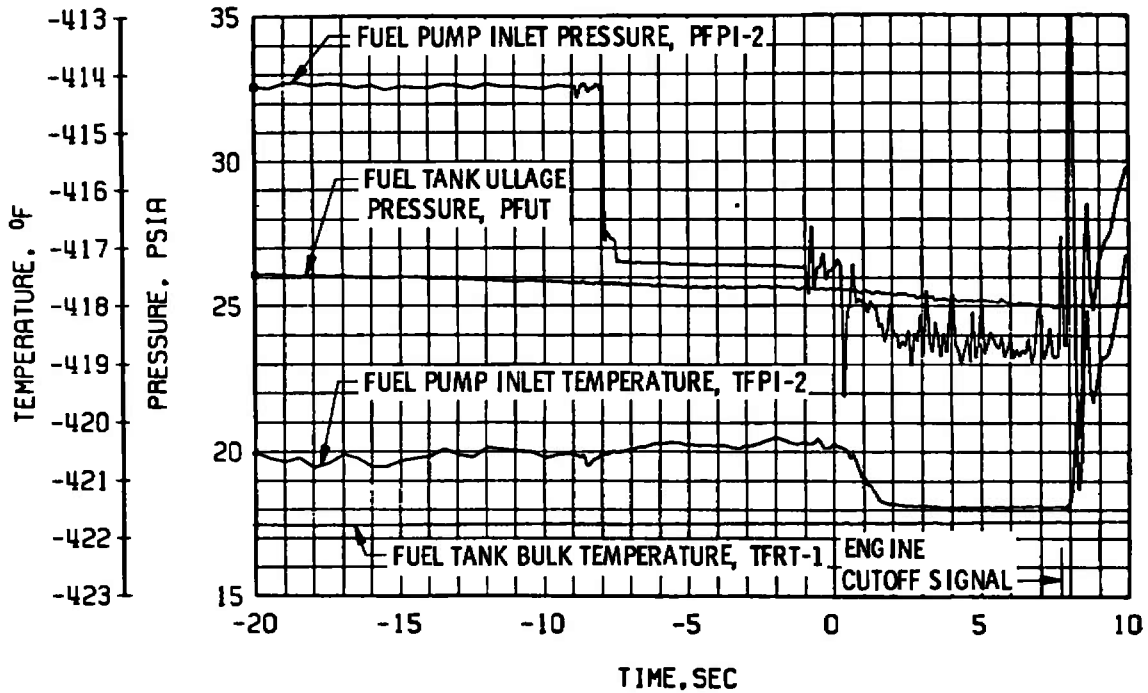
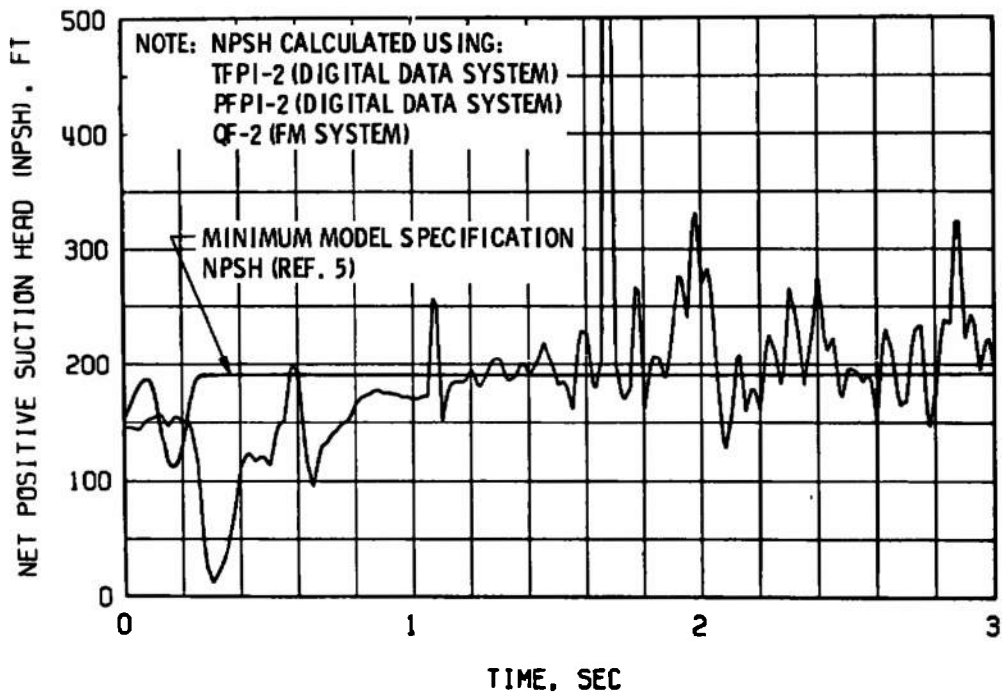


Fig. 128 Fuel Pump Start Transient Performance, Firing 33D

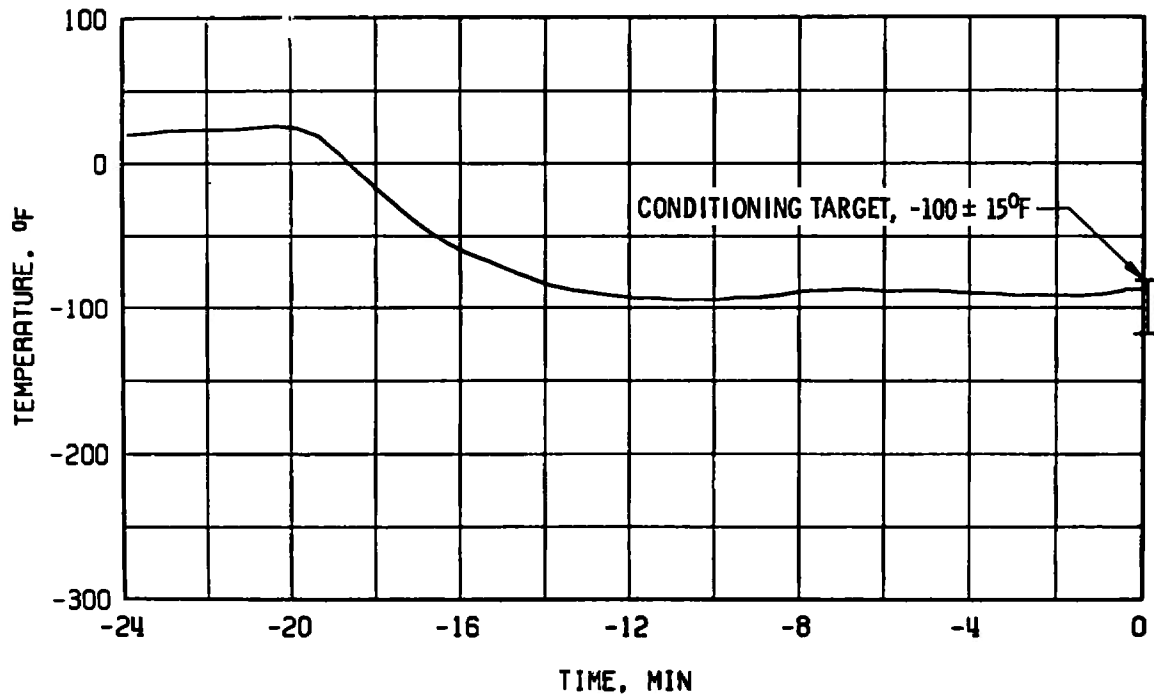


a. Duct Pressure and Temperature Transients

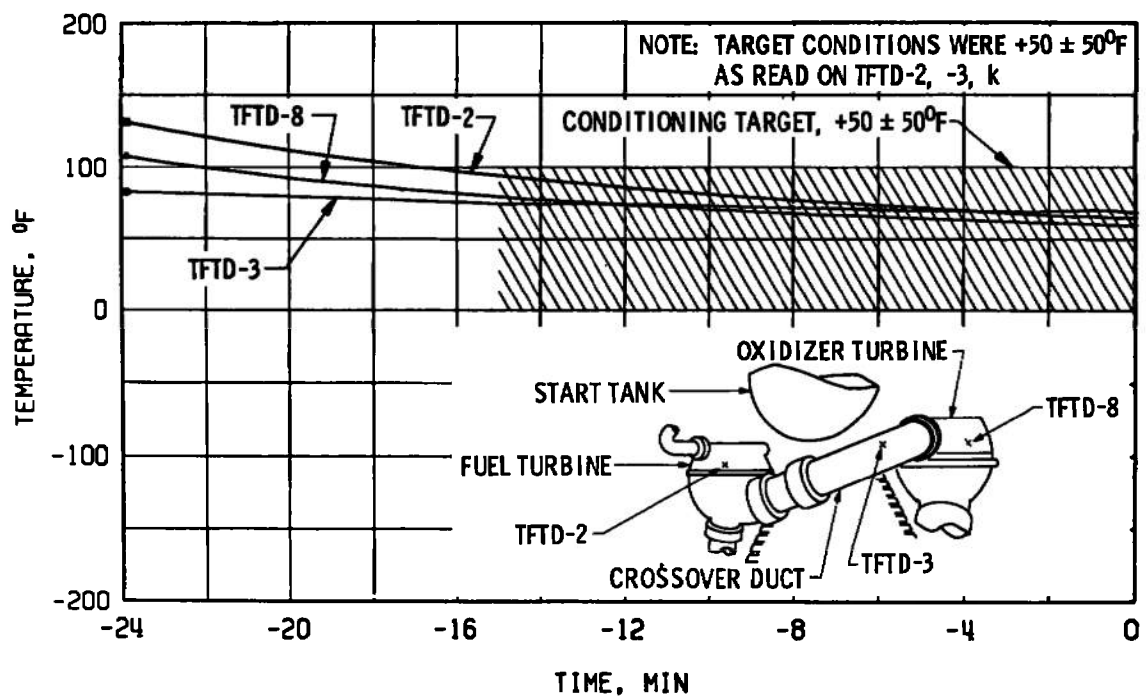


b. Fuel Pump NPSH during Start Transient, Firing 33D

Fig. 129 Fuel Low Pressure Duct Performance, Firing 33D



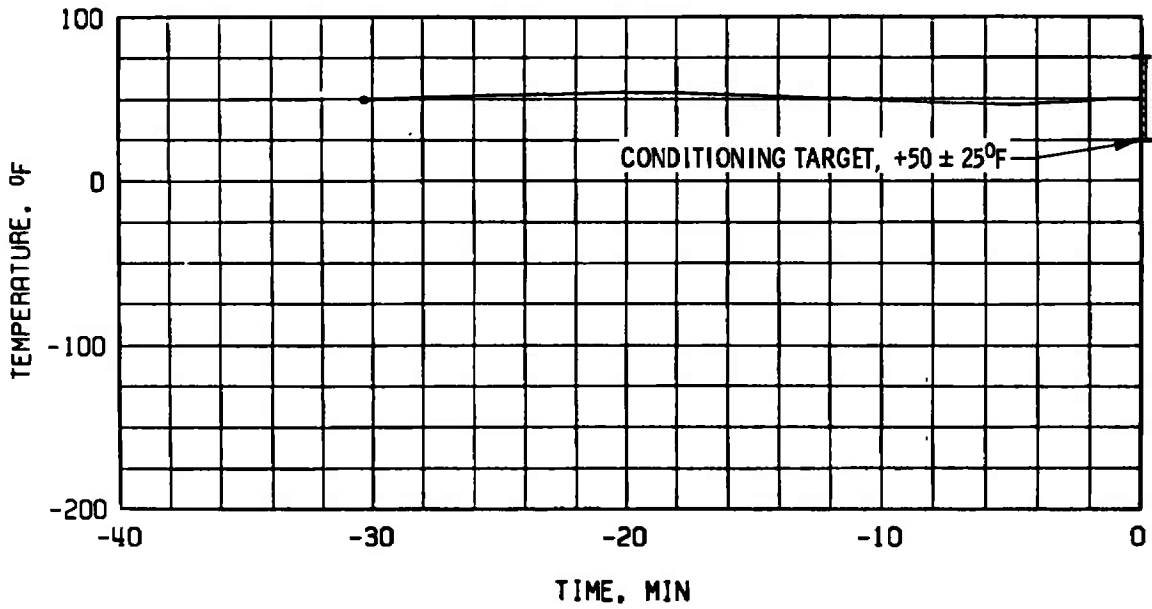
a. Thrust Chamber Throat, TTC-1P



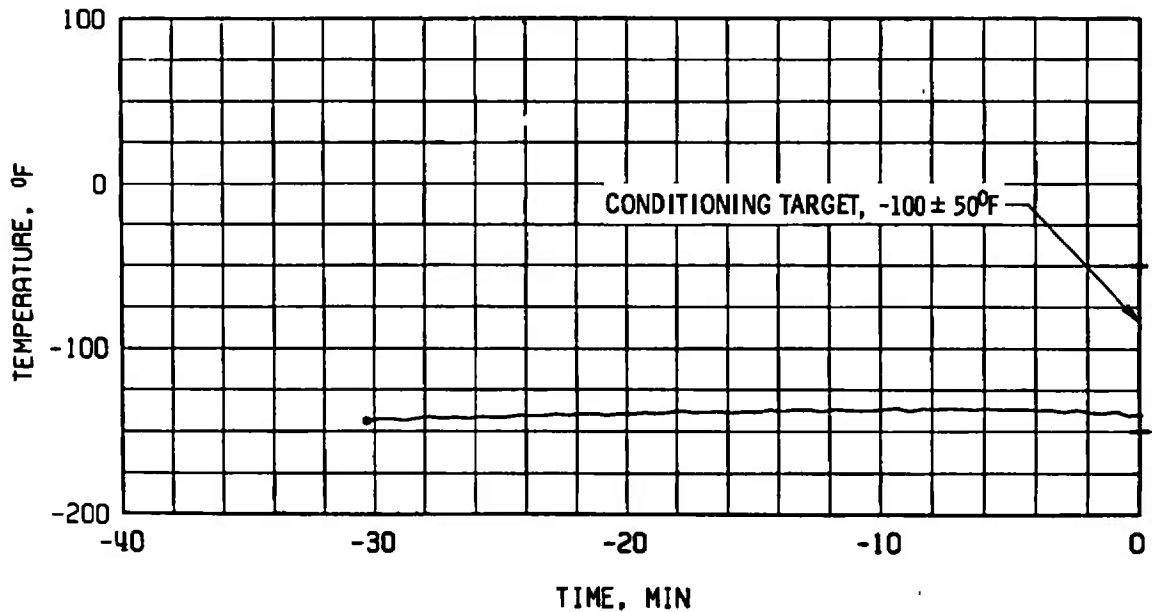
b. Crossover Duct, TFTD

Fig. 130 Thermal Conditioning History of Engine Components, Firing 33E





c. Start Tank Discharge Valve, TSTDVOC



d. Main Oxidizer Valve Second-Stage Actuator, TSOVC-1

Fig. 130 Concluded

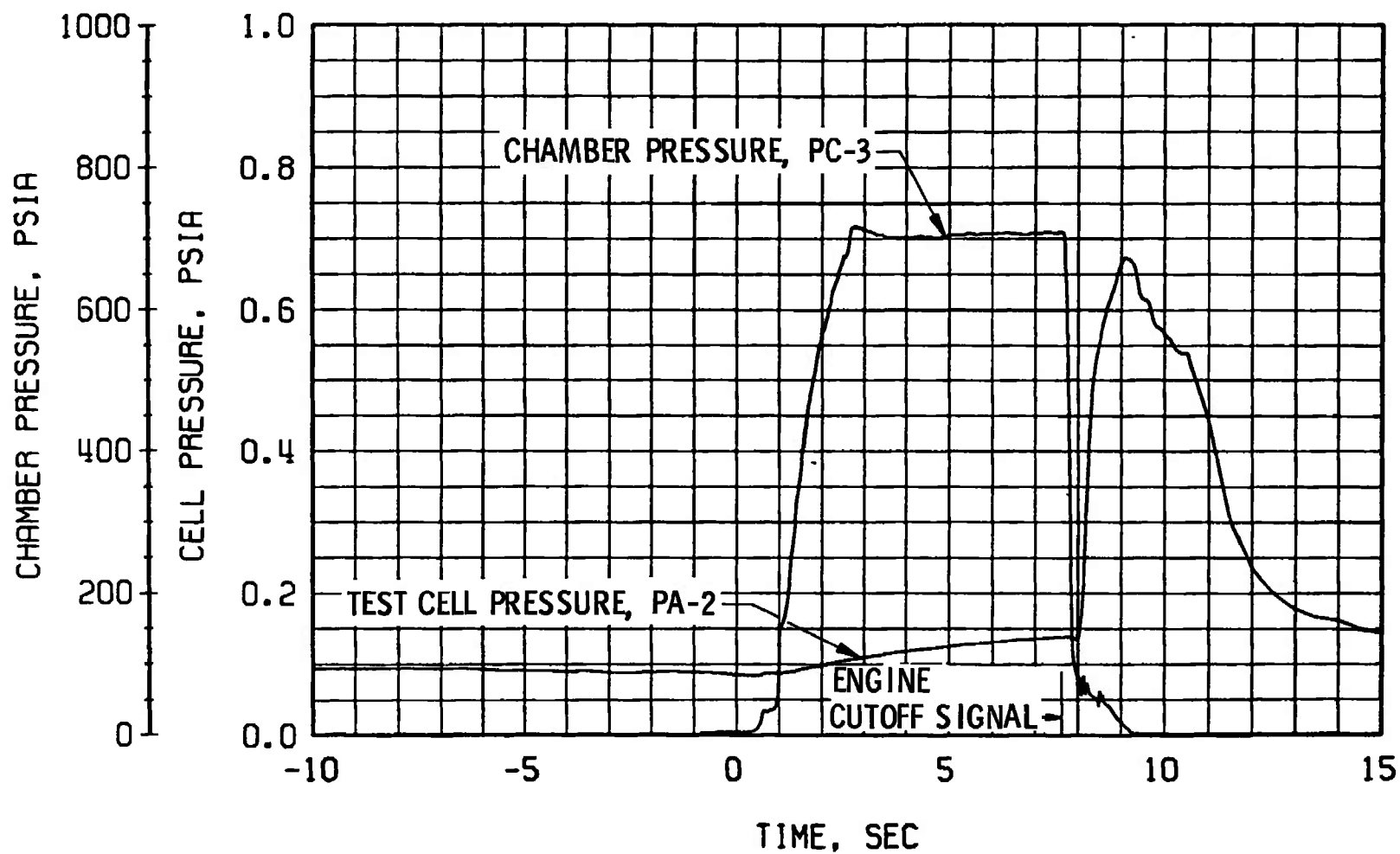
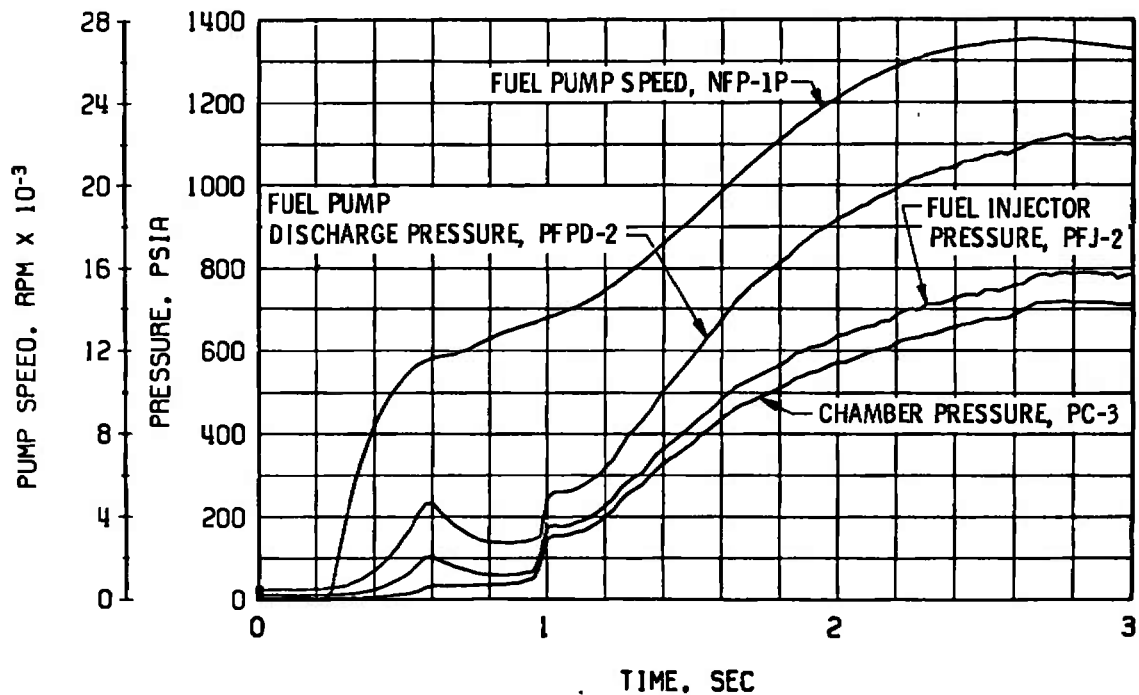
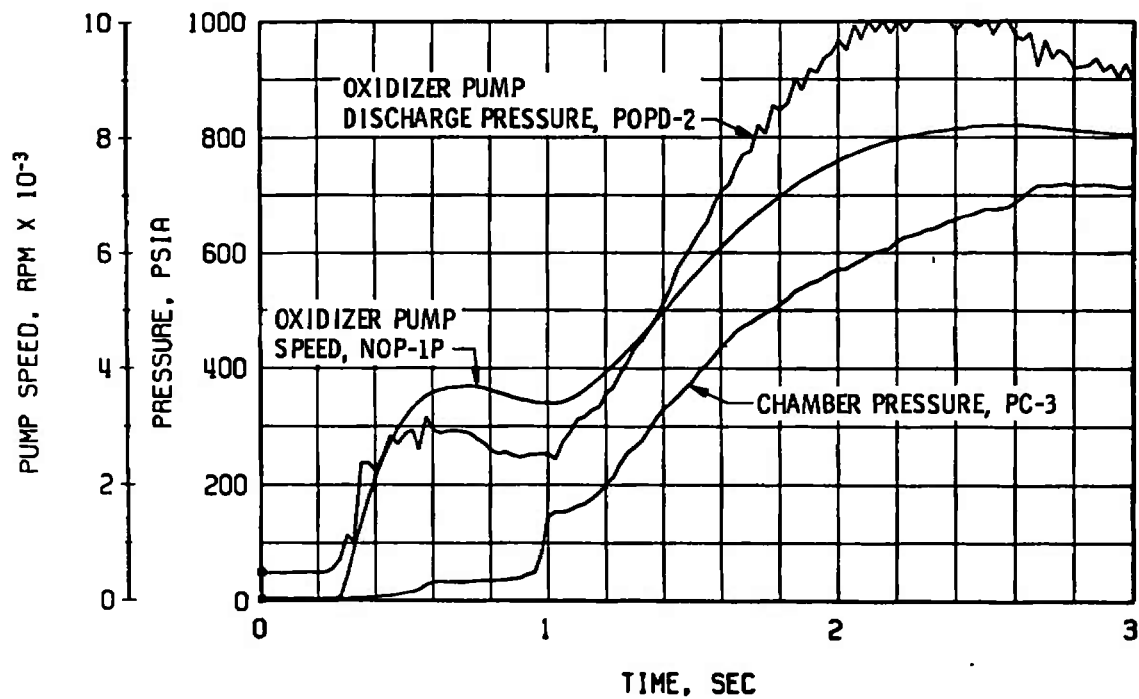


Fig. 131 Engine Ambient and Combustion Chamber Pressures, Firing 33E

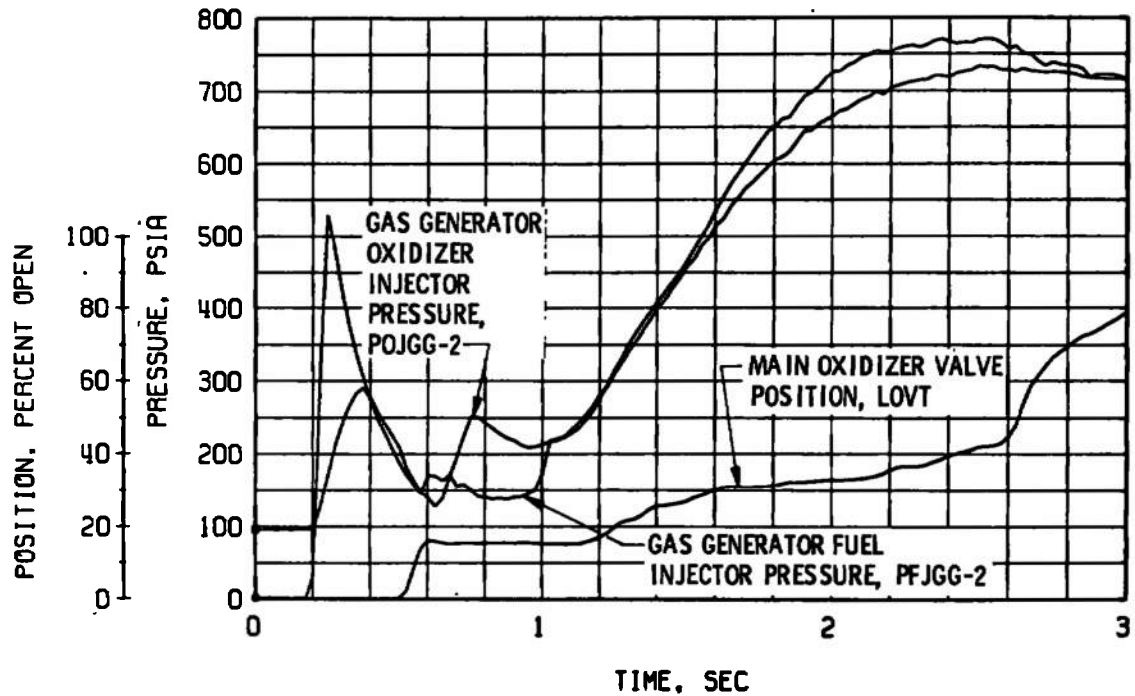


a. Thrust Chamber Fuel System, Start

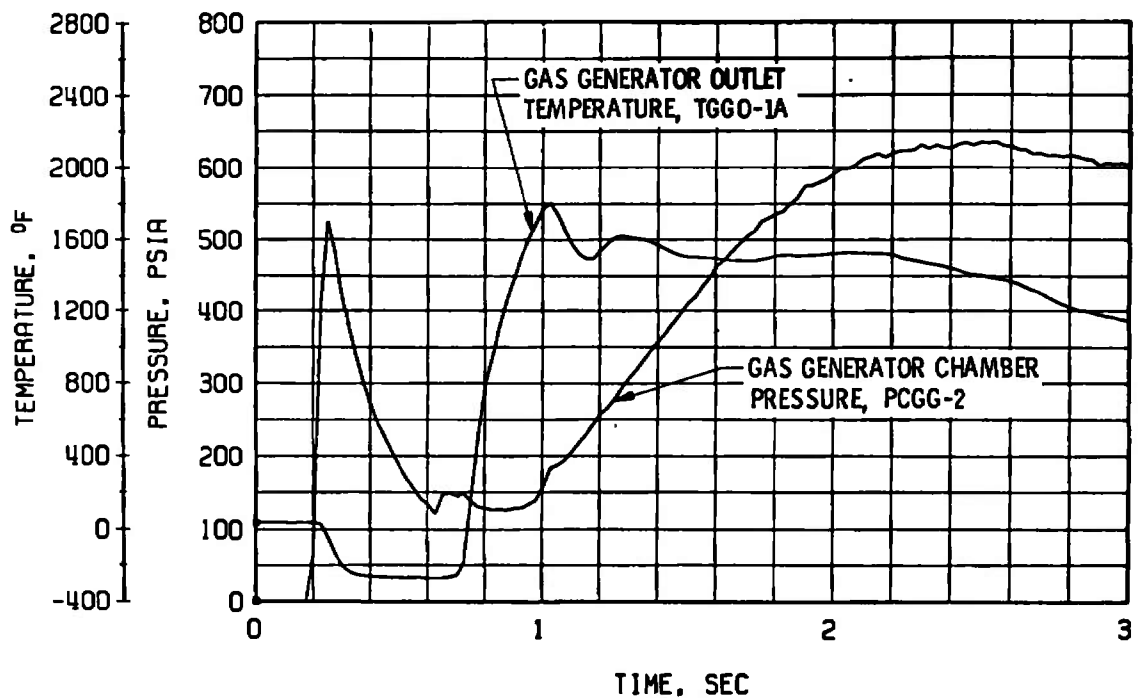


b. Thrust Chamber Oxidizer System, Start

Fig. 132 Engine Transient Operation, Firing 33E

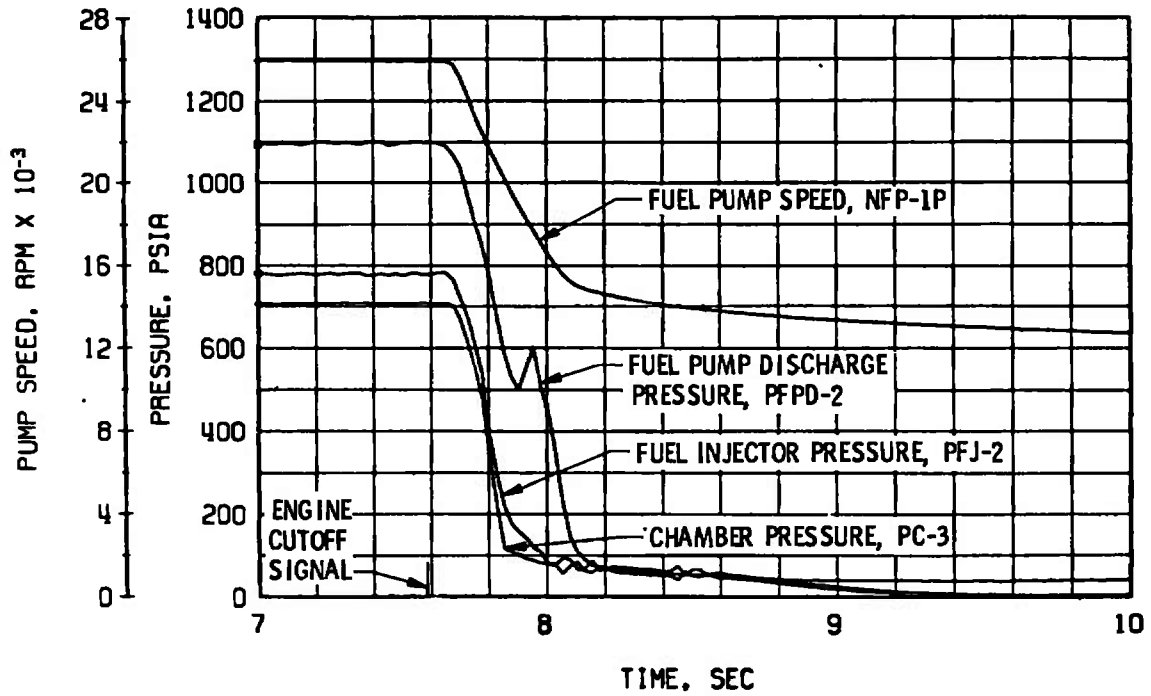


c. Gas Generator Injector Pressures and Main Oxidizer Valve Position, Start

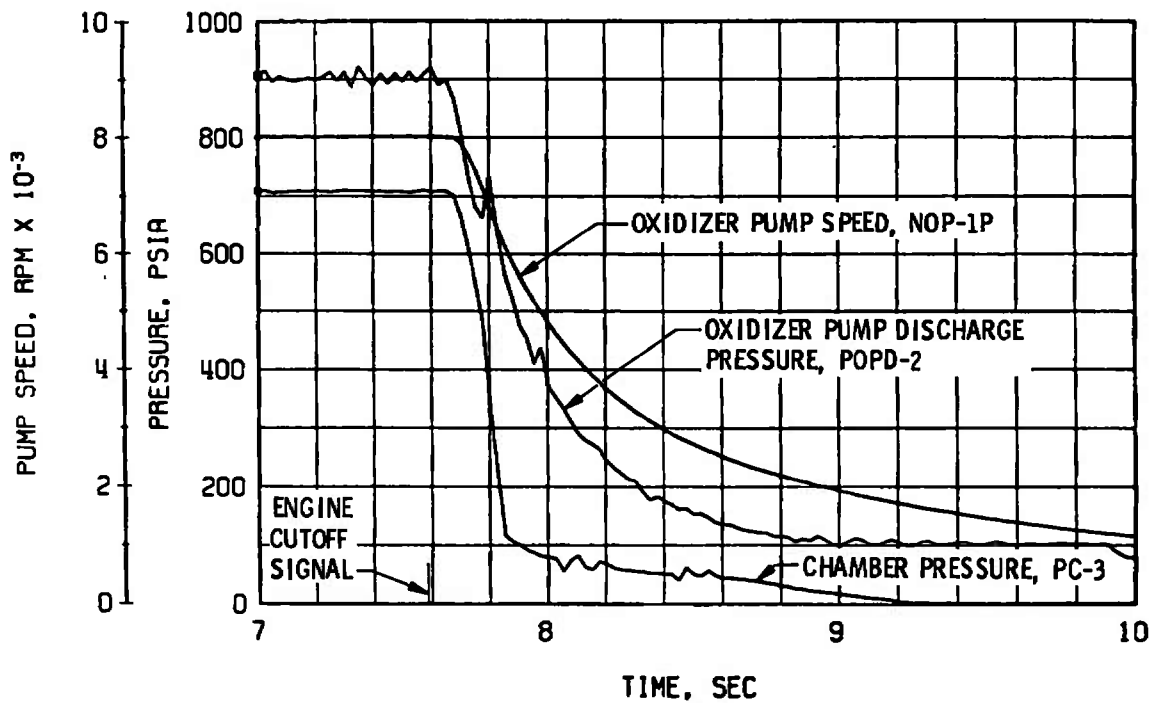


d. Gas Generator Chamber Pressure and Temperature, Start

Fig. 132 Continued

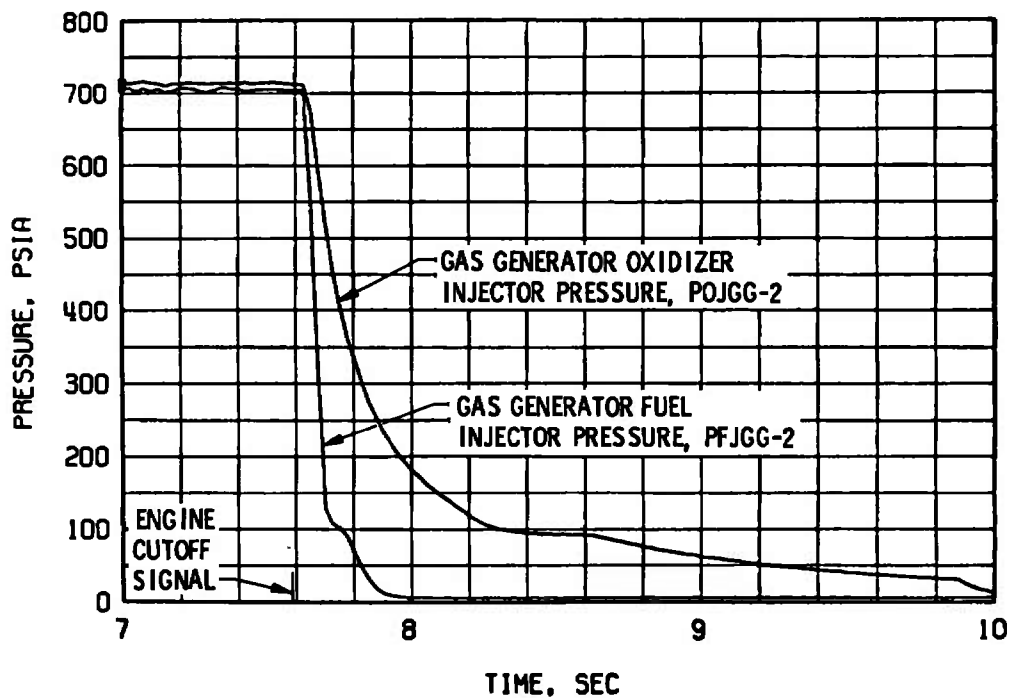


e. Thrust Chamber Fuel System, Shutdown

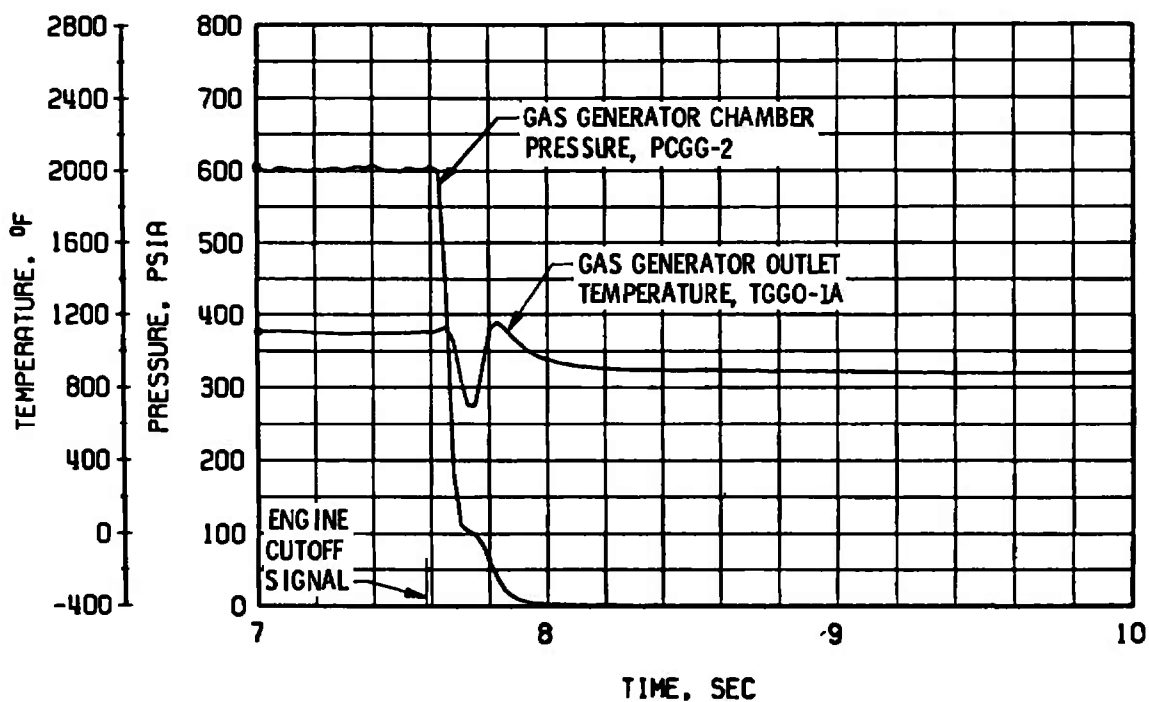


f. Thrust Chamber Oxidizer System, Shutdown

Fig. 132 Continued



g. Gas Generator Injector Pressures, Shutdown



h. Gas Generator Chamber Pressure and Temperature, Shutdown

Fig. 132 Concluded

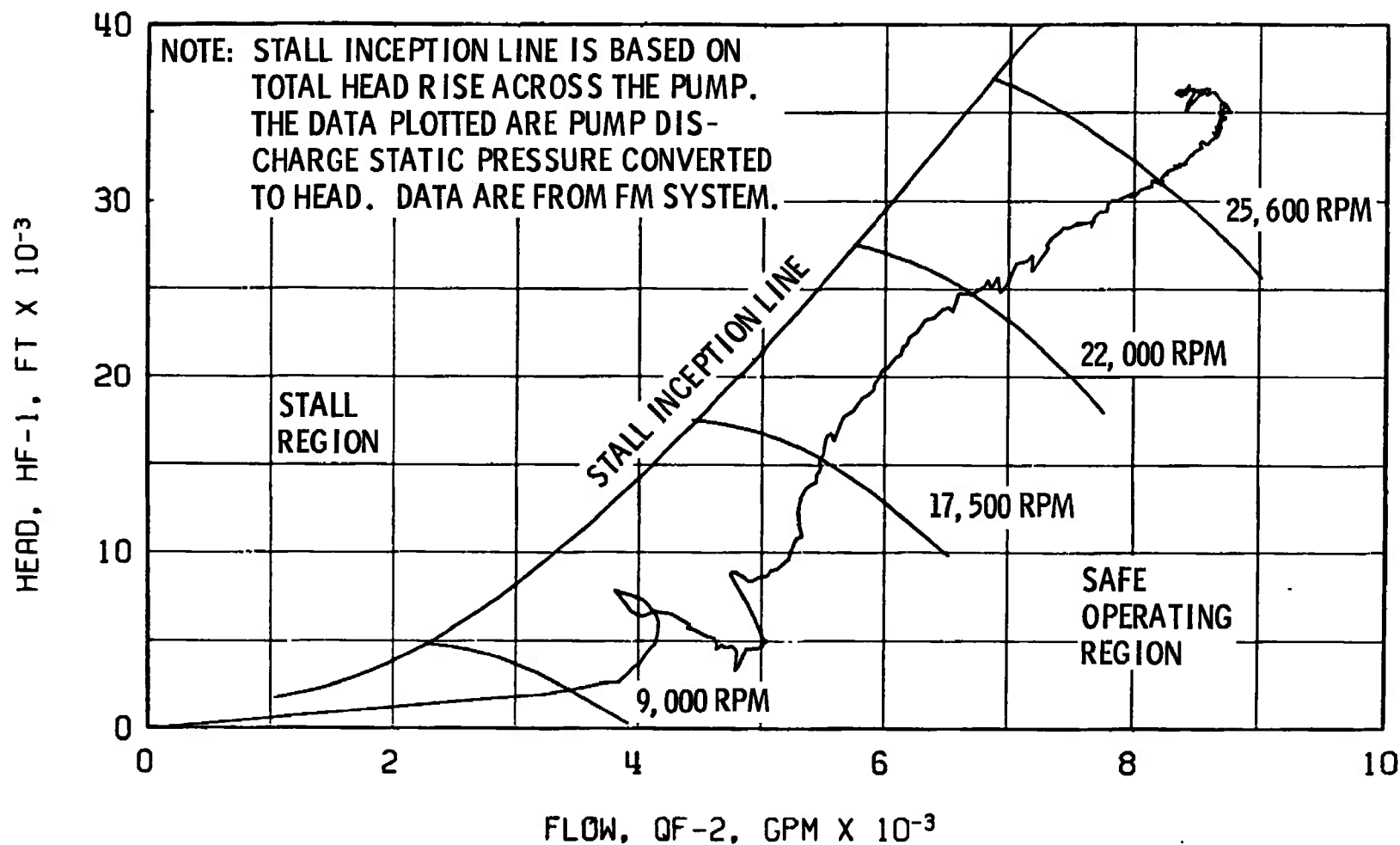
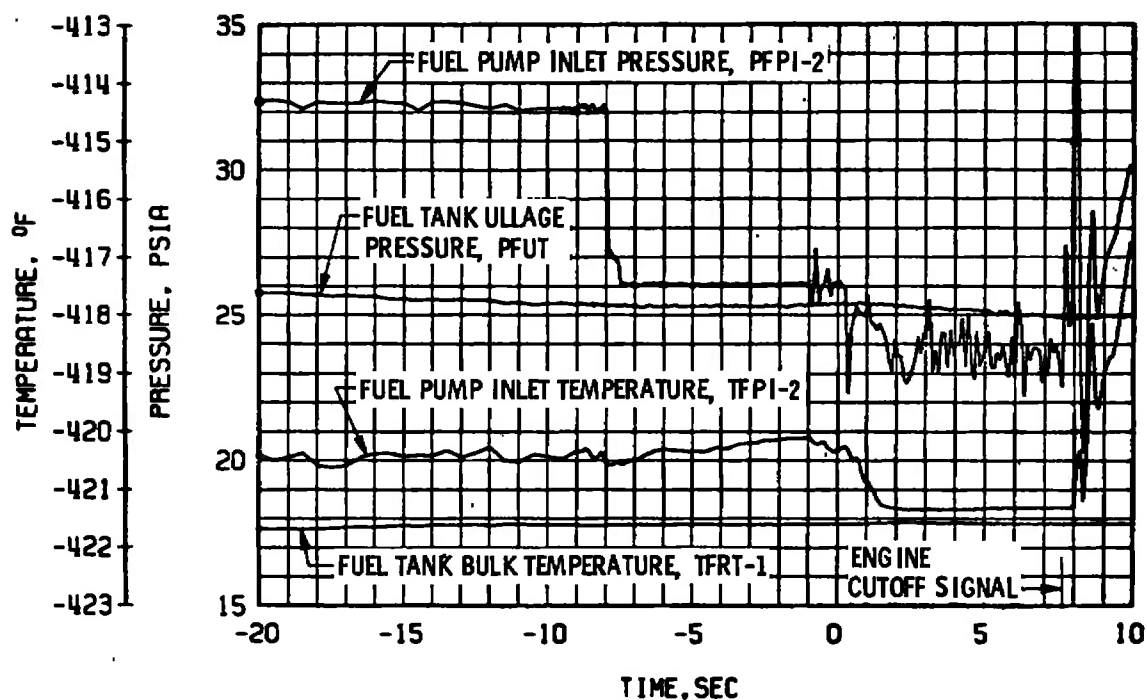
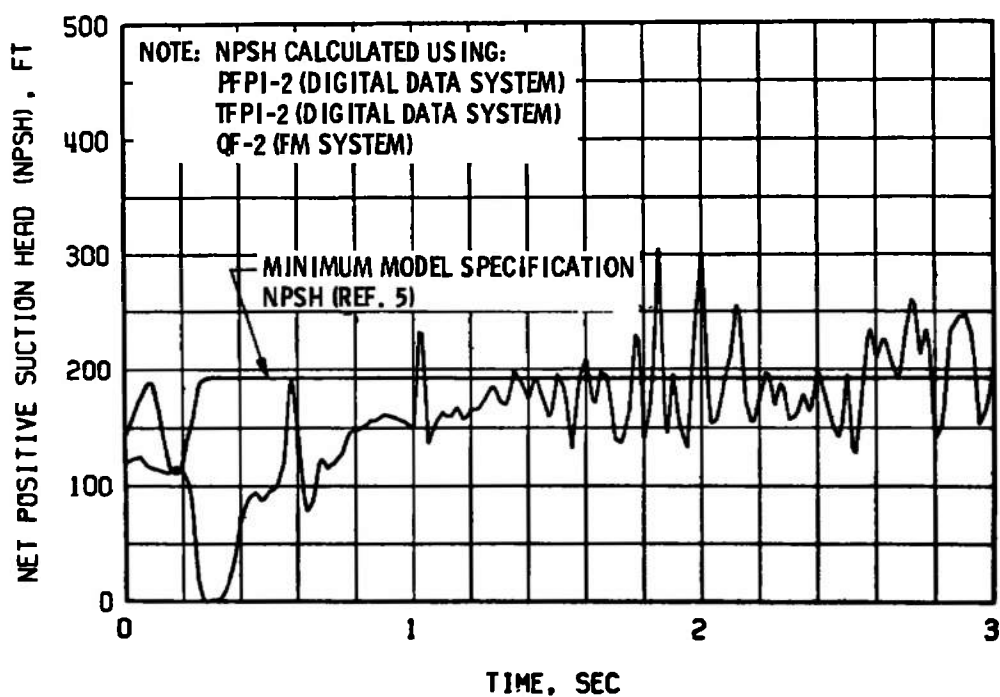


Fig. 133 Fuel Pump Start Transient Performance, Firing 33E



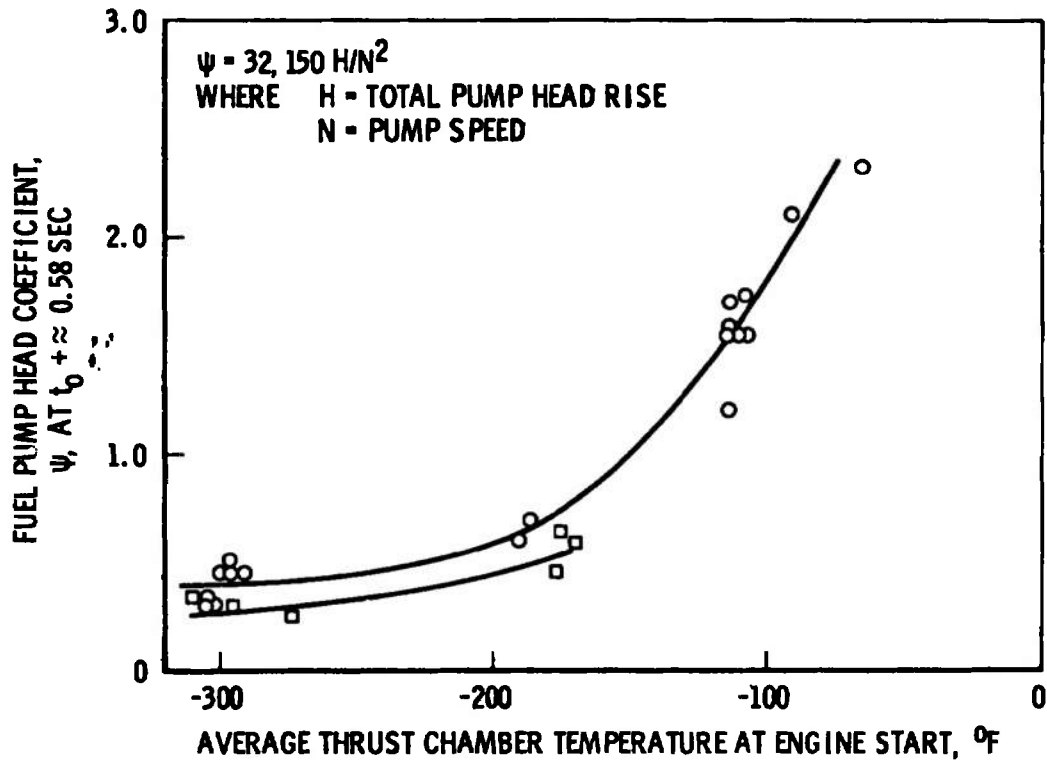
a. Duct Pressure and Temperature Transients



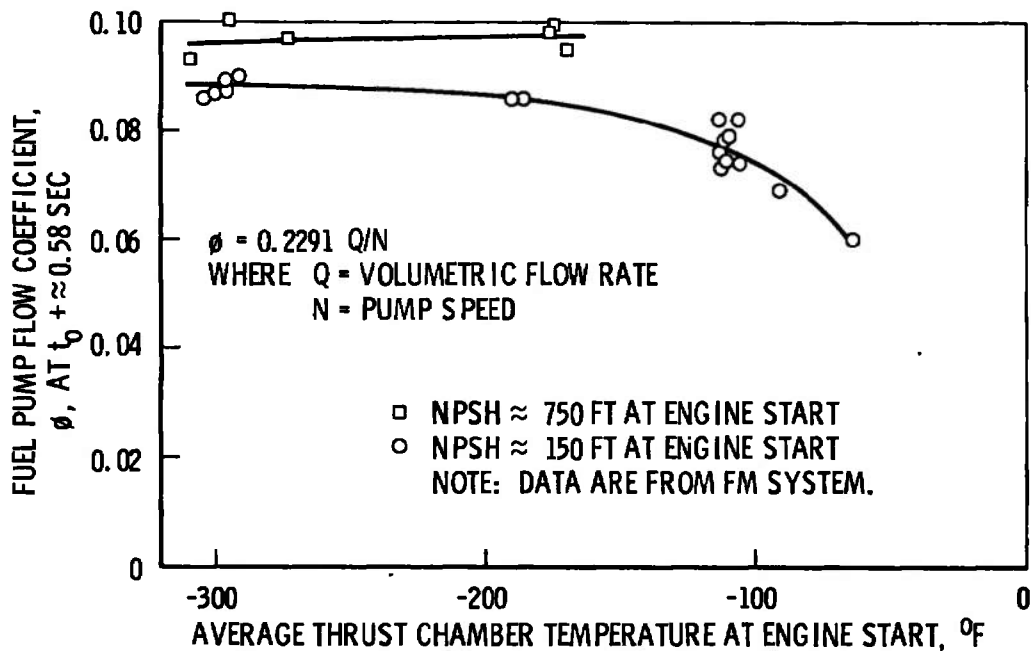
b. Fuel Pump NPSH during Start Transient, Firing 33E

Fig. 134 Fuel Low Pressure Duct Performance, Firing 33E





a. Thrust Chamber Temperature Effect on Fuel Pump Head Coefficient



b. Thrust Chamber Temperature Effect on Fuel Pump Flow Coefficient

Fig. 135 Thrust Chamber Temperature Effect on Fuel Pump Operating Characteristics

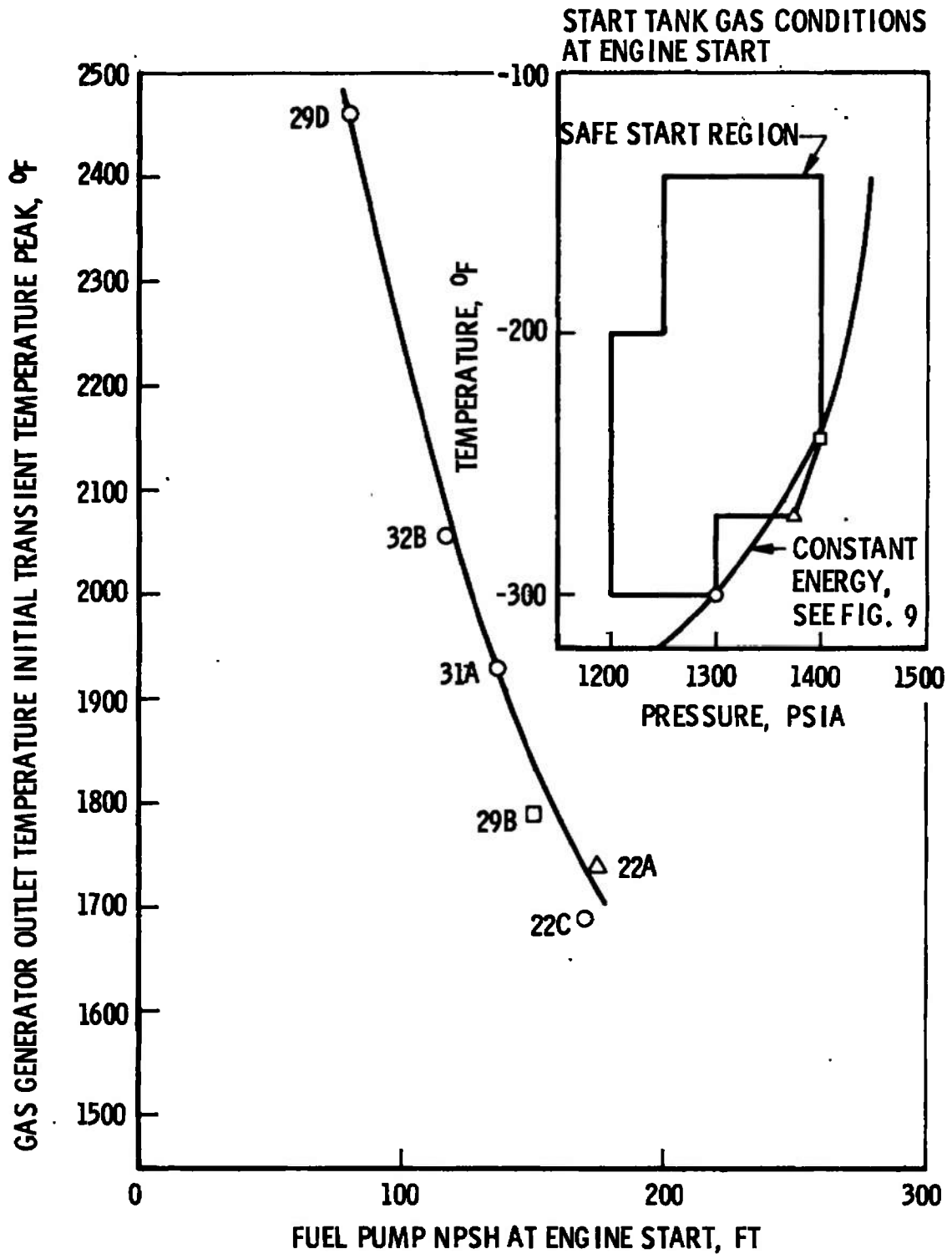


Fig. 136 Fuel Pump NPSH Effect on Gas Generator Initial Peak Temperature

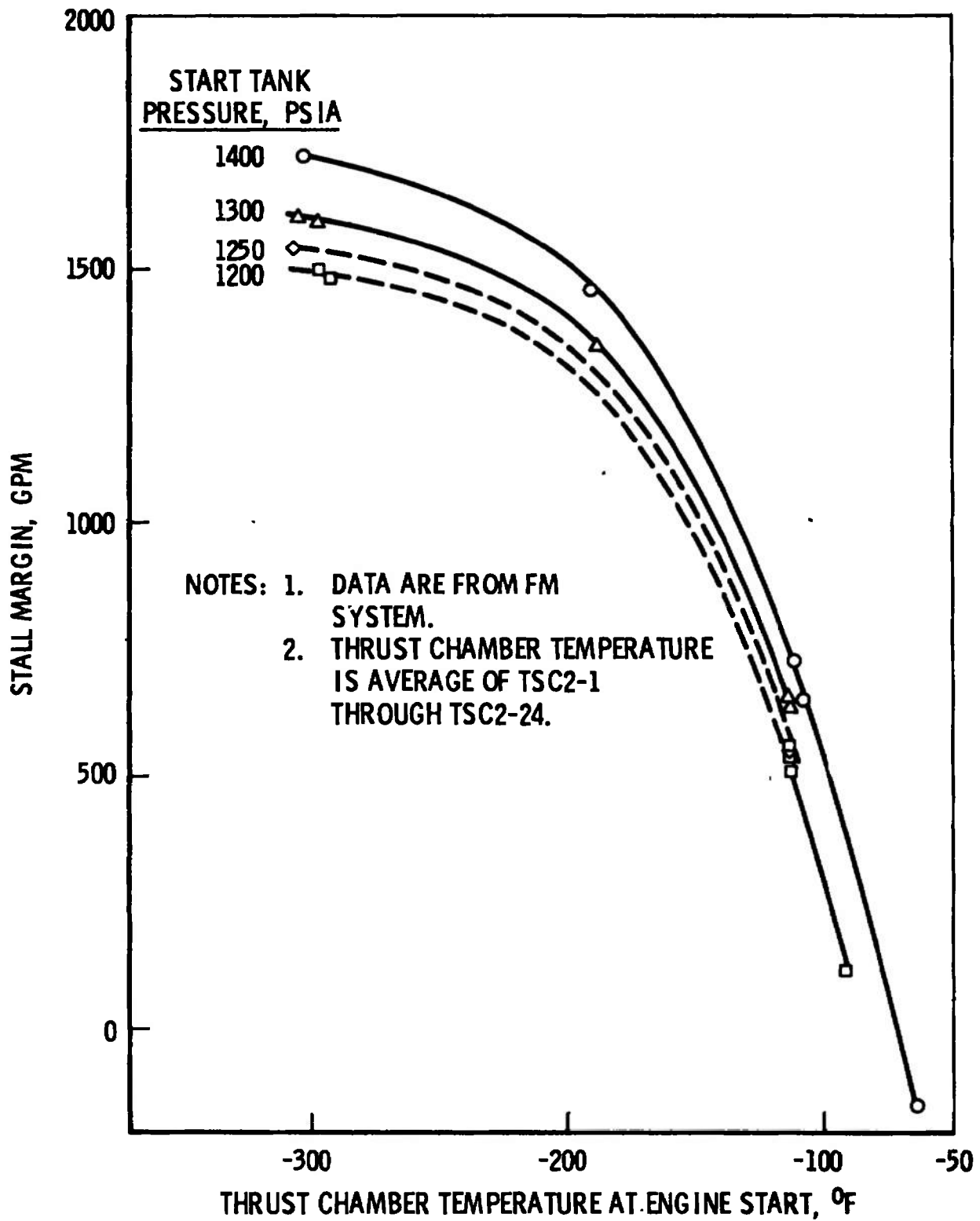


Fig. 137 Thrust Chamber Temperature Effect on Fuel Pump Stall Margin during Start Tank Discharge

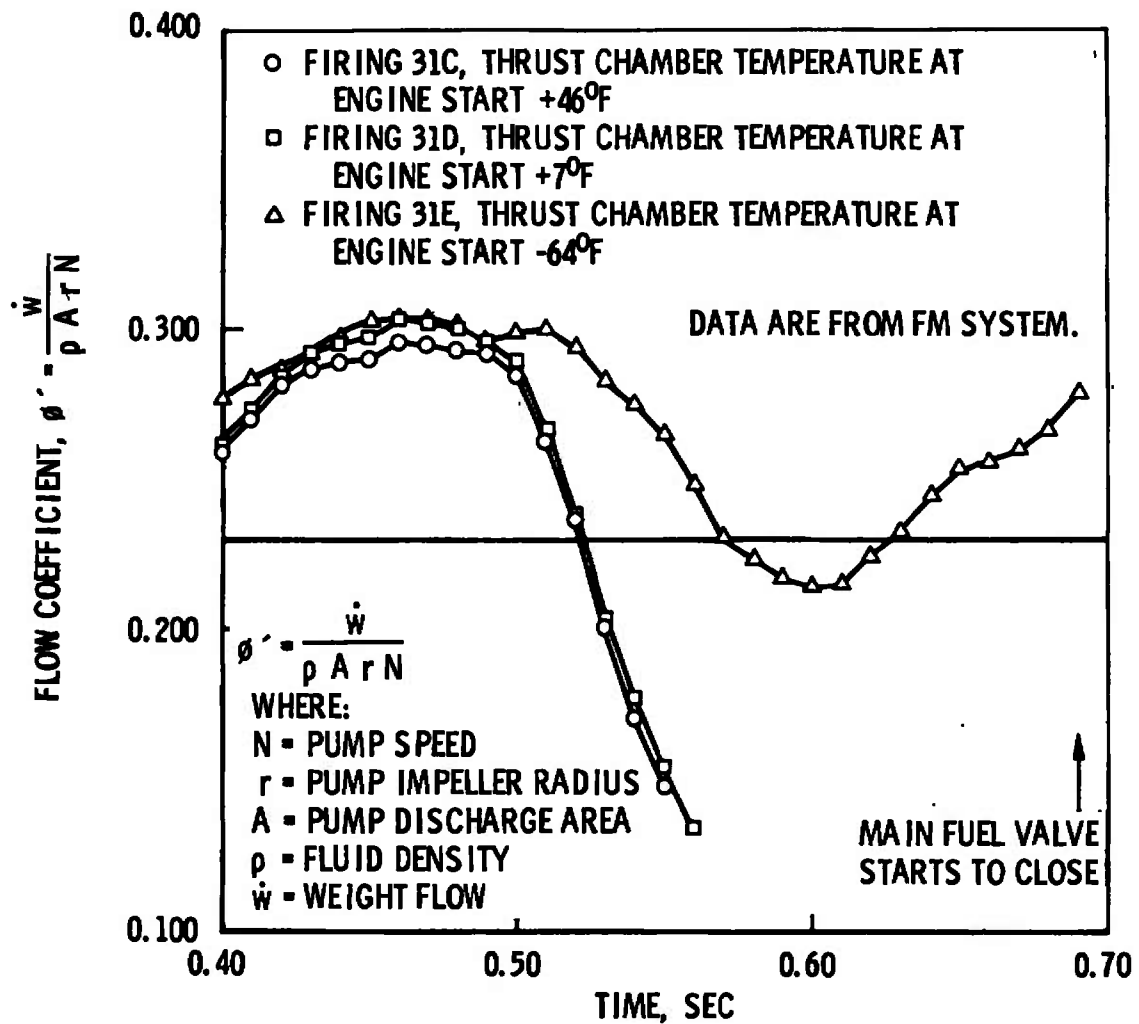
Fig. 138 Fuel Pump Start Transient Flow Coefficient,  $\phi'$

**TABLE I**  
**MAJOR ENGINE COMPONENTS**

| Part Name                                                       | P/N         | S/N     |
|-----------------------------------------------------------------|-------------|---------|
| Thrust Chamber Body                                             | 206600-3    | 4072755 |
| Thrust Chamber Injector Assembly                                | 208021-11   | 4071421 |
| Fue. Turbopump Assembly                                         | 400160-31   | 4072328 |
| Oxidizer Turbopump Assembly                                     | 458175-81   | 5545876 |
| Start Tank                                                      | 303435      | 0038    |
| Augmented Spark Igniter                                         | 206280-81   | 4078806 |
| Gas Generator Fuel Injector and Combustor                       | 308350-11   | 4069543 |
| Gas Generator Oxidizer Injector and Poppet Assembly             | 303323      | 4091740 |
| Helium Regulator Assembly                                       | 551048      | 4072700 |
| Electrical Control Package                                      | 502670-51   | 4087776 |
| Primary Flight Instrumentation Package                          | 703685      | 4077301 |
| Auxiliary Flight Instrumentation Package                        | 703680      | 4077313 |
| Main Fuel Valve (Tests 28 and 29)                               | 403120      | 4062172 |
| ↓<br>(Test 30)                                                  | 409920X6    | 4062093 |
| ↓<br>(Tests 31, 32, and 33)                                     | 409120      | 4051082 |
| Main Oxidizer Valve                                             | 411031      | 4086563 |
| Gas Generator Control Valve (Tests 28, 29, 30, and 31)          | 306040      | 4074100 |
| ↓<br>(Tests 32 and 33)                                          | 306040-31   | 4082100 |
| Start Tank Discharge Valve                                      | 306875      | 4081218 |
| Oxidizer Turbine Bypass Valve (Tests 28, 29, 30, and 31)        | 409930      | 4081242 |
| ↓<br>(Tests 32 and 33)                                          | 409940      | 4082266 |
| Propellant Utilization Valve                                    | 251351-11   | 4066732 |
| Main-Stage Control Valve (Four-Way)                             | 555767      | 8284307 |
| Ignition Phase Control Valve (Four-Way)                         | 055707      | 9284303 |
| Helium Control Valve (Three-Way)                                | NA5-27273   | 340918  |
| Start Tank Vent and Relief Valve                                | 557548      | 4332981 |
| Helium Tank Vent Valve                                          | NA5-27273   | 340918  |
| Fuel Bleed Valve                                                | 309034      | 4077233 |
| Oxidizer Bleed Valve                                            | 309029      | 4076750 |
| Augmented Spark Igniter Oxidizer Valve                          | 308890      | 4086945 |
| Pressure Actuated Shutoff Valve Assembly (Tests 29, 30, and 31) | 557817      | 4067200 |
| ↓<br>(Tests 32 and 33)                                          | 556127-11   | 4347601 |
| Pressure Actuated Purge Control Valve                           | 558126      | 4089662 |
| Start Tank Fill/Refill Valve                                    | 558000      | 4072695 |
| Fuel Flowmeter                                                  | 251225      | 4076564 |
| Oxidizer Flowmeter                                              | 251210      | 4077137 |
| Fuel Injector Temperature Transducer                            | NA5-27441   | 12350   |
| Restartable Ignition Detect Probe                               | NA5-2728612 | 102     |

**TABLE II  
SUMMARY OF ENGINE ORIFICES**

| Orifice Name                                 | Part Number                                                | Diameter                                         | Date Effective                                                               | Comments                  |
|----------------------------------------------|------------------------------------------------------------|--------------------------------------------------|------------------------------------------------------------------------------|---------------------------|
| Gas Generator Fuel Supply Line               | RD251-4107                                                 | 0.489 in.                                        | December 28, 1967                                                            |                           |
| Gas Generator Oxidizer Supply Line           | RD251-4106                                                 | 0.276 in.                                        | December 28, 1967                                                            |                           |
| Oxidizer Turbine Bypass Valve Nozzle         | RD273-8002                                                 | 1.430 in.                                        | November 17, 1967                                                            |                           |
| Main Oxidizer Valve Closing Control<br>↓     | 410437-084<br>410437-075<br>XEOR<br>920651-7<br>410437-075 | 8.42 scfm<br>7.52 scfm<br>8.30 scfm<br>7.52 scfm | January 11, 1968<br>February 12, 1968<br>February 28, 1968<br>March 11, 1968 | Thermostatic Orifice<br>↓ |
| Oxidizer Turbine Exhaust Manifold            | RD251-9004                                                 | 10.0 in.                                         | Installed before AEDC Delivery                                               |                           |
| Augmented Spark Igniter Oxidizer Supply Line | 406361-3                                                   | 0.125 in.                                        | February 8, 1968                                                             |                           |

**TABLE III**  
**ENGINE MODIFICATIONS**  
**(BETWEEN TESTS J4-1801-28 AND J4-1801-33)**

| Modification Number                | Completion Date   | Description of Modification                                                                             |
|------------------------------------|-------------------|---------------------------------------------------------------------------------------------------------|
| Test J4-1801-28, February 15, 1968 |                   |                                                                                                         |
| RFD <sup>1</sup> March 1, 1968     | February 8, 1968  | 0.037-in. -diam Augmented Spark Igniter Orifice Installed                                               |
| RFD 69-1-67                        | February 8, 1968  | Antiflood Valve Returned to Original Configuration                                                      |
| RFD 85-67                          | February 12, 1968 | Main Oxidizer Valve Retimed to 1900 <sup>+20</sup> <sub>-10</sub> msec                                  |
| ECP <sup>2</sup> J2-470R1          | February 9, 1968  | Pressure Actuated Purge Control Valve Replaced, P/N 558126, S/N 4089662                                 |
| Test J4-1801-29, February 22, 1968 |                   |                                                                                                         |
| ECP J2-605                         | February 20, 1968 | Fuel Inlet Duct Vent Port Check Valve and Bleed Plug Replaced                                           |
| ECP J2-607R2                       | February 21, 1968 | Application of Cold Test to Vent Port Check Valve                                                       |
| Test J4-1801-30, March 1, 1968     |                   |                                                                                                         |
| RFD 9-68                           | February 27, 1968 | Installation of a Dual Gas Generator Outlet Temperature System<br>Redundant: P/N NA5-27342T4<br>S/N 615 |
| RFD 8-68                           | February 23, 1968 | Replacement of Main Fuel Valve P/N 409920X6, S/N 4062093                                                |
| RFD 1-68                           | February 28, 1968 | Retime Main Oxidizer Valve to 1700 msec                                                                 |
| Test J4-1801-31, March 8, 1968     |                   |                                                                                                         |
| RFD 10-68                          | March 5, 1968     | Installation of the Gas Generator Control Valve Conditioning System                                     |
| RFD 11-68                          | March 5, 1968     | Addition of Thermocouples to the Main Fuel Valve                                                        |
| Test J4-1801-32, March 14, 1968    |                   |                                                                                                         |
| RFD 85-67                          | March 12, 1968    | Main Oxidizer Valve Retimed to 1750 msec                                                                |
| RFD 44A-67                         | March 11, 1968    | Gas Generator Oxidizer Bootstrap Line Conditioning System Removed                                       |
| RFD 17-68                          | March 10, 1968    | Oxidizer Turbine Bypass Valve Replacement                                                               |
| RFD 18-68                          | March 10, 1968    | Fast Shutdown Valve Replacement                                                                         |
| Test J4-1801-33, March 20, 1968    |                   |                                                                                                         |

<sup>1</sup>Rocketdyne Field Directive

<sup>2</sup>Engineering Change Proposal

**TABLE IV**  
**ENGINE COMPONENT REPLACEMENTS**  
**(BETWEEN TESTS J4-1801-28 AND J4-1801-33)**

| Replacement                        | Completion Date | Component Replaced          |
|------------------------------------|-----------------|-----------------------------|
| Test J4-1801-28, February 15, 1968 |                 |                             |
| None                               |                 |                             |
| Test J4-1801-29, February 22, 1968 |                 |                             |
| None                               |                 |                             |
| Test J4-1801-30, March 1, 1968     |                 |                             |
| None                               |                 |                             |
| Test J4-1801-31, March 8, 1968     |                 |                             |
| UCR <sup>1</sup> 007370            | March 1, 1968   | Main Fuel Valve             |
| Test J4-1801-32, March 14, 1968    |                 |                             |
| UCR 007373                         | March 10, 1968  | Gas Generator Control Valve |
| Test J4-1801-33, March 20, 1968    |                 |                             |

<sup>1</sup>Unsatisfactory Condition Report



**TABLE V**  
**ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE**

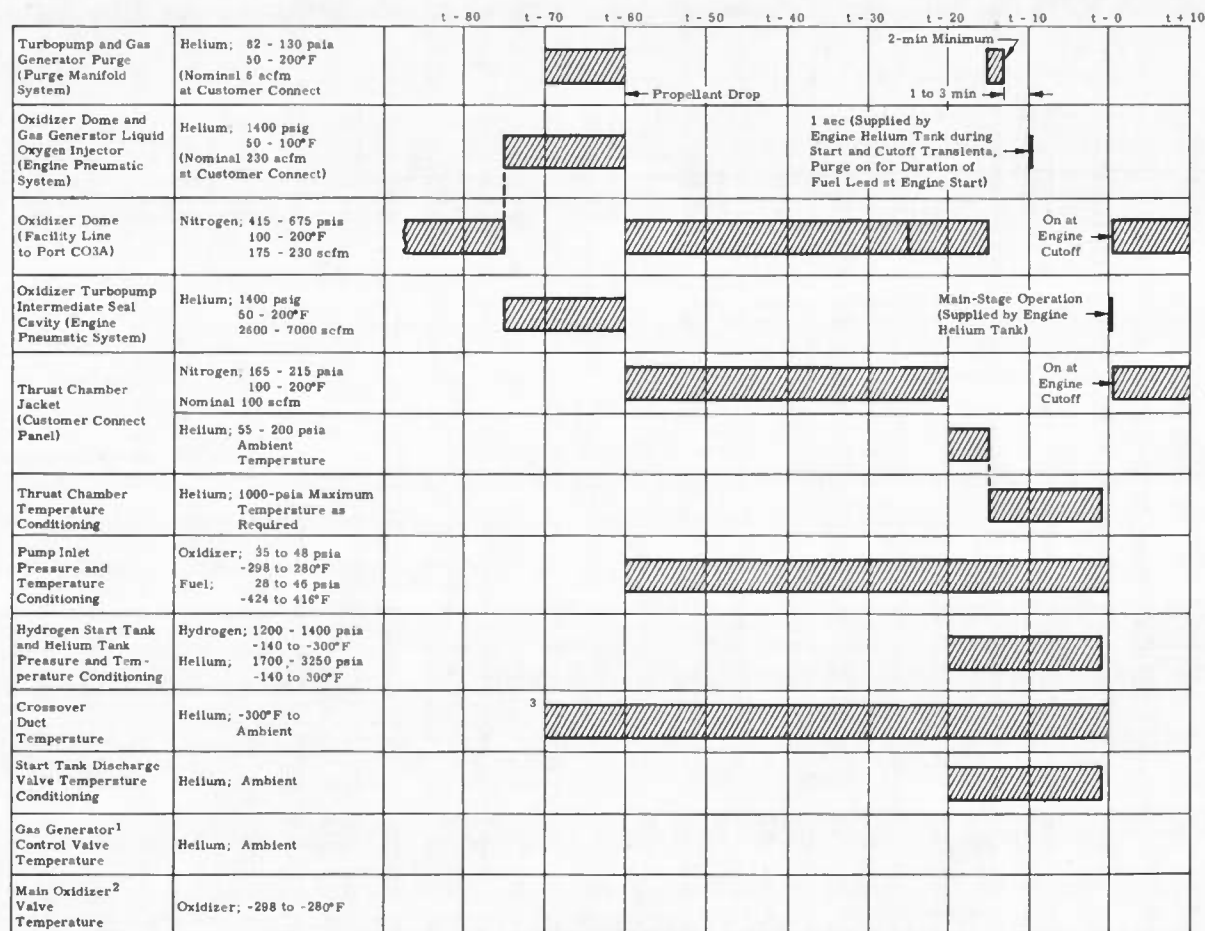
<sup>1</sup>Required on Tests 31 and 32 Only<sup>2</sup>Ambient Helium to be Used if Necessary to Achieve Required Target<sup>3</sup>Conditioning Temperature to be Maintained for the Last 30 min of Pre-Fire

**TABLE VI**  
**SUMMARY OF TEST REQUIREMENTS AND RESULTS**

| Firing Number: J4-1601-                                                                |                     | 28A                     |  | 28B          |  | 28C                     |  | 28A <sup>Ⓢ</sup> |  | 28B <sup>Ⓢ</sup> |  | 28C <sup>Ⓢ</sup> |  | 291 <sup>Ⓢ</sup> |  | 295 <sup>Ⓢ</sup> |  | 00A <sup>Ⓢ</sup> |  |
|----------------------------------------------------------------------------------------|---------------------|-------------------------|--|--------------|--|-------------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|
| Target                                                                                 |                     | Actual                  |  | Target       |  | Actual                  |  | Target           |  | Actual           |  | Target           |  | Actual           |  | Target           |  | Actual           |  |
| Time of Day, hr/Firing Date                                                            |                     | 1900 7/15/68            |  | 1922 7/15/68 |  | 2000 7/15/68            |  | 1418 7/22/68     |  | 1526 7/22/68     |  | 1621 7/22/68     |  | 1706 7/22/68     |  | 1855 7/22/68     |  | 1925 7/1/68      |  |
| Pressure Altitude at Engine Start, ft (Ref. 1)                                         |                     | 0                       |  | 0            |  | 0                       |  | 0                |  | 0                |  | 0                |  | 0                |  | 0                |  | 0                |  |
| Firing Duration, sec <sup>Ⓢ</sup>                                                      |                     | 0                       |  | 0            |  | 0.552                   |  | 7.509            |  | 7.509            |  | 7.509            |  | 7.509            |  | 7.509            |  | 7.509            |  |
| Fuel Pump Inlet Conditions at Engine Start                                             | Pressure, psia      | 40.0 ± 1.0              |  | 36.4         |  | 40.0 ± 1.0              |  | 36.4             |  | 40.0 ± 1.0       |  | 36.4             |  | 40.0 ± 1.0       |  | 36.4             |  | 40.0 ± 1.0       |  |
|                                                                                        | Temperature, °F     | -422.0 ± 0.4            |  | -421.8       |  | -422.0 ± 0.4            |  | -421.8           |  | -422.0 ± 0.4     |  | -422.0           |  | -420.4 ± 0.4     |  | -420.5           |  | -420.0 ± 0.4     |  |
| Oxidizer Pump Inlet Conditions at Engine Start                                         | Pressure, psia      | 30.0 ± 1.0 <sup>Ⓢ</sup> |  | 26.2         |  | 30.0 ± 1.0 <sup>Ⓢ</sup> |  | 26.7             |  | 30.0 ± 1.0       |  | 26.5             |  | 45.0 ± 1.0       |  | 44.7             |  | 45.0 ± 1.0       |  |
|                                                                                        | Temperature, °F     | ---                     |  | ---          |  | 294.5 ± 0.4             |  | 293.5            |  | 294.5 ± 0.4      |  | 294.1            |  | 294.5 ± 0.4      |  | 294.0            |  | 294.5 ± 0.4      |  |
| Start Tank Conditions at Engine Start                                                  | Pressure, psia      | ---                     |  | ---          |  | 1400 ± 10               |  | 1381             |  | 1400 ± 10        |  | 1412             |  | 1400 ± 10        |  | 1420             |  | 1400 ± 10        |  |
|                                                                                        | Temperature, °F     | ---                     |  | ---          |  | -240 ± 10               |  | -240             |  | -240 ± 10        |  | -245             |  | -240 ± 10        |  | -236             |  | -240 ± 10        |  |
| Helium Tank Conditions at Engine Start                                                 | Pressure, psia      | ---                     |  | ---          |  | 2103                    |  | 2278             |  | ---              |  | 2279             |  | ---              |  | 2304             |  | ---              |  |
|                                                                                        | Temperature, °F     | ---                     |  | ---          |  | -59                     |  | ---              |  | -53              |  | ---              |  | -48              |  | ---              |  | -43              |  |
| Thrust Chamber Temperature Conditions at Engine Start, °F                              | Thrust              | -250 ± 25               |  | -265         |  | -250 ± 25               |  | -263             |  | -250 ± 25        |  | -255             |  | -270 ± 25        |  | -284             |  | -100 ± 25        |  |
|                                                                                        | Average             | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Crossover Duct Temperature at Engine Start, °F <sup>Ⓢ</sup>                            | TFTD-2              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                        | TFTD-2              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F <sup>Ⓢ</sup> | TFTD-2              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                        | TFTD-2              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Fuel Lead Time, sec <sup>Ⓢ</sup>                                                       | TFTD-6              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                        | TFTD-6              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Propellant in Engine Time, min                                                         |                     | 30                      |  | 27           |  | 30                      |  | 27               |  | 30               |  | 27               |  | 30               |  | 27               |  | 30               |  |
| Propellant Recirculation Time, min                                                     |                     | 10                      |  | 10           |  | 10                      |  | 10               |  | 10               |  | 10               |  | 10               |  | 10               |  | 10               |  |
| Start Sequence Logic                                                                   |                     | Normal                  |  | Normal       |  | Normal                  |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F                     | TOBS-1 <sup>Ⓢ</sup> | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                        | TOBS-2A             | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Gas Generator Control Valve Body Temperature at Engine Start, °F                       | TOBS-4              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                        | TOBS-4              | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F                        |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Vibration Safety Counts Duration, msec and Occurrence Time, sec from t <sub>0</sub>    |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Gas Generator Outlet Temperature, °F                                                   | Initial Peak        | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                        | Second Peak         | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Thrust Chamber Ignition (P <sub>c</sub> = 100 psi) Time, sec (Ref. 1) <sup>Ⓢ</sup>     |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. 1) <sup>Ⓢ</sup>           |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Main-Stage Pressure No. 2, sec (Ref. 1) <sup>Ⓢ</sup>                                   |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Time Chamber Pressure Attains 550 psia, sec (Ref. 1) <sup>Ⓢ</sup>                      |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Propellant Utilization Valve Position, Engine Start/t <sub>0</sub> + 10 sec            |                     | ---                     |  | ---          |  | ---                     |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |

- Notes: <sup>Ⓢ</sup> Data reduced from oscillogram.  
<sup>Ⓢ</sup> Component conditioning to be maintained within limits for last 15 min before engine start.  
<sup>Ⓢ</sup> Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.  
<sup>Ⓢ</sup> Stream system inoperative for this test.  
<sup>Ⓢ</sup> Fuel lead tests only.  
<sup>Ⓢ</sup> Helium used instead of liquid oxygen.  
<sup>Ⓢ</sup> Stall approach monitor activated.  
<sup>Ⓢ</sup> Turbine overtemp trip activated.  
<sup>Ⓢ</sup> Power not supplied to propellant utilization panel.  
<sup>Ⓢ</sup> Monitored as gas generator control valve body temperature during test 92.  
<sup>Ⓢ</sup> Gas generator overtemperature cutoff.  
<sup>Ⓢ</sup> Gas generator fuel poppet leak prevented desired conditioning.  
<sup>Ⓢ</sup> Terminated by the stall approach monitor.

TABLE VI (Continued)

| Firing Number: J4-1801-                                                              |                     | 31A <sup>①</sup> |  | 31B <sup>①</sup> |  | 31C <sup>①</sup> |  | 31D <sup>①</sup> |  | 31E <sup>①</sup> |  | 32A <sup>①</sup> |  | 32B <sup>①</sup> |  | 33C <sup>①</sup> |  |
|--------------------------------------------------------------------------------------|---------------------|------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|------------------|--|
| Target                                                                               |                     | Actual           |  | Actual           |  | Actual           |  | Actual           |  | Actual           |  | Actual           |  | Actual           |  | Actual           |  |
| Time of Day, hr/Firing Date                                                          |                     | 1747 3/8/68      |  | 1415 3/8/68      |  | 1640 3/8/68      |  | 1710 3/8/68      |  | 1747 3/8/68      |  | 1143 3/14/68     |  | 1243 3/14/68     |  | 1333 3/14/68     |  |
| Pressure Altitude at Engine Start, ft (Ref. 1)                                       |                     | 100,000          |  | 100,000          |  | 100,000          |  | 100,000          |  | 100,000          |  | 100,000          |  | 100,000          |  | 100,000          |  |
| Firing Duration, sec <sup>②</sup>                                                    |                     | 32.300           |  | 32.574           |  | 0.800            |  | 0.813            |  | 0.800            |  | 0.803            |  | 7.800            |  | 7.880            |  |
| Fuel Pump Inlet Conditions at Engine Start                                           | Pressure, psia      | 28.0 ± 0.5       |  | 28.8 ± 0.5       |  | 28.0             |  | 28.7             |  | 28.5 ± 0.5       |  | 28.8             |  | 28.5 ± 0.5       |  | 28.3             |  |
|                                                                                      | Temperature, °F     | -420.4 ± 0.4     |  | -420.4 ± 0.4     |  | -420.5           |  | -420.4 ± 0.8     |  | -420.0           |  | -420.4 ± 0.4     |  | -420.1           |  | -420.4           |  |
| Oxidizer Pump Inlet Conditions at Engine Start                                       | Pressure, psia      | 45.0 ± 1.0       |  | 49.3             |  | 53.0 ± 0.5       |  | 32.8             |  | 45.0 ± 1.0       |  | 44.6             |  | 45.0 ± 1.0       |  | 44.9             |  |
|                                                                                      | Temperature, °F     | -284.8 ± 0.4     |  | -294.0           |  | -294.3           |  | -284.8 ± 0.4     |  | -294.4           |  | -284.8 ± 0.4     |  | -294.2           |  | -284.8           |  |
| Start Tank Conditions at Engine Start                                                | Pressure, psia      | 1200 ± 10        |  | 1307             |  | 1204             |  | 1400 ± 10        |  | 1405             |  | 1400 ± 10        |  | 1390             |  | 1200 ± 10        |  |
|                                                                                      | Temperature, °F     | -500 ± 10        |  | -298             |  | -200 ± 10        |  | -188             |  | -240 ± 10        |  | -240             |  | -300 ± 10        |  | -300 ± 10        |  |
| Helium Tank Conditions at Engine Start                                               | Pressure, psia      | ---              |  | 2076             |  | ---              |  | 2155             |  | ---              |  | 2077             |  | ---              |  | 2172             |  |
|                                                                                      | Temperature, °F     | ---              |  | -257             |  | ---              |  | -198             |  | ---              |  | -230             |  | ---              |  | -203             |  |
| Thrust Chamber Temperature Conditions at Engine Start, °F                            | Thrust              | -278 ± 25        |  | -284             |  | -278 ± 25        |  | -281             |  | -280 ± 25        |  | -284             |  | -278 ± 25        |  | -280             |  |
|                                                                                      | Average             | ---              |  | -298             |  | ---              |  | -291             |  | ---              |  | -280             |  | ---              |  | -278             |  |
| Crossover Fuel Temperature at Engine Start, °F                                       | TFTD-1              | +80 ± 30         |  | 39               |  | -100 ± 20        |  | -123             |  | +80 ± 50         |  | -21 <sup>③</sup> |  | +80 ± 50         |  | -42 <sup>③</sup> |  |
|                                                                                      | TFTD-2              | ---              |  | 83               |  | ---              |  | -100             |  | ---              |  | 40               |  | ---              |  | 33               |  |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F            | TFTD-3              | ---              |  | 44               |  | ---              |  | -103             |  | ---              |  | 40               |  | ---              |  | 32               |  |
|                                                                                      | TFTD-4              | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Fuel Lead Time, sec <sup>④</sup>                                                     |                     | 1.008            |  | 1.000            |  | 1.001            |  | 1.000            |  | 1.002            |  | 1.000            |  | 1.000            |  | 1.001            |  |
| Propellant to Engine Time, min                                                       |                     | 89               |  | 147              |  | 30               |  | 81               |  | 30               |  | 64               |  | 30               |  | 35               |  |
| Propellant Recirculation Time, min                                                   |                     | 10               |  | 12               |  | 10               |  | 10               |  | 10               |  | 10               |  | 10               |  | 10               |  |
| Start Sequence Logic                                                                 |                     | Normal           |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  | Normal           |  |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F                   | TOBS-1 <sup>⑤</sup> | ---              |  | +16              |  | ---              |  | -3               |  | ---              |  | -83              |  | ---              |  | -42              |  |
|                                                                                      | TOBS-2A             | ---              |  | 7                |  | ---              |  | 13               |  | ---              |  | 7                |  | ---              |  | -8               |  |
| Gas Generator Control Valve Body Temperature at Engine Start, °F                     | TOBS-4              | ---              |  | -98              |  | ---              |  | -43              |  | ---              |  | -53              |  | ---              |  | -58              |  |
|                                                                                      | TOBS-6              | ---              |  | -25              |  | Minimum          |  | -10              |  | Minimum          |  | -22              |  | Minimum          |  | -44              |  |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F                      |                     | 80 ± 25          |  | 45               |  | 80 ± 25          |  | 43               |  | 60 ± 25          |  | 51               |  | 60 ± 25          |  | 47               |  |
| Vibration Safety Counts Duration, msec and Occurrence Time, sec from tq              |                     | ---              |  | 144              |  | ---              |  | 0.005            |  | ---              |  | 1.042            |  | ---              |  | 0                |  |
| Gas Generator Outlet Temperature, °F                                                 | Initial Peak        | ---              |  | 1030             |  | ---              |  | 1440             |  | ---              |  | ---              |  | ---              |  | ---              |  |
|                                                                                      | Second Peak         | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Thrust Chamber Ignition (P <sub>c</sub> = 100 psia) Time, sec (Ref. tq) <sup>⑥</sup> |                     | ---              |  | 0.993            |  | ---              |  | 1.084            |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. tq) <sup>⑦</sup>        |                     | ---              |  | 0.958            |  | ---              |  | 1.042            |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Main-Stage Pressure No. 2, sec (Ref. tq) <sup>⑧</sup>                                |                     | ---              |  | 1.693            |  | ---              |  | 1.848            |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Time Chamber Pressure Attains 850 psia, sec (Ref. tq) <sup>⑨</sup>                   |                     | ---              |  | 2.004            |  | ---              |  | 2.153            |  | ---              |  | ---              |  | ---              |  | ---              |  |
| Propellant Utilization Valve Position, Engine Start/tq + 10 sec                      |                     | Null             |  | Null             |  | Null             |  | Null             |  | Null             |  | Null             |  | Null             |  | Null             |  |

Notes: ① Data reduced from oscillogram.

② Component conditioning to be maintained within limits for last 15 min before engine start.

③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.

④ Steam system inoperative for this test.

⑤ Fuel lead tests only.

⑥ Helium used instead of liquid oxygen.

⑦ Null approach monitor activated.

⑧ Turbine overspeed trip activated.

⑨ Power not supplied to propellant utilization panel.

⑩ Monitored as gas generator control valve body temperature during test 32.

⑪ Gas generator overtemperature cutoff.

⑫ Gas generator fuel poppet leak prevented desired conditioning.

⑬ Terminated by the stall approach monitor.

TABLE VI (Concluded)

| Firing Number: J4-1001-                                                              |                 | 53D          |  | 33E          |  | 53F          |  | 53G          |  | 53A          |  | 53B          |  | 53C          |  | 53D          |  | 53E          |  |
|--------------------------------------------------------------------------------------|-----------------|--------------|--|--------------|--|--------------|--|--------------|--|--------------|--|--------------|--|--------------|--|--------------|--|--------------|--|
| Target                                                                               |                 | Actual       |  | Target       |  | Actual       |  | Target       |  | Actual       |  | Target       |  | Actual       |  | Target       |  | Actual       |  |
| Time of Day, hr/Firing Date                                                          |                 | 1453 3/14/68 |  | 1454 3/14/68 |  | 1455 3/14/68 |  | 1456 3/14/68 |  | 1457 3/14/68 |  | 1458 3/14/68 |  | 1459 3/14/68 |  | 1460 3/14/68 |  | 1461 3/14/68 |  |
| Pressure Altitude at Engine Start, ft (Ref. 1)                                       |                 | 100,000      |  | 100,000      |  | 100,000      |  | 100,000      |  | 100,000      |  | 100,000      |  | 100,000      |  | 100,000      |  | 100,000      |  |
| Firing Duration, sec                                                                 |                 | 1.150        |  | 0.990        |  | 1.138        |  | 1.150        |  | 1.138        |  | 1.150        |  | 1.137        |  | 1.150        |  | 1.137        |  |
| Fuel Pump Inlet Conditions at Engine Start                                           | Pressure, psia  | 28.5 ± 0.5   |  | 28.0         |  | 28.5 ± 0.5   |  | 28.5         |  | 28.5 ± 0.5   |  | 28.7         |  | 28.5 ± 0.5   |  | 28.0         |  | 28.5 ± 0.5   |  |
|                                                                                      | Temperature, °F | -420.4 ± 0.4 |  | -420.8       |  | -420.4 ± 0.4 |  | -420.4       |  | -420.4 ± 0.4 |  | -420.0       |  | -420.4 ± 0.4 |  | -420.3       |  | -420.4 ± 0.4 |  |
| Oxidizer Pump Inlet Conditions at Engine Start                                       | Pressure, psia  | 48.0 ± 1.0   |  | 45.1         |  | 45.0 ± 1.0   |  | 45.4         |  | 45.0 ± 1.0   |  | 45.4         |  | 45.0 ± 1.0   |  | 45.7         |  | 45.0 ± 1.0   |  |
|                                                                                      | Temperature, °F | -294.5 ± 0.4 |  | -294.2       |  | -294.5 ± 0.4 |  | -295.2       |  | -294.5 ± 0.4 |  | -294.5       |  | -294.5 ± 0.4 |  | -294.4       |  | -294.5 ± 0.4 |  |
| Start Tank Conditions at Engine Start                                                | Pressure, psia  | 1300 ± 10    |  | 1188         |  | 1300 ± 10    |  | 1301         |  | 1300 ± 10    |  | 1305         |  | 1300 ± 10    |  | 1306         |  | 1300 ± 10    |  |
|                                                                                      | Temperature, °F | -300 ± 10    |  | -302         |  | -300 ± 10    |  | -199         |  | -300 ± 10    |  | -381         |  | -300 ± 10    |  | -383         |  | -300 ± 10    |  |
| Helium Tank Conditions at Engine Start                                               | Pressure, psia  | ---          |  | 2217         |  | ---          |  | 2262         |  | ---          |  | 2184         |  | ---          |  | 2160         |  | ---          |  |
|                                                                                      | Temperature, °F | ---          |  | -187         |  | ---          |  | -185         |  | ---          |  | -289         |  | ---          |  | -187         |  | ---          |  |
| Thrust Chamber Temperature Conditions at Engine Start, °F                            | Throat          | -75 ± 15     |  | -84          |  | -85 ± 15     |  | -84          |  | -85 ± 15     |  | -90          |  | -84          |  | -85 ± 15     |  | -88          |  |
|                                                                                      | Average         | ---          |  | -102         |  | ---          |  | -112         |  | ---          |  | -122         |  | ---          |  | -108         |  | -117         |  |
| Crossover Duct Temperature at Engine Start, °F                                       | TFTD-2          | 80 ± 50      |  | 39           |  | 50 ± 50      |  | 27           |  | 50 ± 50      |  | 38           |  | 50 ± 50      |  | 83           |  | 50 ± 50      |  |
|                                                                                      | TFTD-3          | ---          |  | 43           |  | ---          |  | 55           |  | ---          |  | 84           |  | ---          |  | 87           |  | ---          |  |
|                                                                                      | TFTD-8          | ---          |  | 39           |  | ---          |  | 27           |  | ---          |  | 37           |  | ---          |  | 84           |  | ---          |  |
| Main Oxidizer Valve Second-Stage Actuator Temperature at Engine Start, °F            |                 | -150 ± 50    |  | -118         |  | -150 ± 50    |  | -117         |  | -150 ± 50    |  | -118         |  | -150 ± 50    |  | -119         |  | -100 ± 50    |  |
| Fuel Load Time, sec                                                                  |                 | 1.000        |  | 1.001        |  | 1.000        |  | 1.000        |  | 1.000        |  | 1.001        |  | 1.000        |  | 1.001        |  | 1.000        |  |
| Propellant in Engine Time, min                                                       |                 | 20           |  | 60           |  | 20           |  | 71           |  | 39           |  | 51           |  | 20           |  | 55           |  | 108          |  |
| Propellant Rectification Time, min                                                   |                 | 10           |  | 43           |  | 10           |  | 23           |  | 10           |  | 11           |  | 10           |  | 11           |  | 10           |  |
| Start Sequence Logic                                                                 |                 | Normal       |  | Normal       |  | Normal       |  | Normal       |  | Normal       |  | Normal       |  | Normal       |  | Normal       |  | Normal       |  |
| Gas Generator Oxidizer Supply Line Temperature at Engine Start, °F                   | TOBS-1          | -25 Minimum  |  | 21           |  | -25 Minimum  |  | 30           |  | -25 Minimum  |  | 10           |  | -25 Minimum  |  | 17           |  | ---          |  |
|                                                                                      | TOBS-2A         | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  |
|                                                                                      | TOBS-4          | ---          |  | -48          |  | ---          |  | -47          |  | ---          |  | -45          |  | ---          |  | -52          |  | -28          |  |
| Gas Generator Control Valve Body Temperature at Engine Start, °F                     |                 | ---          |  | 32           |  | ---          |  | 35           |  | ---          |  | 37           |  | ---          |  | 38           |  | ---          |  |
| Start Tank Discharge Valve Body Temperature at Engine Start, °F                      |                 | 50 ± 25      |  | 30           |  | 50 ± 25      |  | 38           |  | 50 ± 25      |  | 55           |  | 50 ± 25      |  | 32           |  | 50 ± 25      |  |
| Vibration Safety Counts Duration, msec and Occurrence Time, sec from t <sub>0</sub>  |                 | ---          |  | 0            |  | ---          |  | 0            |  | ---          |  | 0            |  | ---          |  | 0            |  | ---          |  |
| Gas Generator Outlet Temperature, °F                                                 | Initial Peak    | ---          |  | ---          |  | 1895         |  | ---          |  | 1778         |  | ---          |  | 1848         |  | ---          |  | 1803         |  |
|                                                                                      | Second Peak     | ---          |  | ---          |  | ---          |  | 1734         |  | ---          |  | 1781         |  | ---          |  | 1810         |  | 2095         |  |
| Thrust Chamber Ignition (P <sub>c</sub> = 100 psia) Time, sec (Ref. t <sub>0</sub> ) |                 | ---          |  | ---          |  | 1.007        |  | ---          |  | 0.978        |  | ---          |  | 0.985        |  | ---          |  | 1.110        |  |
| Main Oxidizer Valve Second-Stage Initial Movement, sec (Ref. t <sub>0</sub> )        |                 | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | 1.301        |  | ---          |  | 1.393        |  |
| Main-Stage Pressure No. 3, sec (Ref. t <sub>0</sub> )                                |                 | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | 1.855        |  | ---          |  | 1.892        |  |
| Time Chamber Pressure Attains 550 psia, sec (Ref. t <sub>0</sub> )                   |                 | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | ---          |  | 1.922        |  | ---          |  | 1.955        |  |
| Propellant Utilization Valve Position, Engine Start to t <sub>0</sub> + 10 sec       |                 | Null         |  | Null         |  | Null         |  | Null         |  | Null         |  | Null         |  | Null         |  | Null         |  | Null         |  |

Notes: ① Data reduced from oscillogram.  
 ② Component conditioning to be maintained within limits for last 15 min before engine start.  
 ③ Component conditioning to be maintained within limits for last 30 min before engine start or coast duration, whichever is longer.  
 ④ Team system inoperative for this test.  
 ⑤ Fuel leak tests only.

⑥ Helium used instead of liquid oxygen.  
 ⑦ Null approach monitor activated.  
 ⑧ Turbine overspeed trip activated.  
 ⑨ Power not supplied to propellant utilization panel.  
 ⑩ Monitored as gas generator control valve body temperature during test 22.  
 ⑪ Gas generator overtemperature cutoff.

⑫ Gas generator fuel poppet leak prevented desired conditioning.  
 ⑬ Terminated by the null approach monitor.

TABLE VII  
ENGINE VALVE TIMINGS

## a. Start

| Firing<br>Number<br>J4-1801- | Start                           |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                    |                                |                                  |                                     |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|------------------------------------|--------------------------------|----------------------------------|-------------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                              | Start Tank Discharge Valve      |                                |                                  |                                 |                                |                                  | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve<br>First Stage |                                |                                  | Main Oxidizer Valve<br>Second Stage |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                              | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal    | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal     | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec |
| 28A                          | ---                             | ---                            | ---                              | ---                             | ---                            | ---                              | -7.800                          | 0.052                          | 0.068                            | ---                                | ---                            | ---                              | ---                                 | ---                            | ---                              | ---                             | ---                            | ---                              | ---                              | ---                            | ---                              | ---                              | ---                            | ---                              |
| 28B                          | ---                             | ---                            | ---                              | ---                             | ---                            | ---                              | -7.905                          | 0.053                          | 0.088                            | ---                                | ---                            | ---                              | ---                                 | ---                            | ---                              | ---                             | ---                            | ---                              | ---                              | ---                            | ---                              | ---                              | ---                            | ---                              |
| 28C                          | 0.0                             | 0.156                          | 0.148                            | ---                             | ---                            | ---                              | -7.804                          | 0.053                          | 0.068                            | 0.449                              | 0.062                          | 0.055                            | ---                                 | ---                            | ---                              | ---                             | ---                            | ---                              | ---                              | ---                            | ---                              | ---                              | ---                            | ---                              |
| 29A                          | 0.0                             | 0.147                          | 0.136                            | 0.448                           | 0.091                          | 0.240                            | -0.998                          | 0.060                          | 0.060                            | 0.448                              | 0.050                          | 0.052                            | 0.448                               | 0.672                          | 2.120                            | 0.448                           | 0.120                          | 0.030                            | 0.448                            | 0.202                          | 0.085                            | 0.448                            | 0.232                          | 0.310                            |
| 29B                          | 0.0                             | 0.147                          | 0.135                            | 0.447                           | 0.085                          | 0.240                            | -1.000                          | 0.057                          | 0.045                            | 0.447                              | 0.055                          | 0.060                            | 0.447                               | 0.585                          | 2.210                            | 0.447                           | 0.120                          | 0.030                            | 0.447                            | 0.200                          | 0.090                            | 0.447                            | 0.225                          | 0.310                            |
| 28C                          | 0.0                             | 0.148                          | 0.140                            | 0.448                           | 0.090                          | 0.235                            | -0.897                          | 0.055                          | 0.065                            | 0.448                              | 0.060                          | 0.060                            | 0.448                               | 0.580                          | 2.260                            | 0.448                           | 0.125                          | 0.040                            | 0.448                            | 0.225                          | 0.120                            | 0.448                            | 0.230                          | 0.310                            |
| 28D                          | 0.0                             | 0.142                          | 0.130                            | 0.447                           | 0.090                          | 0.235                            | -1.000                          | 0.052                          | 0.070                            | 0.447                              | 0.060                          | 0.055                            | ---                                 | ---                            | ---                              | 0.447                           | 0.127                          | 0.038                            | 0.447                            | 0.230                          | 0.130                            | 0.447                            | 0.225                          | 0.350                            |
| 28E                          | 0.0                             | 0.140                          | 0.130                            | 0.448                           | 0.090                          | 0.230                            | -1.000                          | 0.055                          | 0.070                            | 0.448                              | 0.050                          | 0.057                            | 0.448                               | 0.713                          | 2.150                            | 0.448                           | 0.123                          | 0.035                            | 0.448                            | 0.213                          | 0.110                            | 0.448                            | 0.227                          | 0.340                            |
| 30A                          | 0.0                             | 0.141                          | 0.128                            | 0.450                           | 0.089                          | 0.241                            | -1.000                          | 0.092                          | 0.039                            | 0.450                              | 0.060                          | 0.054                            | 0.450                               | 0.560                          | 1.833                            | 0.450                           | 0.114                          | 0.039                            | 0.450                            | 0.198                          | 0.090                            | 0.450                            | 0.233                          | 0.288                            |
| 31A                          | 0.0                             | 0.145                          | 0.130                            | 0.450                           | 0.090                          | 0.230                            | -1.000                          | 0.067                          | 0.060                            | 0.450                              | 0.055                          | 0.055                            | 0.450                               | 0.535                          | 2.005                            | 0.450                           | 0.110                          | 0.037                            | 0.450                            | 0.185                          | 0.077                            | 0.450                            | 0.215                          | 0.300                            |
| 31B                          | 0.0                             | 0.133                          | 0.126                            | 0.448                           | 0.089                          | 0.240                            | -1.000                          | 0.055                          | 0.075                            | 0.448                              | 0.056                          | 0.054                            | 0.448                               | 0.594                          | 1.855                            | 0.448                           | 0.114                          | 0.033                            | 0.448                            | 0.194                          | 0.082                            | 0.448                            | 0.230                          | 0.280                            |
| 31C                          | 0.0                             | 0.145                          | 0.132                            | 0.450                           | ---                            | ---                              | -1.000                          | 0.060                          | 0.055                            | 0.450                              | 0.055                          | 0.055                            | 0.450                               | ---                            | ---                              | 0.450                           | ---                            | ---                              | 0.450                            | ---                            | ---                              | 0.450                            | ---                            | ---                              |
| 31D                          | 0.0                             | 0.144                          | 0.134                            | 0.448                           | ---                            | ---                              | -1.000                          | 0.055                          | 0.085                            | 0.449                              | 0.055                          | 0.050                            | 0.449                               | ---                            | ---                              | 0.449                           | ---                            | ---                              | 0.449                            | ---                            | ---                              | 0.449                            | ---                            | ---                              |
| 31E                          | 0.0                             | 0.147                          | 0.135                            | 0.450                           | ---                            | ---                              | -1.000                          | 0.055                          | 0.065                            | 0.450                              | 0.055                          | 0.055                            | 0.450                               | ---                            | ---                              | 0.450                           | ---                            | ---                              | 0.450                            | ---                            | ---                              | 0.450                            | ---                            | ---                              |
| 32A                          | 0.0                             | 0.138                          | 0.127                            | 0.448                           | 0.091                          | 0.236                            | -0.999                          | 0.066                          | 0.059                            | 0.448                              | 0.060                          | 0.052                            | 0.448                               | 0.571                          | 2.162                            | 0.448                           | 0.116                          | 0.027                            | 0.448                            | 0.185                          | 0.077                            | 0.448                            | 0.229                          | 0.295                            |
| 32B                          | 0.0                             | 0.140                          | 0.128                            | 0.450                           | 0.080                          | 0.234                            | -1.000                          | 0.110                          | 0.036                            | 0.450                              | 0.058                          | 0.052                            | 0.450                               | 0.580                          | 2.218                            | 0.450                           | 0.120                          | 0.027                            | 0.450                            | 0.180                          | 0.091                            | 0.450                            | 0.232                          | 0.282                            |
| 32C                          | 0.0                             | 0.146                          | 0.134                            | 0.450                           | 0.082                          | 0.224                            | -1.000                          | 0.056                          | 0.068                            | 0.450                              | 0.060                          | 0.052                            | 0.450                               | ---                            | ---                              | 0.450                           | 0.124                          | 0.026                            | 0.450                            | 0.192                          | 0.085                            | 0.450                            | 0.235                          | 0.290                            |
| 32D                          | 0.0                             | 0.137                          | 0.129                            | 0.448                           | 0.092                          | ---                              | -1.000                          | 0.053                          | 0.068                            | 0.448                              | 0.055                          | 0.056                            | 0.448                               | ---                            | ---                              | 0.448                           | 0.118                          | 0.026                            | 0.448                            | 0.184                          | ---                              | 0.448                            | ---                            | ---                              |
| 32E                          | 0.0                             | 0.137                          | 0.124                            | 0.447                           | 0.092                          | 0.240                            | -0.999                          | 0.054                          | 0.070                            | 0.447                              | 0.057                          | 0.053                            | 0.447                               | ---                            | ---                              | 0.447                           | 0.115                          | 0.031                            | 0.447                            | 0.184                          | 0.083                            | 0.447                            | 0.237                          | 0.287                            |
| 32F                          | 0.0                             | 0.136                          | 0.125                            | 0.446                           | 0.093                          | 0.238                            | -0.999                          | 0.050                          | 0.067                            | 0.446                              | 0.058                          | 0.052                            | 0.446                               | ---                            | ---                              | 0.446                           | 0.119                          | 0.024                            | 0.446                            | 0.189                          | 0.080                            | 0.446                            | 0.240                          | 0.295                            |
| 32G                          | 0.0                             | 0.140                          | 0.130                            | 0.448                           | 0.093                          | 0.238                            | -1.001                          | 0.055                          | 0.066                            | 0.448                              | 0.058                          | 0.054                            | 0.448                               | ---                            | ---                              | 0.448                           | 0.115                          | 0.027                            | 0.448                            | 0.186                          | 0.082                            | 0.448                            | 0.243                          | 0.288                            |
| 33A                          | 0.0                             | 0.140                          | 0.124                            | 0.450                           | 0.093                          | 0.236                            | -1.001                          | 0.053                          | 0.083                            | 0.450                              | 0.055                          | 0.051                            | 0.450                               | 0.751                          | 2.132                            | 0.450                           | 0.113                          | 0.029                            | 0.450                            | 0.188                          | 0.086                            | 0.450                            | 0.207                          | 0.280                            |
| 33B                          | 0.0                             | 0.140                          | 0.130                            | 0.448                           | 0.090                          | 0.238                            | -1.000                          | 0.053                          | 0.071                            | 0.448                              | 0.057                          | 0.058                            | 0.448                               | 0.855                          | 2.015                            | 0.448                           | 0.122                          | 0.025                            | 0.448                            | 0.192                          | 0.083                            | 0.448                            | 0.210                          | 0.278                            |
| 33C                          | 0.0                             | 0.144                          | 0.134                            | 0.447                           | 0.089                          | 0.236                            | -1.002                          | 0.053                          | 0.068                            | 0.447                              | 0.057                          | 0.057                            | 0.447                               | 0.870                          | 1.986                            | 0.447                           | 0.123                          | 0.025                            | 0.447                            | 0.192                          | 0.081                            | 0.447                            | 0.210                          | 0.274                            |
| 33D                          | 0.0                             | 0.137                          | 0.125                            | 0.445                           | 0.081                          | 0.236                            | -1.000                          | 0.053                          | 0.072                            | 0.445                              | 0.058                          | 0.057                            | 0.445                               | 0.682                          | 2.152                            | 0.445                           | 0.124                          | 0.026                            | 0.445                            | 0.188                          | 0.083                            | 0.445                            | 0.229                          | 0.275                            |
| 33E                          | 0.0                             | 0.136                          | 0.125                            | 0.446                           | 0.088                          | 0.235                            | -1.003                          | 0.051                          | 0.071                            | 0.446                              | 0.055                          | 0.058                            | 0.446                               | 0.624                          | 2.151                            | 0.446                           | 0.120                          | 0.026                            | 0.448                            | 0.187                          | 0.080                            | 0.446                            | 0.205                          | 0.277                            |

- Notes: 1. All valve signal times are referenced to  $t_0$ .  
 2. Valve delay time is the time required for initial valve movement after the valve "open" or valve "closed" solenoid has been energized.  
 3. Data are reduced from an oscillogram.  
 4. Final sequence check is conducted without propellants within 12 hr before testing.

TABLE VII (Continued)

## b. Shutdown

| Firing<br>Number<br>J4-1801- | Shutdown                        |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                              | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve             |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                              | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec |
| 28A                          | ---                             | 0.080                          | 0.300                            | ---                             | ---                            | ---                              | ---                             | ---                            | ---                              | ---                              | ---                            | ---                              | ---                              | ---                            | ---                              |
| 28B                          | ---                             | 0.118                          | 0.312                            | ---                             | ---                            | ---                              | ---                             | ---                            | ---                              | ---                              | ---                            | ---                              | ---                              | ---                            | ---                              |
| 28C                          | 0.652                           | 0.095                          | 0.343                            | ---                             | ---                            | ---                              | ---                             | ---                            | ---                              | ---                              | ---                            | ---                              | ---                              | ---                            | ---                              |
| 29A                          | 7.588                           | 0.140                          | 0.370                            | 7.588                           | 0.080                          | 0.195                            | 7.588                           | 0.060                          | 0.025                            | 7.588                            | 0.030                          | 0.015                            | 7.588                            | 0.272                          | 0.450                            |
| 29B                          | 7.585                           | 0.140                          | 0.375                            | 7.585                           | 0.080                          | 0.185                            | 7.585                           | 0.065                          | 0.020                            | 7.585                            | 0.035                          | 0.020                            | 7.585                            | 0.275                          | 0.375                            |
| 28C                          | 7.587                           | 0.138                          | 0.365                            | 7.587                           | 0.080                          | 0.180                            | 7.587                           | 0.078                          | 0.020                            | 7.587                            | 0.036                          | 0.017                            | 7.587                            | 0.268                          | 0.400                            |
| 28D                          | 1.074                           | 0.118                          | 0.320                            | 1.074                           | ---                            | ---                              | 1.074                           | 0.083                          | 0.030                            | 1.074                            | 0.045                          | 0.023                            | 1.074                            | 0.118                          | 0.460                            |
| 29E                          | 7.570                           | 0.145                          | 0.370                            | 7.570                           | 0.080                          | 0.185                            | 7.570                           | 0.080                          | 0.030                            | 7.570                            | 0.020                          | 0.020                            | 7.570                            | 0.280                          | 0.420                            |
| 30A                          | 7.587                           | 0.128                          | 0.365                            | 7.587                           | 0.082                          | 0.193                            | 7.587                           | 0.064                          | 0.036                            | 7.587                            | 0.031                          | 0.017                            | 7.587                            | 0.285                          | 0.553                            |
| 31A                          | 32.58                           | 0.125                          | 0.350                            | 32.58                           | 0.087                          | 0.188                            | 32.58                           | 0.058                          | 0.024                            | 32.58                            | 0.030                          | 0.017                            | 32.58                            | 0.310                          | 0.440                            |
| 31B                          | 32.58                           | 0.123                          | 0.350                            | 32.58                           | 0.080                          | 0.188                            | 32.58                           | 0.068                          | 0.030                            | 32.58                            | 0.030                          | 0.018                            | 32.58                            | 0.343                          | 0.485                            |
| 31C                          | 0.620                           | 0.085                          | 0.265                            | 0.820                           | ---                            | ---                              | 0.620                           | ---                            | ---                              | 0.620                            | ---                            | ---                              | 0.620                            | ---                            | ---                              |
| 31D                          | 0.612                           | 0.088                          | 0.250                            | 0.612                           | ---                            | ---                              | 0.612                           | ---                            | ---                              | 0.612                            | ---                            | ---                              | 0.612                            | ---                            | ---                              |
| 31E                          | 0.804                           | 0.090                          | 0.263                            | 0.604                           | ---                            | ---                              | 0.804                           | ---                            | ---                              | 0.604                            | ---                            | ---                              | 0.604                            | ---                            | ---                              |
| 32A                          | 7.583                           | 0.117                          | 0.348                            | 7.583                           | 0.075                          | 0.188                            | 7.583                           | 0.073                          | 0.021                            | 7.593                            | 0.031                          | 0.028                            | 7.583                            | 0.218                          | 0.457                            |
| 32B                          | 7.581                           | 0.125                          | 0.378                            | 7.581                           | 0.077                          | 0.186                            | 7.581                           | 0.082                          | 0.022                            | 7.591                            | 0.035                          | 0.025                            | 7.581                            | 0.216                          | 0.408                            |
| 32C                          | 1.148                           | 0.110                          | 0.318                            | 1.148                           | ---                            | ---                              | 1.148                           | 0.085                          | 0.021                            | 1.148                            | 0.048                          | 0.024                            | 1.148                            | 0.115                          | 0.470                            |
| 32D                          | 0.683                           | 0.098                          | 0.280                            | 0.663                           | ---                            | ---                              | 0.883                           | ---                            | ---                              | 0.663                            | ---                            | ---                              | 0.863                            | ---                            | ---                              |
| 32E                          | 1.138                           | 0.110                          | 0.307                            | 1.138                           | ---                            | ---                              | 1.138                           | 0.084                          | 0.024                            | 1.138                            | 0.047                          | 0.028                            | 1.138                            | 0.117                          | 0.475                            |
| 32F                          | 1.137                           | 0.109                          | 0.308                            | 1.137                           | ---                            | ---                              | 1.137                           | 0.083                          | 0.020                            | 1.137                            | 0.049                          | 0.026                            | 1.137                            | 0.115                          | 0.500                            |
| 32G                          | 1.137                           | 0.110                          | 0.310                            | 1.137                           | ---                            | ---                              | 1.137                           | 0.085                          | 0.018                            | 1.137                            | 0.048                          | 0.025                            | 1.137                            | 0.123                          | 0.525                            |
| 33A                          | 32.578                          | 0.107                          | 0.280                            | 32.576                          | 0.072                          | 0.178                            | 32.578                          | 0.074                          | 0.024                            | 32.578                           | 0.031                          | 0.022                            | 32.576                           | 0.238                          | 0.620                            |
| 33B                          | 7.582                           | 0.115                          | 0.340                            | 7.682                           | 0.075                          | 0.183                            | 7.582                           | 0.081                          | 0.020                            | 7.592                            | 0.034                          | 0.024                            | 7.682                            | 0.246                          | 0.510                            |
| 33C                          | 7.590                           | 0.115                          | 0.334                            | 7.580                           | 0.076                          | 0.190                            | 7.590                           | 0.077                          | 0.025                            | 7.590                            | 0.035                          | 0.022                            | 7.580                            | 0.241                          | 0.493                            |
| 33D                          | 7.588                           | 0.115                          | 0.337                            | 7.589                           | 0.075                          | 0.185                            | 7.589                           | 0.079                          | 0.017                            | 7.588                            | 0.034                          | 0.020                            | 7.588                            | 0.243                          | 0.470                            |
| 33E                          | 7.592                           | 0.114                          | 0.338                            | 7.592                           | 0.078                          | 0.188                            | 7.592                           | 0.081                          | 0.020                            | 7.592                            | 0.038                          | 0.020                            | 7.592                            | 0.238                          | 0.470                            |

- Notes: 1. All valve signal times are referenced to  $t_0$ .  
2. Valve delay time is the time required for the initial valve movement after the valve "open" or valve "closed" solenoid has been energized.  
3. Data are reduced from an oscillogram.  
4. Final sequence check is conducted without propellants within 12 hr before testing.

TABLE VII (Concluded)  
c. Final Sequence

| Firing<br>Number<br>J4-1801- | Start                           |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                    |                                |                                  |                                     |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|------------------------------------|--------------------------------|----------------------------------|-------------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                              | Start Tank Discharge Valve      |                                |                                  |                                 |                                |                                  | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve<br>First Stage |                                |                                  | Main Oxidizer Valve<br>Second Stage |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                              | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal    | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal     | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec |
| 28                           | 0                               | 0.087                          | 0.110                            | 0.450                           | 0.090                          | 0.245                            | -1.000                          | 0.045                          | 0.070                            | 0.450                              | 0.053                          | 0.050                            | 0.450                               | 0.625                          | 1.910                            | 0.450                           | 0.043                          | 0.040                            | 0.450                            | 0.150                          | 0.070                            | 0.450                            | 0.220                          | 0.320                            |
| 29                           | 0                               | 0.100                          | 0.112                            | 0.445                           | 0.090                          | 0.250                            | -1.000                          | 0.045                          | 0.070                            | 0.445                              | 0.050                          | 0.050                            | 0.445                               | 0.630                          | 1.955                            | 0.445                           | 0.080                          | 0.035                            | 0.445                            | 0.155                          | 0.070                            | 0.445                            | 0.220                          | 0.260                            |
| 30                           | 0                               | 0.097                          | 0.113                            | 0.450                           | 0.090                          | 0.245                            | -1.000                          | 0.045                          | 0.065                            | 0.450                              | 0.050                          | 0.047                            | 0.450                               | 0.570                          | 1.750                            | 0.450                           | 0.080                          | 0.042                            | 0.450                            | 0.150                          | 0.067                            | 0.450                            | 0.200                          | 0.350                            |
| 31                           | 0                               | 0.100                          | 0.110                            | 0.450                           | 0.095                          | 0.240                            | -1.000                          | 0.045                          | 0.072                            | 0.450                              | 0.050                          | 0.045                            | 0.450                               | 0.572                          | 1.788                            | 0.450                           | 0.090                          | 0.032                            | 0.450                            | 0.150                          | 0.070                            | 0.450                            | 0.200                          | 0.280                            |
| 32                           | 0                               | 0.100                          | 0.115                            | 0.450                           | 0.093                          | 0.247                            | -1.001                          | 0.045                          | 0.075                            | 0.450                              | 0.053                          | 0.044                            | 0.450                               | 0.617                          | 1.924                            | 0.450                           | 0.091                          | 0.027                            | 0.450                            | 0.141                          | 0.077                            | 0.450                            | 0.211                          | 0.300                            |
| 33                           | 0                               | 0.136                          | 0.125                            | 0.446                           | 0.088                          | 0.235                            | -1.003                          | 0.051                          | 0.071                            | 0.446                              | 0.055                          | 0.058                            | 0.446                               | 0.674                          | 2.151                            | 0.448                           | 0.120                          | 0.026                            | 0.448                            | 0.187                          | 0.080                            | 0.446                            | 0.205                          | 0.277                            |

| Firing<br>Number<br>J4-1801- | Shutdown                        |                                |                                  |                                 |                                |                                  |                                 |                                |                                  |                                  |                                |                                  |                                  |                                |                                  |
|------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|---------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|----------------------------------|--------------------------------|----------------------------------|
|                              | Main Fuel Valve                 |                                |                                  | Main Oxidizer Valve             |                                |                                  | Gas Generator<br>Fuel Poppet    |                                |                                  | Gas Generator<br>Oxidizer Poppet |                                |                                  | Oxidizer Turbine<br>Bypass Valve |                                |                                  |
|                              | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Closing<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Closing<br>Time,<br>sec | Time<br>of<br>Opening<br>Signal  | Valve<br>Delay<br>Time,<br>sec | Valve<br>Opening<br>Time,<br>sec |
| 28                           | ---                             | 0.088                          | 0.130                            | ---                             | 0.088                          | 0.239                            | ---                             | 0.052                          | 0.052                            | ---                              | 0.052                          | 0.028                            | ---                              | 0.212                          | 0.570                            |
| 29                           | ---                             | 0.087                          | 0.237                            | ---                             | 0.087                          | 0.130                            | ---                             | 0.082                          | 0.025                            | ---                              | 0.054                          | 0.020                            | ---                              | 0.150                          | 0.550                            |
| 30                           | ---                             | 0.083                          | 0.243                            | ---                             | 0.086                          | 0.130                            | ---                             | 0.080                          | 0.030                            | ---                              | 0.050                          | 0.023                            | ---                              | 0.233                          | 0.580                            |
| 31                           | ---                             | 0.085                          | 0.237                            | ---                             | 0.084                          | 0.130                            | ---                             | 0.077                          | 0.028                            | ---                              | 0.050                          | 0.022                            | ---                              | 0.233                          | 0.580                            |
| 32                           | ---                             | 0.083                          | 0.243                            | ---                             | 0.083                          | 0.133                            | ---                             | 0.103                          | 0.032                            | ---                              | 0.062                          | 0.031                            | ---                              | 0.207                          | 0.523                            |
| 33                           | ---                             | 0.083                          | 0.237                            | ---                             | 0.065                          | 0.129                            | ---                             | 0.104                          | 0.029                            | ---                              | 0.064                          | 0.032                            | ---                              | 0.228                          | 0.567                            |

- Notes: 1. All valve signal times are referenced to  $t_0$ .  
 2. Valve delay time is the time required for initial valve movement after the valve "open" or "closed" solenoid has been energized.  
 3. Final sequence check is conducted without propellants and within 12 hr before testing.  
 4. Data reduced from oscillogram.

**TABLE VIII**  
**ENGINE PERFORMANCE SUMMARY**

| Firing Number J4-1801-         |                                  | 31B     |            | 33A     |            |
|--------------------------------|----------------------------------|---------|------------|---------|------------|
|                                |                                  | Site    | Normalized | Site    | Normalized |
| Overall Engine Performance     | Thrust, $lb_f$                   | 229,621 | 228,406    | 228,923 | 227,566    |
|                                | Chamber Pressure, psia           | 775     | 767        | 772     | 765        |
|                                | Mixture Ratio                    | 5.7     | 5.7        | 5.7     | 5.6        |
|                                | Fuel Weight Flow, $lb_m/sec$     | 82.5    | 81.7       | 82.5    | 81.8       |
|                                | Oxidizer Weight Flow, $lb_m/sec$ | 467.7   | 463.5      | 466.3   | 461.2      |
|                                | Total Weight Flow, $lb_m/sec$    | 550.2   | 545.2      | 548.8   | 543.0      |
| Thrust Chamber Performance     | Mixture Ratio                    | 5.9     | 5.9        | 5.9     | 5.9        |
|                                | Total Weight Flow, $lb_m/sec$    | 543     | 538        | 542     | 536        |
|                                | Characteristic Velocity, ft/sec  | 7807    | 7804       | 7804    | 7808       |
| Fuel Turbopump Performance     | Pump Efficiency, percent         | 73      | 73         | 73      | 73         |
|                                | Pump Speed, rpm                  | 27,071  | 26,889     | 27,204  | 26,975     |
|                                | Turbine Efficiency, percent      | 60      | 60         | 62      | 62         |
|                                | Turbine Pressure Ratio           | 7.2     | 7.2        | 7.1     | 7.1        |
|                                | Turbine Inlet Temperature, °F    | 1267    | 1249       | 1254    | 1230       |
|                                | Turbine Weight Flow, $lb_m/sec$  | 7.1     | 7.1        | 7.0     | 7.0        |
| Oxidizer Turbopump Performance | Pump Efficiency, percent         | 81      | 80         | 81      | 80         |
|                                | Pump Speed, rpm                  | 8713    | 8659       | 8684    | 8630       |
|                                | Turbine Efficiency, percent      | 49      | 49         | 49      | 49         |
|                                | Turbine Pressure Ratio           | 2.7     | 2.7        | 2.6     | 2.6        |
|                                | Turbine Inlet Temperature, °F    | 815     | 802        | 820     | 802        |
|                                | Turbine Weight Flow, $lb_m/sec$  | 6.3     | 6.3        | 6.2     | 6.2        |
| Gas Generator Performance      | Mixture Ratio                    | 0.98    | 0.97       | 0.97    | 0.96       |
|                                | Chamber Pressure, psia           | 693     | 688        | 685     | 679        |

- Notes:
1. Site data are calculated from test data.
  2. Normalized data are corrected to standard pump inlet and engine ambient pressure conditions.
  3. Input data are test data averaged from 29 to 30 sec, except as noted.
  4. Site and normalized data were computed using the Rocketdyne PAST 640 modification zero computer program.



### **APPENDIX III INSTRUMENTATION**

The instrumentation for AEDC tests J4-1801-28 through -33 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

**TABLE III-1**  
**INSTRUMENTATION LIST**  
**(FOR TESTS J4-1801-28 THROUGH 33)**

| <u>AEDC Code</u>    | <u>Parameter</u>                            | <u>Tap No.</u> | <u>Range</u>                        | <u>Micro-SADIC</u> | <u>Magnetic Tape</u> | <u>Oscillograph</u> | <u>Strip Chart</u> | <u>X-Y Plotter</u> |
|---------------------|---------------------------------------------|----------------|-------------------------------------|--------------------|----------------------|---------------------|--------------------|--------------------|
|                     | <u>Current</u>                              |                | <u>amp</u>                          |                    |                      |                     |                    |                    |
| ICC                 | Control                                     |                | 0 to 30                             | x                  |                      | x                   |                    |                    |
| IIC                 | Ignition                                    |                | 0 to 30                             | x                  |                      | x                   |                    |                    |
|                     | <u>Event</u>                                |                |                                     |                    |                      |                     |                    |                    |
| EASIOV <sup>①</sup> | Augmented Spark Igniter Oxidizer Valve Open |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EECL                | Engine Cutoff Lockin                        |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EECO                | Engine Cutoff Signal                        |                | On/Off                              | x                  | x                    | x                   |                    |                    |
| EES                 | Engine Start Command                        |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EFBVC               | Fuel Bleed Valve Closed Limit               |                | Open/Closed                         | x                  |                      |                     |                    |                    |
| EFVVC/O             | Fuel Prevalve Closed/Open Limit             |                | Closed/Open                         | x                  |                      | x <sup>②</sup>      |                    |                    |
| EHCS                | Helium Control Solenoid                     |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EID                 | Ignition Detected                           |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EIPCS               | Ignition Phase Control Solenoid             |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EMCS                | Main-Stage Control Solenoid                 |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EMP-1               | Main-Stage Pressure No. 1                   |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EMP-2               | Main-Stage Pressure No. 2                   |                | On/Off                              | x                  |                      | x                   |                    |                    |
| EOBVC               | Oxidizer Bleed Valve Closed Limit           |                | Open/Closed                         | x                  |                      |                     |                    |                    |
| EOPVC               | Oxidizer Prevalve Closed Limit              |                | Closed                              | x                  |                      | x                   |                    |                    |
| EOPVO               | Oxidizer Prevalve Open Limit                |                | Open                                | x                  |                      | x                   |                    |                    |
| ESTDCS              | Start Tank Discharge Control Solenoid       |                | On/Off                              | x                  | x                    | x                   |                    |                    |
| RASIS-1             | Augmented Spark Igniter Spark No. 1         |                | On/Off                              |                    |                      | x                   |                    |                    |
| RASIS-2             | Augmented Spark Igniter Spark No. 2         |                | On/Off                              |                    |                      | x                   |                    |                    |
| RGGS-1              | Gas Generator Spark No. 1                   |                | On/Off                              |                    |                      | x                   |                    |                    |
| RGGS-2              | Gas Generator Spark No. 2                   |                | On/Off                              |                    |                      | x                   |                    |                    |
|                     | <u>Flows</u>                                |                | <u>gpm</u>                          |                    |                      |                     |                    |                    |
| QF-1A               | Fuel                                        | PFF            | 0 to 9000                           | x                  |                      | x                   |                    |                    |
| QF-2                | Fuel                                        | PFFA           | 0 to 9000                           | x                  | x                    | x                   |                    | x <sup>②</sup>     |
| QF-2SD              | Fuel Flow Stall Approach Monitor            |                | 0 to 9000                           | x                  |                      | x                   |                    |                    |
| QFRP                | Fuel Recirculation                          |                | 0 to 160                            | x                  |                      |                     |                    |                    |
| QO-1A               | Oxidizer                                    | POF            | 0 to 3000                           | x                  |                      | x                   |                    |                    |
| QO-2                | Oxidizer                                    | POFA           | 0 to 3000                           | x                  | x                    | x                   |                    |                    |
| QORP                | Oxidizer Recirculation                      |                | 0 to 50                             | x                  |                      |                     | x                  |                    |
|                     | <u>Heat Flux</u>                            |                | <u>watts<br/>Sq. cm<sup>2</sup></u> |                    |                      |                     |                    |                    |
| RTCEP <sup>①</sup>  | Radiation Thrust Chamber Exhaust Plume      |                | 0 to 7                              | x                  |                      |                     |                    |                    |
|                     | <u>Position</u>                             |                | <u>Percent<br/>Open</u>             |                    |                      |                     |                    |                    |
| LFLPD <sup>①</sup>  | Fuel Low Pressure Duct                      |                | ±1 in.                              |                    |                      |                     | x                  |                    |
| LFVT                | Main Fuel Valve                             |                | 0 to 100                            | x                  |                      | x                   |                    |                    |

TABLE III-1 (Continued)

| <u>AEDC<br/>Code</u> | <u>Parameter</u>                               | <u>Tap<br/>No.</u> | <u>Range</u><br><u>Percent</u><br><u>Open</u> | <u>Micro-<br/>SADIC</u> | <u>Magnetic<br/>Tape</u> | <u>Oscillo-<br/>graph</u> | <u>Strip<br/>Chart</u> | <u>X-Y<br/>Plotter</u> |
|----------------------|------------------------------------------------|--------------------|-----------------------------------------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
|                      | <u>Position</u>                                |                    |                                               |                         |                          |                           |                        |                        |
| LGGVT                | Gas Generator Valve                            |                    | 0 to 100                                      | x                       |                          | x                         | x                      |                        |
| LOTBVT               | Oxidizer Turbine Bypass Valve                  |                    | 0 to 100                                      | x                       |                          | x                         |                        |                        |
| LOVT                 | Main Oxidizer Valve                            |                    | 0 to 100                                      | x                       | x                        | x                         |                        |                        |
| LPUTOP               | Propellant Utilization Valve                   |                    | 0 to 100                                      | x                       |                          | x                         | x                      |                        |
| LSTDVT               | Start Tank Discharge Valve                     |                    | 0 to 100                                      | x                       |                          | x                         |                        |                        |
|                      | <u>Pressure</u>                                |                    | <u>psia</u>                                   |                         |                          |                           |                        |                        |
| PA1                  | Test Cell                                      |                    | 0 to 0.5                                      | x                       |                          | x                         |                        |                        |
| PA2                  | Test Cell                                      |                    | 0 to 1.0                                      | x                       | x                        |                           |                        |                        |
| PA3                  | Test Cell                                      |                    | 0 to 5.0                                      | x                       |                          |                           | x                      |                        |
| PC-1P                | Thrust Chamber                                 | CG1                | 0 to 1000                                     | x                       |                          |                           | x                      |                        |
| PC-3                 | Thrust Chamber                                 | CG1A               | 0 to 1000                                     | x                       | x                        | x                         |                        |                        |
| PCGG-1P              | Gas Generator Chamber<br>Pressure              |                    | 0 to 1000                                     | x                       | x                        | x                         |                        |                        |
| PCGG-2               | Gas Generator Chamber                          | GG1A               | 0 to 1000                                     | x                       |                          |                           |                        |                        |
| PFASIJ               | Augmented Spark Igniter Fuel<br>Injection      |                    | 0 to 1000                                     | x                       |                          |                           |                        |                        |
| PFJ-1A               | Main Fuel Injection                            | CF2                | 0 to 1000                                     | x                       |                          | x                         |                        |                        |
| PFJ-2                | Main Fuel Injection                            | CF2A               | 0 to 1000                                     | x                       | x                        |                           |                        |                        |
| PFJGG-1A             | Gas Generator Fuel Injection                   | GF4                | 0 to 1000                                     | x                       |                          |                           |                        |                        |
| PFJGG-2              | Gas Generator Fuel Injection                   | GF4                | 0 to 1000                                     | x                       |                          | x                         |                        |                        |
| PFM1                 | Fuel Jacket Inlet Manifold                     | CF1                | 0 to 2000                                     | x                       |                          |                           |                        |                        |
| PFPC-1A              | Fuel Pump Balance Piston<br>Cavity             | PF5                | 0 to 1000                                     | x                       |                          |                           |                        |                        |
| PFPD-1P              | Fuel Pump Discharge                            | PF3                | 0 to 1500                                     | x                       |                          |                           |                        | x <sup>②</sup>         |
| PFPD-2               | Fuel Pump Discharge                            | PF2                | 0 to 1500                                     | x                       | x                        | x                         |                        |                        |
| PFPI-1               | Fuel Pump Inlet                                |                    | 0 to 100                                      | x                       |                          | x                         |                        | x                      |
| PFPI-2               | Fuel Pump Inlet                                |                    | 0 to 200                                      | x                       |                          | x                         | x <sup>②④</sup>        | x                      |
| PFPI-3 <sup>①</sup>  | Fuel Pump Inlet                                |                    | 0 to 200                                      |                         | x                        | x <sup>③</sup>            |                        |                        |
| PFPPSD-1             | Fuel Pump Primary Seal Drain                   |                    | 0 to 200                                      | x                       |                          |                           |                        |                        |
| PFPPSD-2             | Fuel Pump Primary Seal Drain                   |                    | 0 to 100                                      | x                       |                          |                           |                        |                        |
| PFPS-1P              | Fuel Pump Interstage                           | PF6                | 0 to 200                                      | x                       |                          |                           |                        |                        |
| PFRPO                | Fuel Recirculation Pump Outlet                 |                    | 0 to 60                                       | x                       |                          |                           |                        |                        |
| PFRPR                | Fuel Recirculation Pump Return                 |                    | 0 to 50                                       | x                       |                          |                           |                        |                        |
| PFST-1P              | Fuel Start Tank                                | TF1                | 0 to 1500                                     | x                       |                          | x                         |                        |                        |
| PFST-2               | Fuel Start Tank                                | TF1                | 0 to 1500                                     | x                       |                          |                           |                        | x                      |
| PFTSP-1              | Fuel Turbine Seal Purge Line                   |                    | 0 to 100                                      | x                       |                          |                           |                        |                        |
| PFUT                 | Fuel Tank Ullage                               |                    | 0 to 100                                      | x                       |                          |                           |                        |                        |
| PFVI                 | Fuel Tank Pressurization Line<br>Nozzle Inlet  |                    | 0 to 1000                                     | x                       |                          |                           |                        |                        |
| PFVL                 | Fuel Tank Pressurization Line<br>Nozzle Throat |                    | 0 to 1000                                     | x                       |                          |                           |                        |                        |
| PGGOC                | Gas Generator Opening Control                  |                    | 0 to 500                                      | x                       |                          |                           |                        |                        |
| PGGVB                | Gas Generator Valve Body                       |                    | 0 to 50                                       | x                       |                          |                           |                        |                        |

TABLE III-1 (Continued)

| <u>AEDC<br/>Code</u> | <u>Parameter</u>                                   | <u>Tap<br/>No.</u> | <u>Range</u> | <u>Micro-<br/>SADIC</u> | <u>Magnetic<br/>Tape</u> | <u>Oscillo-<br/>graph</u> | <u>Strip<br/>Chart</u> | <u>X-Y<br/>Plotter</u> |
|----------------------|----------------------------------------------------|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
|                      | <u>Pressure</u>                                    |                    | <u>psia</u>  |                         |                          |                           |                        |                        |
| PHECMO               | Pneumatic Control Module Outlet                    |                    | 0 to 750     | x                       |                          |                           |                        |                        |
| PHEOP                | Oxidizer Recirculation Pump<br>Purge               |                    | 0 to 150     | x                       |                          |                           |                        |                        |
| PHES                 | Helium Supply                                      |                    | 0 to 5000    | x                       |                          |                           |                        |                        |
| PHET-1P              | Helium Tank                                        | NN1                | 0 to 3500    | x                       |                          | x                         |                        |                        |
| PHET-2               | Helium Tank                                        | NN1                | 0 to 3500    | x                       |                          |                           | x <sup>②</sup>         | x <sup>①</sup>         |
| PHRO-1A              | Helium Regulator Outlet                            | NN2                | 0 to 750     | x                       | x                        |                           |                        |                        |
| POBSC                | Oxidizer Bootstrap Conducing                       |                    | 0 to 50      | x                       |                          |                           |                        |                        |
| POBV                 | Gas Generator Oxidizer Bleed<br>Valve              | GO2                | 0 to 2000    | x                       |                          |                           |                        |                        |
| POJ-1A               | Main Oxidizer Injection                            | CO3                | 0 to 1000    | x                       |                          | x                         |                        |                        |
| POJ-2                | Main Oxidizer Injection                            | CO3A               | 0 to 1000    | x                       |                          | x                         |                        |                        |
| POJGG-1A             | Gas Generator Oxidizer Injection                   | GO5                | 0 to 1000    | x                       |                          | x                         |                        |                        |
| POJGG-2              | Gas Generator Oxidizer Injection                   | GO5                | 0 to 1000    | x                       |                          |                           |                        |                        |
| POPBC-1A             | Oxidizer Pump Bearing Coolant                      | PO7                | 0 to 500     | x                       |                          |                           |                        |                        |
| POPD-1P              | Oxidizer Pump Discharge                            | PO3                | 0 to 1500    | x                       |                          |                           |                        |                        |
| POPD-2               | Oxidizer Pump Discharge                            | PO2                | 0 to 1500    | x                       | x                        | x                         |                        |                        |
| POPI-1               | Oxidizer Pump Inlet                                |                    | 0 to 100     | x                       |                          |                           |                        | x                      |
| POPI-2               | Oxidizer Pump Inlet                                |                    | 0 to 200     | x                       |                          |                           |                        | x                      |
| POPI-3               | Oxidizer Pump Inlet                                |                    | 0 to 100     |                         |                          | x                         |                        |                        |
| POPSC-1A             | Oxidizer Pump Primary Seal<br>Cavity               | PO6                | 0 to 50      | x                       |                          |                           |                        |                        |
| PORPO                | Oxidizer Recirculation Pump<br>Outlet              |                    | 0 to 115     | x                       |                          |                           |                        |                        |
| PORPR                | Oxidizer Recirculation Pump<br>Return              |                    | 0 to 100     | x                       |                          |                           |                        |                        |
| POTI-1A              | Oxidizer Turbine Inlet                             | TG3                | 0 to 200     | x                       |                          |                           |                        |                        |
| POTO-1A              | Oxidizer Turbine Outlet                            | TG4                | 0 to 100     | x                       |                          |                           |                        |                        |
| POUT                 | Oxidizer Tank Ullage                               |                    | 0 to 100     | x                       |                          |                           |                        |                        |
| POVCC                | Main Oxidizer Valve Closing<br>Control             |                    | 0 to 500     | x                       | x                        |                           |                        |                        |
| POVI                 | Oxidizer Tank Pressurization<br>Line Nozzle Inlet  |                    | 0 to 1000    | x                       |                          |                           |                        |                        |
| POVL                 | Oxidizer Tank Pressurization<br>Line Nozzle Throat |                    | 0 to 1000    | x                       |                          |                           |                        |                        |
| PPUVI-1A             | Propellant Utilization Valve<br>Inlet              | PO8                | 0 to 1000    | x                       |                          |                           |                        |                        |
| PPUVO-1A             | Propellant Utilization Valve<br>Outlet             | PO9                | 0 to 500     | x                       |                          |                           |                        |                        |
| PTCFJP               | Thrust Chamber Fuel Jacket<br>Purge                |                    | 0 to 100     | x                       |                          |                           |                        |                        |
| PTCP                 | Thrust Chamber Purge                               |                    | 0 to 15      | x                       |                          |                           |                        |                        |
| PTPP                 | Turbopump and Gas Generator<br>Purge               |                    | 0 to 250     | x                       |                          |                           |                        |                        |
|                      | <u>Speeds</u>                                      |                    | <u>rpm</u>   |                         |                          |                           |                        |                        |
| NFP-1P               | Fuel Pump                                          | PFV                | 0 to 30,000  | x                       | x                        | x                         |                        |                        |
| NFRP                 | Fuel Recirculation Pump                            |                    | 0 to 15,000  | x                       |                          |                           |                        |                        |
| NOP-1P               | Oxidizer Pump                                      | POV                | 0 to 12,000  | x                       | x                        | x                         |                        |                        |
| NORP                 | Oxidizer Recirculation Pump                        |                    | 0 to 15,000  | x                       |                          |                           |                        |                        |

TABLE III-1 (Continued)

| AEDC Code            | Parameter                              | Temp No. | Range         | Micro-SADIC | Magnetic Tape  | Oscillo-graph | Strip Chart     | X-Y Plotter |
|----------------------|----------------------------------------|----------|---------------|-------------|----------------|---------------|-----------------|-------------|
|                      | <u>Temperatures</u>                    |          | <u>°F</u>     |             |                |               |                 |             |
| C2035 <sup>②③</sup>  | Temperature Oxidizer Bootstrap         |          | -300 to +250  | x           |                |               |                 |             |
| C2036 <sup>②</sup>   | Temperature Oxidizer Bootstrap         |          | -300 to +250  | x           |                |               |                 |             |
| C2037 <sup>②</sup>   | Temperature Oxidizer Bootstrap         |          | -300 to +250  | x           |                |               |                 |             |
| TA1                  | Test Cell (North)                      |          | -50 to +800   | x           |                |               |                 |             |
| TA2                  | Test Cell (East)                       |          | -50 to +800   | x           |                |               |                 |             |
| TA3                  | Test Cell (South)                      |          | -50 to +800   | x           |                |               |                 |             |
| TA4                  | Test Cell (West)                       |          | -50 to +800   | x           |                |               |                 |             |
| TAIP-1A              | Auxiliary Instrument Package           |          | -300 to +200  | x           |                |               |                 |             |
| TBPM                 | Bypass Manifold                        |          | -325 to +200  | x           |                |               |                 |             |
| TBSC                 | Oxidizer Bootstrap Conditioning        |          | -350 to +150  | x           |                |               |                 |             |
| TECP-1P              | Electrical Controls Package            | NST1A    | -300 to +200  | x           |                |               | x               |             |
| TFASIJ               | Augmented Spark Igniter Fuel Injection | 1FT1     | -425 to +100  | x           |                | x             |                 |             |
| TFASIL-1             | Augmented Spark Igniter Line           |          | -300 to +200  | x           |                |               |                 |             |
| TFASIL-2             | Augmented Spark Igniter Line           |          | -300 to +300  | x           |                |               |                 |             |
| TFBV-1A              | Fuel Bleed Valve                       | GFT1     | -425 to -375  | x           |                |               |                 |             |
| TFD-1                | Fire Detection                         |          | 0 to 1000     | x           |                |               |                 |             |
| TFJ-1P               | Main Fuel Injection                    | CFT2     | -425 to +250  | x           | x <sup>①</sup> | x             |                 |             |
| TFPD-1P              | Fuel Pump Discharge                    | PFT1     | -425 to -400  | x           | x              | x             |                 |             |
| TFPD-2               | Fuel Pump Discharge                    | PFT1     | -425 to -400  | x           |                |               |                 |             |
| TFPDD                | Fuel Pump Discharge Duct               |          | -320 to +300  | x           |                |               |                 |             |
| TFPI-1               | Fuel Pump Inlet                        |          | -425 to -400  | x           |                |               | x <sup>①</sup>  | x           |
| TFPI-2               | Fuel Pump Inlet                        |          | -425 to -400  | x           |                |               | x <sup>②③</sup> | x           |
| TFPI-3               | Fuel Pump Inlet                        |          | -425 to -400  | x           |                |               |                 |             |
| TFPPSD-1             | Fuel Pump Primary Seal Drain           |          | -425 to +100  | x           |                |               |                 |             |
| TFPSP-1              | Fuel Pump Seal Purge                   |          | -425 to +100  | x           |                |               |                 |             |
| TFRPO                | Fuel Recirculation Pump Outlet         |          | -425 to -410  | x           |                |               |                 |             |
| TFRPR                | Fuel Recirculation Pump Return Line    |          | -425 to -250  | x           |                |               |                 |             |
| TFRT-1               | Fuel Tank                              |          | -425 to -410  | x           |                |               |                 |             |
| TFRT-3               | Fuel Tank                              |          | -425 to -410  | x           |                |               |                 |             |
| TFST-1P              | Fuel Start Tank                        | TFT1     | -350 to +100  | x           |                |               |                 |             |
| TFST-2               | Fuel Start Tank                        | TFT1     | -350 to +100  | x           |                |               |                 | x           |
| TFTD-1               | Fuel Turbine Discharge Duct            |          | -200 to +800  | x           |                |               |                 |             |
| TFTD-2               | Fuel Turbine Discharge Duct            |          | -200 to +1000 | x           |                |               | x               |             |
| TFTD-3               | Fuel Turbine Discharge Duct            |          | -200 to -1000 | x           |                |               | x               |             |
| TFTD-3R <sup>④</sup> | Fuel Turbine Discharge Line            |          | -200 to -900  | x           |                |               |                 |             |
| TFTD-4               | Fuel Turbine Discharge Duct            |          | -200 to +1000 | x           |                |               |                 |             |
| TFTD-5               | Fuel Turbine Discharge Duct            |          | -200 to +1400 | x           |                |               |                 |             |
| TFTD-6               | Fuel Turbine Discharge Duct            |          | -200 to +1400 | x           |                |               |                 |             |
| TFTD-7               | Fuel Turbine Discharge Duct            |          | -200 to +1400 | x           |                |               |                 |             |
| TFTD-8               | Fuel Turbine Discharge Duct            |          | -200 to +1400 | x           |                |               | x               |             |
| TFTI-1P <sup>②</sup> | Fuel Turbine Inlet                     | TFT1     | 0 to 1800     | x           |                |               | x <sup>④</sup>  |             |
| TFTO                 | Fuel Turbine Outlet                    | TFT2     | 0 to 1800     | x           |                |               |                 |             |

TABLE III-1 (Continued)

| <u>AEDC<br/>Code</u> | <u>Parameter</u>                                   | <u>Tap<br/>No.</u> | <u>Range</u> | <u>Micro-<br/>SADIC</u> | <u>Magnetic<br/>Tape</u> | <u>Oscillo-<br/>graph</u> | <u>Strip<br/>Chart</u> | <u>X-Y<br/>Plotter</u> |
|----------------------|----------------------------------------------------|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
|                      | <u>Temperatures</u>                                |                    | <u>°F</u>    |                         |                          |                           |                        |                        |
| TFTSD-1              | Fuel Turbine Seal Drain Line                       |                    | -300 to +100 | x                       |                          |                           |                        |                        |
| TGGO-1A              | Gas Generator Outlet                               | GGT1               | 0 to 1800    | x                       |                          | x                         | x <sup>③</sup>         |                        |
| TGGVRS               | Gas Generator Valve Retaining<br>Screw             |                    | -100 to +100 | x                       |                          |                           | x                      |                        |
| THET-1P              | Helium Tank                                        | NNT1               | -350 to +100 | x                       |                          |                           | x <sup>②</sup>         | x <sup>①</sup>         |
| TMFV-1 <sup>②</sup>  | Main Fuel Valve                                    |                    | -100 to +300 | x                       |                          |                           |                        |                        |
| TMFV-2 <sup>②</sup>  | Main Fuel Valve                                    |                    | -100 to +300 | x                       |                          |                           |                        |                        |
| TNODP                | Liquid Oxygen Dome Purge                           |                    | 0 to -300    | x                       |                          |                           |                        |                        |
| TOBS-1               | Oxidizer Bootstrap Line                            |                    | -300 to +250 | x                       |                          |                           |                        |                        |
| TOBS-2               | Oxidizer Bootstrap Line                            |                    | -300 to -250 | x                       |                          |                           |                        |                        |
| TOBS-2A              | Oxidizer Bootstrap Line                            |                    | -300 to +250 | x                       |                          |                           |                        |                        |
| TOBS-2B              | Oxidizer Bootstrap Line                            |                    | -300 to +250 | x                       |                          |                           |                        |                        |
| TOBS-3 <sup>④</sup>  | Oxidizer Bootstrap Line                            |                    | -300 to +250 | x                       |                          |                           |                        |                        |
| TOBS-4               | Oxidizer Bootstrap Line                            |                    | -300 to +250 | x                       |                          |                           |                        |                        |
| TOBV-1A              | Oxidizer Bleed Valve                               | GOT2               | -300 to -250 | x                       |                          |                           |                        |                        |
| TOPB-1A              | Oxidizer Pump Bearing Coolant                      | POT4               | -300 to -250 | x                       |                          |                           |                        |                        |
| TOPD-1P              | Oxidizer Pump Discharge                            | POT3               | -300 to -250 | x                       | x                        | x                         | x                      |                        |
| TOPD-2               | Oxidizer Pump Discharge                            | POT3               | -300 to -250 | x                       |                          |                           |                        |                        |
| TOPI-1               | Oxidizer Pump Inlet                                |                    | -310 to -270 | x                       |                          |                           |                        | x                      |
| TOPI-2               | Oxidizer Pump Inlet                                |                    | -310 to -270 | x                       |                          |                           |                        | x                      |
| TORPO                | Oxidizer Recirculation Pump<br>Outlet              |                    | -300 to -250 | x                       |                          |                           |                        |                        |
| TORPR                | Oxidizer Recirculation Pump<br>Return              |                    | -300 to -140 | x                       |                          |                           |                        |                        |
| TORT-1               | Oxidizer Tank                                      |                    | -300 to -287 | x                       |                          |                           |                        |                        |
| TORT-1B              | Oxidizer Tank                                      |                    | -300 to -287 | x                       |                          |                           |                        |                        |
| TORT-3               | Oxidizer Tank                                      |                    | -300 to -287 | x                       |                          |                           |                        |                        |
| TOTBV-1 <sup>⑤</sup> | Oxidizer Turbine Bypass Valve                      |                    | -100 to +300 | x                       |                          |                           |                        |                        |
| TOTBV-2 <sup>⑤</sup> | Oxidizer Turbine Bypass Valve                      |                    | -100 to +300 | x                       |                          |                           |                        |                        |
| TOTI-1P              | Oxidizer Turbine Inlet                             | TGT3               | 0 to 1200    | x                       |                          |                           | x                      |                        |
| TOTO-1P              | Oxidizer Turbine Outlet                            | TGT4               | 0 to 1000    | x                       |                          |                           |                        |                        |
| TOVL                 | Oxidizer Tank Pressurization<br>Line Nozzle Throat |                    | -300 to +100 | x                       |                          |                           |                        |                        |
| TPCC                 | Prechill Controller                                |                    | -425 to -300 | x                       |                          |                           |                        |                        |
| TPIP-1P              | Primary Instrument Package                         |                    | -300 to +200 | x                       |                          |                           |                        |                        |
| TSC2-1               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-2               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-3               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-4               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-5               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-6               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-7               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-8               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-9               | Thrust Chamber Skin                                |                    | -300 to +500 | x                       |                          |                           |                        |                        |

TABLE III-1 (Concluded)

| <u>AEDC<br/>Code</u> | <u>Parameter</u>                                | <u>Tap<br/>No.</u> | <u>Range</u> | <u>Micro-<br/>SADIC</u> | <u>Magnetic<br/>Tape</u> | <u>Oscillo-<br/>graph</u> | <u>Strip<br/>Chart</u> | <u>X-Y<br/>Plotter</u> |
|----------------------|-------------------------------------------------|--------------------|--------------|-------------------------|--------------------------|---------------------------|------------------------|------------------------|
| <u>Temperatures</u>  |                                                 |                    | <u>°F</u>    |                         |                          |                           |                        |                        |
| TSC2-10              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-11              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-12              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-13              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           | x                      |                        |
| TSC2-14              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-15              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-16              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-17              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-18              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-19              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-20              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-21              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-22              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       | a                        |                           |                        |                        |
| TSC2-23              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSC2-24              | Thrust Chamber Skin                             |                    | -300 to +500 | x                       |                          |                           |                        |                        |
| TSOVAL-1             | Oxidizer Valve Closing Control Line             |                    | -200 to +100 | x                       |                          |                           |                        |                        |
| TSOVC-1              | Oxidizer Valve Actuator Cap                     |                    | -325 to +150 | x                       |                          |                           | x                      |                        |
| TSTC                 | Start Tank Conditioning                         |                    | -350 to +150 | x                       |                          |                           |                        |                        |
| TSTDVOC              | Start Tank Discharge Valve Opening Control Port |                    | -350 to +100 | x                       |                          |                           | x                      |                        |
| TTC-1P               | Thrust Chamber Jacket (Control)                 | CS1                | -425 to +500 | x                       |                          |                           | x                      |                        |
| TTC-2 <sup>①</sup>   | Thrust Chamber Jacket (Control)                 | CS1A               | -425 to +500 | x                       |                          |                           | x                      |                        |
| TTCEP-1              | Thrust Chamber Exit                             |                    | -425 to +500 | x                       |                          |                           |                        |                        |
| TTFP                 | Turbopump Purge                                 |                    | -150 to +150 | x                       |                          |                           | x <sup>②</sup>         |                        |
| <u>Vibrations</u>    |                                                 |                    | <u>g's</u>   |                         |                          |                           |                        |                        |
| UFPR                 | Fuel Pump Radial 90 deg                         |                    | ±200         |                         | x                        | x <sup>②</sup>            |                        |                        |
| UOPR                 | Oxidizer Pump Radial 90 deg                     |                    | ±200         |                         | x                        |                           |                        |                        |
| UTCD-1               | Thrust Chamber Dome                             |                    | ±500         |                         | x                        | x                         |                        |                        |
| UTCD-2               | Thrust Chamber Dome                             |                    | ±500         |                         | x                        | x                         |                        |                        |
| UTCD-3               | Thrust Chamber Dome                             |                    | ±500         |                         | x                        | x                         |                        |                        |
| U1VSC                | No. 1 Vibration Safety Counts                   |                    | On/Off       |                         |                          | x                         |                        |                        |
| U2VSC                | No. 2 Vibration Safety Counts                   |                    | On/Off       |                         |                          | x                         |                        |                        |
| <u>Voltage</u>       |                                                 |                    | <u>volts</u> |                         |                          |                           |                        |                        |
| VCB                  | Control Bus                                     |                    | 0 to 36      | x                       |                          | x                         |                        |                        |
| VIB                  | Ignition Bus                                    |                    | 0 to 36      | x                       |                          | x                         |                        |                        |
| VIDA                 | Ignition Detect Amplifier                       |                    | 9 to 16      | x                       |                          | x                         |                        |                        |
| VPUTEF               | Propellant Utilization Valve Excitation         |                    | 0 to 5       | x                       |                          |                           |                        |                        |

①Applies to test 28 only.

②Does not apply to test 28.

③Applies to tests after test 29.

④Does not apply to tests after test 29.

⑤Applies to tests after test 30.

⑥Does not apply to tests after test 30.

⑦Applies to tests after test 31.

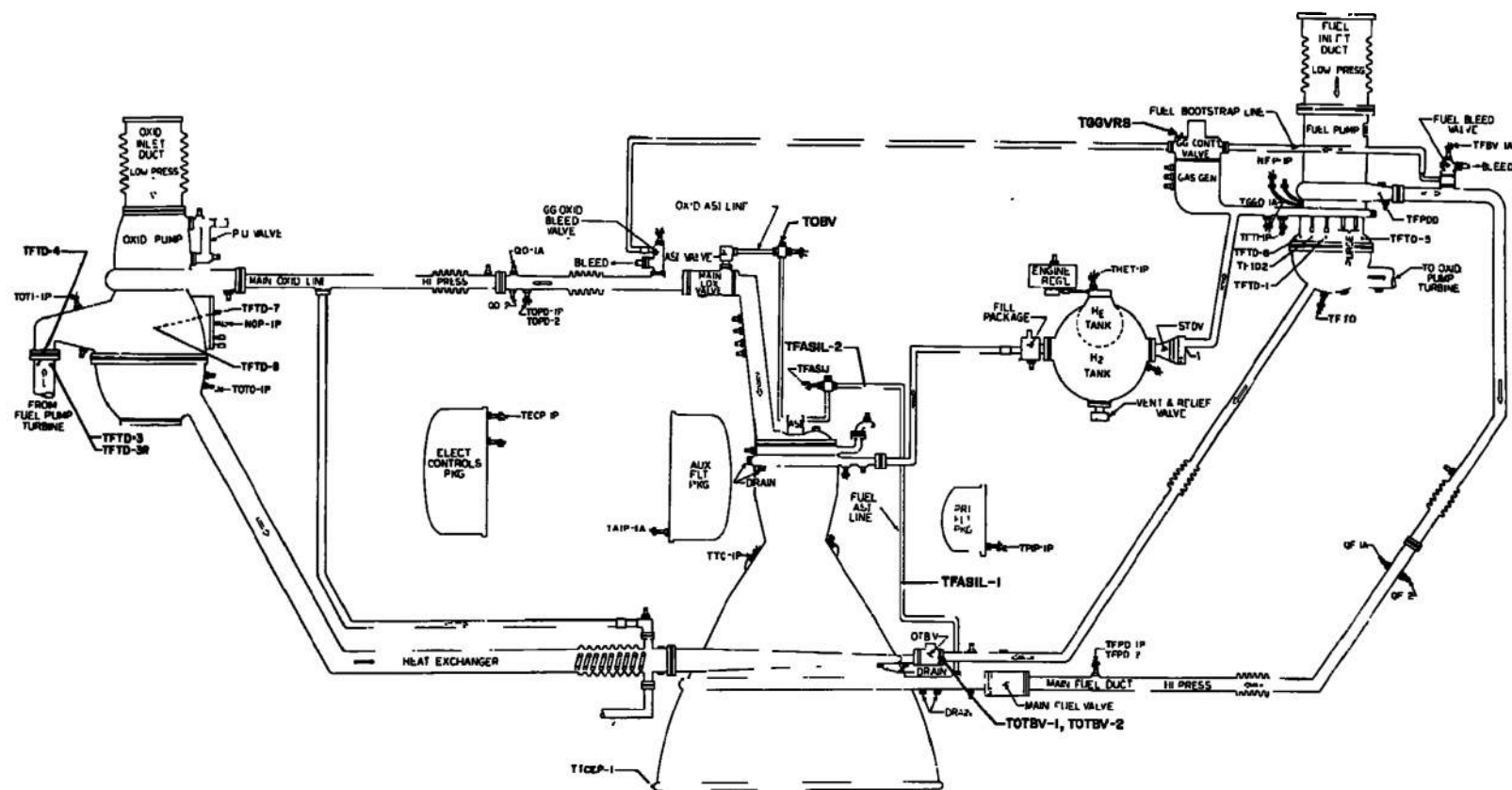
⑧Does not apply to tests after test 31.

⑨Applies to tests after test 32.

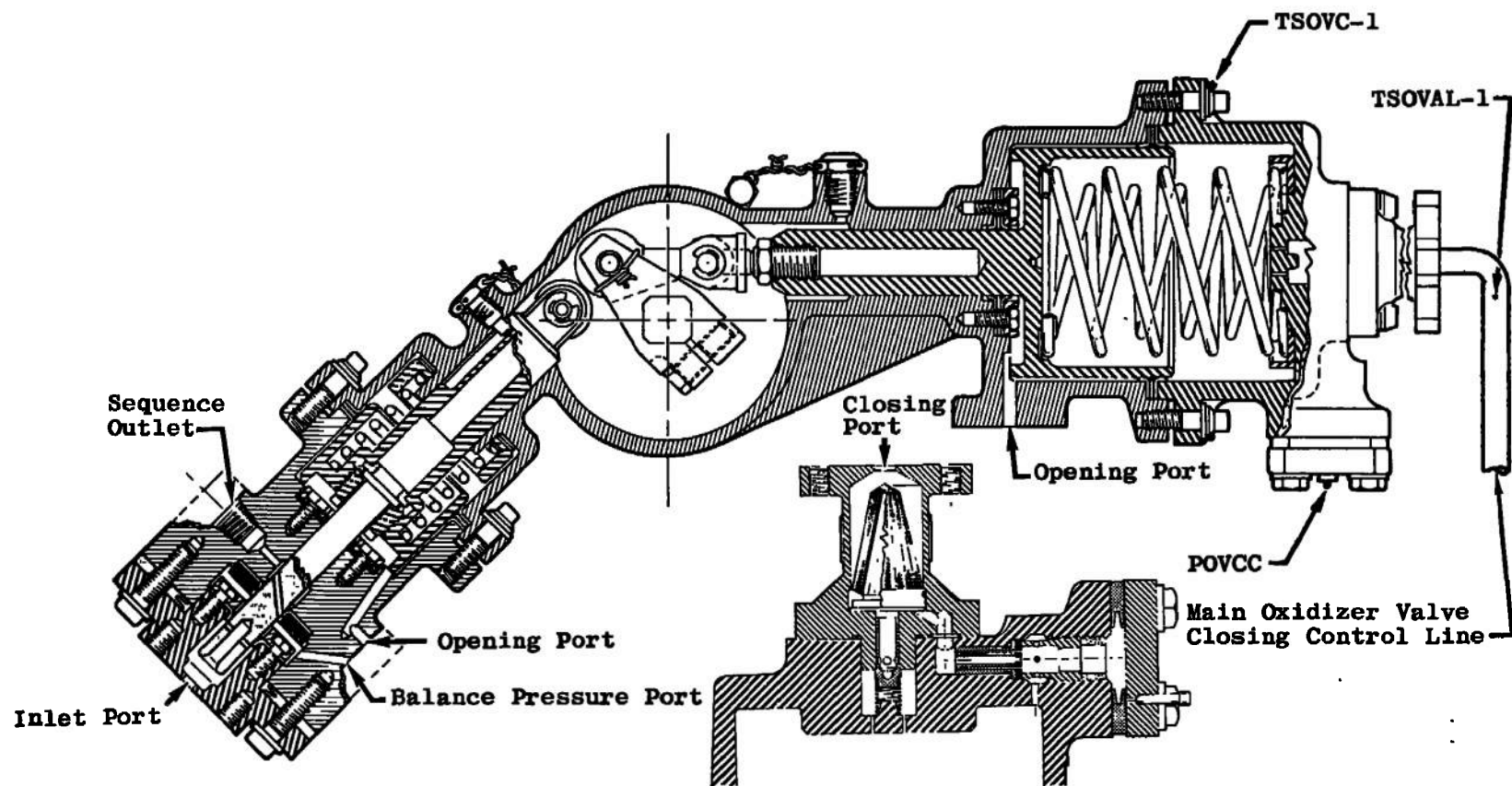
⑩Does not apply to tests after test 32.

**AEDC-TR-68-160**

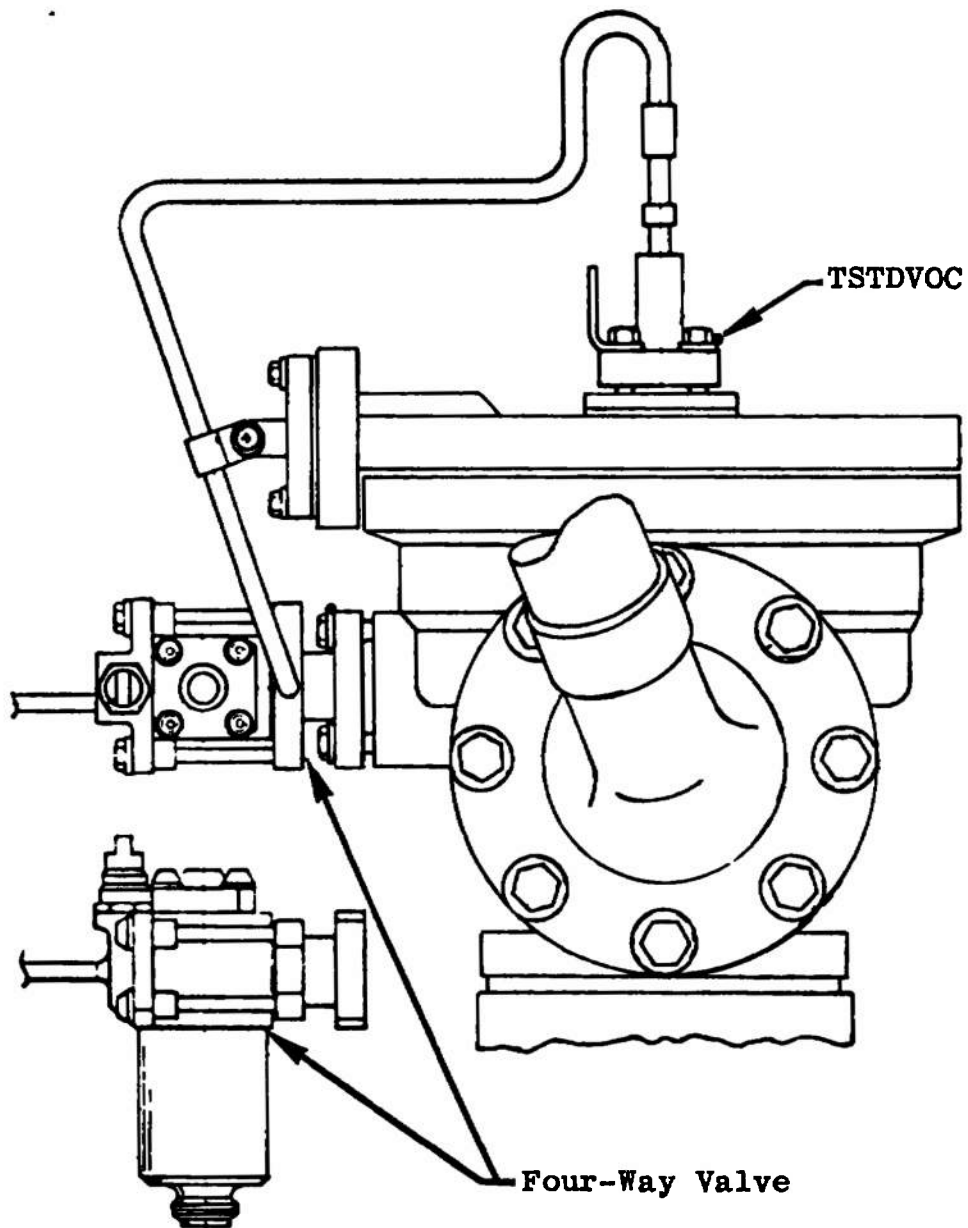




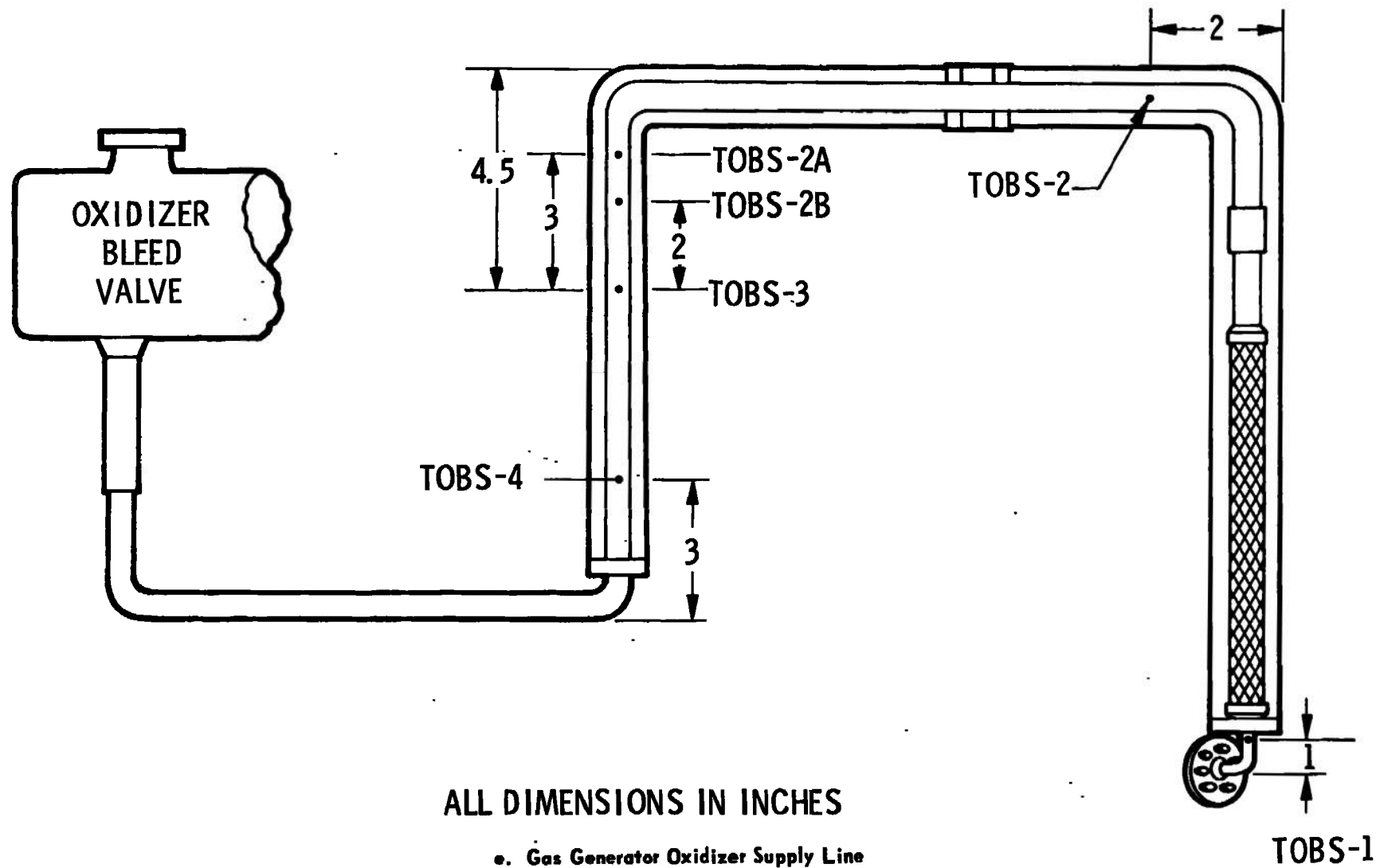
**b. Engine Temperature, Flow, and Speed. Instrumentation Locations**  
**Fig. III-1 Continued**



c. Main Oxidizer Valve  
Fig. III-1 Continued



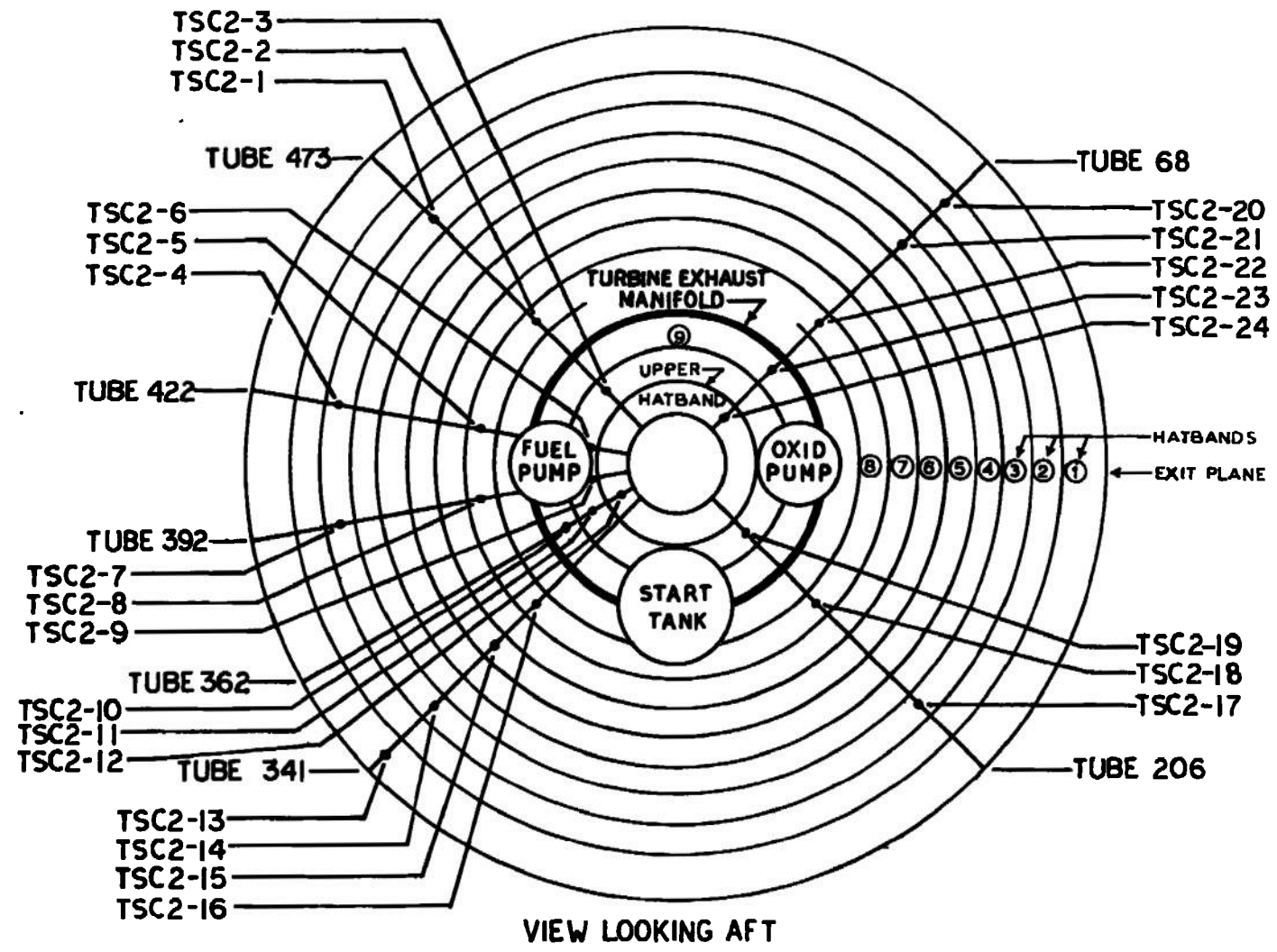
d. Start Tank Discharge Valve  
Fig. III-1 Continued



ALL DIMENSIONS IN INCHES

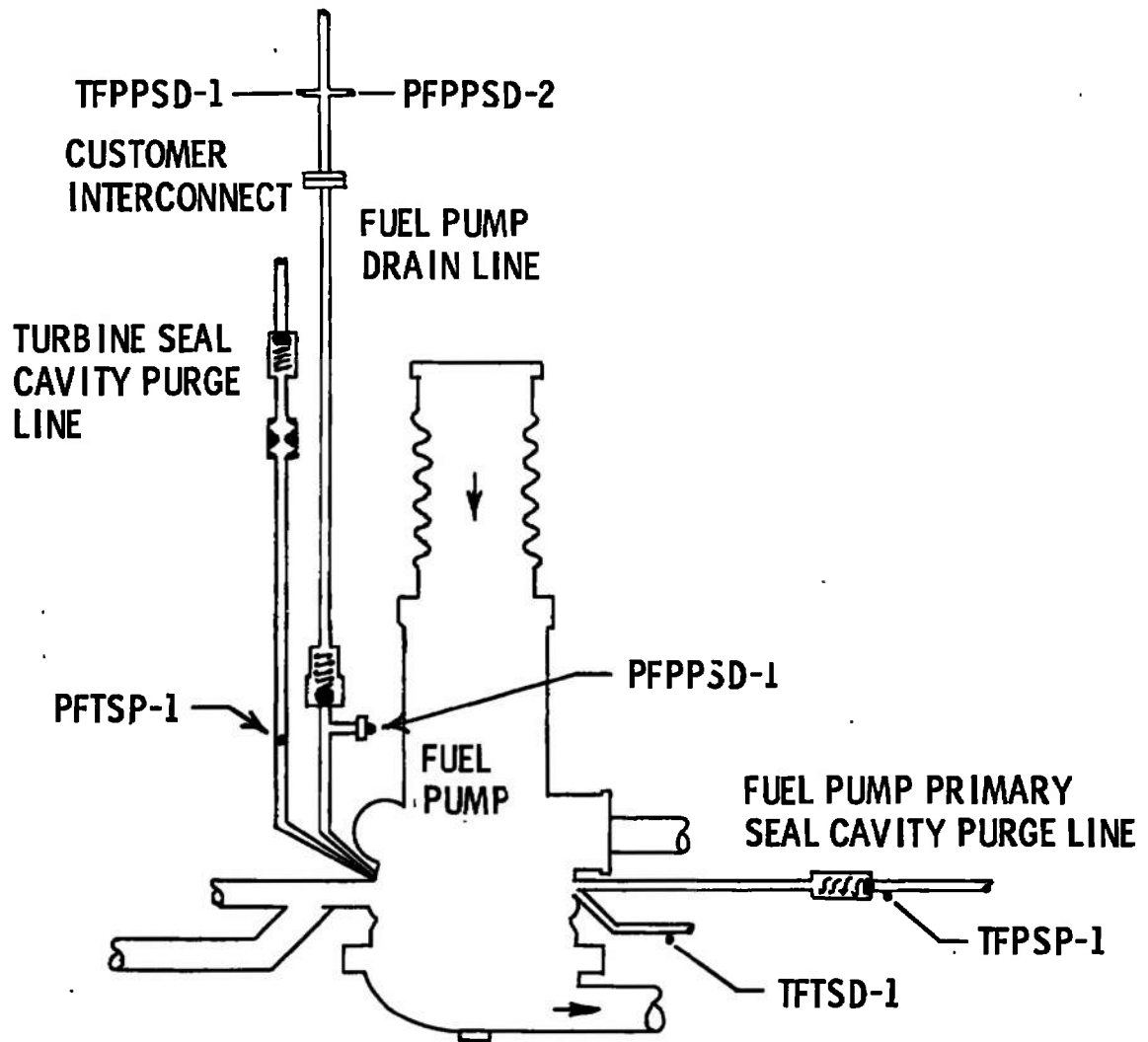
e. Gas Generator Oxidizer Supply Line

Fig. III-1 Continued

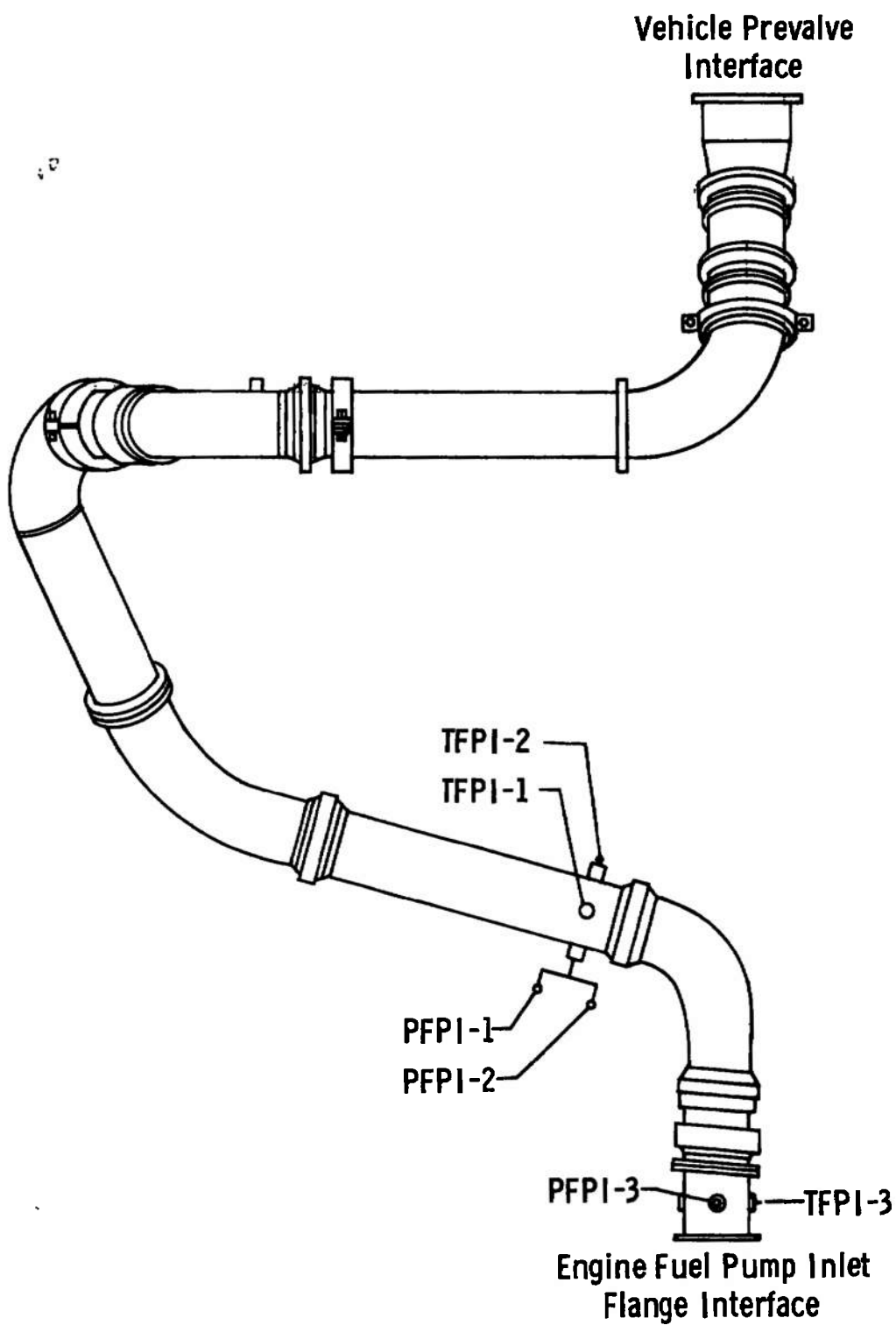


VIEW LOOKING AFT

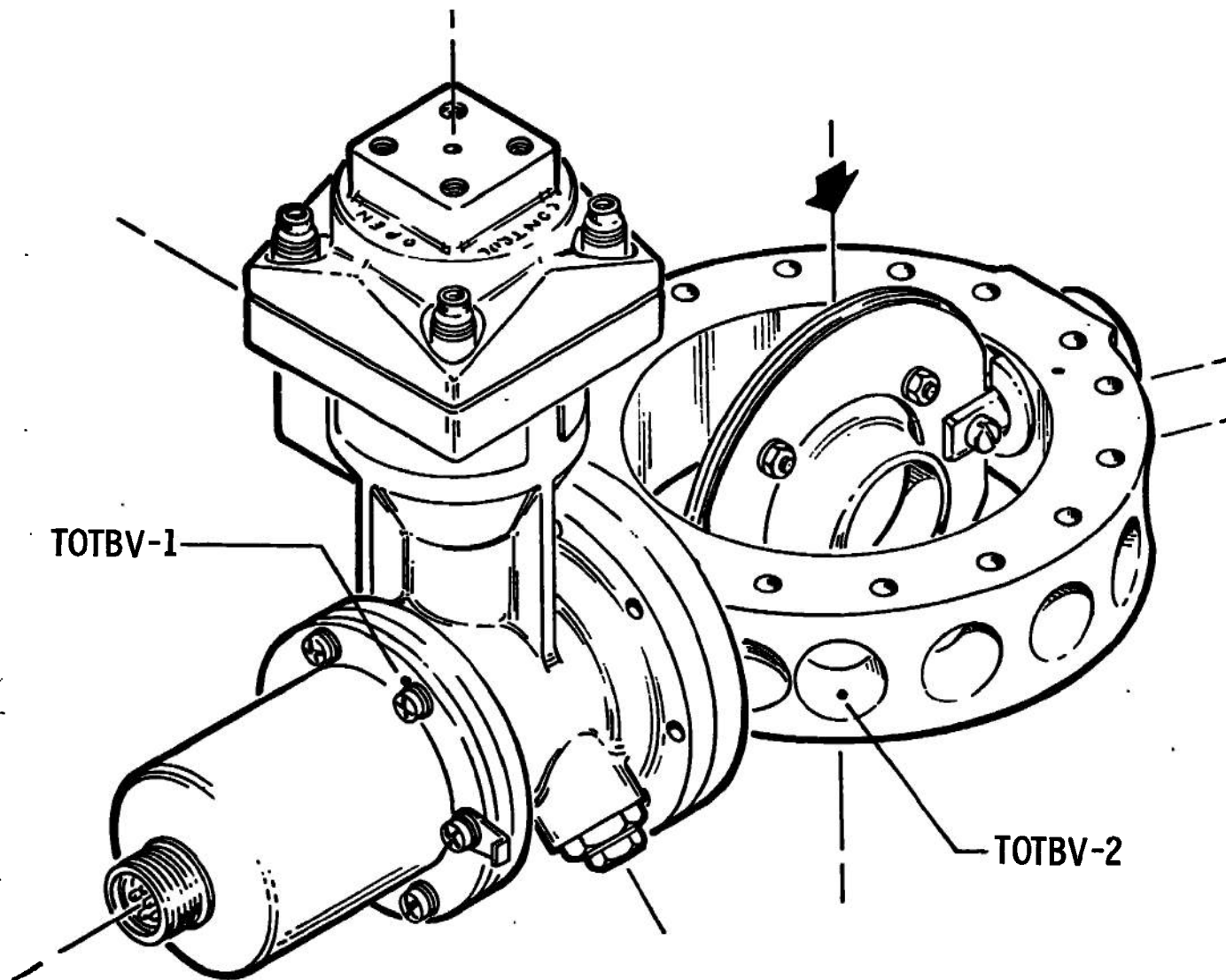
f. Thrust Chamber  
Fig. III-1 Continued



g. Fuel Pump and Turbine Purge and Drain Line  
Fig. III-1 Continued



h. Fuel Low Pressure Duct  
Fig. III-1 Continued



i. Oxidizer Turbine Bypass Valve  
Fig. III-1 Concluded



**APPENDIX IV**  
**METHODS OF CALCULATION (PERFORMANCE PROGRAM)**

**TABLE IV-1**  
**PERFORMANCE PROGRAM DATA INPUTS**

| Item No. | Parameter                                                     |
|----------|---------------------------------------------------------------|
| 1        | Thrust Chamber (Injector Face) Pressure, psia                 |
| 2        | Thrust Chamber Fuel and Oxidizer Injection Pressures, psia    |
| 3        | Thrust Chamber Fuel Injection Temperature, °F                 |
| 4        | Fuel and Oxidizer Flowmeter Speeds, Hz                        |
| 5        | Fuel and Oxidizer Engine Inlet Pressures, psia                |
| 6        | Fuel and Oxidizer Pump Discharge Pressures, psia              |
| 7        | Fuel and Oxidizer Engine Inlet Temperatures, °F               |
| 8        | Fuel and Oxidizer (Main Valves) Temperatures, °F              |
| 9        | Propellant Utilization Valve Center Tap Voltage, volts        |
| 10       | Propellant Utilization Valve Position, volts                  |
| 11       | Fuel and Oxidizer Pump Speeds, rpm                            |
| 12       | Gas Generator Chamber Pressure, psia                          |
| 13       | Gas Generator (Bootstrap Line at Bleed Valve) Temperature, °F |
| 14       | Fuel* and Oxidizer Turbine Inlet Pressure, psia               |
| 15       | Oxidizer Turbine Discharge Pressure, psia                     |
| 16       | Fuel and Oxidizer Turbine Inlet Temperature, °F               |
| 17       | Oxidizer Turbine Discharge Temperature, °F                    |

\*At AEDC, fuel turbine inlet pressure is calculated from gas generator chamber pressure.

## NOMENCLATURE

|                |                                                                 |
|----------------|-----------------------------------------------------------------|
| A              | Area, in. <sup>2</sup>                                          |
| B              | Horsepower, hp                                                  |
| C*             | Characteristic velocity, ft/sec                                 |
| C <sub>p</sub> | Specific heat at constant pressure, Btu/lb/°F                   |
| D              | Diameter, in.                                                   |
| H              | Head, ft                                                        |
| h              | Enthalpy, Btu/lb <sub>m</sub>                                   |
| M              | Molecular weight                                                |
| N              | Speed, rpm                                                      |
| P              | Pressure, psia                                                  |
| Q              | Flow rate, gpm                                                  |
| R              | Resistance, sec <sup>2</sup> /ft <sup>3</sup> -in. <sup>2</sup> |
| r              | Mixture ratio                                                   |
| T              | Temperature, °F                                                 |
| TC*            | Theoretical characteristic velocity, ft/sec                     |
| W              | Weight flow, lb/sec                                             |
| Z              | Pressure drop, psi                                              |
| β              | Ratio                                                           |
| γ              | Ratio of specific heats                                         |
| η              | Efficiency                                                      |
| θ              | Degrees                                                         |
| ρ              | Density, lb/ft <sup>3</sup>                                     |

## SUBSCRIPTS

|    |                                |
|----|--------------------------------|
| A  | Ambient                        |
| AA | Ambient at thrust chamber exit |
| B  | Bypass nozzle                  |

|     |                               |
|-----|-------------------------------|
| BIR | Bypass nozzle inlet (Rankine) |
| BNI | Bypass nozzle inlet (total)   |
| C   | Thrust chamber                |
| CF  | Thrust chamber, fuel          |
| CO  | Thrust chamber, oxidizer      |
| CV  | Thrust chamber, vacuum        |
| E   | Engine                        |
| EF  | Engine fuel                   |
| EM  | Engine measured               |
| EO  | Engine oxidizer               |
| EV  | Engine, vacuum                |
| e   | Exit                          |
| em  | Exit measured                 |
| F   | Thrust                        |
| FIT | Fuel turbine inlet            |
| FM  | Fuel measured                 |
| FY  | Thrust, vacuum                |
| f   | Fuel                          |
| G   | Gas generator                 |
| GF  | Gas generator fuel            |
| GO  | Gas generator oxidizer        |
| H1  | Hot gas duct No. 1            |
| H1R | Hot gas duct No. 1 (Rankine)  |
| H2R | Hot gas duct No. 2 (Rankine)  |
| IF  | Inlet fuel                    |
| IO  | Inlet oxidizer                |
| ITF | Isentropic turbine fuel       |
| ITO | Isentropic turbine oxidizer   |
| N   | Nozzle                        |
| NB  | Bypass nozzle (throat)        |

|                |                                       |
|----------------|---------------------------------------|
| NV             | Nozzle, vacuum                        |
| O              | Oxidizer                              |
| OC             | Oxidizer pump calculated              |
| OF             | Outlet fuel pump                      |
| OFIS           | Outlet fuel pump isentropic           |
| OM             | Oxidizer measured                     |
| OO             | Oxidizer outlet                       |
| PF             | Pump fuel                             |
| PO             | Pump oxidizer                         |
| PUVO           | Propellant utilization valve oxidizer |
| RNC            | Ratio bypass nozzle, critical         |
| SC             | Specific, thrust chamber              |
| SCV            | Specific thrust chamber, vacuum       |
| SE             | Specific, engine                      |
| SEV            | Specific, engine vacuum               |
| T              | Total                                 |
| T <sub>o</sub> | Turbine oxidizer                      |
| TEF            | Turbine exit fuel                     |
| TEFS           | Turbine exit fuel (static)            |
| TF             | Fuel turbine                          |
| TIF            | Turbine inlet fuel (total)            |
| TIFM           | Turbine inlet, fuel, measured         |
| TIFS           | Turbine inlet fuel isentropic         |
| TIO            | Turbine inlet oxidizer                |
| t              | Throat                                |
| V              | Vacuum                                |
| v              | Valve                                 |
| XF             | Fuel tank repressurant                |
| XO             | Oxidizer tank repressurant            |

## PERFORMANCE PROGRAM EQUATIONS

## MIXTURE RATIO

Engine

$$r_E = \frac{W_{EO}}{W_{EF}}$$

$$W_{EO} = W_{OM} - W_{XO}$$

$$W_{EF} = W_{FM} - W_{XF}$$

$$W_E = W_{EO} + W_{EF}$$

Thrust Chamber

$$r_C = \frac{W_{CO}}{W_{CF}}$$

$$W_{CO} = W_{OM} - W_{XO} - W_{GO}$$

$$W_{CF} = W_{FM} - W_{XF} - W_{GF}$$

$$W_{XO} = 0.9 \text{ lb/sec}$$

$$W_{XF} = 2.1 \text{ lb/sec}$$

$$W_{GO} = W_T - W_{GF}$$

$$W_{GF} = \frac{W_T}{1 + r_C}$$

$$W_T = \frac{P_{TIF} A_{TIF} K_7}{TC * TIF}$$

$$K_7 = 32.174$$

$$W_C = W_{CO} + W_{CF}$$

## CHARACTERISTIC VELOCITY

Thrust Chamber

$$C^* = \frac{K_7 P_c A_t}{W_C}$$

$$K_7 = 32.174$$

**DEVELOPED PUMP HEAD**

Flows are normalized by using the following inlet pressures, temperatures, and densities.

$$P_{IO} = 39 \text{ psia}$$

$$P_{IF} = 30 \text{ psia}$$

$$\rho_{IO} = 70.79 \text{ lb/ft}^3$$

$$\rho_{IF} = 4.40 \text{ lb/ft}^3$$

$$T_{IO} = -295.212^\circ\text{F}$$

$$T_{IF} = -422.547^\circ\text{F}$$

**Oxidizer**

$$H_O = K_4 \left( \frac{P_{OO}}{\rho_{OO}} - \frac{P_{IO}}{\rho_{IO}} \right)$$

$$K_4 = 144$$

$$\rho = \text{National Bureau of Standards Values } f(P, T)$$

**Fuel**

$$H_f = 778.16 \Delta h_{OFIS}$$

$$\Delta h_{OFIS} = h_{OFIS} - h_{IF}$$

$$h_{OFIS} = f(P, T)$$

$$h_{IF} = f(P, T)$$

**PUMP EFFICIENCIES****Fuel, Isentropic**

$$\eta_f = \frac{h_{OFIS} - h_{IF}}{h_{OF} - h_{IF}}$$

$$h_{OF} = f(P_{OF}, T_{OF})$$

**Oxidizer, Isentropic**

$$\eta_O = \eta_{OC} Y_O$$

$$\eta_{OC} = K_{40} \left( \frac{Q_{PO}}{N_O} \right)^2 + K_{50} \left( \frac{Q_{PO}}{N_O} \right) + K_{60}$$

$$K_{40} = 5.0526$$

$$K_{50} = 3.8611$$

$$K_{60} = 0.0733$$

$$Y_O = 1.000$$

## TURBINES

## Oxidizer, Efficiency

$$\eta_{TO} = \frac{B_{TO}}{B_{ITO}}$$

$$B_{TO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_5 = 0.001818$$

$$W_{PO} = W_{OM} + W_{PUVO}$$

$$W_{PUVO} = \sqrt{\frac{Z_{PUVO} \rho_{OO}}{R_v}}$$

$$Z_{PUVO} = A + B (P_{OO})$$

$$A = -1597$$

$$B = 2.3818$$

$$\text{IF } P_{OO} \geq 1010 \text{ Set } P_{OO} = 1010$$

$$\ln R_v = A_3 + B_3 (\theta_{PUVO}) + C (\theta_{PUVO})^3 + D_3 (e)^{\frac{\theta_{PUVO}}{7}} + E_3 (\theta_{PUVO}) (e)^{\frac{\theta_{PUVO}}{7}} + F_3 \left[ (e)^{\frac{\theta_{PUVO}}{7}} \right]^2$$

$$A_3 = 5.5659 \times 10^{-1}$$

$$B_3 = 1.4997 \times 10^{-2}$$

$$C_3 = 7.9413 \times 10^{-6}$$

$$D_3 = 1.2343$$

$$E_3 = -7.2554 \times 10^{-2}$$

$$F_3 = 5.0691 \times 10^{-2}$$

## Fuel, Efficiency

$$\eta_{TF} = \frac{B_{TF}}{B_{ITF}}$$

$$B_{ITF} = K_{10} \Delta h_f W_T$$

$$\Delta h_f = h_{TIF} - h_{TEF}$$

$$B_{TF} = B_{PF} = K_5 \left( \frac{W_{PF} H_f}{\eta_f} \right)$$

$$W_{PF} = W_{FM}$$

$$K_{10} = 1.4148$$

$$K_5 = 0.001818$$

## Oxidizer, Developed Horsepower

$$B_{TO} = B_{PO} + K_{56}$$

$$B_{PO} = K_5 \frac{W_{PO} H_O}{\eta_O}$$

$$K_{56} = -15$$

## Fuel, Developed Horsepower

$$B_{TF} = B_{PF}$$

$$B_{PF} = K_5 \frac{W_{PF} H_f}{\eta_f}$$

$$W_{PF} = W_{FM}$$

## Fuel, Weight Flow

$$W_{TF} = W_T$$

## Oxidizer, Weight Flow

$$W_{TO} = W_T - W_B$$

$$W_B = \left[ \frac{2K_7 \gamma_{H_2}}{\gamma_{H_2}-1} (P_{RNC})^{\frac{2}{\gamma_{H_2}}} \right]^{\frac{1}{2}} \left[ 1 - (P_{RNC})^{\frac{\gamma_{H_2}-1}{\gamma_{H_2}}} \right] \frac{A_{NB} P_{BNI}}{(R_{H_2} T_{BIR})^{\frac{1}{2}}}$$

$$P_{RNC} = f(\beta_{NB}, \gamma_{H_2})$$

$$\beta_{NB} = \frac{D_{NB}}{D_B}$$

$$\gamma_{H_2} \cdot M_{H_2} = f(T_{H_2R}, r_G)$$

$$A_{NB} = K_{13} D_{NB}$$

$$K_{13} = 0.7854$$

$$T_{BIR} = T_{TIO} + 460$$

$$P_{BNI} = P_{TEFS}$$

$$P_{TEFS} = \text{Iteration of } P_{TEF}$$

$$P_{TEF} = P_{TEFS} \left[ 1 + K_8 \left( \frac{W_T}{P_{TEFS}} \right)^2 \frac{T_{H_2R}}{D^4_{TEF} M_{H_2}} \left( \frac{\gamma_{H_2}-1}{\gamma_{H_2}} \right) \right]^{\frac{\gamma_{H_2}}{\gamma_{H_2}-1}}$$

$$K_8 = 38.8983$$



## GAS GENERATOR

## Mixture Ratio

$$r_G = D_1 (T_{H1})^3 + C_1 (T_{H1})^2 + B_1 (T_{H1}) + A_1$$

$$A_1 = 0.2575$$

$$B_1 = 5.586 \times 10^{-4}$$

$$C_1 = -5.332 \times 10^{-9}$$

$$D_1 = 1.1312 \times 10^{-11}$$

$$T_{H1} = T_{TIFM}$$

## Flows

$$TC^*_{TIF} = D_2 (T_{H1})^3 + C_2 (T_{H1})^2 + B_2 (T_{H1}) + A_2$$

$$A_2 = 4.4226 \times 10^3$$

$$B_2 = 3.2267$$

$$C_2 = -1.3790 \times 10^{-3}$$

$$D_2 = 2.6212 \times 10^{-7}$$

$$P_{TIF} = P_{TIFS} \left[ 1 + K_8 \left( \frac{W_T}{P_{TIFS}} \right)^2 \cdot \frac{T_{H1R}}{D^4_{TIF} M_{H1}} \frac{\gamma_{H1} - 1}{\gamma_{H1}} \right]^{\frac{\gamma_{H1}}{\gamma_{H1} - 1}}$$

$$K_8 = 38.8983$$

Note:  $P_{TIF}$  is determined by iteration.

$$T_{H1R} = T_{TIF}$$

$$M_{H1}, \gamma_{H1}, C_p, r_{H1} = f(T_{H1R}, r_G)$$

# **APPENDIX V** **METHODS OF CALCULATION (HEAD RISE AND FLOW COEFFICIENTS)**

## **FLOW COEFFICIENT, $\phi$**

$$\phi = \frac{V_f}{V_T}$$

where  $V_f$  = Absolute fluid velocity at inducer inlet, ft/sec

$$V_f = \frac{Q}{(448.9) A} \quad \begin{array}{l} Q = \text{Flow rate, gpm} \\ A = \text{Inducer annulus area, ft}^2 \text{ (specified as 0.2856 ft}^2 \text{ by Rocketdyne)} \end{array}$$

$$V_f = \frac{Q}{128.2}$$

and  $V_T$  = Absolute velocity of inducer rotor tip, ft/sec

$$V_T = \left(\frac{\pi}{60}\right) (D_T) (N) \quad \begin{array}{l} N = \text{Pump speed, rpm} \\ D_T = \text{Inducer rotor tip diameter, ft (specified as 0.653 ft by Rocketdyne)} \end{array}$$

Therefore,

$$\phi = \left[ \frac{1}{(128.2) (0.0340)} \right] \frac{Q}{N}$$

$$\phi = 0.2291 \frac{Q}{N}$$

## **HEAD RISE COEFFICIENT**

$$\psi = \frac{H}{(V_{T^1})^2} = \frac{(H)(g)}{(V_{T^1})^2}$$

where  $H$  = Total pump head rise, ft

$$g = 32.174 \text{ ft/sec}^2$$

and  $V_{T^1}$  = Absolute velocity of pump rotor tip, ft/sec

$$V_{T^1} = \left(\frac{\pi}{60}\right) (D_{T^1}) (N) \quad \begin{array}{l} N = \text{Pump speed, rpm} \\ D_{T^1} = \text{Pump rotor tip diameter, ft (specified as 0.6043 ft by Rocketdyne)} \end{array}$$

$$V_{T^1} = 0.03164N$$

Therefore,

$$\psi = \left[ \frac{32.174}{(0.03164)^2} \right] \frac{H}{N^2}$$

$$\psi = 32,150 \frac{H}{N^2}$$

UNCLASSIFIED

Security Classification

## DOCUMENT CONTROL DATA - R &amp; 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  
ARO, Inc., Operating Contractor,  
Arnold Air Force Station, Tennessee

## 2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

## 2b. GROUP

N/A

## 3 REPORT TITLE

ALTITUDE DEVELOPMENTAL TESTING OF THE J-2 ROCKET ENGINE IN PROPULSION  
ENGINE TEST CELL (J-4) (TESTS J4-1801-28 THROUGH J4-1801-33)

## 4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

February 15 and 22, March 1, 8, 14, and 20, 1968 - Interim Report

## 5. AUTHOR(S) (First name, middle initial, last name)

C. H. Kunz and H. J. Counts, Jr., ARO, Inc. This document has been approved for public release  
its distribution is unlimited. *Per AF  
Letter dated 12 Feb 69  
William C. Cook*

## 6. REPORT DATE

October 1968

## 7a. TOTAL NO OF PAGES

301

## 7b. NO OF REFS

6

## 8a. CONTRACT OR GRANT NO

F40600-69-C-0001

## 9a. ORIGINATOR'S REPORT NUMBER(S)

AEDC-TR-68-160

b. System 921E

c. Project 9194

## 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

N/A

## 10 DISTRIBUTION STATEMENT

Each transmittal of this document outside the Department of Defense must  
have prior approval of NASA, Marshall Space Flight Center (I-E-J),  
Huntsville, Alabama.

## 11 SUPPLEMENTARY NOTES

Available in DDC.

## 12 SPONSORING MILITARY ACTIVITY

NASA, Marshall Space  
Flight Center (I-E-J),  
Huntsville, Alabama

## 13 ABSTRACT

Twenty-four firings and two fuel lead tests of the Rocketdyne J-2 rocket engine were conducted during test periods J4-1801-28 through J4-1801-33 between February 15 and March 20, 1968, in Test Cell J-4 of the Large Rocket Facility. This testing was in support of the J-2 engine application to the S-II stage of the Saturn V vehicle. The firings were accomplished at pressure altitudes ranging from 55,000 to 116,000 ft at engine start. The primary objective of these firings was to investigate fuel pump operation under conditions of lower than minimum engine model specification fuel pump net positive suction head and maximum thrust chamber fuel flow resistance utilizing an S-II stage center engine configuration fuel low pressure duct designed to simulate the fluid dynamic characteristics experienced during flight. Engine components were thermally conditioned to temperatures as expected during flight. Engine operation appeared to be satisfactory. The total accumulated firing duration for the six test periods was 190 sec. The total firing duration of this engine at AEDC through test period J4-1801-33 is 940 sec, resulting from 79 engine firings.

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of NASA, Marshall Space Flight Center (I-E-J), Huntsville, Alabama.

| 14 | KEY WORDS                                                                                                                                                                                                                | LINK A |    | LINK B |    | LINK C |    |
|----|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|----|--------|----|--------|----|
|    |                                                                                                                                                                                                                          | ROLE   | WT | ROLE   | WT | ROLE   | WT |
|    | J-2 rocket engines<br>altitude testing<br>Saturn<br>3 fuel pump operation<br>engine operation<br>temperature conditioning<br><br>1. Missiles -- Saturn<br>2 Rocket Motors -- J-2<br>4 " " " " -- Performance<br><br>16-3 |        |    |        |    |        |    |