Rockwell International

Rocketdyne Division
6633 Canoga Avenue
Canoga Park, California 91304

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FAILURE CONTROL TECHNIQUES FOR THE SSME

NAS8-36305

PHASE I

FINAL REPORT

PREPARED FOR:

NASA MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA 35812

PREPARED BY

M. H. Taniguchi

M. H. TANIGUCHI
SYSTEMS DYNAMICS

APPROVED BY

R. E. Brewster

R. E. BREWSTER
PROJECT ENGINEER
CONTROL SYSTEM ENGINEERING

W. W. Palmquist

W. W. PALMQUIST
PROJECT MANAGER
SSME TECHNOLOGY PROGRAMS

CONTENTS

CONTENTS (CONT'D)

INTRODUCTION

Since ground testing of the Space Shuttle Main Engine (SSME) began in 1975, the detection of engine anomalies and the prevention of major damage have been achieved by a multi-faceted detection/shutdown system. This system continues the monitoring task today and consists of: sensors, automatic redline and other limit logic, redundant sensors and controller voting logic, conditional decision logic and human monitoring. Typically, on the order of 300-500 measurements are sensed and recorded for each test, while on the order of 100 are used for control and monitoring.

Despite the extensive monitoring by the current detection system, twenty-seven (27) major incidents have occurred. This number seems to be insignificant when percentage compared with over 1200 hot-fire tests which have taken place since 1976. However, when examining each incident for the effects listed below the number suggests the requirement and future benefit for a more advanced failure detection system.

- Program schedule delay impact
- Engine damage costs
- Facility damage costs
- Repair costs to the facility and engine
- Failure analysis costs
- Loss of high time engine fleet leader components
- Loss of failure evidence

The time impact has ranged from 3-weeks to 24-weeks. For individual tests the estimated cost impact of engine and direct facility damage has ranged from $1-million (in 1980 dollars) to $26-million (in 1982 dollars) per test; in terms of repair/analysis it has ranged from $.24-million (in 1982 dollars) to $3-million (in 1985 dollars). Figure 1, on the next page itemizes some of the damage, cost, and time delay effects for forty (40) tests with significant anomalies including the 27-major incident tests. Tests 901-364, 901-436, and 750-259 listed in Figure-1 are incident tests where engines were totally lost. The current replacement cost for an engine is estimated at $45-million, LEGEND-----

NOTE: Time slices which are underlined indicate the CRT's which were examined in depth and/or used for criteria table generation.

Abbreviations/Annotations:

x----A complete report was examined.
P----A partial report was examined.
I----Part-I of a NASA incident report.
II----Part-II of a NASA incident report.
UA----The item was unavailable.
NA----Not Applicable
*----Indicates a major incident test

MCC----Main Combustion chamber
OPOV---Oxidizer Preburner Oxidizer Valve
LOX----Liquid Oxygen
EDM----Electrical Discharge Machining
HCF----High Cycle Fatigue
HAL----Heat Addition to LOX
PWC----Pressure Wall Containment
FPB----Fuel Preburner

1 FOLDOUT FRAME

Damage Nomenclature Key:

ID No.	Component
1	Low Pressure Fuel Turbopump
2	High Pressure Fuel Turbopump
3	Fuel Preburner
4	Fuel Side Valves
5	Fuel Side Ducts
6	Low Pressure Oxidizer Turbopump
7	High Pressure Oxidizer Turbopump, and Heat Exchanger
8	Oxidizer Preburner
9	Oxidizer Side Valves
10	Oxidizer Ducts & POGO
11	Hot Gas Manifold
12	Main Injector
13	Main Combustion Chamber
14	Nozzle
15	Stand Equipment
16	Stand Structure
17	Controller

Suffix to ID No.	Meaning
A	Component destroyed
B	Component heavily damaged
C	Component lightly damaged

2 FOLDOUT FRAME

Test	Description	REFERENCE CRT TIME SLICES	ROCKETDYNE Incident Report	NASA Report	Engine Number	Date	Damage	Damage Cost	Damage Delay	Power Level Anomaly Occurs	Cutoff Time
Injector Failure:											
*Test 901-173	(LOX Post Fractures, Erosion-MCC)	161.1-201.1, 196.5-201.5,									
		197-202 SEC	UA	UA	0002	31 Mar 78	12B, 13C, 14B	UA	UA	92%	201.16 sec
*Test 901-331	(LOX Post Fractures, Erosion-MCC)	110-150, 232-233.5, 220-230,									
		230-235 SEC	UA	P (I)	2108	15 Jul 81	7C, 12A, 13B, 14B	$4.1M	24-Weeks	100%	233.14 sec
*Test 750-148	(LOX Post Fractures, Erosion-MCC)	11-16, 12-16, and 14.5-16 SEC	UA	x (I, II)	0110	2 Sep 81	12B, 13C, 14B	$7.0M	8-Weeks	105%	16.00 sec
*Test 901-183	(LOX Post Fractures, Erosion-MCC)	10-22, 22-27, 22-51, 46-51,									
		22.5-26.5 SEC	UA	UA	0005	5 Jun 78	12C, 13C, 14C	UA	UA	92%	51.10 sec
*Test 902-198	(LOX Post Fractures, Erosion-MCC)	4.8-8.5 and 4-9 SEC	UA	x (I, II)	2004	23 Jul 80	12C, 13C, 14C	$1.0M	12-Weeks	102%	8.50 sec
*Test 901-307	(LOX Post Fractures, Erosion-FPB)	0-4, 24-29, 10-81, 15-75,									
		60-75 SEC	x	UA	0009	28 Jan 81	2C, 3B	UA	UA	109%	75.03 sec
Test 902-244	(LOX Post Fractures, Erosion-FPB)	(Test 901-244 examined w/Test 901-307)	x	UA							
*Test SF10-01	(FPB Anomalies)	0-130, 70-75, 70-80, 80-100,									
		100-105 SEC	UA	x (I, II)	0006	12 Jul 80	2C, 3C, 5C, 14C, 15C, 17C	$1.5M	16-Weeks	102%	106.60 sec
STS-8	(Localized: FPB Damage, PWC Failure)	Anomaly occurred after c/o	UA	UA							
*Test 750-160	(Fuel Blockage: Water Left in FPB Injector by EDM Process)	0-4 SEC	x	x (I)	0110	12 Feb 82	2B, 3B, 7B, 11A, 12A, 13B, 14A	$15.0M	12-Weeks	NA, (@ Start)	3.16 sec
Control Failure:											
*Test 901-284	(Erroneous Sensor, Lee Jet, PWC Failure)	0-7, 3-7, 2-7 SEC with Test Overlays	x	x (I, II)	0010	30 Jul 80	1C, 2C, 3C, 4C, 5C, 7A, 9B, 10A, 14B, 15C, 17B	$9.2M	16-Weeks	100%	9.88 sec
*Test 902-132	(Main Oxidizer Valve Mis-Indexed)	0-2.5 SEC with Test Overlays	UA	UA	0006	3 Oct 78	2B, 7C, 11B, 12B	UA	UA	NA, (@ Start)	2.36 sec
Duct, Manifold, or Heat Exchanger Failure:											
*Test 750-041	(Steerhorn Anomaly, Fuel Leak)	Anomaly occurred after cutoff	x	x (I, II)	0201	14 May 79	2B, 3B, 5C, 7B, 11B, 12B, 13C, 14B	$8.5M	8-Weeks	NA, (@ Start)	4.30 sec
*Test SF6-03	(Steerhorn Anomaly, Fuel Leak)	Anomaly occurred after cutoff	x	P (II)	2002	4 Nov 79	1C, 2B, 7B, 11B, 12A, 13A, 14B	UA	6-Weeks	NA, (@ Cutoff)	10.60 sec
*Test 750-259	(MCC Outlet Manifold Neck, Fuel Leak)	89-101, 98-101.5, 95-102, 100-101.5 SEC	x	UA	2308	27 Mar 85	3B,4A,5A,6A,7B,8C,9A,10A,12A,13A,14B,15C,17A	UA	UA	109%	101.50 sec
FRF-2	(MCC Outlet Manifold Neck, Fuel Leak)	Anomaly discovered after cutoff	UA	UA							
Test 901-485	(Nozzle Tube Rupture, Fuel Leak)	15-20, 20-30, 23.5-28.5 SEC	UA	UA	2105	24 Jul 85	14C	UA	UA	109%	Prog. Duration
*Test 750-175	(Catastropic Structural: HCF in High	90-100, 100-101.5, 103.5-113.5									
	Pressure Oxidizer Duct)	113.5-116 SEC	x	UA	2208	27 Aug 82	1C, 4B, 7B, 9B, 10A, 11C, 13B, 14B, 16C	$11.0M	8-Weeks	111%	115.60 sec
*Test 901-222	(Heat Exchanger, Weld Failure, HAL)	0-5, 3-5, and 4-5 w/Test Overlays	x	P (I)	0007	5 Dec 78	7B, 11B, 12B	UA	UA	NA, (@ Start)	4.33 sec
Test 902-112	(Fuel Blockage: Solidified Nitrogen										
	Blockage of the fuel pump inlet duct)	0-6, 4-6, 4.5-7.5 SEC	x	UA	0101	10 Jun 78	1B, 2B, 7B, 12C	UA	UA	92%	5.75 sec
Test 901-345	(Localized: MCC Cavity Burst Diaphragm Leak)	Anomaly occurred after cutoff	UA	UA							
Valve Failure:											
*Test SF6-01	(Main Fuel Valve: Structural, Fuel Leak)	16.5-19 SEC	x	x (I, II)	2002	2 Jul 79	2C, 4B, 14C, 16C, 17C	$8.3M	14-Weeks	100%	18.58 sec
*Test 901-225	(Main Oxidizer Valve: HAL)	10-100, 100-256, 255-256, 115-130 SEC	x	P(I), P(II)	2001	27 Dec 78	1C,4A,5C,6B,7B,9A,10A,11A,12B,13B,14C,15B,16B,17C	$10.0M	4-6 Weeks	100%	255.63 sec
*Test 750-168	(OPOV Component: Seal Failure)	Anomaly occurred after cutoff	x	UA	0107	15 May 82	7B, 11B, 12B, 13C	$4.4M	8-Weeks	NA,(@ Cutoff)	Prog. Duration
High Pressure Oxidizer Turbopump Failure:											
*Test 901-110	(Rotor/Seal Support, HAL)	55-65, 64.2-74.2 SEC	x	x (I, II)	0003	24 Mar 77	4B,5C,6C,7A,8C,9B,10A,12C,13C,14C,15B,17B	$3.3M	4-Weeks	75%	74.00 sec
*Test 901-136	(Rotor/Seal Support)	10-160, 160-300.2, 295.2-300.2,									
		160-170, 170-280 SEC	x	x	0004	8 Sep 77	4A,5C,6C,7A,8C,9B,10A,12C,13C,14C,15B,17B	$2.4M	4-Weeks	90%	300.20 sec
*Test 902-120	(Heat Addition to LOX)	30.5-40.5, 40.5-42.0 SEC	x	x(I),P(II)	0101	18 Jul 78	4B, 6B, 7B, 9C, 10A, 13C, 14C, 15C, 17B	$1.65M	5-Weeks	100%	41.81 sec
High Pressure Fuel Turbopump Failure:											
*Test 901-340	(Turn Around Duct Cracked/Torn)	250-290, 280-300, 275-295, 286-291 SEC	UA	UA	0107	15 Oct 81	2A, 3C, 12C, 14C	UA	UA	109%	405.50 sec
Test 901-363	(Turn Around Duct Cracked/Torn)	120-130, 130-145 SEC	UA	UA	2013	30 Mar 82	2C	UA	UA	109%	Prog. Duration
Test 902-118	(Turn Around Duct Cracked/Torn)	4.5-7.5 SEC	UA	UA	0101	21 Jul 78	2B, 13B	UA	UA	92%	6.84 sec
Test 902-383	(Localized: Turn Around Duct Cracked/Torn)	Anomaly occurred after cutoff	UA	UA							
*Test 901-436	(Coolant Liner Buckle)	596-606, 606.611.1, 609-611.5	UA	UA	0108	14 Feb 84	2A, 5A (Engine was totally gutted and retired)	UA	UA	109%	611.06 sec
*Test 901-364	(Hotgas Intrusion to Rotor Cooling)	100-392.2, 382.2-392.2, 350-360,									
		383-393, 360-400 SEC	x	x (I, II)	2013	7 Apr 82	2A, 5A (Engine was totally gutted and retired)	$26.0M	8-Weeks	109%	392.15 sec
Test 902-209	(Hotgas Intrusion to Rotor Cooling)	610-650, 650-690 SEC	UA	UA	2008	16 Nov 80	2C, 3C	UA	UA	90%	Prog. Duration
Test 750-165	(Hotgas Intrusion to Rotor Cooling)	0-300 SEC	UA	UA	0107	15 May 82	7B, 11B, 12B, 13C	$4.4M	8-Weeks	NA (@Cutoff)	Prog. Duration
*Test 901-147	(Power Transfer Failure, Turbine Blades)	10-29, 29-31.5 SEC	UA	UA	2103	1 Dec 77	NA	UA	UA	NA (@Throttle)	31.36 sec
*Test 902-249	(Power Transfer Failure, Turbine Blades)	100-200, 100-450 SEC	UA	x (I, II)	0204	21 Sep 81	2A, 7B, 11A, 12A, 13A, 14A	$15.1M	3-Weeks	109%	450.58 sec
*Test 902-095	(Power Transfer Failure, Turbine Blades)	0-55, 34-51, 7-10, 0-51 SEC	UA	UA	0002	17 Nov 77	2A, 12B, 13B	UA	UA	95%	51.09 sec
Test 901-346	(Localized: Turbine Blades)	100-500, 400-500, 373-383, 383-410 SEC	UA	UA	0107	19 Nov 81	2B	UA	UA	109%	Prog. Duration
Test 901-362	(Power Transfer Failure)	230-250, 250-500 SEC	UA	UA	2013	27 Mar 82	2C, 7C, 12C, 13C	UA	UA	109%	Prog. Duration
Test 901-410	(Power Transfer Failure)	10-100, 100-550, 500-550, 500-540 SEC	UA	UA	2014	20 May 83	2B	UA	UA	104%	Prog. Duration

Figure-1: Summary Information for Incident Tests and therefore, the three engines represent a 1987-dollar loss of $0.135 billion. The impact of lost high time fleet leader components and failure evidence cannot be measured precisely. Their absence however is certainly felt in the important area of data base refinement for engine flight life expectancy and component condition monitoring.

In recognition of both the system required and advances in detection and computing technology, the SAFD (SSME Anomaly and Failure Detection) program was initiated under NASA MSFC contract number NAS8-36305. It's objectives are:

1. To define an improved anomaly detection/shutdown system for the SSME (Space Shuttle Main Engine).

2. To eventually build and install the improved detection system for SSME test stand applications.

To achieve the SAFD objectives, the program has been structured into three phases. The objective and content of each phase are listed below.

<u>Phase I: Feasibility Study</u>. The goal of Phase I (this study) is to generate a feasibility recommendation and a preliminary conceptual design based on a failure data base that can be used by NASA/MSFC to make an informed decision on the continuation of the effort. The feasibility study consists of five study tasks which are; Collect/Analyze Engine Test Data (Section 2), Feasibility/Criteria Development (Section 3.0), Survey/Acquire Failure Detection Methods (Section 4.0), Quantify Engine and Test Stand Data (Section 5.0), Phase II/III Plan Development (Section 6.0) and a final task to provide a Phase I Final Report.

<u>Phase II (Option 1): Development</u>. Should Phase I determine that the objectives are feasible, Phase II (Option 1) will be exercised. In Phase II selected failure detection algorithms and failure simulations will be accomplished to quantify system requirements for the proposed failure detection system. Phase II includes five tasks which are; Develop Failure Simulation Models, Implement Detection Methods, Quantify Failure Detection Methods, Define Primitive System Concepts and submit a Final Report.

Phase III (Option 2): Design. During Phase III (Option 2), the SAFD system will be designed for implementation in a test stand. This Phase consists of three tasks which are; Final System Design Specification/Cost Estimates including functional, software and hardware requirements, work breakdown structure and cost estimation; Definition of Future Research Needs and a Final Report.

SUMMARY

Phase I has been completed and the results are presented in this final report in the sections described below which conform to the Phase I tasks described above. Section 1.0 below was not included as a Phase I task however, it is included for reference purposes in discussing the other tasks.

Section 1.0: Section I describes the Space Shuttle Main Engine (SSME) in terms of an overview of the engine, the major components and the modes of operation. This section is included to facilitate understanding of the results which follow in the remaining sections.

Section 2.0: This section summaries the contents of the Phase I study which are presented in Sections 3.0, 4.0 and 5.0 below. A description of the SSME Data Acquisition Systems used during all SSME testing is given. The operational characteristics of the SSME Data Acquisition instrumentation are noted.

Section 3.0: This section presents the conditions, premises and guidelines for constructing the anomaly detection system and a preliminary scheme for the system's development (Phase II).

Section 4.0: This section presents the literature review results conducted to survey and acquire failure detection methods. Ten failure and isolation techniques are discussed as a result of this review.

Section 5.0: This section describes the results of examining data from forty (40) past incident tests. The results are presented in four (4) categories, i.e.: general overview, data base support to detection system development, delineation of data base and data base observations and comments. Three extensive data tables are included.

Section 6.0: This section presents the Phase II/III Plan Development including task descriptions, schedules and organization.

CONCLUSION AND RECOMMENDATION

Based on the Phase I Study results and conclusions as shown in Section 3.0, an improved anomaly detection/shutdown system for SSME Test Stand operation has been found to be feasible and it is recommended that this study continue into Phase II.

1.0 SSME DESCRIPTION

This section provides a description of the Space Shuttle Main Engine (SSME) by outlining the propulsion system under three headings: engine overview, major components, and modes of operation.

1.1 ENGINE OVERVIEW

The SSME is a liquid-propellant, pump-fed, regeneratively cooled rocket engine with variable thrust. It is the first reusable engine system of its kind. Three SSME's are the Space Shuttle vehicle's main propulsion system. They are ignited on the ground at launch and operate in parallel with the solid rocket boosters during the initial ascent phase and continue to operate for approximately 520 seconds total firing duration. The SSME operates at a mixture ratio (liquid oxygen/ liquid hydrogen) of 6:1 and a chamber pressure of approximately 3000 psia to produce a sea level thrust of 375,000 lbs and a vacuum thrust of 470,000 lbs (rated power level). The engines are throttleable over a thrust range of 65 to 109 percent of the rated power level. This provides a higher thrust level during lift-off and the initial ascent phase, and allows orbiter acceleration to be limited to 3 g's during the final ascent phase. The SSME uses a staged combustion cycle. In this cycle the propellants are partially burned in preburners producing hydrogen-rich gas to power the high-pressure turbopumps. The fuel-rich steam is then routed to the main injector where it is injected, along with additional oxidizer and fuel, into the main combustion chamber (at a high mixture ratio and high pressure). Hydrogen is used to cool all combustion devices directly in contact with high-temperature combustion products. The SSME is mounted with an electronic controller package which operates in conjunction with engine sensors, valves, actuators, and spark igniters to provide a self-contained system for engine control, checkout, and monitoring. The controller provides responsive control of engine thrust and mixture ratio through the digital computer in the controller, updating the instructions to the engine control elements 50 times per second (every 20 milliseconds). Additionally, precise engine performance is achieved through closed-loop control, utilizing 16-bit computation, 12-bit input/output resolution, and self-calibrating analog-to-digital conversion. Engine reliability is enhanced by a dual redundant control system that allows normal operation after the first failure and a fail-safe shutdown after a second failure of any control system component. High-reliability electronic parts are used throughout the controller.

1.2 MAJOR COMPONENTS

Besides the controller, a myriad of other key components establish the SSME's performance and physical characteristics. Some of the latter components are: turbopumps, preburners, combustion devices, and valves. Figure-1.1 presents a schematic of the first three components and the hot-gas manifold which joins them together. Figure-1.2 identifies a number of the engine system's valves. A description of the above cited components are presented along with their standard abbreviations used in literature.

1.2.1 Turbopumps. Four turbopumps, two low-pressure and two high-pressure are used by the SSME system. The low-pressure fuel turbopump (LPFTP) and the low-pressure oxidizer turbopump (LPOTP) are located at the inlet to respective high pressure fuel and oxidizer turbopumps (see Figure-1.2). The low pressure pumps operate at relatively low speed to permit low pressures in the vehicle tanks. The function of these pumps is to provide NPSH (Net Positive Suction Head) to the high pressure turbopumps (preventing their cavitation). The LPOTP's turbine is powered by high pressure LOX (liquid oxygen) from the high pressure oxidizer turbopump discharge. The LPFTP's turbine is powered by gaseous hydrogen from the main combustion chamber coolant circuit.

The high pressure oxidizer turbopump (HPOTP) consists of two centrifugal-type pumps on a common shaft directly driven by a two-stage, hot-gas turbine. The main pump supplies oxidizer to the main chamber injector, the heat exchanger, LPOTP turbine, and preburner oxidizer pump (the other HPOTP constituent). The preburner pump raises the pressure of the LOX and supplies oxidizer to the preburners. At 109% of rated power level the shaft spins at 29194 rpm.

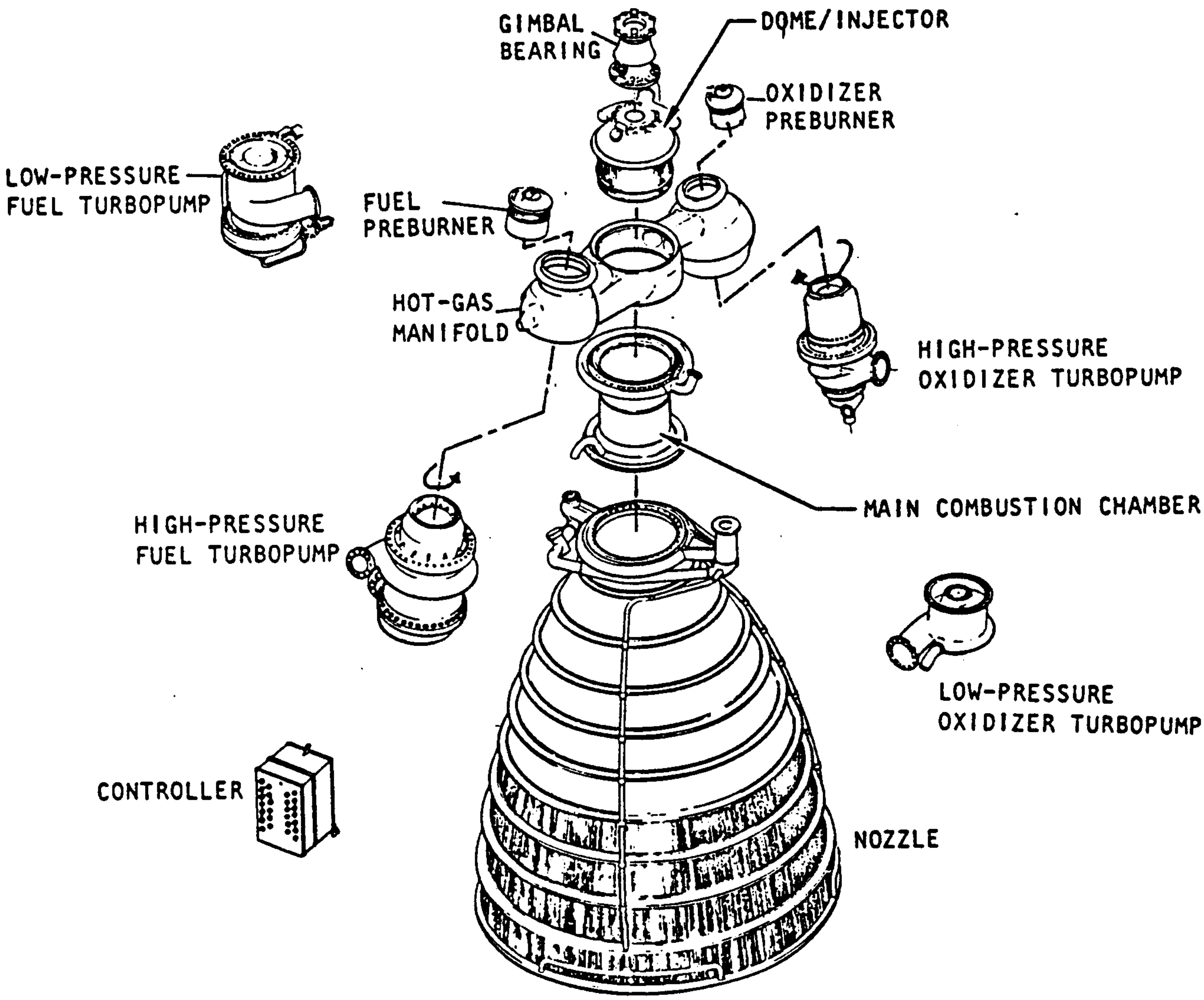

Figure 1.1: SSME Hot-Gas Manifold Linking --Turbopumps, Preburners, and Combustion Devices

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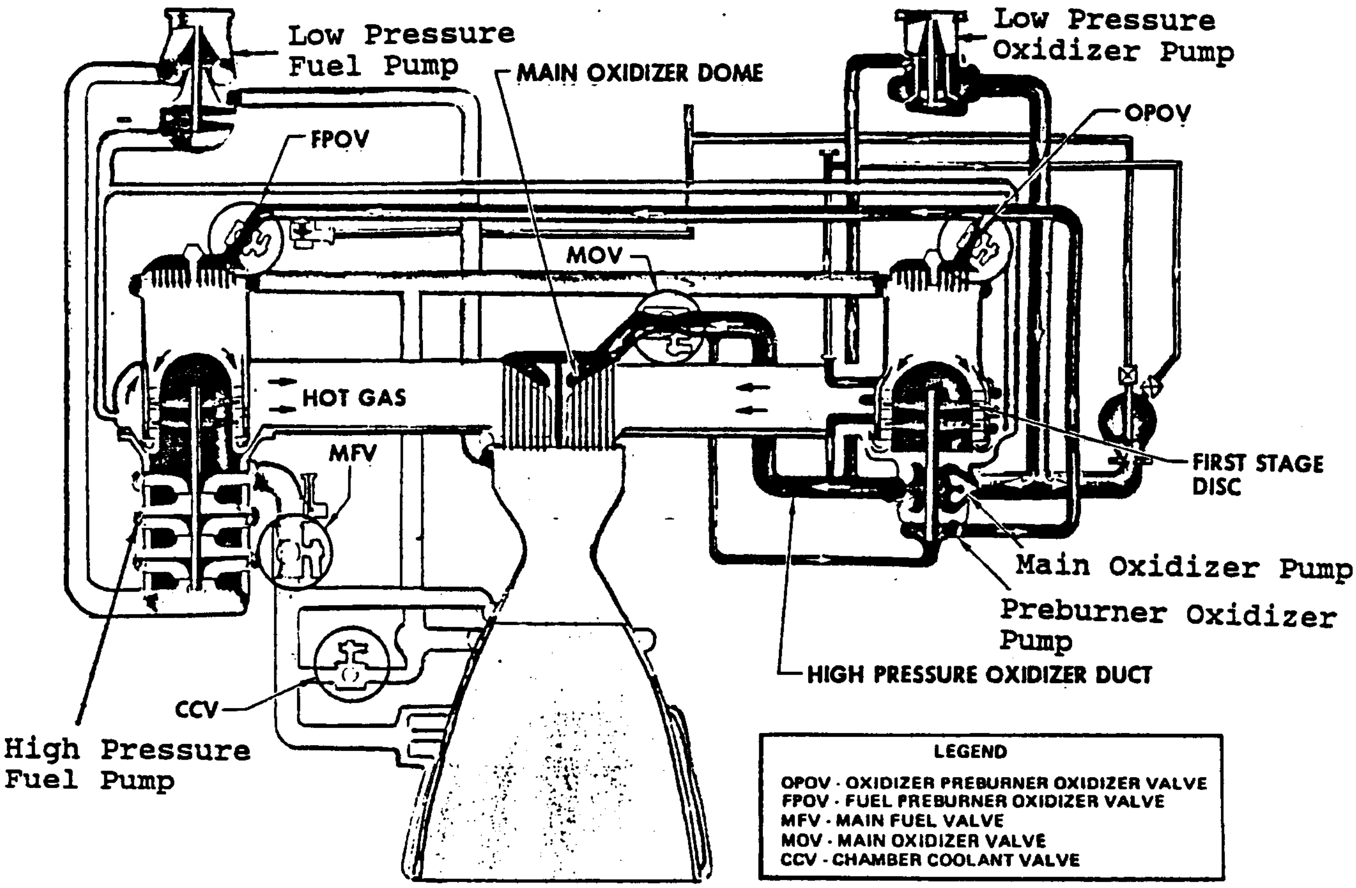

Figure 1.2: SSME Propellant Flow Schematic

The high pressure fuel turbopump (HPFTP) is a three-stage, centrifugal flow pump, directly driven by a two-stage hot-gas turbine. The pump provides fuel for: cooling the main combustion chamber, nozzle, and hot-gas manifold, driving the LPFTP turbine, and pressurizing the vehicle fuel tank. At 109% of rated power level the pump spins at 36595 rpm.

1.2.2 Preburners. The power for the HPFTP and HPOTP is generated from fuel-rich gases from respective preburners, the fuel preburner (FPB) and the oxidizer preburner (OPB) (see Figure-1.2). Each preburner consists of a combustor (with fuel-cooled liner) and a baffled, coaxial element injector. Each combustor's fuel and oxidizer come from the nozzle coolant circuit and the preburner oxidizer pump. The OPB's hot-gas is directed to the HPOTP turbine, LOX heat exchanger (which provides gaseous oxygen for vehicle oxidizer tank pressurization), and the hot-gas manifold. The FPB's hot-gas is directed to the HPFTP turbine and the hot-gas manifold.

1.2.3 Combustion Devices. The hot-gas from both preburners are eventually mixed with HPOTP LOX at the exit of the main injector's elements. This mixing along with separate mixing of HPOTP LOX and coolant circuit hydrogen permit a uniform distribution of propellants to the main combustion chamber (MCC). The injector elements support primary and secondary plates. The primary plate separates combustion chamber hot-gas from cooling circuit hydrogen. The latter fluid is separated from preburner hot-gas by the secondary plate. The plates, in turn, are transpiration cooled by the cooling circuit hydrogen.

The MCC is a cylindrical, regeneratively cooled, structural chamber that contains the burning propellant gases and initiates their expansion from the chamber throat. The expansion ratio from the throat to the nozzle attach flange is 5:1. It is flange attached to the hot-gas manifold (see Figure 1.1). The MCC consists of a coolant liner, a high strength structural jacket, coolant inlet and outlet manifolds, a throat ring, and two thrust vector control actuator support struts.

1.2.4 Valves. The fluid control for the MCC and for the interconnected components upstream is achieved by five valves, i.e. the MFV, CCV, MOV, FPOV, and OPOV. These valves are shown in Figure-1.2. A function description of each is listed:

Abbreviation	Description
MFV	Main Fuel Valve, controls engine fuel downstream of the HPFTP, i.e. thrust chamber coolant circuits, the LPFTP turbine, hot-gas manifold coolant circuit, OPB, FPB, and three augmented spark igniters (ASI's).
CCV	Chamber Coolant Valve, controls MCC and nozzle coolant flow.
MOV	Main Oxidizer Valve, controls LOX flowrate to the main injector and the main chamber augmented spark igniter (ASI).
FPOV	Fuel Preburner Oxidizer Valve, regulates LOX flow to the fuel preburner.
OPOV	Oxidizer Preburner Oxidizer Valve, regulates LOX flow to the oxidizer preburner.

1.3 MODES OF OPERATION

The electronic controller controls the five valves by open-loop and/or closed loop command during three basic modes of the SSME's operation, i.e.: start, main stage and cutoff. During start and cutoff modes the valve position versus time profiles are as shown in Figure 1.3. The valve profiles during start, for instance, reflect the requirements for: controlling main injector LOX dome, FPB and OPB prime times and minimizing FPB temperature spikes. The valve profiles during cutoff, for instance, reflect the requirements for: satisfying the ICD (Interface Control Document) thrust decay rate and

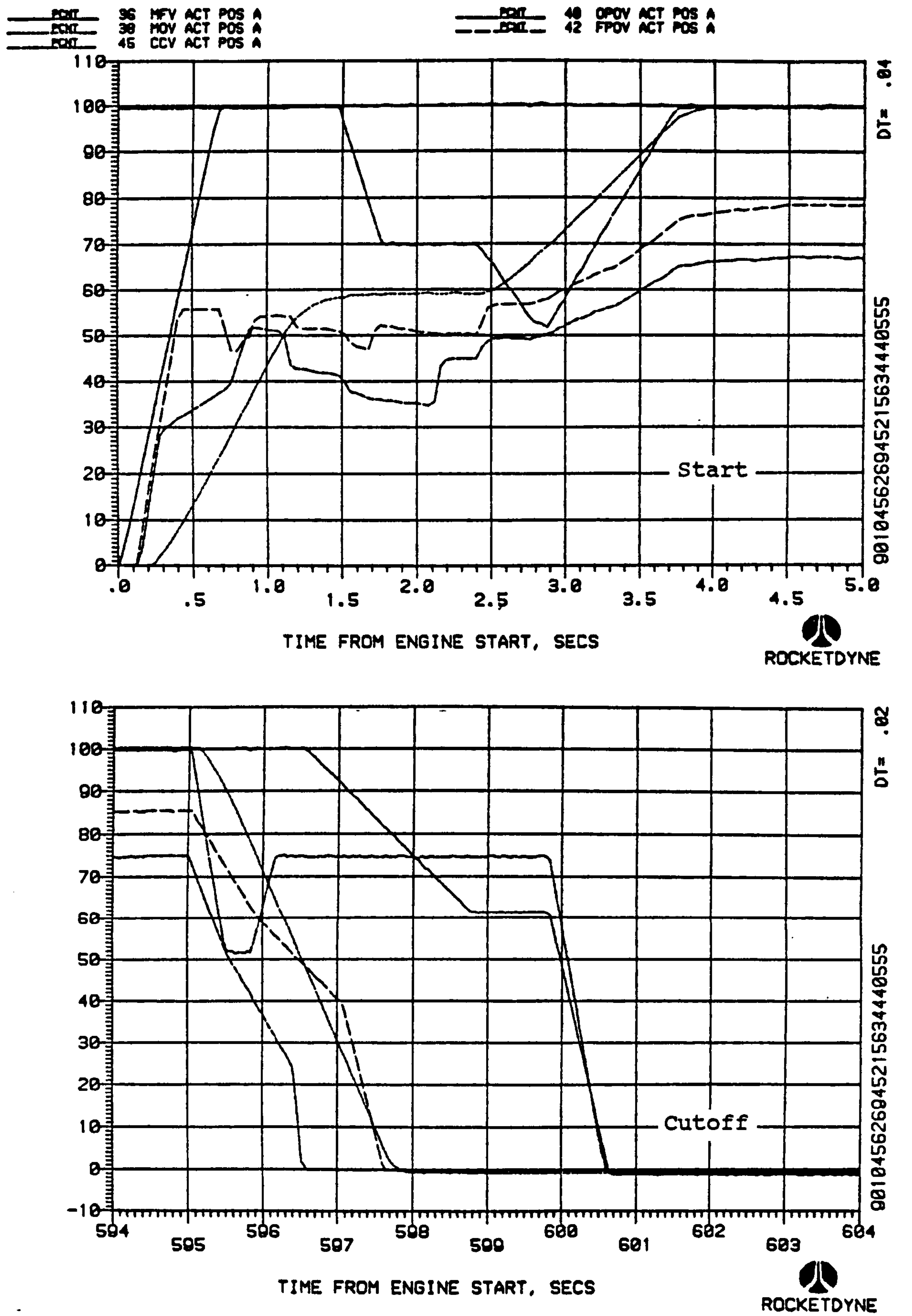

Figure 1.3: SSME Valve Position Dynamics During Start and Cutoff

controlling preburner power and preventing HPFTP stall. During main stage, the FPOV and OPOV are under closed loop operation with the controller; the other three valves are not permitted to change their positions (except the CCV as a function MCC chamber pressure). The FPOV and OPOV will change their position to maintain the commanded power level chamber pressure and mixture ratio.

2.0 PHASE I CONTENT SUMMARY

2.1 PHASE I PURPOSE

The objectives of Phase I were:

1. To establish the feasibility of constructing the anomaly detection system around the SSME's current instrumentation and recording system, and

2. To define a preliminary scheme for the detection system's algorithm and decision making logic.

2.2 CURRENT SSME INSTRUMENTATION AND RECORDING SYSTEM

All SSME test stands have three (3) data acquisition systems, the command and data simulator (CADS), the facility recording (FR) system, and the analog high frequency recording (AHFR) system. The AHFR system consists of 6 to 14 tape recorders; each recorder has 14 to 28 tracks and capable of a frequency response of 0-20 kHz. The system receives its data from such sources as: turbopump internal strain gages and external accelerometers, main combustion chamber inlet strain gages, gimbal bearing accelerometers, and preburner (longitudinal and radial) accelerometers. The command and data simulator is a digital computer unit in the teststand blockhouse. This CADS unit receives and displays engine measurements from the SSME controller every 40 milli-seconds (25 samples/second). The CADS measurements are displayed with parameter identifiers (PIDS), ranging from 1 to 299. The facility recording system consists of two separate digital computers. One computer receives data directly from engine mounted sensors and the other from sensors mounted on certain facility components. These measurements are sampled every 20 milliseconds (50 samples/second) and are displayed with PIDS, ranging from 300 to 1999.

The three figures on the following pages further describe the CADS and FR measurements. A directory is presented here:

Figure	Description
2	CAD and FR Measurement Samplings
3	CAD and FR Transducer Repeatability, Response and/or Range
4	CAD and FR Shutdown Parameter Samplings with Monitoring Limits

2.3 PHASE I TASKS

To achieve the objectives of Phase I, two broad tasks were accomplished. The detailed conclusions and results of each task are presented in Section 3.0, 4.0 and 5.0, respective. The tasks consisted of (1) examining the elements of the aforementioned digital recording systems* along with incident documentation and (2) reviewing the current literature on failure detection techniques. The CAD and FR recording systems were screened for interfacing with added SAFD test electronics and sensor singal tap-off. Forty (40) past incident tests were studied:

- To assess the feasibility of using existing digital* sensor measurements for early anomaly detection (prior to redline time). Some of the assessment criteria were: damage-reducing effectiveness, sufficient changes from nominal conditions, and sufficient numbers of sensors reflecting the anomaly.

- To define sensor deviations under normal operating conditions for a typical test and from test-to-test.

FOLDOUT FRAME

PARAMETER	CADS DATA PID #	CADS DATA ENGINE MEASURE-MENT	CADS DATA OTHER DATA	FACILITY DATA PID #	FACILITY DATA ENGINE MEASURE-MENT	FACILITY DATA EQUIV. ENG. MEASURE-MENT	FACILITY DATA FACILITY MEASURE-MENT
Hard Fail Identification	4		X				
Hard Fail Test Number 1	5		X				
Hard Fail Test Number 2	6		X				
Hard Fail Test Number 3	7		X				
Mixture Ratio	8		X				
Preburner Pump Discharge Temperature Average	12	X		549		X	
High Pressure Fuel Pump Inlet Temperature Average	15	X					
Main Combustion Chamber Coolant Discharge Pressure A	17	X					
Main Combustion Chamber Coolant Discharge Temperature B	18	X					
Main Combustion Chamber Oxidizer Injector Temperature B	21	X		595		X	
Main Combustion Chamber Hot Gas Injector Pressure A	24	X		367		X	
Low Pressure Oxidizer Pump Speed B	30	X		734		X	
Low Pressure Fuel Pump Speed A	32	X		754		X	
Heat Exchanger Discharge Pressure B	34	X		878		X	
Main Fuel Valve Actuator Position A	36	X					
Main Oxidizer Valve Actuator Position A	38	X					
Oxidizer Preburner Oxidizer Valve Actuator Position A	40	X					
Fuel Preburner Oxidizer Valve Actuator Position A	42	X					
Coolant Control Valve Actuator Position A	45	X					
High Pressure Fuel Pump Discharge Pressure A	52	X		459		X	
High Pressure Fuel Pump Coolant Liner Pressure A	53	X					
Fuel Preburner Chamber Pressure A	58	X		410		X	
Preburner Pump Discharge Pressure B	59	X		341		X	
Main Combustion Chamber Chamber Pressure Average	63	X					
High Pressure Fuel Pump Inlet Pressure Average	86	X					
High Pressure Oxidizer Pump Discharge Pressure A	90	X		334		X	
High Pressure Oxidizer Turbine Intermediate Seal Cavity Pressure A	91	X					
Digital Self Test Register 2A	154		X				
Digital Self Test Register 2B	155		X				
Digital Self Test Register 1A	156		X				
Digital Self Test Register 1B	157		X				
Oxidizer Preburner Oxidizer Valve Command Limit	171		X				

PARAMETER	CADS DATA PID #	CADS DATA ENGINE MEASURE-MENT	CADS DATA OTHER DATA	FACILITY DATA PID #	FACILITY DATA ENGINE MEASURE-MENT	FACILITY DATA EQUIV. ENG. MEASURE-MENT	FACILITY DATA FACILITY MEASURE-MENT
Main Fuel Valve Command	172		X				
Main Oxidizer Valve Command	173		X				
Coolant Control Valve Command	174		X				
Fuel Preburner Oxidizer Valve Command	175		X				
Oxidizer Preburner Oxidizer Valve Command	176		X				
High Pressure Oxidizer Pump Inlet Pressure A	209	X					
High Pressure Oxidizer Pump Intermediate Seal Purge PR.	211	X					
Pogo Precharge Pressure	222	X					
High Pressure Fuel Turbine Discharge Temperature A	231	X					
High Pressure Fuel Turbine Discharge Temperature B	232	X					
High Pressure Oxidizer Turbine Discharge Temperature A	233	X					
High Pressure Oxidizer Turbine Discharge Temperature B	234	X					
High Pressure Fuel Pump Speed A	260	X		764		X	
Hard Fail Parameter Value 2	264		X				
Hard Fail Parameter Value 3	265		X				
Fuel Mass Flow	267		X				
Anti Flood Valve Position A	268	X					
Vehicle Command 1	280		X				
Vehicle Command 2	281		X				
Time Reference	286		X				
Main Combustion Chamber Pressure (Controller Reference)	287		X				
Failure Identification Count	289		X				
Identification Word 1	291		X				
Identification Word 2	292		X				
Engine Status Word	293		X				
Hard Fail Parameter Value 1	294		X				
High Pressure Oxidizer Pump Balance Cavity Pressure 1A				327	X		
High Pressure Oxidizer Pump Balance Cavity Pressure 2A				328	X		
Main Combustion Chamber Oxidizer Injection Pressure				395	X		
Low Pressure Fuel Turbine Inlet Pressure				436	X		
High Pressure Fuel Pump Balance Cavity Pressure				457	X		
Oxidizer Preburner Chamber Pressure				480	X		

2 FOLDOUT FRAME

PARAMETER	CADS DATA PID #	CADS DATA ENGINE MEASURE-MENT	CADS DATA OTHER DATA	FACILITY DATA PID #	FACILITY DATA ENGINE MEASURE-MENT	FACILITY DATA EQUIV. ENG. MEASURE-MENT	FACILITY DATA FACILITY MEASURE-MENT
High Pressure Fuel Pump Coolant Liner Temperature				650	X		
High Pressure Fuel Pump Drain Pressure (D16)				657	X		
High Pressure Fuel Pump Drain Temperature (D16)				658	X		
High Pressure Fuel Pump Discharge Temperature				659	X		
Facility Fuel Flowmeter Discharge Pressure				817			X
Engine Fuel Inlet Pressure 1				821			X
Fuel Pressurization Venturi Inlet Pressure				836			X
Fuel Pressurization Venturi Delta Pressure				837			X
Facility Oxidizer Flowmeter Discharge Pressure				854			X
Engine Oxidizer Inlet Pressure 1				858			X
Heat Exchanger Interface Temperature				879			X
Heat Exchanger Venturi Inlet Pressure				881			X
Heat Exchanger Venturi Inlet Temperature				882			X
Heat Exchanger Venturi Delta Pressure				883			X
High Pressure Oxidizer Pump Primary Seal Drain Pressure				951	X		
High Pressure Oxidizer Turbine Primary Seal Drain PR.				990	X		
Facility Fuel Flowmeter Discharge Temperature T1				1017			X
Engine Fuel Inlet Temperature				1021			X
Fuel Pressurization Venturi Inlet Temperature				1036			X
Facility Oxidizer Flowmeter Discharge Temperature T1				1054			X
Engine Oxidizer Inlet Temperature				1058			X
High Pressure Oxidizer Pump Oxidizer Seal Drain Temp.				1187	X		
High Pressure Oxidizer Pump Turbine Secondary Seal Drain Temperature				1188	X		
High Pressure Oxidizer Pump Turbine Primary Seal Drain Temperature				1190	X		
Main Combustion Chamber Liner Cavity Pressure P1				1951	X		

Figure-2: CAD and FR Measurement Samplings

PARAMETER (TRANSDUCER TYPE)(1)	USE(2)	REPEATABILITY(3)	RESPONSE	SCALED RANGE(SR)(4) (SENSED RANGE)(5)	ENGINE OPERATING(6) RANGE (SENSED OR) (7)
Oxidizer Tank Pressurant Pressure (A)	MR	±.5% SR	100 Hz	0-7000 psia	1300 to 4900 psia
HPOT Turbine Discharge Temperature (D)	LC,MR	±2% SR	0.1 sec TC(8)	460 to 2500°R	1000 to 1600°R
LOW PRESSURE FUEL TURBOPUMP					
LPFT Discharge Pressure (A)	PC,SV,MR	±.25% SR	100 Hz	0-300 psia	150 to 280 psia
LPFT Discharge Temperature (C)	PC,SV,MR	±2% SR	0.2 sec TC	30 to 55°R	35 to 45°R
LPFT Shaft Speed (E)	MR,ND			0-20,000 rpm (0-2667 pps)	14,380 to 16,210 rpm (1918 to 2162 pps)
Fuel Flowrate (E)	PC,MR,ND	±.4% SR	150 Rad/Sec	0-18,000 gpm (0-268 pps)	16,123 to 16,342 gpm (241-245 pps)
LOW PRESSURE OXIDIZER TURBOPUMP					
LPOT Discharge Pressure (A)	SV,MR	±.5% SR	100 Hz	0-600 psia	270 to 575 psia
LPOT Shaft Speed (E)	MR,ND			0-6000 rpm (0-1600 pps)	3876 to 5308 rpm (1034 to 1416 pps)
HYDRAULIC CONTROL SYSTEM					
Hydraulic System Pressure (F)	SV,MR,EC	+.5% SR	100 Hz	0-4000 psia	2700 to 3100 psia
Main Oxidizer Valve Temperature (C)	SV	±2% SR	0.2 sec TC	360-760°R	460-620°R
Main Fuel Valve Temperature (C)	SV	±2% SR	0.2 sec TC	360-760°R	460-620°R
PNEUMATIC CONTROL ASSEMBLY					
OPB System Purge Pressure (A)	MR,EC,SV	+.5% SR	100 Hz	0-1500 psia (7500 psia)(11)	0-750 psia
Fuel System Purge Pressure (A)	MR,EC,SV	±.5 SR	100 Hz	0-600 psia	0-400 psia
FPB System Purge Pressure (A)	MR,EC,SV	±.5% SR	100 Hz	0-1500 psia (7500 psia)(11)	0-750 psia
Emergency Shutdown PAV Pressure (A)	MR,EC,SV	±.5% SR	100 Hz	0-1500 psia (7500 psia)(11)	0-750 psia
HPOP Intermediate Seal Cavity Pr. (A)	MR	±.5 SR	100 Hz	0-300 psia	0-20 psia
HPOP Primary Seal Drain Pressure (A)	LC,MR	±.5 SR	100 Hz	0-300 psia	0-100 psia
HPOT Intermediate Seal Purge Pr. (A)	LC,MR,EC,SV	±.5% SR	100 Hz	0-300 psia	50 to 60 psia
CONTROLLER					
Controller Internal Pressure (9)	MR,EC			0-50 psia	0-30 psia
Controller Internal Temperature (9)	MR			140 to 760°R	460 to 660°R
POGO SYSTEM (10)					
POGO Precharge Pressure (A)	LC	±.5% SR	100 Hz	0-1500 psia (7500 psia)(11)	0-1500 psia
MAIN COMBUSTION CHAMBER					
MCC Coolant Temperature (D)	MR	±2% SR	2.0 sec TC	400 to 1160°R	520 to 735°R
MCC Coolant Pressure (A)	MR	±.5% SR	100 Hz	0-7000 psia	2000 to 5400 psia
MCC Fuel Injector Pressure (A)	MR	±.5% SR	100 Hz	0-4500 psia	1500 to 3850 psia
Main Combustion Chamber Pressure (A)	PC,MR,LC,ND	±.25% SR	100 Hz	0-3500 psia	1400 to 3300 psia
MCC LOX Injector Temperature (A)	MR	±2% SR	0.2 sec TC	160-210°R	178-201°R
HIGH PRESSURE FUEL TURBOPUMP					
HPFT Discharge Pressure (A)	MR,ND	±.5% SR	100 Hz	0-9500 psia	3200 to 7400 psia
HPFT Shaft Speed (E)	LC,MR,ND			0-45,000 rpm (0-3000 pps)	35,576 to 39,056 rpm (2372 to 2604 pps)
HPFT Turbine Discharge Temperature (D)	LC,MR	±2% SR	0.1 sec TC(8)	460 to 2500°R	1200 to 1820°R
FUEL PREBURNER					
Fuel Preburner Chamber Pressure (A)	MR,ND	±.5% SR	100 Hz	0-7000 psia	2200 to 6200 psia
HIGH PRESSURE OXIDIZER TURBOPUMP					
HPOT Discharge Pressure (A)	MR,ND	±.5% SR	100 Hz	0-7000 psia	2375 to 5400 psia
HPOT Boost Stage Discharge Temp (A)	SV,MR	±2% SR	0.2 sec TC	160 to 210°R	178 to 201°R
HPOT Boost Stage Discharge Pressure (A)	MR,ND	±.5% SR	100 Hz	0-9500 psia	4200 to 8800 psia

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CADS (Computer and Data Simulator)

CADS SYSTEM
ENGINE TRANSDUCER REPEATABILITY, RESPONSE AND RANGE

NOTES:

1. Transducer Type (Ref. Para. 4.4.2): A - RC7001 Pressure, Low Level; C - RC7002 Cryogenic Temperature; D - RC7004 Hot Gas Temperature: E - RC7005 Speed and Flow; F - RC7007 Low Level Analog Output for Hydraulic Oil Service.
2. Use: PC - Performance Control; LC - Limit Control or Limit Shutdown; EC - Engine Checkout; MR - Maintenance Recording; ND - Non-flight Data; SV - Status Verification and Engine Ready.
3. Repeatability - Repeatability is defined in the Applicable Component Specification (Ref. Para. 4.4.2).
4. Scaled Range - For pressure, the rated full-scale range of the transducer; for temperature, the band to which the controller input circuit is designed; for flow and speed, the volumetric flowrate or shaft rotational velocity; for vibration, the rated range of the accelerometer.
5. (Sensed Range) - The output of speed and flow transducers in pulses per second (pps) corresponding to the scaled range.
6. Operating Range - The upper and lower values of the operating parameters of the engine based on the engine balance of DVS-SSME-101, Volume II.
7. (Sensed OR) - The outputs of the speed and flow transducers in pulses per second (pps) corresponding to the values of the operating ranges.
8. Time constant for hot gas temperature transducer is that expected in the turbine discharge environment. The transducers will be acceptance tested to a 0.3 sec. time constant in water. It can be shown analytically that this translates to the time constant in the table.
9. Transducers used for sensing controller internal pressure and temperature will be supplied and verified as parts of the controller.
10. POGO Gas Supply Pressure Effectivity Only: Engine S/N 0005 and Subs (0002 and 0003 modified at recycle), also 2003 and Subs; Retrofit: 2001, 2002 and 0104. HPFT Inlet Accelerometer Effectivity Only: Engines S/N 2001, 2002, 2003 and 0104. Effectivity of all other POGO Instrumentation: Engines S/N 0104, 2001 through 2007.
11. These transducers are provided with 5 time full scale overrange protection. Effectivity Only: Engine S/N 0006 and subs (0005 modified at recycle) and 2004 and subs (2003 modified at recycle).

FR (Facility Recorder) System

PID Number	Sensor Type	Repeatability	Response	Filter
327, 328, 436, 457, 480, 657, 817, 821, 836, 854, 858, 881, 951, 990, 1951	Pressure Transducer	0.5% FS	10 to 40 Hz(1)	5 Hz
837, 883	Delta Pressure Transducer	(2)	10 Hz	5 Hz
659, 1017, 1021, 1058, 1054	Temperature Bulb	.25°R	0.5 Hz	5 Hz
650, 658, 882, 1036, 1187, 1188, 1190	Thermocouple	6° ≤ 300°R 4° 300 - 800 °R 1/2% > 800°R	0.1 to 2 Hz	5 Hz

1. Assumes small changes while at pressure.
2. Unknown effects due to lack of calibration at line pressures. If Taber 2104 with line pressure calibration substituted: approximately 1%.

Figure-3: CAD and FR Transducer Repeatability, Response, and/or Range

FOLDOUT FRAME

Parameter		Lower Limit	Upper Limit
HPFT Turbine Discharge Temperature Ch. A (2C)			
Start +5.04 sec. to Start +5.8 sec.		-	1760°R
Start +5.8 sec. to Shutdown		-	1850°R
HPFT Turbine Discharge Temperature Ch. B (2C)			
Start +5.04 sec. to Start +5.8 sec.		-	1820°R
Start +5.8 sec. to Shutdown		-	1960°R
HPOT Turbine Discharge Temperature Ch. A (2B)			
Start +2.3 sec. to Start +5.8 sec.			1560°R
Start +3.8 sec. to Start +5.8 sec.		550°R	1560°R
Start +5.8 sec. to Shutdown		550°R	1760°R
HPOT Turbine Discharge Temperature Ch. B (2B)			
Start +2.3 sec. to Start +5.8 sec.			1560°R
Start +3.8 sec. to Start +5.8 sec.		550°R	1560°R
Start +5.8 sec. to Shutdown		550°R	1760°R
HPFT Turbine Discharge Temp T' Limit	(4)		50°R below channel upper limit (depending on time)
HPOT Turbine Discharge Temp T' Limit	(4)	50° above channel lower limit	50° below channel upper limit (depending on time)
HPOP IMSL Purge Pressure	(2A)	170 psia	-
HPOT Secondary Seal Cavity Pressure	(2A)	-	100 psia
HPFP Coolant Liner Pressure	(2C)	-	Variable (5)
Preburner S/D Purge Pressures Ch. A: Fuel; Ch. B: Oxidizer	(2A)	-	300 psia

NOTES:

1. Each sensor channel of the listed parameters shall be individually checked against the limits.

2. Limit Shutdown monitoring shall be initiated at the following times:

   (a) At Start for HPOP IMSL Purge Pressure, HPOT Secondary Seal Cavity Pressure, and Preburner Shutdown Purge Pressures.

   (b) At Start +2.3 seconds for the HPOT TDT upper limit and at Start +3.8 seconds for HPOT TDT lower limit.

   (c) At Start +5.04 seconds for HPFP TDT and HPFP Coolant Liner Pressure.

   Monitoring shall then be performed continuously until Start +2.3 seconds for Preburner Shutdown Purge Presures, and for other parameters, until initiatin of Shutdown Phase or when both sensor channels of a particular parameter have been permanently disqualified.

3. A sensor channel shall be considered to have exceeded Limit Shutdown Monitor limits (Redlines") if its readings are equal to or outside listed limits for three consecutive major cycles.

4. The T' or blueline limits are not Limit Shutdown Monitor limits, but shall be used to test for actuator control switchover in the event of an RVDT miscompare. After such a miscompare, if both channels of either HPOT TDT or HPFT TDT are outside their respective T' limits, actuator control shall be switched to channel B. Monitoring times for T' limits correspond to the monitoring times for the respective Limit Shutdown Monitor limits.

5. The upper limits for HPFP Cooland Liner Pressure shall be initialized at Start +5.04 seconds to 4000 psia. Beginning at that time the limits shall then be calculated in each major cycle as a linear function of MCC Pc:

   $$\text{limit} = A_0 + A_1 * (\text{PcReal}) + (\text{limit tolerance})$$

   Nominal values for the coefficients are A_0 = -97.3 psi, A_1 = 1.1583, and limit tolerance = 451 psi. Calculation of the limit shall be bypassed in any major cycle that both channels of MCC Pc are not qualified.

CADS (Computer and Data Simulator)

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Parameters	Lower Limit	Upper Limit
Facility Fuel Flowmeter Discharge Temperature	-	39.8°R
Engine Fuel Inlet Pressure	2 psig	-
Engine Oxidizer Inlet Pressure	10 psig	-
Main Combustion Chamber Liner Cavity Pressure	-	65 psig
High Pressure Fuel Pump Speed	-	38,500 rpm
High Pressure Oxidizer Pump Seal Drain Pressure	-	40 psia

FR (Facility Recorder) System

Figure-4: CAD and FR Shutdown Parameter Samplings with Monitoring Limits

- To establish the data base which would assist in defining:

  - How sensitive the detection system should be to certain anomaly changes (i.e. some anomaly changes may result in only minor damage).

  - What are the experienced anomaly characteristics the detection system should be able to detect. (Programs with new technology and design have the potential of reviving some of the basic failure characteristics.)

The latter study utilized CRT-time slice plots and written documentation, see Figure-1. Approximately fifty-seven (57) sensor measurements were generated for each time-slice indicated in the figure. The written documentation consisted of available Rocketdyne incident reports, briefing charts, internal reports, and NASA investigation reports.

*<u>NOTE</u>: Phase I's objectives incorporating both the AHFR system and the digital recording systems could be achieved in another study. This study would require sufficient test data be assembled to adequately define the nominal 'g-level's. Extensive investigation would be required to define the appropriate hardware and software integration scheme for AHFR, CADS and FR measurements.

The literature review of detection techniques consisted of contacts with industry leaders, including Alphatech and Intermetrics, as well as surveys of over seventy (70) papers.

The methods and material which were reviewed are listed below:

I. Alphatech Material/Approach.

II. Intermetric Material.

III. Bank of Kalman Filters Technique.

IV. Failure Sensitive Filter Technique.

V. Observers Technique.

VI. Voting Technique.

VII. Innovations Based Failure Detection Scheme.

  A. Generalized Likelihood Ratio (GLR) Test.

  B. Sequential Probability Ratio Tests (SPRT).

  C. Weighted Sum Square Residual (WSSR) Test.

  D. Modified Kalman Filter.

VIII. Parameter Estimation Technique.

IX. Jump Process Technique.

3.0 PHASE I CONCLUSIONS AND DEFINITION FOR DETECTION SYSTEM DEVELOPMENT

This section presents the conditions, premises, and/or guide lines for constructing the SAFD anomaly detection system and a preliminary scheme for the system's development (Phase II).

3.1 DETECTION SYSTEM FEASIBILITY

The construction of an anomaly detection system is attainable using available recording systems and under well-founded premises and/or guidelines. An existing CADS-II system* possesses data ports which can permit a separate system (such as the SAFD) to access the data tables from the controller (both A and B channels). The only equipment necessary to achieve the acquisition is an interface unit to interpret the signal coming from the CADS II system. The estimated cost of building this unit is $50-thousand (in 1986 dollars). The FR sensor measurements can be tapped off from the facility recording channels.

*NOTE: The CADS II system appears to have the capabilities required by the SAFD detection system (except it would exclude the FR measurements from the detection system). The CADS II system is built around the INTEL 8086/8087 combination of processors, making floating point arithmetic available. It takes advantage of the Multibus I 16-bit architecture allowing the addition of a large supply of high speed processor boards (680xx series, for example), as well as analog or digital input processor boards. Since the processor boards reside on the CADS II bus, it would be a fairly straightforward task to modify the operating system to allow a "SAFD processor" to send shutdown commands to the CADS processors (to directly initiate an engine shutdown). The CADS II system can also store any SAFD data on a magnetic tape along with the controller data for later analysis. If the option of solely using CADS-measurement data is deemed acceptable (during detection system development-Phase II), cost and software development will be determined. The cost of developing the SAFD system as an integrated part of CADS II would certainly be much less than designing a separate computer system.

Based on an assessment of past incident test data and written documentation (described in Section 5.0), the detection system is also attainable under six (6) premises and/or guidelines. These are:

1. Even though action to prevent reoccurrence has been taken as a result of the major incidents, future programs (test bed, for example) require the advanced detection system be sensitive (but not be limited) to previous experienced anomaly characteristics. These characteristics can be initially grouped into classes of failure types (see Figure-1). Each of these types can in turn have innumerable failure modes which can propagate to characteristics of another given class. In addition, programs with new technology and design have the potential of reviving some of the basic failure modes (see Section 5.0 for test evidence).

2. The detection system's response to a failure should consist of a cutoff signal.

3. The detection system should be limited in scope:

   • To ground tests of the SSME (flight applications will require modifications in the ground detection system's priorities and design for engine shutdown).

   • To steady state operations of the SSME. A detection system sensitive to anomalies occurring during start or throttle should be formulated in a future study. For this latter study sufficient test data should be gathered to adequately define the "nominal" start and throttle transient envelope profiles.

4. The detection system's input data should be tapped from the current set of CADS and/or FR sensor measurements. Under the premise of item-1 above and Section 5.0's data base, the measurements are sufficient for the SAFD detection system. The sufficiency is in terms of:

- Number of sensor measurements indicating an anomaly.

- Damage reducing effectiveness, i.e. a sufficient interim from first measurement indications of an anomaly to redline cutoff time (such that major damage can be avoided).

- Magnitude of (anomaly induced) change from nominal conditions.

5. The detection system's development requires the following concerns to be acknowledged or accounted for.

   a. Recognition of an anomaly serious enough to warrant a shutdown.

   b. Recognition of sensor malfunctions to avoid a premature shutdown.

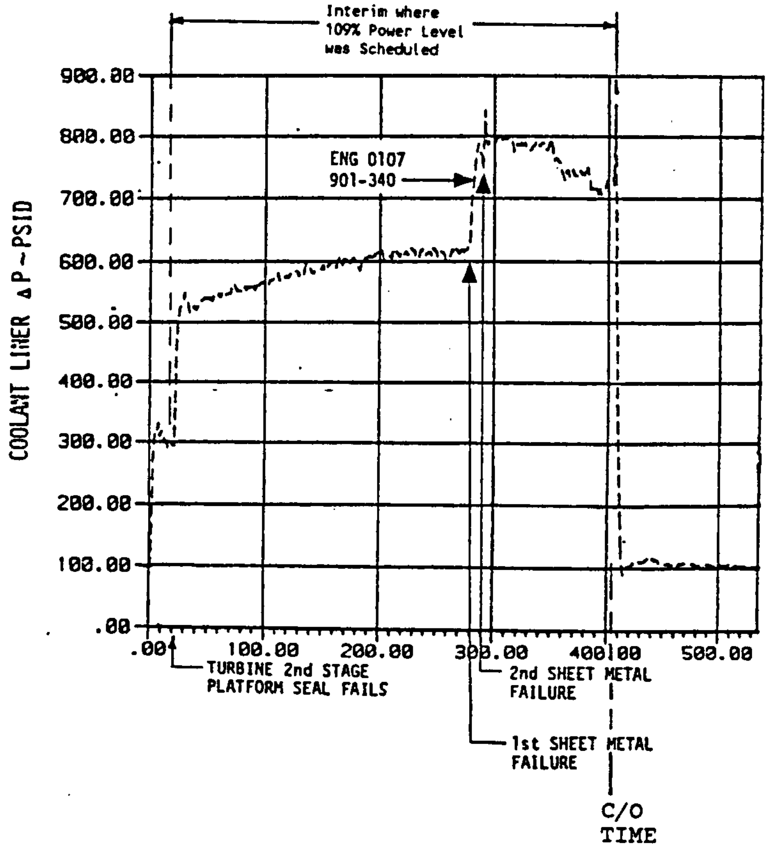
   c. Recognition for a sufficient number of sensors to be incorporated into the detection system. There should be sufficient numbers which indicate a failure even if a few sensors either malfunction and/or do not reveal anomaly indications.

   d. Recognition that the sensors (to be incorporated into the detection system) should represent key aspects of the SSME operation. If all sensors of the detection system malfunction, the resulting premature shutdown would be justified for safety and adequate test monitoring concerns.

   e. Recognition of the engine operating state and goals.

   f. Recognition of the different manner in which anomalies reveal themselves.

g. The system's shutdown should be rapid enough to improve upon the current detection system's performance. In several anomaly tests, particularly the HPFTP (High Pressure Fuel Turbopump) failures, the time intervals from first indications of an anomaly to the current redline cutoff are substantial. The sensor measurement trace below is from test 901-340 where the HPFTP was destroyed. Section 5.0 presents additional measurement trace examples. Figure-5 presents a summary of time intervals for twenty-eight anomaly tests.



h. Recognition that even after extensive simulated testing with actual incident and nominal test data, as well as, model generated data from FMEA (Failure Mode Effects Analysis) critical-1 tables, the SAFD system may signal a premature shutdown (due to unforeseen circumstances).

ALGORITHM SENSOR EVALUATION TABLE: SENSOR VS. TEST-TO-TEST PERCENT CHANGE FROM STEADY STATE CONDITIONS

X---Parameter does not exist for the test number.
M---Parameter malfunction.
NC---No change is strikingly indicated.
NS---Sensor has not settled adequately to steady state conditions.

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TYPICAL PID NO.(S)	PARAMETER	*901 -173	901 -331	750 -148	901 -183	902 -198	901 -307	SF10 -01	*901 -284	750 -259	901 -485	901 -136
366-371	(INJ CLNT PR) -(MCC HG IN PR)	124.4	125.0	30.0	157.1	4.2	X	X	X	X	X	3.3
366-383	(INJ CLNT PR) -(MCC PC)	30.0	7.2	50.7	9.7	5.3	X	X	X	X	NC	.8
371-383	(MCC HG IN PR) -(MCC PC)	4.1	17.6	10.6	2.4	21.8	NC	X	X	100.0	X	2.2
395-383	(MCC OX INJ PR) -(MCC PC)	5.6	25.5	9.9	1.4	X	8.0	X	270.8	92.1	NC	1.7
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	X	X	X	X	X	25.0	X	X	X	X	X
459-383	(HPFP DS PR) -(MCC PC)	6.7	1.6	9.0	.8	1.9	NC	X	70.0	X	NC	.4
412-371	(FPB PC) -(MCC HG IN PR)	5.3	3.2	4.2	NC	3.4	NC	X	X	4.1	NC	.2
480-371	(OPB PC) -(MCC HG IN PR)	3.9	5.6	4.2	NC	6.6	NC	X	X	5.7	NC	1.1
63, 163	MCC PC	4.4	3.6	6.4	.3	1.5	.4	1.8	31.0	3.9	NC	.3
566	MCC CLNT DS T	X	10.2	10.6	1.0	12.5	NC	4.0	79.8	275.0	NC	NS
24	MCC FU INJ PR	4.4	5.3	M	NS	1.8	3.4	X	43.2	56.3	NC	NS
764	HPFP SPEED	1.5	1.2	1.5	X	.4	NC	NC	19.4	100.0	NC	1.1
663	HPFT DS T1 A	7.5	10.1	30.9	1.6	84.1	4.0	6.3	25.1	24.9	NC	1.5
664	HPFT DS T1 B	7.5	10.7	M	1.4	5.5	4.6	5.3	M	14.0	NC	2.4
233	HPOT DS T1	4.9	41.0	32.6	.5	30.1	4.4	8.0	69.7	24.0	4.0	1.9
234	HPOT DS T2	3.0	40.0	37.6	.3	28.5	4.5	9.0	M	3.9	3.1	1.4
854	FAC OX FM DS PR	NC	NC	4.7	NC	3.7	NC	X	28.0	NC	NC	NC
858, 860	ENG OX IN PR	NC	9.7	8.6	NC	3.4	NC	X	51.6	36.3	NC	NC
302	LPOP DS PS	3.4	5.8	3.8	NC	4.7	9.2	X	28.6	55.9	NC	NC
878	HX INT PR	.9	4.7	3.4	NS	4.5	1.5	X	53.5	1.0	1.7	.8
879	HX INT T	.4	7.2	.7	.2	15.4	3.8	X	7.6	6.1	NS	1.9
883	HX VENT DP	1.1	4.3	NS	NC	1.9	NC	X	53.6	X	1.8	.5
40	OPOV ACT POS	4.2	7.2	8.0	1.1	5.0	3.4	3.4	31.7	1.8	1.0	3.0
42	FPOV ACT POS	1.8	6.6	2.2	.4	2.3	1.3	2.2	5.4	5.7	NC	1.8
Number of above parameters over 2% change:		15	20	18	3	17	10	7	16	16	2	4
Sample sensor interval (sec) from anomaly start time to cutoff time:		.48	.95	.55	27.1	2.9	20.3	5.15	6.03	.17	8.1	96.

PARAMETER	901 -340	901 -363	901 -436	902 -118	*901 -364	901 -362	901 -410	902 -095	902 -249	*901 -225	902 -112	901 -346
(INJ CLNT PR) -(MCC HG IN PR)	X	X	X	45.7	X	X	X	NC	X	M	NC	X
(INJ CLNT PR) -(MCC PC)	X	X	NS	6.8	X	X	X	.4	X	12.9	NC	X
(MCC HG IN PR) -(MCC PC)	17.7	2.0	X	6.9	11.9	6.8	4.0	.8	X	M	NC	NC
(MCC OX INJ PR) -(MCC PC)	1.8	1.5	9.6	4.8	NC	NC	NC	NC	3.2	38.9	NC	NC
(HPFP CL LNR PR)-(MCC HG IN PR)	31.0	30.2	X	X	45.0	X	50.0	X	X	X	X	18.9
(HPFP DS PR) -(MCC PC)	1.9	1.0	4.2	2.1	1.6	1.2	NC	NC	2.2	3.3	4.3	NC
(FPB PC) -(MCC HG IN PR)	4.8	.8	X	7.9	4.3	2.8	5.5	NC	X	M	6.2	NC
(OPB PC) -(MCC HG IN PR)	3.3	1.2	X	4.5	3.1	NC	NC	NC	X	M	NC	NC
MCC PC	1.6	.5	3.9	NC	.8	.4	NC	NC	NC	6.0	3.3	NC
MCC CLNT DS T	.7	M	3.3	X	1.4	2.2	NC	M	4.2	X	X	3.3
MCC FU INJ PR	2.2	.6	1.9	X	.7	X	NC	.9	1.1	5.1	X	8.2
HPFP SPEED	1.4	.3	5.7	.9	.3	.3	.5	NC	4.3	4.2	10.9	.5
HPFT DS T1 A	6.4	1.3	20.0	13.9	2.4	1.7	2.0	NC	23.4	15.1	23.8	3.2
HPFT DS T1 B	6.0	1.9	22.8	10.1	3.0	1.6	1.0	M	9.2	15.1	21.6	3.3
HPOT DS T1	5.3	.6	2.6	2.3	5.3	NC	1.8	NS	6.9	12.3	7.4	5.8
HPOT DS T2	4.6	.7	1.5	2.4	6.3	NC	2.3	NS	4.9	12.3	9.0	2.6
FAC OX FM DS PR	NC	NC	NC	NC	144.0	NC	NC	9.2	220.0	6.5	NC	NC
ENG OX IN PR	NC	NC	4.8	NC	144.0	NC	NC	8.7	220.0	23.7	NC	NC
LPOP DS PS	2.1	NC	8.8	NC	34.4	NC	NC	2.1	20.0	45.8	4.4	NC
HX INT PR	1.0	.6	NC	X	.5	.6	NC	1.1	1.1	5.1	1.5	1.0
HX INT T	2.7	NS	.4	X	4.7	NS	NS	NS	4.2	M	X	5.8
HX VENT DP	1.5	.6	NC	X	NS	.7	NC	NS	3.8	2.2	X	1.7
OPOV ACT POS	2.1	3.1	3.6	NC	3.9	1.8	3.2	2.7	7.0	NS	2.3	3.1
FPOV ACT POS	4.4	1.0	11.9	2.8	2.9	1.0	.3	NC	3.5	.4	8.3	3.5
Number of above parameters over 2% change:	13	3	12	12	14	3	6	4	15	15	11	10
Sample sensor interval (sec) from anomaly start time to cutoff time:	116.	114.	.56	1.84	189.	175.	90.	10.3	351.	.18	.75	400.

Figure-5: Test Sensor Measurement Samplings for Percent Changes from Steady State Conditions and Time Intervals from Anomaly Indications to (Redline) Cutoff

However, the cost of the premature shutdown ($250-thousand for engineering teststand personnel and facilities), would be more than offset by the millions of dollars saved for just one proper SAFD system shutdown command. Figure-1 displays such damage costs of previous incident tests.

6. The detection system should utilize the algorithm framework to be described in the following section. The detection techniques reviewed and outlined in Section 4.0 should be considered in some form if the latter scheme does not prove performance effective. The techniques should not be considered initially in the system development phase for reasons of:

   - Need for a simple structured detection system.

   - Need in some cases for a quick performance responding system (i.e. 500 milliseconds before current redline cutoff).

   - Concern for susceptibility to instrument errors and random disturbances.

3.2 DETECTION SYSTEM DEVELOPMENT

The preliminary scheme for the SAFD's system development consists of an initial coding framework and basic approaches which may be used to measure the system's performance.

3.2.1 Coding Framework

The initial program coding framework incorporates the considerations cited in Section 3.1. The salient features of the framework are the three (3) approaches to sensing anomalies. The approaches are tailored to meet anomalies when they: occur shortly after a scheduled transient, occur slowly (e.g. 100-seconds before major damage), and occur rapidly (e.g. 500

milliseconds or less before major damage). The framework encompasses: input provisions, computations, decision making logic, and diagnostics. Diagnostics will be displayed, for example: to indicate corrective action for input errors or inconsistencies, to indicate the anomaly area within the SSME, and to identify the detection system's scanning approach which signaled an engine shutdown. A brief content description of the first three framework components are presented on the following pages. Figure-6 summarizes how they are logically linked with the three (3) anomaly sensing approaches.

1. Input provisions. Some of these provisions consist of:

   a. Stored input data, i.e.

   •Expected steady state average values (AVG1) for the number of engine sensors monitored by the detection system. There will be sufficient numbers of sensors which will indicate an anomaly even if a few monitored sensor measurements malfunction. The average values can be test data based or from an off-design model (influence coefficient governed) prediction for different power levels (to be start or throttled to for a particular test).

   •Standard deviations (SD's) for each sensor's average value, as well as, multiplying N-factors on the SD's (i.e. N1, N2, and N3, see Figure-6 for the overall system utilization). The values for the SD's will be based on the data base described in Section 5.0. The N-factors will be derived from integrity verifications of the detection system on sensor measurement data indicating either SSME anomaly or nominal operation. The data reflecting anomaly operations will come from previous tests (causing major damage) and from transient and/or off-design model simulations of selected FMEA (Failure Mode Effects Analysis) critical-1 failure modes. The data reflecting nominal operations will come from previous nominal tests and transient model simulations of sensor measurement variations (for example noise, bias, or drift). During the latter verifications, the detection system's ability to detect anomalies rapidly enough to improve upon the current detection system's performance and its ability to avoid a premature shutdown will be two (of several) significant criteria for final value assignments of the N-factors.

•Scheduling times for throttle and tank venting.

b. <u>CAD and FR sensor measurements monitored</u> by the system

•Selection of the sensor measurements to be monitored are based on Section 5.0 data tables and recognition that the measurements should represent key aspects of the SSME operation. If all sensors of the detection system malfunction, the resulting premature shutdown would be justified for safety and adequate monitoring concerns.

2. <u>Computations</u>. The computations will be initiated during steady state power level intervals (see Figure-6 for the approximate time interims). During <u>scheduled</u> <u>transients</u> (i.e. scheduled start, throttling, or tank venting), detection system parameters holding calculated values will be re-initialized; computations will begin again once steady state operation is achieved. The computations will consist of, for instance:

   a. <u>Delta-P calculations</u> around components (from individual sensor measurements).

   b. <u>Average steady state values</u> (<u>AVG2</u>) <u>computed</u> for up to 2-seconds. After 2-seconds AVG2 values will be updated with new values (<u>AVGINC</u>) averaged from an 80 millisecond interim.

   c. Two-seconds after scheduled transients, the <u>AVG2</u> <u>value</u> for each sensor is <u>stored</u> under the array name <u>AVG3</u>.

3. <u>Decision Making Logic</u>. The logic decisions will apply during steady state power level intervals (see Figure-6 for the approximate time interims). During scheduled transients logic parameters will be re-initialized; logic decisions will again apply once steady state operation is achieved. The decision logic will consist of, for instance:

   a. <u>Logic to identify</u> possible sensor malfunctions or <u>to verify</u> an anomaly is being sensed, i.e. cross checking with other parameters for change; for instance FPOV (Fuel Preburner Oxidizer Valve) or OPOV (Oxidizer Preburner Oxidizer Valve) positions, or cross checking for consistent directions in change for given directions of change (from other sensor measurements).

   b. For a 2-3 second interim after the end time of a scheduled transient, <u>scanning Approach-1</u> will be used exclusively to screen for anomaly induced changes in sensor measurements. If sufficient and consistent numbers of sensors meet the condition below, a cutoff signal will be initiated. This approach is intended to detect anomalies occurring shortly after a scheduled transient.

$$AVG2 > (AVG1 \pm N1 * SD)$$

   c. At the conclusion of scanning Approach-1's interim until the start time of the next scheduled transient, <u>scanning Approach-2 or Approach-3</u> will be used to screen for anomaly induced changes in sensor measurements. If sufficient and consistent numbers of sensors meet the respective conditions below, a cutoff signal will be initiated. Approach-2 is intended to detect anomalies occurring slowly (for example,100-seconds before major damage); Approach-3 is intended for those anomalies occurring rapidly (for example, less than 500 milliseconds before major damage).

Approach-2 condition: AVG2 > (AVG3 ± N2 * SD)

Approach-3 condition: AVGINC > (AVG2 ± N3 * SD)

3.2.2 Detection System Performance Measurement. During the latter portion of the verification effort (for the programming framework in Figure-6), three (3) measurements for the detection system's performance may be utilized. These measurements are generally described in Figure-7; they will be refined during detection system development for application.

Initial Algorithm Logic and Computation Scheme	Computation or Logic Checking Applicability During Test	Detection Purpose (If Applicable)
Inputs: -Expected steady state average values (AVG1) for algorithm sensing; the values are for applicable main stage conditions. -Standard deviation (σ) for each sensing parameter's AVG1 value. -Scheduling times for throttle and venting.		
Sensor test data are each computed for average steady-state values. -The above values (AVG2) are computed for up to 2-seconds. -After 2-seconds AVG2 values are updated with new values averaged from an 80 msec interim (AVGINC) -AVG2 values are reinitialized and recomputed subsequent to transient throttle or tank venting end time. -The AVG2 values are stored as AVG3 and used in Approach-2 if Approach-1 does not signal a cutoff. The stored values progressively (in time) represent either the average from start time +6 to +8 seconds, or from throttle/vent end time +1 to +3 seconds.	-From start time +5 sec until initiation time of a throttle or tank venting. -From throttle or venting end time +1 sec until another transient initiation time.	
Scanning Approach-1: If sufficient and consistent numbers of sensors meet the condition below, a cutoff signal will be initiated: $AVG2 > (AVG1 \pm N1 * \sigma)$ Where, σ -Standard deviation, input, N1 -A sufficiently large multiplying factor on the standard deviation to avoid premature cutoff thru normal overshoot or slight miscalculations in predicted steady state averages (AVG1). The value for "N1" is based on algorithm simulations using anomaly and nominal test data.	-From start time +5 to +8 sec. -From throttle or vent end time +1 sec to +3 sec.	-To detect anomalies occurring shortly after a system transient. -To account for detection shortcomings of Approach-2 and/or -3, e.g. use of the computed steady-state average, AVG2 to establish cutoff decisions
If "TIME" is within Approach-1's Applicability Interim — Yes (return to Scanning Approach-1)		
Scanning Approach-2: If sufficient and consistent numbers of sensors meet the condition below, a cutoff signal will be initiated: $AVG2 > (AVG3 \pm N2 * \sigma)$ Where, N2 -A multiplying factor on the standard deviation; the value of "N2" is based on algorithm simulations using anomaly and nominal test data.	-From start time +8 sec until initiation time of a throttle or tank venting. -From throttle or venting end time +3 sec until another transient initiation time.	-To detect anomalies which could occur gradually in time, i.e. e.g. anomaly induced changes in steady state measurements have taken 100+ seconds before redline cutoff and subsequent major damage.
Scanning Approach-3: If sufficient and consistent numbers of sensors meet the condition below, a cutoff signal will be initiated: $AVGINC > (AVG2 \pm N3 * \sigma)$ Where, AVGINC -The average steady state values from an 80msec interim. N3 -A multiplying factor on the standard deviation; the value of "N3" is based on algorithm simulations using anomaly and nominal test data.	-From start time +8 sec until initiation time of a throttle or tank venting. -From throttle or venting end time +3 sec until another transient initiation time.	-To detect anomalies which could occur rapidly in time, i.e. e.g. anomaly induced changes in steady state measurements have taken +500 msec or less before redline cutoff and subsequent major damage. -To account for sensor drift.

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NOTE: For this initial scheme the following relation is envisioned: $N1 > N2 > N3$.

Figure-6: SAFD Initial Algorithm Framework

Possible Approaches to Measuring the SAFD's Detection System Performance:

General: The detection performance relates to how effective the selected algorithm is in detecting a failure. If the detection algorithm requires a large amount of core memory and is "slow" to respond, the concept is not acceptable. The response of the concept in detecting various induced failures can be quantified in the following terms:

Hit..............A failure occurs and detection is accomplished by the selected concept.

Miss.............The concept detects no failure(s) for which it was programmed, despite the fact that such a failure was induced.

False Alarm......A condition in which the concept incorrectly detects a failure when no failure actually occurred.

Response Time....Length of time after the failure before detection of the failure occurs. Time to detect.

The detection performance may be measured as follows:

I. Hit/Miss Ratio:

$$\text{DSCORE} = \frac{\text{NIF - NOH*WT1}}{\text{NIF}}$$

where:
NIF....Number of induced failures.
NOH....Number of hits.
WT1....Chosen weighting portion of the weight importanace of this criteria.

WT1= 80 will yield 40 points.

II. Time to Detect: (15 points score)

Rationale: The advanced electronic control design for the SSME (Space Shuttle Main Engine) takes approximately 40-60 millseconds to detect a failure (assuming a 3-hit criteria); therefore the concept is penalized for times greater than this. A 120-180 millisecond time results in a worst score. The concept is penalized for excessive parameter changes between when the failure was induced to when the failure was detected for steady state opeation. A parameter change of 10% results in a worst score.

The typical scoring equation: DSCORE = (AMAX1(0., (TFD-TFI-60))/120) * WITD + (PNTI - PNTD)/PNTI * WPF

where:
TFD....Time failure detected.
TFI....Time failure induced.
PNTI...Parameter value when failure induced.
PNTD...Parameter value when failure detected.
WITD...Weight on induced time delay.
WPF....Weight on percent parameter change.

III. Number of False Alarms.

Ground Rules- For every 10 hits, one false alarm is tolerable, three false alarms scores 15 points.

Scoring: DSCORE = NOFA/NOH * 50.

where:
NOFA...Number of false alarms.
NOH....Number of hits.

Figure-7: Detection System Performance Measurements

4.0 LITERATURE REVIEW RESULTS

A literature search was performed on Failure Detection and Isolation (FDI) techniques. A list of over 70 papers were collected and contacts made with two research firms, Alphatech (Boston, Massachusetts) and Intermetrics (Cambridge, Massachusetts). A bibliography of the collected literature (in three pages) may be found at the end of this section. The methods/material which were reviewed are listed below. Each are subsequently discussed.

I. Alphatech Material/Approach.
II. Intermetric Material.
III. Bank of Kalman Filters Technique.
IV. Failure Sensitive Filter Technique.
V. Observers Technique.
VI. Voting Technique.
VII. Innovations Based Failure Detection Scheme.
   A. Generalized Likelihood Ratio (GLR) Test.
   B. Sequential Probability Ratio Tests (SPRT).
   C. Weighted Sum Square Residual (WSSR) Test.
   D. Modified Kalman Filter.
VIII. Parameter Estimation Technique.
IX. Jump Process Technique.

I. Alphatech Material/Approach.

Since all Failure Detection and Isolation (FDI) techniques are fundamentally based on models of system redundancy, it is not surprising that model error creates problems in FDI techniques which do not adequately address the issue. A design methodology described by Alphatech (ref. 29 & 37) provides an interesting framework for analyzing the impacts of such errors on FDI performance. A simple description can be found on page 4 of ref. 29. The difficulty with this method lies in the computational burden associated with the large number of linear models required to generate the redundancy relations for each steady state operating point. More work on a practical level needs to be done before this technique is plausible for plant failure detection.

Robustness of an FDI system is defined by Alphatech as a measure of FDI performance. They consider the probability of a false alarm as a measure of FDI robustness. The FDI algorithm must also have robustness in the presence of unavoidable modeling errors. The overall design process is to design the FDI system to have the best performance when averaged over all the likely error sources.

II. Intermetric Material.

A very comprehensive review of failure detection techniques can be found in ref. 30 and 40. In ref. 30 Intermetrics Corporation reviewed over 73 publications on failure detection. In this review three key areas of implementation were discussed:

1. Kalman Filtering. System states are often estimated using the sequential optimal Bayes linear estimator, known as the Kalman filter. For real time applications a reduced-order Kalman filter (extended) must be used. This is due to the computer memory and computation delay required for full-state Kalman filters.

2. "Truth" Modeling Derivation. When the "truth" model or the error model is derived, it is assumed that the state description has filter residuals that are unbiased and white for the nominal operating case. The filter residuals can be nonwhite or biased for the following reasons:

    a. Because a failure occurred.

    b. Because a bad measurement was received.

    c. Because of the use of a reduced-order Kalman filter (suboptimal).

Any failure detection approach that does not account for the last two reasons above will attribute any nonwhiteness as solely due to the occurrence of a failure. One possible solution to this problem involves the on-line calculation of the mean and variance from the windowing of statistics, i.e.:

a. Sampling a "frame" of time at a steady-state level and estimating the variance.

b. Comparing the above to a suboptimal estimate from a reduced order extended Kalman error covariance matrix.

c. Developing a "metric" based on the error between the statistical estimates.

3. <u>Robust Techniques</u>. Three other approaches to solving the nonwhite filter residual problem can be termed "robust" techniques.

a. Voting between three (or more) comparable components.

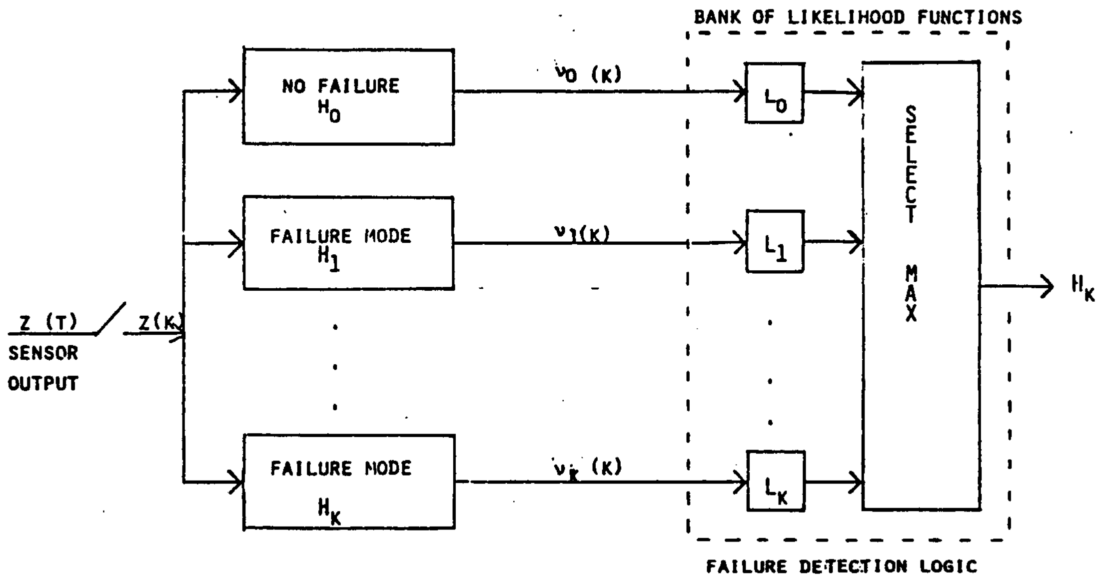
b. Mid-value selection (between three comparable components).

c. Reliance on parity equation checks between either identically redundant systems or functionally redundant systems or combinations of systems which together cover the function of another system (known as analytical redundant systems).

NOTE: The first two of the above techniques are present in the SSME controller electronics (e.g. self-checking processors and sensor voting logic). The third type can be related to the SSME (Space Shuttle Main Engine) actuator electronics voting logic. This failure detection scheme relies on 2nd order transfer function simulation of the actuator dynamics that is then compared against the actuator's actual position. An error is then generated and a threshold value of 6% to 10% is then used to trigger engine shutdown.

III. Bank of Kalman Filters Technique.

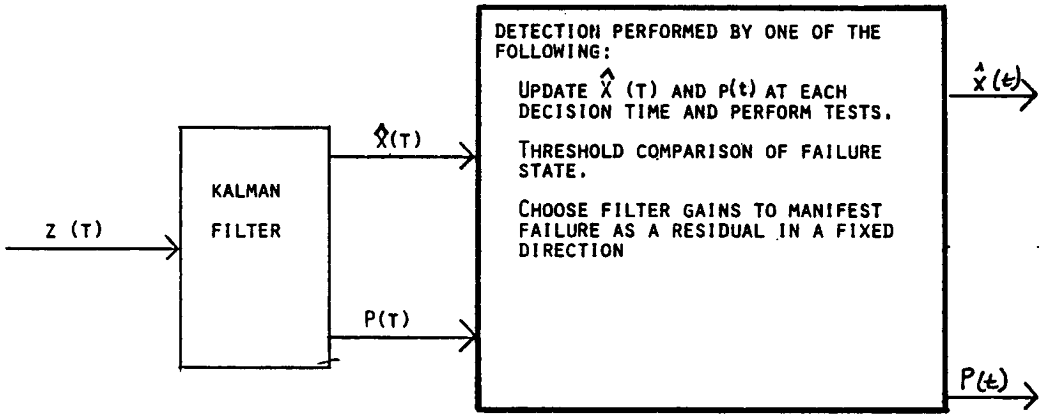
This technique employs a group ('bank') of Kalman filters to hypothesize each failure mode. Normal operation of the system is represented by the null hypothesis, H-sub-o. The failure hypotheses are labeled as H-sub-i. The residuals of each filter are monitored and likelihood functions (e.g.probability density functions) are generated. Other statistical tests (ref. 60) can also be performed on the filter innovations. The hypothesis with the maximum likelihood of occurrence is then selected as representing the true failure mode. Concepts underlying the bank of filter's approach are discussed in ref. 61 and 62. The concept is schematically shown below:



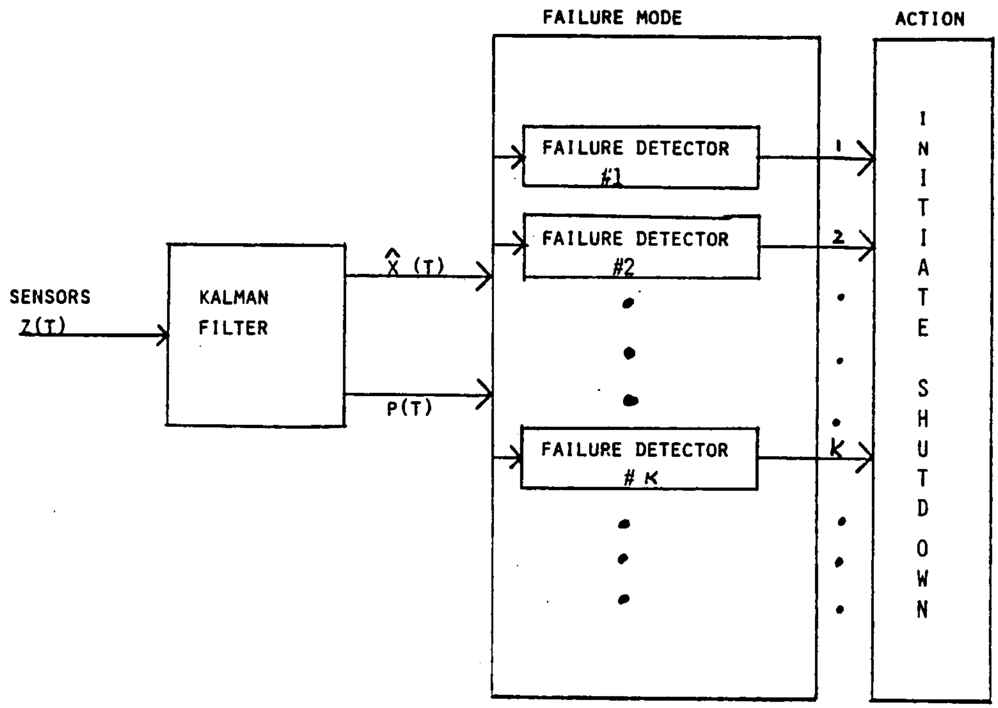
The advantages of the bank of filters technique are: (1) it provides a good yardstick for comparison with simple techniques, and (2) it allows insight into the failure propagation dynamics after detection. The disadvantages are: (1) the bank of filters approach results in excessive computational complexity, and (2) there is the possibility of the bank of filters becoming oblivious and failures going undetected.

IV. Failure Sensitive Filter Technique.

Failure sensitive filters can be classified as filters using failure states in dynamics and detection filters. The block diagram below illustrates this technique.



1. Failure State Augmented Filters. This type of filter augments the state vector with failure states to form a higher dimensional system in state space. Several techniques which use these filters and are sensitive to specific types of failures have been developed. Kerr (ref. 63) discusses an approach where a bounded region is defined around the nominal and estimated trajectories and tests are performed to determine overlapping of the two regions. It is a geometrical approach and simulates failures as states (for detection purposes). The figure below demonstrates this concept.



2. <u>Detection Filters</u>. Detection filters were developed by Beard (ref. 64) and Jones (ref. 65). The basic idea is to select the gain matrix such that filter innovations tend to zero in the no-failure state and give an indication of plant failure in the failed state. Beard's choice of gains is directed towards making the innovations point in a fixed direction in case of a failure. For example, it is easy to show that if a component fails, the components of the filter residual vector have distinguishing characteristics that are large relative to other component failure characteristics.

   The major advantage of detection filters is the simplicity with which they can be used. The disadvantages are: (1) susceptibility to instrument errors and random disturbances, (2) applicable in theory only to linear regimes where the model structure does not change, (3) modeling errors may appear as soft failures, (4) criteria for declaring faults are hard to set, and (5) in general, this method requires measurements of all state variables.

If the mathematical model of a system is "close to" the actual physical system, Kalman filtering is the optimal technique for estimation. Performance may be degraded, however, due to modeling errors and the tendency of Kalman filters to become "oblivious" to the sensor outputs. As more and more information is received, the state estimation error covariance is decreased. Consequently, the filter gains are reduced and the filter band-width is reduced.

If a failure occurs early in the measurement sequence, while the filter gain and bandwidth are large, the filter can respond properly to the change. However, as the error covariance and gain decrease, the filter begins to "know the state too well". Thus, as time goes on, it becomes oblivious to incoming information and fails to track the actual system behavior. In fault tolerant systems, it is desired to have filters which are sensitive to new data so that abrupt changes are reflected in the filter behavior.

Two techniques exist for avoiding the oblivious filter. They are the exponentially age weighted filtering and the limited memory filtering (ref. 66). Both techniques ensure that the filter gains on all failure modes never approach zero. Hence, the filters remain sensitive to failures.

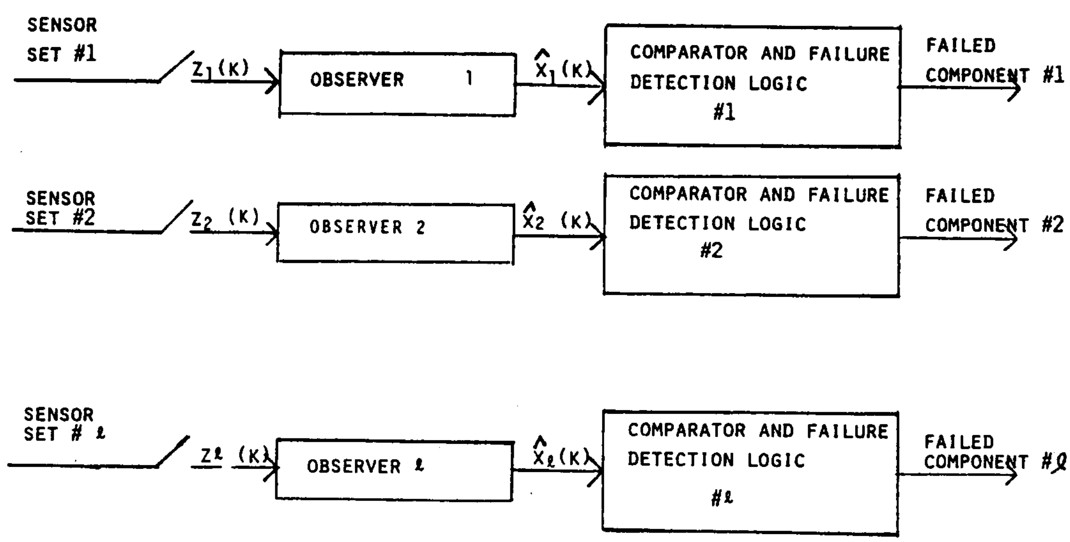
V. <u>Observers Technique</u>.

A traditional scheme for protecting a system against failures in its feedback sensors is to provide the system with three (or more sets of sensors, so that there is redundancy in the feedback information. A voting logic may then be used to identify a faulty component's output sensor. This approach works well in systems where redundant instrument sets do not cause cost, weight, or size problems.

The technique of using observers requires only one set of instruments for each incident type. The redundancy provided by multiple sets of instruments is provided artificially in the failure detection computer by a subsystem of multiple observers (see the figure below). It is assumed that the single set of instruments consists of three or more individual sensors. The outputs of each set of sensors is used to drive an observer, which is designed for that incident type. Thus each incident type has its own observer. Each observer estimates the states, so there is redundancy in estimates. These observer estimates are compared in a voting manner. For perfect components and perfect system dynamics, the estimates will converge to the real state vector in a very short time.

If a component fails, however, the observer estimate (corresponding to that component) is in error and a comparison between the estimated states identifies the faulty component. Ref. 67 discusses a scheme using multiple observers.

A plant failure detection system will utilize a set of sensors feeding in to an observer that simulates the behavior of the normal system but is sensitized to detecting a particular plant failure mode.



BANK OF OBSERVERS TECHNIQUE

VI. Voting Technique.

When redundant sensor channel information is available (analytic or hardware redundancy) voting techniques are useful. These methods work very well for hard failures and certain types of soft failures.

The standard voting process considers three (or more) "identical" signals. A marked deviation in one of the three redundant signals is sufficient to identify a failure. A recent voting scheme is presented in ref. 68 by Broen.

The voting test technique has the following advantages (from ref. 30):

1. Can be applied either directly to the raw measurements prior to possible contamination from subsequent processing or applied to subsequently filtered and therefore further refined estimates of the sources of potential problems; or applied to both.

2. Voting tests can be posed in a form that is compatible for representation as a parity vector/table cross checking to simplify failure isolation.

3. To account for differing accuracies of contributing components, parity equations can be modified from merely being equated to zero, to being equated to a quantity that is operationally equivalent to zero (for all practical purposes) by using variable decision thresholds for comparison. This can provide sufficient additional leeway for expected standard deviations of each participant along with components to account for noise and maneuvers.

4. Sophisticated generalization of the voting test operates on the output of the Kalman filter and gently de-weights dissenting contributions to the overall solution.

The disadvantages of the voting technique include:

1. Detection of hard failure is possible, but only for systems with a high level of parallel redundancy.

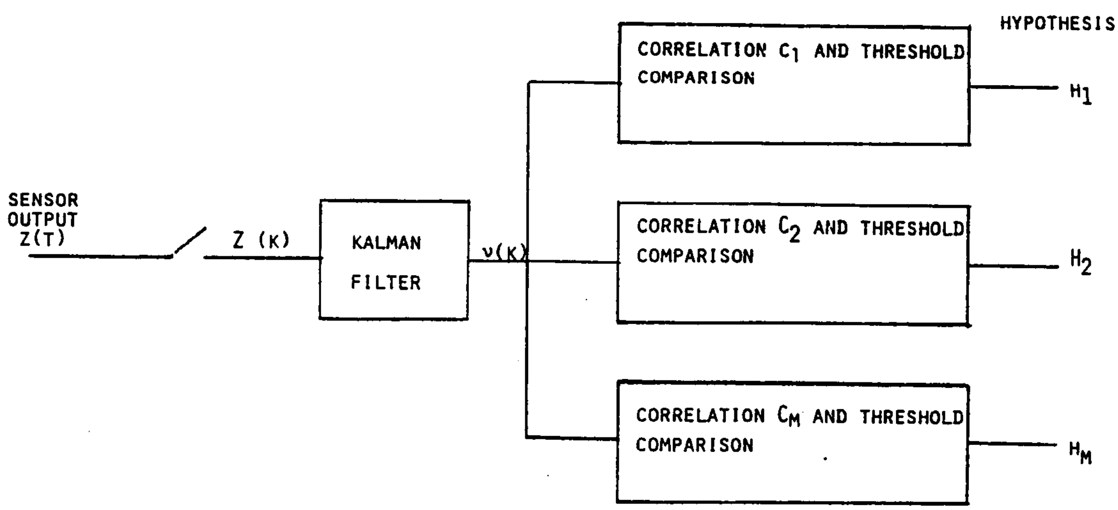
2. Soft failures, like bias shifts, are hard to detect.

VII. Innovations-Based Failure Detection Schemes.

These schemes involve monitoring of the innovations of a filter based on the hypothesis of no-failure operation of the system. For a system described by a set of linear differential equations, a Kalman filter is often used to generate this innovation process (or sequence). Mehira and Peschon (ref. 60) have discussed various innovations in testing for failure detection and isolation. Four detection schemes will be discussed here.

A. Generalized Likelihood Ratio (GLR) Test.

The generalized likelihood ratio (GLR) technique requires existing functional redundancy to extract fault detection information. This technique monitors the output of one Kalman filter, see the block diagram below:



INNOVATIONS BASED DETECTION SCHEME

A bank of simple correlation operations and threshold comparisons is driven by the filter innovations. These very complex correlations were obtained from two papers. The first paper is titled "The Controversy Over Use of SPRT and GLR Techniques and Other Loose-Ends in Failure Detection. The second paper is titled "A Conservative View of the GLR Failure and Event Detection Approaches". See reference 3 and 5 respectively.

The GLR technique detects the onset of abrupt changes in linear systems. It allows simultaneous detection of failure, the time of occurrence of failure and the extent of the failure. The failure of a plant produces a nonwhite residual.

$$\gamma(k) = \gamma'(k) + G_i\,(k,\theta)\gamma \qquad (1)$$

where $\gamma'(k)$ is the residual for the normal operating filter and $G_i(k,\theta)$ describes the effect of failure γ of type "i", occurring at a time θ on a residual at time "k". A set of hypotheses are established to distinguish between failure and no failure modes, as follows:

H_o = No failure mode.
H_i = Failure mode of type "i" (γ and θ unknown)

The generalized likelihood ratio is defined as:

$$L_i(k) = \frac{P\,(\gamma(1),\ldots\gamma(k))/H_i,\ \theta = \hat{\theta}\,(k),\ \gamma = \hat{\gamma}\,(k)}{P(\gamma(1),\ldots\gamma(k))/H_o} \qquad (2)$$

where "P" is the probability density function of the innovations sequence ($\gamma(i)$, $i = 1, \ldots k$), given the hypothesis H_i and given the maximum likelihood estimates of θ and γ.

When a failure occurs, the decision rule for choosing between a failure and no failure is

$$\text{for } H_i \text{ TRUE: } L_i(k)>\lambda_D \qquad (3)$$
$$\text{for } H_o \text{ TRUE: } L_o(k)<\lambda_D$$

where λ_D is a predetermined threshold.

The advantages of this technique are: (1) built in functional relationships allow reduced requirements for multiple redundancy, (2) the technique is computationally feasible, (3) fast failure recovery is obtained since the time of failure occurrence is explicitly determined. The technique therefore does not have oblivious features.

The major disadvantage of this technique is that it is very sensitive to modeling errors. An accurate model is therefore required for a good estimate of failure parameters.

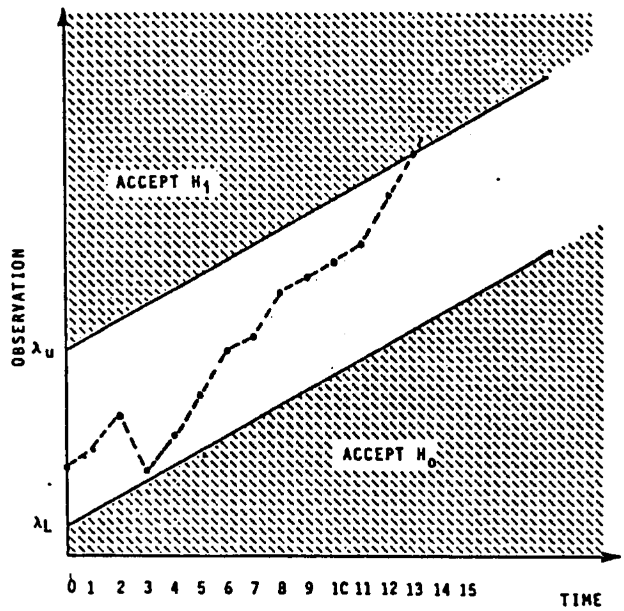
The likelihood ratio (LR) technique is in principle similar to GLR technique except that it does not involve prediction of failure time or the extent of failure. The LR is simply a ratio of two probabilities, i.e.:

$$L_i(k) = \frac{P(\gamma(1),\ldots\gamma(k))/H_i}{P(\gamma(1),\ldots\gamma(k))/H_o} \qquad (4)$$

B. Sequential Probability Ratio Tests (SPRT).

The sequential probability ratio test (SPRT) differs from the likelihood ratio test (LR) in that SPRT compares the likelihood ratio $L_i(k)$ (equation (4)) against two thresholds

If the ratio exceeds one threshold or falls below the other, a decision is made corresponding to the threshold that was crossed (see the schematic below). The decision is, however, deferred until a threshold is crossed.



This technique requires a valid state estimate at each time step for the control logic. Therefore a decision on whether or not a failure has occurred has to be made. This reduces the SPRT to a simple hypothesis test.

C. <u>Weighted Sum Square Residual (WSSR) Test</u>.

This technique was devised to suppress extremely large residuals, obtained from bad sensor data, by modifying the least squares criterion. A very small weighting is given to large residuals. This method essentially involves performing a static test at each point in time, incorporating the new measurement and the predicted estimate of this measurement based on previous data.

To be more specific, this technique (ref. 61) uses filter innovations for decision making. The innovation sequence $\gamma(k)$ is white with known covariance if the model is perfect and there is no failure. In case of a failure the residual becomes:

$$\gamma(k) = \text{White Noise} + \text{Effect of Failure}$$

and the detector is used to identify the failure using a'priori knowledge of white noise covariance and the new statistics.

To detect a failure, one therefore has to compute the quantity, over the last "N" observations.

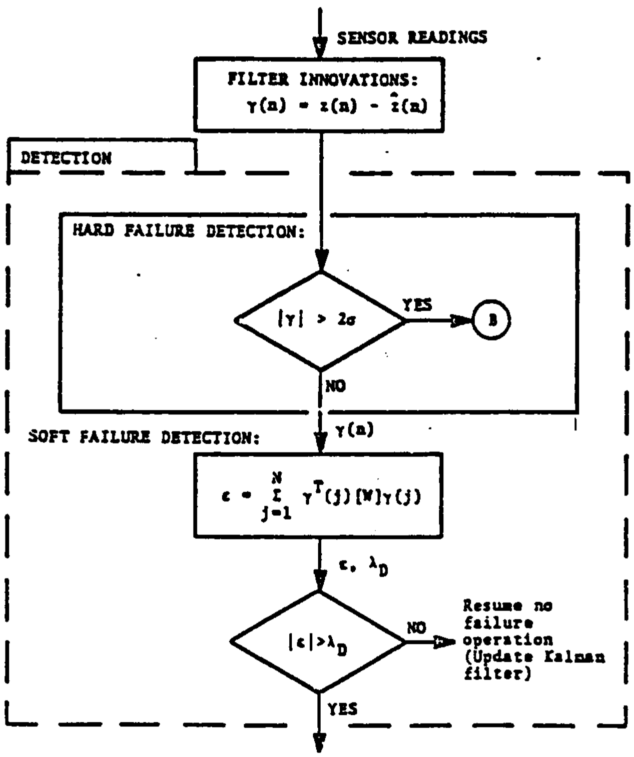
$$l_i(k) = \frac{1}{N} \sum_{j = k - N + 1}^{k} \gamma^T(j) V^{-1}(j) \gamma(j) \tag{5}$$

where $\gamma(j)$ is given by ref. 77.

The quantity $l(k)$ is called the weighted sum square residual. For normal (no failure) operation, $l(k)$ is expected to remain small. However, in case of a failure, $l(k)$ will increase. If λ is the threshold value to make a decision between H_o and H_i, we have:

$$l(k) \begin{cases} < \lambda \text{ implies } H_o \text{ true} \\ > \lambda \text{ implies } H_i \text{ true} \end{cases} \tag{6}$$

The size of "N" and λ are chosen to provide acceptable trade-off between false alarms and misses. A flow chart for this technique is in the figure below:

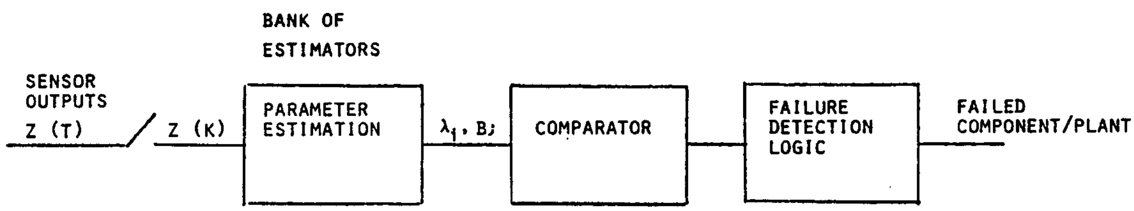


D. <u>Modified Kalman Filter</u>.

This procedure uses the functional redundancy in the system together with a modified Kalman filter as a means of fault detection. Several methods have been developed which modify the design of the Kalman filter to achieve specific requirements. For example, a nonlinear single-stage filter algorithm with filter gains calculated using a linearized system model is discussed in ref. 74. This approach reduces the computational burden of a bank of Kalman filters running in parallel. A second example is the application of nonlinear filtering to failure detection in linear systems. This is discussed in ref. 75. This approach derives linear optimal estimator equations using nonlinear filtering equations. Several other techniques are discussed in ref. 76 and 77. These techniques control the estimate error divergence in the case of a failure.

VIII. Parameter Estimation Technique.

The failure modes (such as scale factor, failure parameters, and bias) are estimated from input and output data. These estimated values are compared with known values and substantial differences between the two indicates a failure. The technique is discussed in ref. 71. A simplified block diagram of the above concept is shown below:



IX. Jump Process Technique.

This technique considers failures as jump processes with known probability distribution (ref. 71). It allows the formulation of failure sensitive control laws and computation of conditional probabilities of failure.

Another technique (ref. 9) based on nonlinear filtering theory reparameterizes the Kalman filter for both tracking the state and detecting a fault. It is, however, limited to specific types of failures. This approach is still in early stages of theoretical development.

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5.0 DATA EXAMINATION RESULTS

This section describes the results of examining data from forty (40) past incident tests (see Figure-1). As outlined in section 2.0, the data included: CRT-time slice plots (CADS and FR sensor measurements) and written documentation. The results are presented under four (4) headings, i.e: general overview, data base support to detection system development, delineation of data base, and data base observations/comments.

5.1 GENERAL OVERVIEW

After screening thru the CRT-data of Figure-1's incident tests (excluding six tests where the incidents occurred after cutoff), 82% revealed pre-cutoff (redline or nominal) indications of an anomaly. Included in the 82% are 20 of 27 major incident tests. The other four tests (approximately 18%) either appeared to reveal no early anomaly indications or the anomaly occurred during a start or throttle transient. A list of these tests along with tests where the incident occurred after cutoff are presented below.

Test Designation	Category
*901-147	Anomaly occurred in the middle of a throttle
*901-222	Anomaly occurred during transient (c/o at 4.3 sec)
901-345	Anomaly occurred after cutoff (c/o)
*902-132	Anomaly occurred during transient (c/o at 2.3 sec)
902-383	Anomaly occurred after cutoff
*750-041	Anomaly occurred after cutoff
*750-160	Anomaly occurred during transient (c/o at 3.2 sec)
750-165	No changes were strikingly indicated
*750-168	Anomaly occurred after cutoff
*SF6-003	Anomaly occurred after cutoff
STS-8	Anomaly occurred after cutoff
FRF-2	No changes were strikingly indicated

*Indicates a major incident

5.2 DATA BASE SUPPORT TO DETECTION SYSTEM DEVELOPMENT

A data base was derived to support the detection system development. This base encompasses the contents of Tables I, IIA, IIB, and III; it ranges from the specific to the general. Tables-IIB thru -III are examples of the specific data; Tables I and Tables IIA are examples of the general. A brief description of and purpose for each table in the system's development are presented on the next page. Each table's contents are described in more detail in section 5.3.

Tables	Brief Background/ Content Description of Tables	Purpose of Tables in the Detection System Development
III-4 thru III-31	These tables were generated for every applicable incident test. Fifty-seven measurements were examined for: •Anomaly induced percentage change from the steady state condition. •Rate of percent change. •Interim from first indications of an anomaly to cutoff (redline or nominal). •Each of the above items were weighted.	-To identify possible sensors for system utilization; the weighing values permit (in most cases) an ease in spotting likely candidates.

Tables	Brief Background/ Content Description of Tables	Purpose of Tables in the Detection System Development
III-1 thru III-3	These tables contain data related to test-to-test sensor measurement envelopes, as well as, the standard deviation (SD) around each sensor measurement's average steady state value. The three SD's (STD1, STD2, and STD3) collectively indicate a sensor's deviation behavior. They also can define different bandwidths around the average steady state sensor measurement, i.e. (from Table III-2 and III-3): BAND1 = AVG1 + STD1 BAND2 = AVG2 + STD2 BAND3= 2 * (3*STD3)	-The sensors identified from the tables above will be further screened for use by Table III-1. For each such selected sensor the worst case bandwidth among BAND1, BAND2, and BAND3 will be used in the sigma value within Figure-6, page 3-9. This figure presents the initial algorithm framework.
IIB-1 thru IIB-32	These tables were generated for every applicable incident test. The tables, for example, describe in all cases, the incident and damage and in most cases the direction of (anomaly induced) changes in selected sensor measurements.	-To identify e.g., how sensitive the system should be to certain anomaly changes (some tests revealed minimal damage). -To be part of a sensor malfunction determining scheme.

Tables	Brief Background/ Content Description of Tables	Purpose of Tables in the Detection System Development
I thru IIA-6	These tables were generated for six (6) failure types (see Figure-1, page 2). They generalize and summarize the anomaly indicating characteristics.	-To assist in defining specific anomaly characteristics which the detection system should be able to detect (in conjunction with the content set of Table IIB).

5.3 DELINEATION OF DATA BASE

As noted in the previous section, the data base consists of three (3) tables. They are headed and subdivided as follows:

1. Criteria Table

TABLE III

SUB-DIVISIONS	CONTENT
III-1	Summary of Sensor Standard Deviations
III-2	Test-to-Test Envelope Data Base Definition
III-3	Data Base for Time Sliced Value Deviations from the Average Steady State Sensor Measurement
	Criteria Tables for Tests:
	w/Injector Failure
III-4	901-173
III-5	901-331
III-6	750-148
III-7	901-183
III-8	902-198
III-9	901-307
III-10	SF10-01
	w/Control Failure
III-11	901-284
	w/Duct, Manifold Failure
III-12	750-259
III-13	901-485
III-14	750-175
III-15	902-112
	w/Valve Failure
III-16	SF6-001
III-17	901-225
	w/HPOTP Failure
III-18	901-110
III-19	901-136
III-20	902-120
	w/HPFTP Failure
III-21	901-340
III-22	901-363
III-23	902-118
III-24	901-436
III-25	901-364
III-26	902-209
III-27	902-249
III-28	902-095
III-29	901-346
III-30	901-362
III-31	901-410

2. Generic Characteristic Table

TABLE II

SUB-DIVISIONS	CONTENT
	Characteristics for:
IIA-1	Injector Failure
IIA-2	Control Failure
IIA-3	Duct, Manifold, HX Failure
IIA-4	Valve Failure
IIA-5	HPOTP Failure
IIA-6	HPFTP Failure
	Failure Summary for Tests:
	w/Injector Failure
IIB-1	901-173
IIB-2	901-331
IIB-3	750-148
IIB-4	901-183
IIB-5	902-198
IIB-6	901-307
IIB-7	SF10-01
	w/Control Failure
IIB-8	901-284
	w/Duct Manifold Failure
IIB-9	750-259
IIB-10	901-485
IIB-11	750-175
IIB-12	902-112
	w/Valve Failure
IIB-13	SF6-01
IIB-14	901-225
	w/HPOTP Failure
IIB-15	901-110
IIB-16	901-136
IIB-17	902-120
	w/HPFTP Failure
IIB-18	901-340
IIB-19	901-363
IIB-20	902-118
IIB-21	901-436
IIB-22	901-364
IIB-23	902-209
IIB-24	902-249
IIB-25	902-095
IIB-26	901-346
IIB-27	901-362
IIB-28	901-410
	w/Anomalies During Transients
IIB-29	901-222*
IIB-30	902-132*
IIB-31	750-160*
IIB-32	901-147*

3. Range & Damage Summary Table

TABLE I

SUB-DIVISIONS	CONTENT
	Range & Damage for:
I-1	Injector -MCC Failure
I-2	Injector -FPB Failure
I-3	Control Failure
I-4	Duct, Manifold, HX-Failure
I-5	Valve Failure
I-6	HPOTP Failure
I-7	HPFTP Failure

The tables above (with four exceptions) focus on anomalies occurring at steady state operation**. This section delineates the contents of each table.

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**NOTE: A definitive cutoff criteria when anomaly induced changes occur during start or throttle should be formulated in a future study. For this latter study sufficient test data should be gathered to adequately define the "nominal" start and throttle profiles. The four (4) incident tests which should be studied are identified with asterisks (*) in the table listing. Tables IIB-29 thru IIB-32 contain descriptions of the incident and damage, exclusive.

Criteria Tables, Table III. Each of 57-sensor measurements (derived for each test time slice) was examined for its pre-cutoff (anomaly induced) percentage change from the steady-state condition, the rate of percent change, and the interim from first indication of an anomaly to cutoff. The latter measurement data were weighted (subjectively) to more easily identify possible sensors for detection system development use. The results for twenty-eight (28) incident tests are presented in Tables III-4 thru III-31. In addition to these results the information/data below are included in the tables:

1. A brief description of the test.

2. A summary of the damage and impact (cost and delay time).

3. A schematic describing the terms used within the table.

4. Weighting provisions for sensor algorithm selection.

Tables III-1 thru III-3 contain measurements of each sensor's variance during steady-state conditions. Table III-1 will be used to refine the selection of detection system sensors, initially assembled from Tables III-4 thru III-28 and assist in other algorithm definitions (as listed on page 5-2). Table III-1 lists three standard deviations. Two standard deviations (STD1 and STD2 in Table III-1) reflect a sensor's test-to-test envelope variance and are derived from test envelope measurements at 2-seconds and 10-seconds from the first early indication of an anomaly. Table III-2 (in three pages) presents a schematic illustrating the necessity of a 2-second and 10-second envelope measurement for each test. Table III-2 also lists the data source of the sensor standard deviations, i.e. ten (10) tests and their corresponding average (under the headings AVG1 and AVG2 in Table III-2). STD3 in Table III-1 measures a sensor's variance around its average steady state value. Table III-3 schematically illustrates the type and volume of data encompassed in this standard deviation. Where available, STD3's standard deviation was assigned from the derivation of data taken every 20 milliseconds over a 5-second interval (generated by New Technology Inc. of Hunstville, Alabama); and where the latter data was unavailable, STD3's value was assigned from the derivation of data taken every 100 milliseconds over a 1-second interval. A comparison in Table III-3 of these two standard deviations (where both existed) reveals a close agreement in most cases.

Using Table III's data set, a list of possible sensor measurements which may be utilized during the detection system development is presented in Figure-5 (of section 3.0).

Generic Characteristic Tables, Table II. These tables describe the generic characteristics of six failure types with examples of sensor measurement traces, as well as describing the anomaly characteristics for individual incident tests. The tables are subdivided into Table IIA and Table IIB. These tables are further subdivided as shown on page 5-3 and are described for content below:

Table IIA — The elements of this subdivision narrate the generic characteristics for six failure types and displays examples of sensor measurement traces.

Table IIB The elements of this subdivision describe the anomaly characteristics for individual incident tests thru:

1. A narration of the incident.

2. A description of the engine/facility damage, along with a schematic.

3. A time line of anomaly indicative parameters, along with the direction of change, and the excursion and duration interval. There are four (4) exceptions to this content; these are tests where the anomaly occurred during a transient.

The data set of Table IIB will be used to identify how sensitive the detection system should be to certain anomaly changes (i.e. some tests revealed minimal damage). Table IIB's parameter direction of change data will be used (along with verification incident tests* and other approaches) to develop the detection system's sensor malfunction decision logic.

*NOTE: Use will be made of the sensor malfunctions which occurred in the twenty-eight incident tests examined. They are summarized here:

Sensor Malfunctions

Sensor Identification	Test No.(s) of Occurence
INJ CLNR PR-MCC HG IN PR	901-225
MCC HG IN PR- MCC PC	901-225
HPFT Delta-P	901-225
HPOT Delta-P	901-225
MCC FU INJ PR	750-148
MCC LN CAV PR	901-331, 750-148, 902-198, 901-284, 750-259, 901-485, 901-363, 901-364, 902-209, 902-249, 901-362, 901-410, 901-436
MCC CLNT DS T	901-363, 902-209, 902-095
MCC OX INJ T	901-410
FAC FU FL CT	901-331
HPFP BAL CAV PR	901-110, 901-364
HPFT DS T1 B	750-148, 901-284, 902-209, 902-095
ENG FU FLOW CT	901-183
PBP DS PR	901-331, 901-284
FAC OX FLOW CT	901-183, 901-307
FAC OX FLOW	901-307
HPOT DS T2	901-284
HPFP DR TEMP	750-259
HX INT T	901-225

Range & Damage Summary Tables, Table I. A data summary of the anomaly indicative parameters in Table IIB are presented in these tables by failure type. This summary is in the form of a data range for the direction of change and the excursion and duration interval. A data range is also defined for the direction of percentage change from steady state conditions. The table concludes with a schematic summary of either the test-to-test damage or the location of the damage source by failure type. The subdivisions of this table are presented on page 5-3.

Tables I and IIA have been used to define three basic failure characteristics which the detection system should be able to detect. These characteristics consist of anomalies which occur:

1. Shortly after a scheduled transient.

    a. "Shortly after" is the approximate interim of +1 to <+3 seconds after the completion time of the scheduled transient.

    b. "Scheduled transient" is defined as a start, throttle, or tank venting.

2. Well after a scheduled transient and occur slowly.

    a. "Well after" is approximately $\geq$+3 seconds after the completion time of the scheduled transient.

    b. "Occur slowly" is where major damage occurs approximately 5 to 300+ seconds after the first anomaly indications.

3. Well after a scheduled transient and occur rapidly.

    a. "Well after" has the same general definition as above.

    b. "Occur rapidly" is where major damage occurs approximately <5 seconds after the first anomaly indications.

5.4 DATA BASE OBSERVATIONS/COMMENTS

This section concludes with data base comments, incident test observations, and/or lessons learned from incident tests (other than re-design needs or life related discoveries).

These topics will be presented by failure type with the following outline structure:

I. Injector Failure.
II. Control Failure.
III. Duct, Manifold, and Heat Exchanger Failure.
IV. Valve Failure.
V. HPOTP (High Pressure Oxidizer Turbopump) Failure.
VI. HPFTP (High Pressure Fuel Turbopump) Failure.

I. Injector Failure

A. Sensitive Sensors. The injector failure sensors listed within Tables I thru IIB were chosen based on:

1. A sensor's closeness to the Level A+B criteria maximum (2.0), see Table III-4 for an example of what is meant by a Level A+B criteria.

2. Item-1's condition is true for the majority of injector failure tests. One of five MCC injector failure tests e.g. was cutoff earlier than the other tests by a malfunctioning sensor. This test's parameters therefore reflect low percentage change from steady state values (less than 1%) as well as low Level A+B values, see Table I-1.

3. The anomaly tests listed below.

MCC Injector Failure Type	FPB Injector Failure Type
Test 901-173	Test 901-307
Test 901-331	SF10-01
Test 902-198	
Test 901-183	
Test 750-148	

B. Injector Failure, Sensitive Sensor Observations. Nine of the fourteen MCC-injector failure sensors (in Table I-1) show the same direction of change for all five data base tests; the remaining five parameters have different directions depending on the extent of damage. For the cases where the secondary and primary faceplates were burned through e.g. the injector hotgas delta-P trace consistently shows a rise from steady state conditions (see Table IIB-1 thru IIB-3). A consistent drop in injector hotgas delta-P is shown if only the primary faceplate was burned through (see Table IIB-4 and IIB-5).

Another observation can be noted in regards to the latter two types of faceplate damage. For burn throughs of only the primary faceplate the algorithm has more than 2.9 seconds for cutoff assessment and implementation; for burn throughs of both the primary and secondary faceplates, the algorithm has less than 1-second.

NOTE: Due to the different damage sources for the preburner injector failures (Test 901-307 and SF10-01), a common direction or trend of anomaly change cannot be defined.

II. Control Failure

A. Sensitive Sensors. The sensors listed in Tables I-3, IIA-2, and IIB-8 were:

1. Based on Test 901-284. This test represents an incident where the engine was miscontrolled due to erroneous chamber pressure measurements.

2. Chosen to match some of the parameters selected for the MCC or FPB injector failures (if the sensors were available).

B. Sensor Observations. Almost all of the available sensor measurements for this miscontrolled chamber pressure failure reflected:

1. Large changes (>3%) in steady state conditions.

2. Maximum Level A+B criteria values (see Table III-11).

3. A time interval between first indications of an anomaly to redline cutoff of approximately 6 seconds.

III. Duct, Manifold, and Heat Exchanger Failure

A. Sensitive Sensors. The sensor measurement ranges presented in Table I-4 are based on the following tests:

750-175
750-259
901-485
902-112

B. <u>Sensor Observations</u>. Half of the above tests reflected sensor measurement changes (induced by an anomaly) which had a duration interval* of less than 500 msec.

*See Table I-4 for a schematic definition of this interval.

C. <u>Lessons Learned</u>. One the tests which had less than a 500 msec duration interval (Test 750-175) provided a lesson on the need for more extensive analysis and testing. Catastrophic failure of the high pressure oxidizer duct was initiated by a high cycle fatigue (HCF) crack adjacent to a specially developed ultrasonicflow transducer. The high cycle fatigue was caused by a combination of thinning the duct wall to install the transducer blocks, physically adding the block masses to the duct, and increasing local stresses brought about by brazing the blocks to the duct wall. From Rocketdyne's incident report (cited in Table IIB-11): "...it is clear that brazed joints are not to be relied upon for HCF application without extensive analysis and testing. The HCF properties of Rocketdyne braze alloys do not exist, but should be presumed to be lower than parent metal properties. Braze fillet geometry is difficult to control, and the surface of braze fillets inherently have shrinkage voids. Therefore, relying on braze fillets to reduce stress concentration is unconservative".

Test 902-112 (another test with less than a 500 msec duration interval) provided insight on relocation of a redline sensor. In this test the facility fuel inlet Franz-screen was partially blocked by solidified nitrogen. Nitrogen was inadvertently introduced into the tank during chilling. Cavitation of both HPFP (High Pressure Fuel Pump) and LPFP (Low Pressure Fuel Pump) occurred due to the LPFP inlet pressure dropping below zero psig. From Rocketdyne's incident summary sheet the facility hardware and procedures were revised; and the fuel inlet pressure redline was relocated from the tank bottom to below the valve and screen.

IV. Valve Failure

A. Sensitive Sensors. The sensor measurement ranges in Table I-5 are based on Test 901-225 and SF6-01.

B. Sensor Observations. In both test cases the measurement changes (induced by an anomaly) had a duration interval of less than 500 msec.

V. HPOTP Failure

A. Sensitive Sensors. The sensor measurement ranges in Table I-6 are based on Test 901-110, 901-136 and 902-120.

B. Sensor Observations. In all cases the measurement changes (induced by an anomaly) had a duration interval greater than 500 msec, however, the percentage change from steady-state conditions was less than 2% in some cases.

C. Lessons Learned. Test 902-120 provided a lesson on the need for more analysis and testing. Failure of the HPOTP was centered on the first time use of a capacitance device which was designed to determine HPOTP shaft, bearing, and bearing cartridge movement. Rubbing between the device pads and speed nut ignited a fire which burned into the turbine end bearings and main pump. From Rocketdyne's incident report (cited in Table IIB-17): "...the following changes were therefore recommended before testing of the HPOTP could be resumed:

1. No capacitance device.
2. Increase the LOX seal slinger clearance.
3. Eliminate round-cornered cup washers.

VI. HPFTP Failure

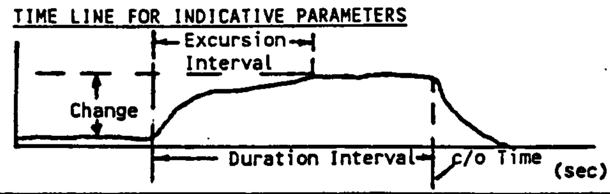
A. Sensitive Sensors. The measurement ranges in Table I-7 were based on eleven incident tests:

901-340	901-364	901-346
901-363	902-209	901-362
902-118	902-095	901-410
901-436	902-249	

B. Sensor Observations. All tests under this category appear to possess sufficient sensors which have large duration intervals (as much as 200 to 300 seconds) and large changes from steady state conditions (>3%).

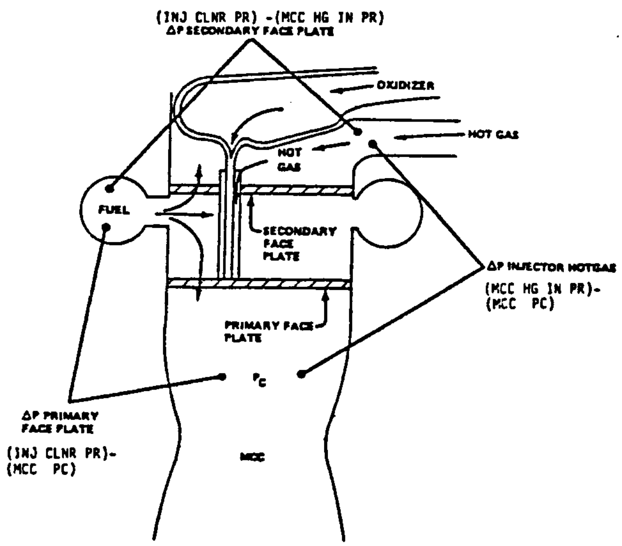
C. Lessons Learned. Test 901-364 (Kaiser Hat Failure) provided a lesson on the need for more analysis and testing. From NASA's incident report (as cited in Table IIB-22): "During the investigation, it was established that all changes, including the nut which caused this failure, (were) reviewed formally both by Rocketdyne and NASA. Late changes to a design, such as the undercut feature of this nut, may not have had the thorough evaluation that the original design had been given. The undercut was made for structural consideration and its significance as a potential flow path cause apparently was overlooked." A schematic of this nut is presented in Table IIB-22.

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:



Type of Incident	Tests Used for Data Range	Comments (if necessary)
Injector (MCC)	901-173 901-183 901-331 902-198 750-148	The two schematics below respectively define the measurement for the adjacent delta-P indicative parameters and the MCC injector burn areas for four of the tests used in deriving the adjacent value ranges.

Sample Indicative Parameters	Range of Percent Change from Steady State	Range of Rate of Change (psi/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
Secondary faceplate delta-P	-157. to -4.17	-666.7 to -5.7	.12 - 4.8	.48 - 27.1
Primary faceplate delta-P	-50.7 to -5.33	-589.3 to -8.4	.15 - 3.5	.48 - 26.8
Hotgas injector delta-P	-21.8 to +17.6	-44.1 to +562.5	.08 -1.45	.48 - 26.5
MCC OX Inlet PR - MCC PC	-9.9 to +25.5	-862.5 to +200.0	.10 - 2.2	.10 - 26.9
HPFP Disch PR - MCC PC	-9.0 to +.77	-1500. to -33.3	.10 - .60	.36 - 27.0
FPB PC - MCC HG IN PR	-4.2 to +5.3	-750. to +216.2	.10 - .50	.60 - 2.75
OPB PC - MCC HG IN PR	-5.55 to +6.63	-1000. to +92.3	.10 - 1.3	.63 - 3.00
MCC PC	-6.43 to -.27	-1000. to -39.5	.11 - .48	.48 -26.89
MCC CL DS T	+1.04 to +12.5	+1.5 to +101.9	.52 - 3.2	.52 - 26.5
HPFT DS T1 A	+1.6 to +84.1	+260 to +3625	.10 - .50	.36 - 26.6
HPFT DS T1 B	+1.4 to +10.7	+147 to +583	.15 - .40	.36 - 26.6
HPOT DS T1	+.53 to +41.0	+24 to +1620	.25 - .74	.36 - 26.6
HPOT DS T2	+.28 to +40.0	+12 to +1560	.25 - .75	.36 - 26.6
LPOP DS PR	-4.73 to +5.76	-66.8 to +170.	.10 - .36	.36 - 2.9



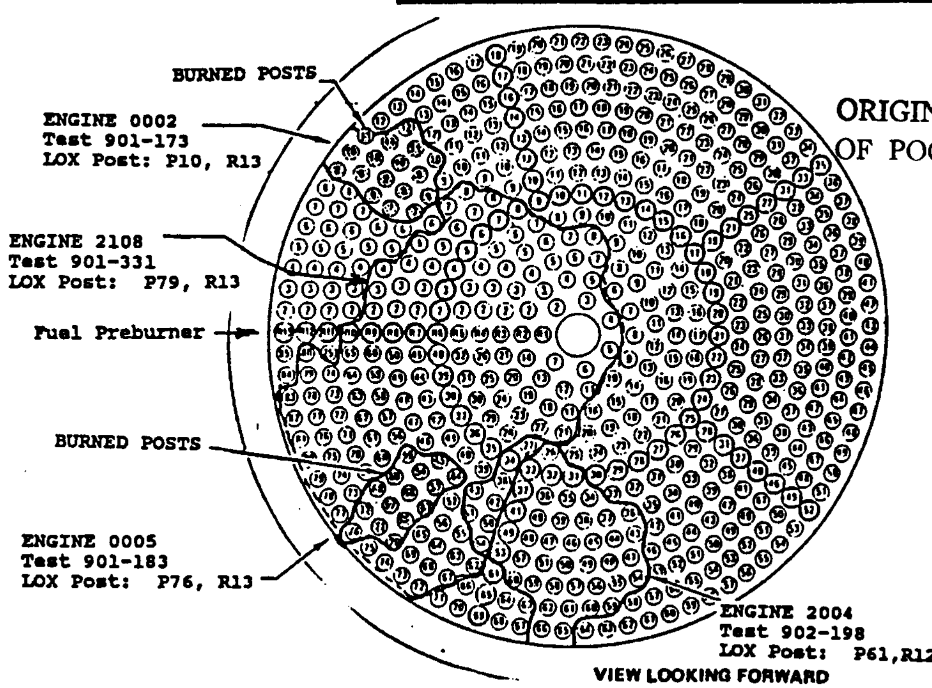
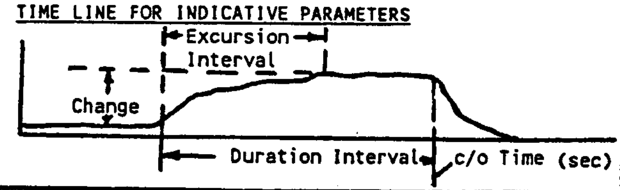


Table I-1: Indicative Parameter Data Range of Incident Types (Injector - MCC)

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Tests Used for Data Range	Comments (if necessary)	Sample Indicative Parameters	Range of Percent Change from Steady State	Rate of Change Range (psi/sec, (pos/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
Injector (FPB)	901-307 SF10-01	The schematic below summarizes the FPB injector burn areas.	HPFT DS T1 A	-4.0 to +6.3	-17.4 to 324.	.25 - 3.5	5.15 -14.0
			HPFT DS T1 B	-4.6 to +5.3	-1.1 to 413.	.15 - 44.	5.15 -44.0
			HPFP CL LR PR-MCC HG IN PR	-25.	-60.0	.5	20.3
			MCC OX Inlet PR - MCC PC	-8.	-.89	28.0	28.0
			HPOT DS T1	-4.4 to +8.	-1.80 to 25.	3.2 -26.0	5.2 - 26.0
			HPOT DS T2	-4.5 to +9.	-1.75 to 26.6	3.2 -28.0	5.2 - 28.0
			LPOP DS PR	-9.2	-.71	31.0	31.0
			OPOV ACT POS	-3.4 to +3.43	-.2 to .88	2.5 - 9.0	5.2 - 37.0

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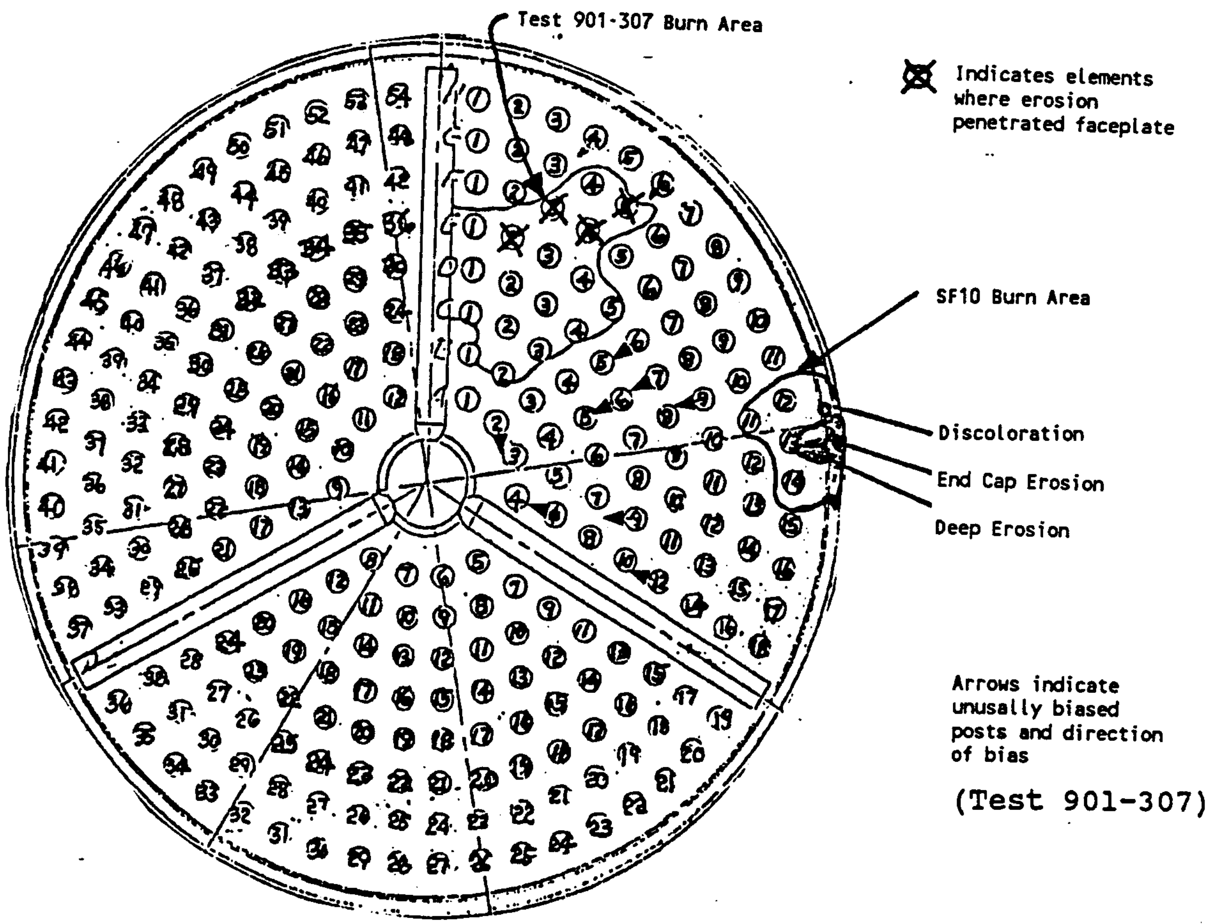
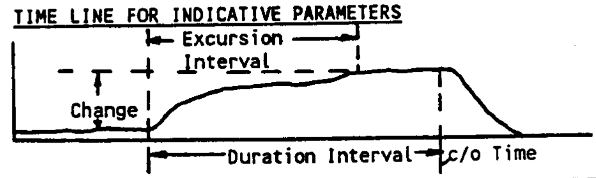


Table I-2: Indicative Parameter Data Range of Incident Types (Injector - FPB)

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:



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Type of Incident	Tests Used for Data Range	Comments (if necessary)	Sample Indicative Parameters	Range of Percent Change from Steady State	Rate of Change Range (psi/sec, (pos/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
Control Failure	901-284	The schematic below illustrates the Lee Jet orifice which dislodged and caused an erroneous sensed value (for the chamber pressure) to the engine Controller.	HPFP DS PR - MCC PC delta-P	-70.	-2961.5	.65	6.03
			MCC PC	+31.	+18000.0	.05	6.03
			HPFT DS T1 A	-25.1	-394.65	.35	6.01
			HPOT DS T1	-69.7	-495.	2.0	5.88
			LPOP DS PR	+28.6	+500.	.2	5.76
			OPOV ACT POS	-31.7	-71.4	.28	6.03

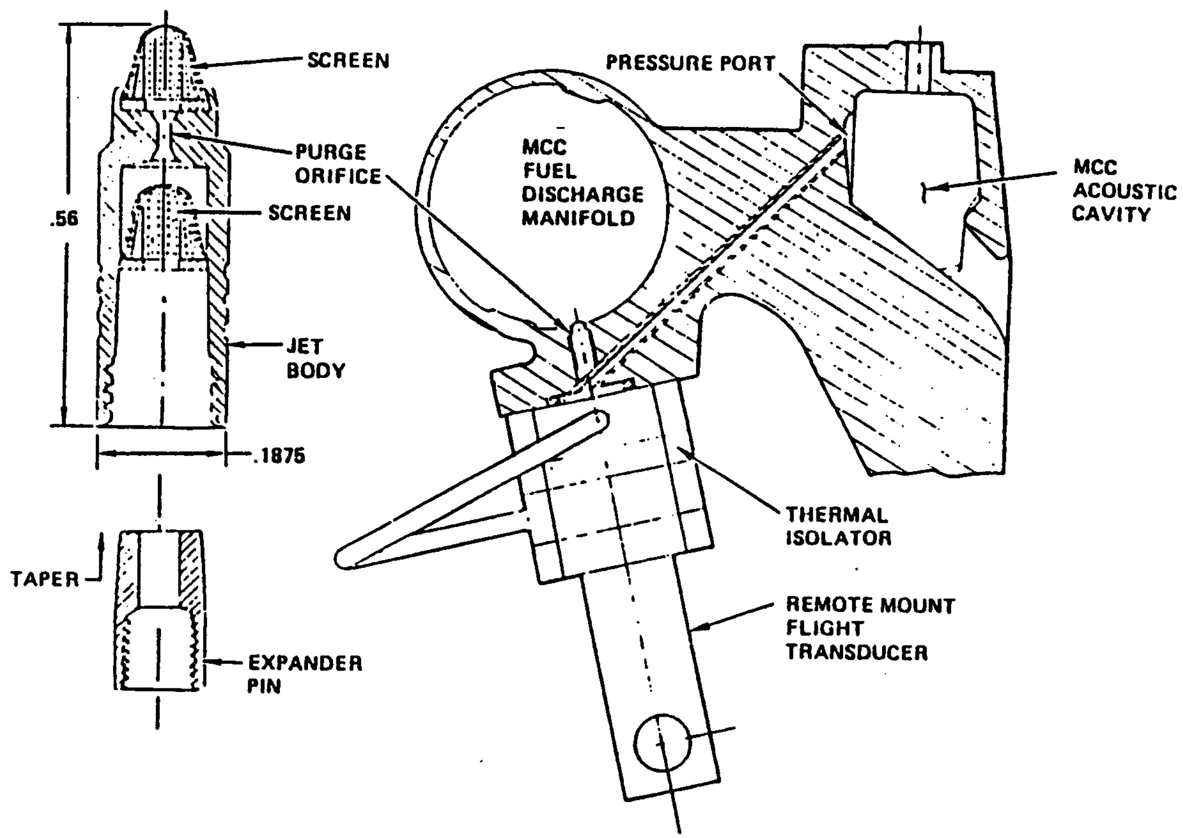
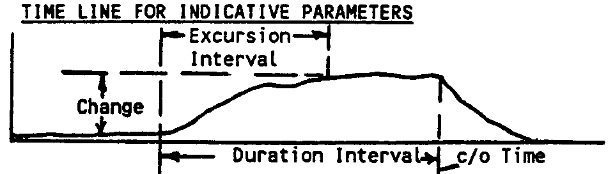


Table I-3: Indicative Parameter Data Range of Incident Types (Control Failure - Erroneous Sensor, Lee Jet)

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:

TIME LINE FOR INDICATIVE PARAMETERS



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Type of Incident	Tests Used for Data Range	Comments (if necessary)	Sample Indicative Parameters	Range of Percent Change from Steady State	Rate of Change Range (psi/sec, (rpm/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
Duct, Manifold, or Heat Exchange Failure	750-175 750-259 901-485 902-112	The value ranges on the right were derived from the listed anomaly tests on the left. The schematic below summarizes the system location of the points of failure for each test, i.e.: the high pressure oxidizer duct, the MCC outlet manifold, the nozzle tube, and the fuel pump inlet duct.	Hotgas Injector delta-P	-100.	-4281.3	.16	.16
			MCC OX Inlet PR - MCC PC	-484.6 to -92.1	-45000 to -3625	.07 - .16	.07 - .16
			FPB PC - MCC HG IN PR	+4.1 to +6.2	+200 to +888.9	.09 - .5	.22 - .5
			OPB PC - MCC HG IN PR	+5.7	+3833.3	.03	.16
			MCC PC	-3.9 to -3.3	-673.7 to -163.6	.19 - .55	.19 - .55
			MCC CL DS T	-275 to -24.7	-15714 to -2300	.05 - .07	.05 - .19
			HPFP SPEED	-5.4 to +27.7	-66667 to +66420	.03 - .45	.06 - .45
			HPFT DS T1 A	-61 to +23.8	-47000 to +690.9	.05 - .55	.05 - .55
			HPFT DS T1 B	-33 to +21.6	-11800 to +1882.4	.05 - .17	.05 - .17
			HPOT DS T1	-33.3 to +7.4	-16667 to +234	.03 - 8.1	.03 - 8.1
			HPOT DS T2	-33.3 to +9.0	-16667 to +600	.03 - 8.0	.03 - 8.0
			LPOP DS PR	-48.3 to -4.4	-2800 to -97.1	.05 - .19	.05 - .19

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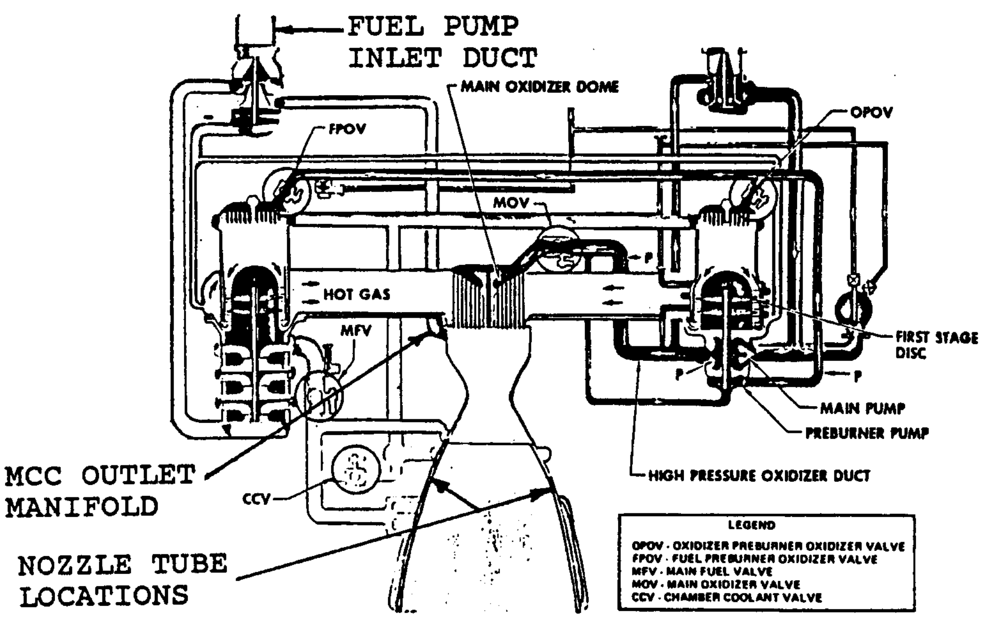
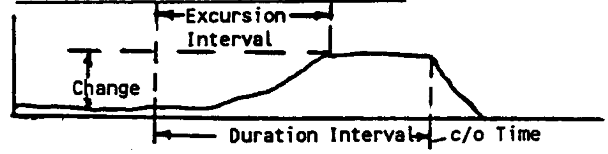


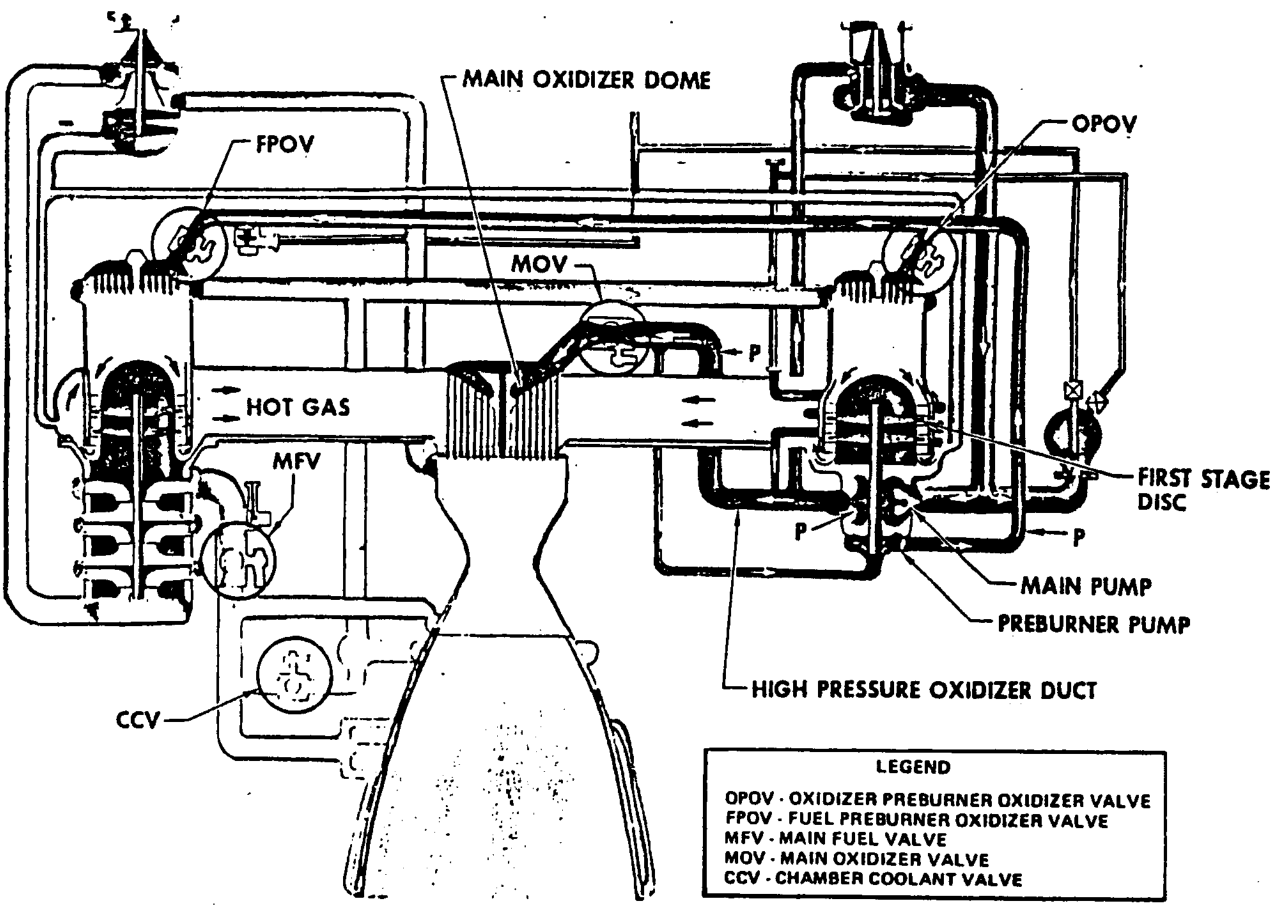
Table I-4: Indicative Parameter Data Range of Incident Types (Duct, Manifold, or Heat Exchanger Failure)

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:

TIME LINE FOR INDICATIVE PARAMETERS



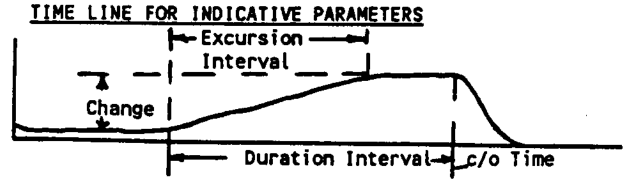
Type of Incident	Tests Used for Data Range	Comments (if necessary)	Sample Indicative Parameters	Range of Percent Change from Steady State	Rate of Change Range (psi/sec, (rpm/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
Valve Failure	901-225 SF6-01	The value ranges on the right were derived from the listed anomaly tests on the left. The schematic below summarizes the system location of the valve failures for each test, i.e.: the MOV and the MFV.	MCC PC	-5 to +6	-3750 to +9000	.02-.04	.12-.14
			HPFT DS T1 A	+15 to +30	+2750 to +4875	.08-.10	.08-.10
			HPFT DS T1 B	+15 to +29	+2750 to +4500	.08-.10	.08-.10
			HPOT DS T1	+12 to +36	+2000 to +4000	.08	.08
			HPOT DS T2	+12 to +36	+2000 to +4000	.08	.08
			HPFP SPEED	+4.2	+30000	.05	.05
			MCC OX IN PR-MCC PC	+38.9	+7000	.04	.10
			Primary faceplate delta-P	-12.9	-1000	.04	.10



SSME Propellant Flow Schematic

Table I-5: Indicative Parameter Data Range of Incident Types (Valve Failure)

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:



Type of Incident	Tests Used for Data Range	Comments (if necessary)
HPOTP Failure	901-110 901-136 902-120	The value ranges on the right were derived from the listed anomaly tests on the left. The schematic below summarizes some of the High Pressure Oxidizer Turbopump failure points, e.g: bearings (BRG), and the special capacitance device.

Sample Indicative Parameters	Range of Percent Change from Steady State	Rate of Change Range (pos/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
HPOT DS T1	+1.4 to +1.7	+2.3 to +31.4	.7 - 11.	16.3 - 25.0
HPOT DS T2	+1.5 to +1.8	+2.7 to +28.6	.7 - 11.	16.3 - 25.0
HPOT PRSL DR T	-32 to +1.3	-370 to +1.46	1. -10.3	14.0 - 17.8
OPOV ACT POS	+.5 to +3.0	+.21 to +100.	.02-25.0	.02 - 25.0

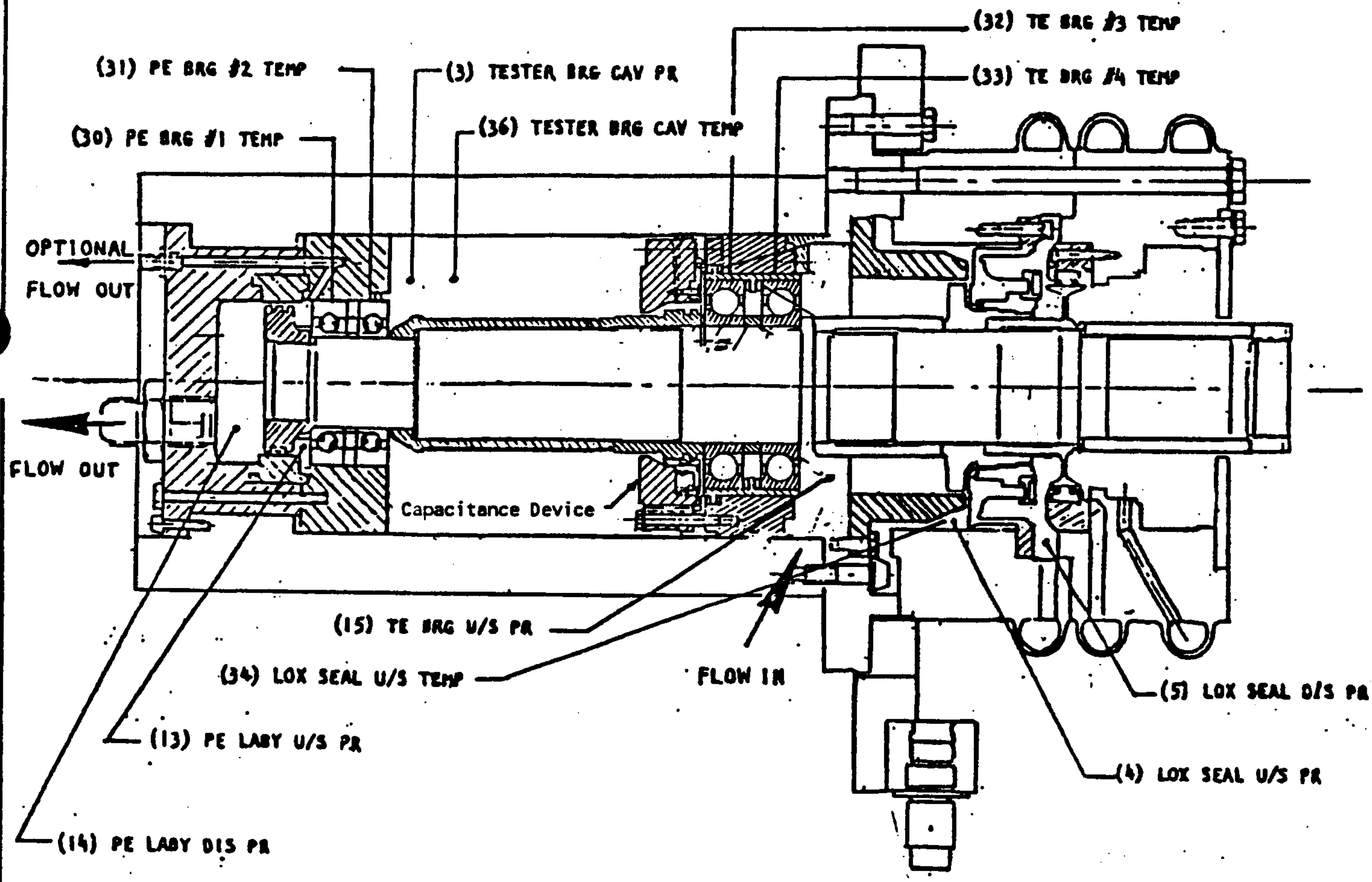
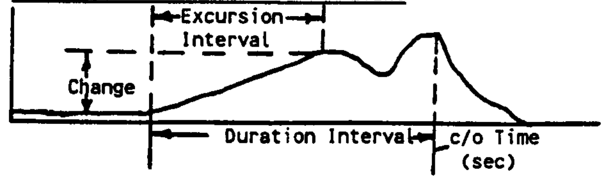


Table I-6: Indicative Parameter Data Range of Incident Types (High Pressure Oxidizer Turbopump (HPOTP) Failure)

INDICATIVE PARAMETER DATA RANGE OF INCIDENT TYPES:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Tests Used for Data Range	Comments (if necessary)	Sample Indicative Parameters	Range of Percent Change from Steady State	Rate of Change Range (psi/sec, rpm/sec, pos/sec, or deg/sec)	Range of Excursion Interval	Range of Duration Interval
HPFTP Failure	901-340 901-363 902-118 901-436 901-364 902-209 902-249 902-095 901-346 901-362 901-410	The value ranges on the right were derived from the listed anomaly tests on the left. The schematic below summarizes some of the High Pressure Fuel Turbopump (HPFTP) failure points, e.g: at the turn around duct, nut, Kaiser cap, and 2nd stage seal.	HPFP CL LNR PR - MCC HG IN PR	-21.1 to +89.7	-23.0 to +55.5	1.1-222.	1.34-400.
			HPFT Delta-P	-2.8 to +18.7	-16. to +467.7	.62 - 92.	.62 - 260.
			HPOT Delta-P	-3.1 to +5.95	-.91 to +161.3	.62 - 69.	.62 -186.2
			HPFP SPEED	-5.7 to +2.90	-4255 to +375.0	.15 -400.	.19 - 485.
			HPFT DS T1 A	-7.3 to +20.0	-1300 to +686.3	.10 -200.	.51 - 495.
			HPFT DS T1 B	-3.2 to +22.8	-10. to +764.7	.40 -210.	.51 -384.9
			HPOT DS T1	-5.3 to +5.30	-22.4 to +237.5	.16 -190.	.16 - 485.
			HPOT DS T2	-6.3 to +9.33	-22.4 to +200.0	.11 -190.	.11 - 485.
			FPOV ACT POS	-3.5 to 11.90	-.99 to + 19.0	.51 -200.	.51 - 345.

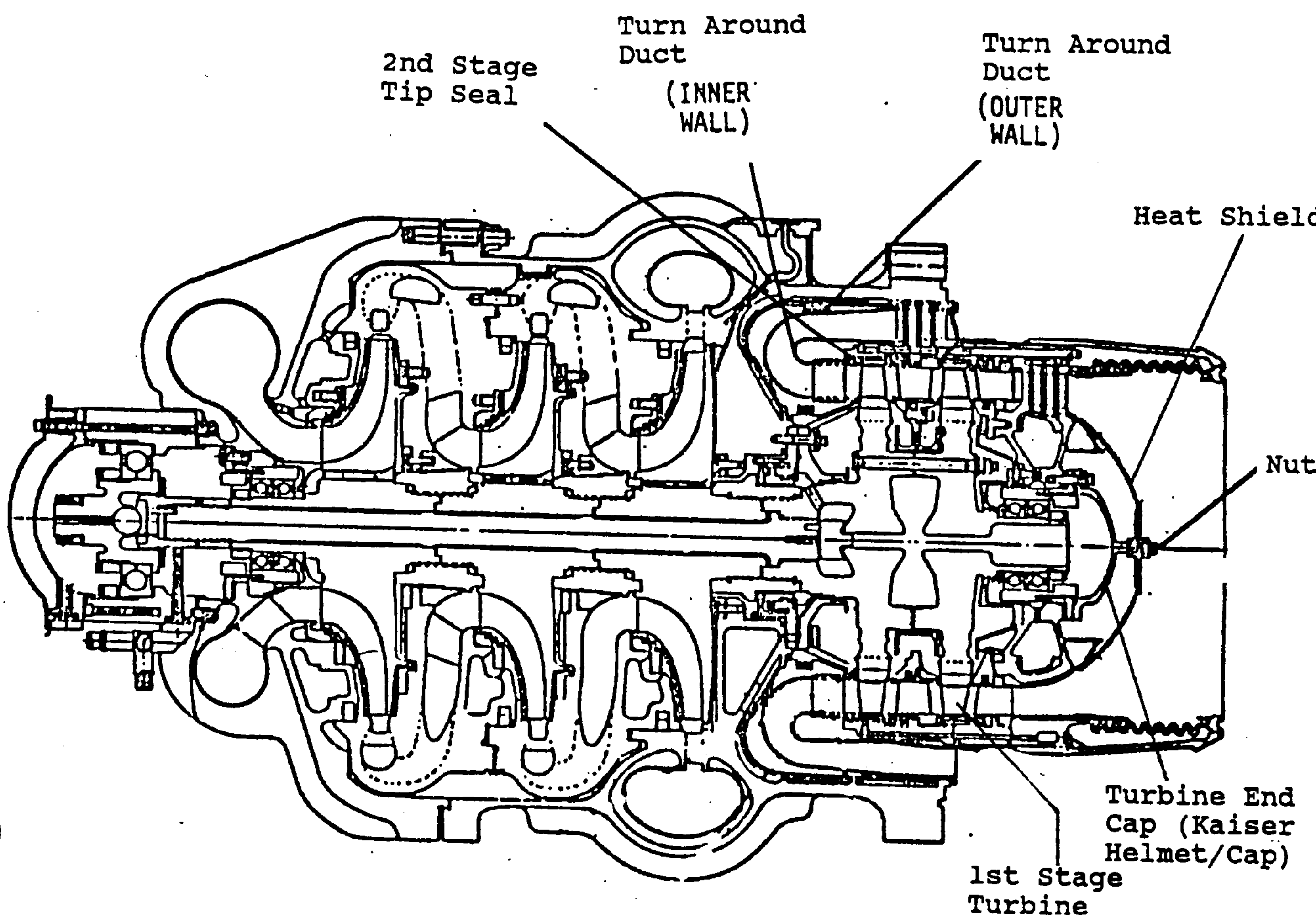


Table I-7: Indicative Parameter Data Range of Incident Types (High Pressure Fuel Turbopump (HPFTP) Failure)

FAILURE MODE QUALITATIVE CHARACTERISTICS:

Type of Incident	Generic Description of Incident Type and Sample Indicative Parameters:
Injector (MCC and FPB)	The MCC (Main Combustion Chamber) injector anomalies observed in five-previous SSME tests can be characterized as being initiated from a LOX injector post element failure. This failure is followed briefly by:

1. Additional damage to other posts and a burn through of either the primary and secondary faceplate, or primary faceplate exclusive.
2. Ejection of burned debris causing damage to the MCC liner and severe damage to the nozzle tubes.
3. A loss in C-star efficiency and the associated MCC pressure.
4. The controller opening of the OPOV (Oxidizer Preburner Oxidizer Valve) in response to the loss of MCC pressure.
5. One of the high pressure turbines exceeding its redline temperature with the above controller response and fuel loss to the preburners.

The FPB (Fuel Preburner) injector anomalies observed in two-previous tests also can be characterized as being initiated from a failure of a LOX injector element post. This causes subsequent damage to other posts, the fuel preburner injector, and moderate to severe damage to the HPFT blades.

MCC Injector Anomaly

Sample Indicative Parameters — CRT Example of the Indicative Parameter's Anomaly Change From Steady State

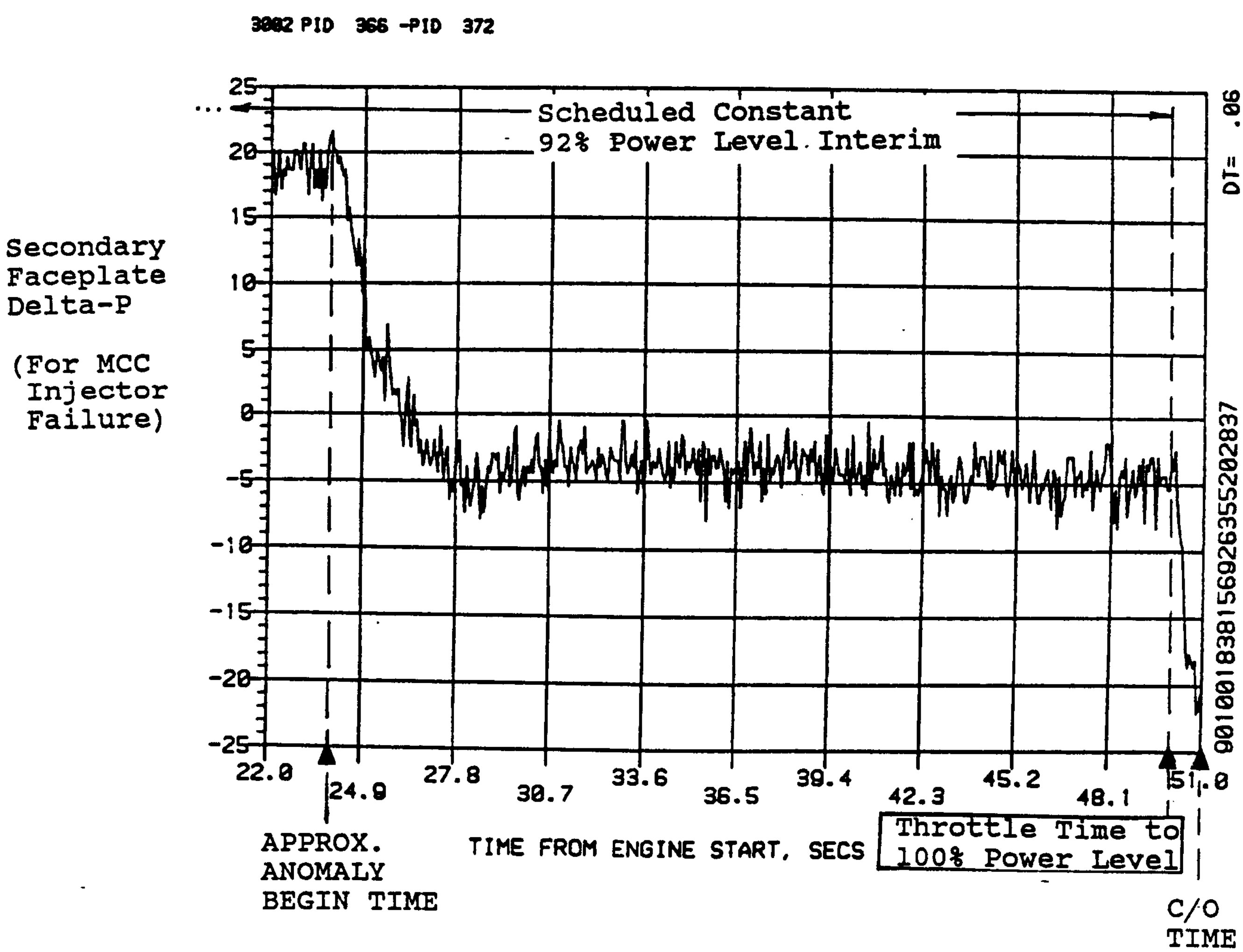


Table-IIA-1: Failure Mode Qualitative Characteristics
--Injector Failure Type (MCC and FPB)

MCC Injector Anomaly

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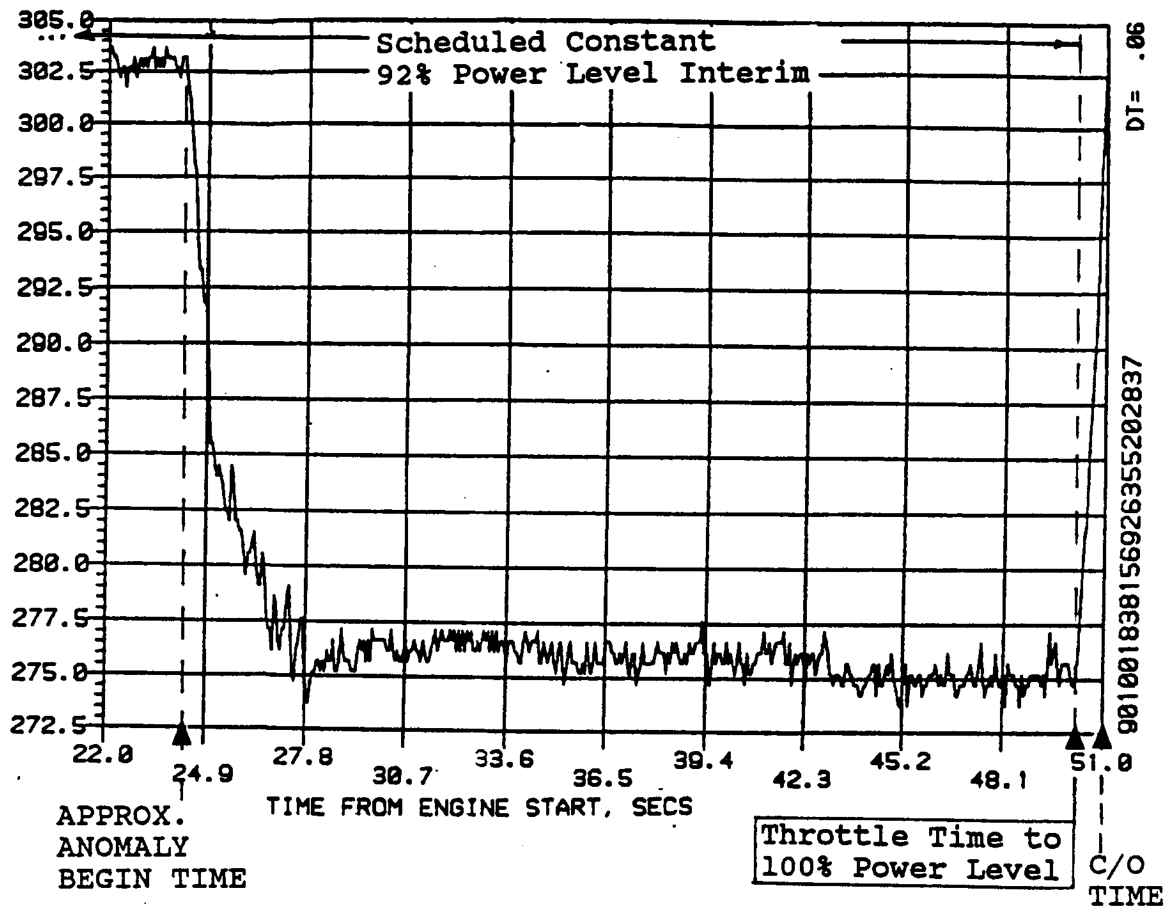
Sample
Indicative
Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

3083 PID 366 -PID 383

Primary
Faceplate
Delta-P

(For MCC
Injector
Failure)



Hotgas
Injector
Delta-P

(For MCC
Injector
Failure)

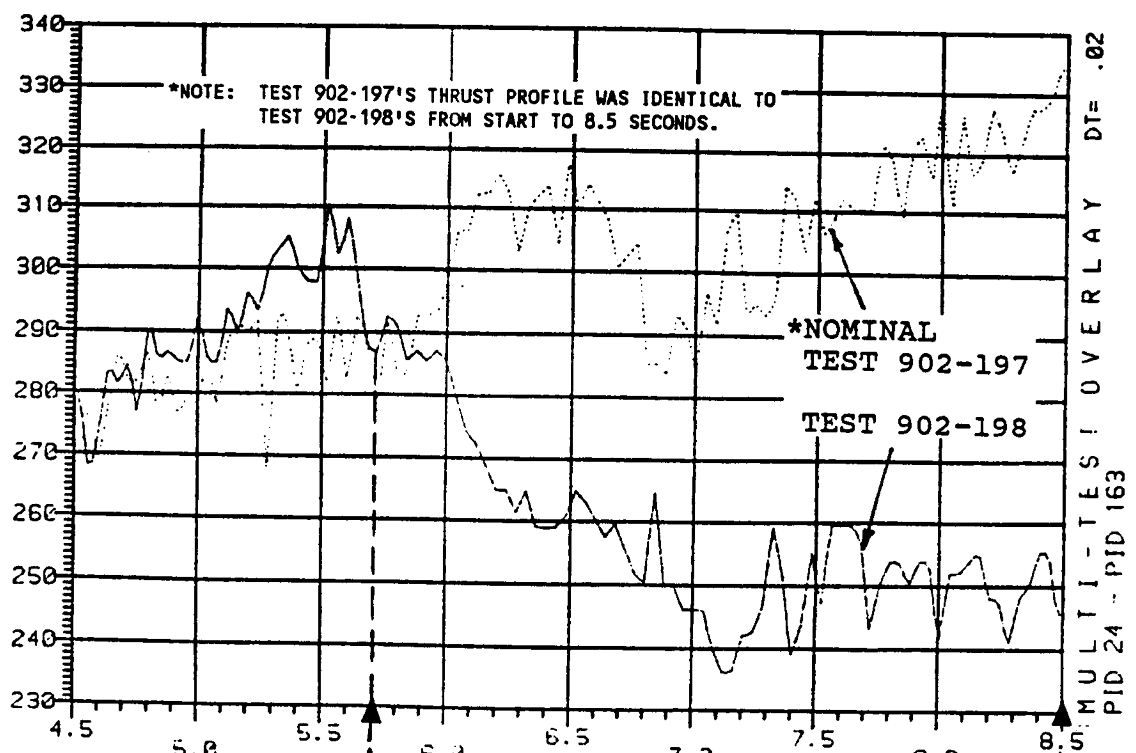


Table-IIA-1: Failure Mode Qualitative Characteristics
(cont.) --Injector Failure Type (MCC and FPB)

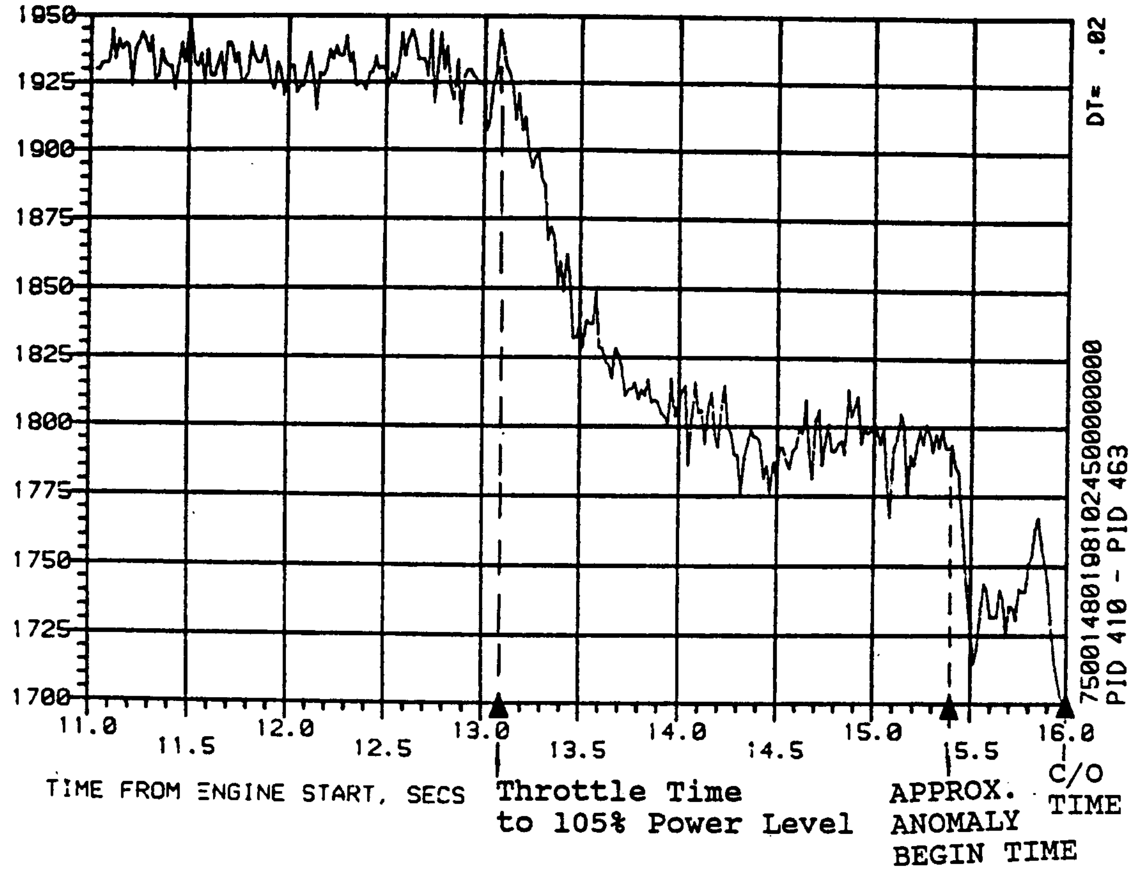
MCC Injector Anomaly

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

FPB PC - MCC HG IN PR

(For MCC Injector Failure)



OPB PC - MCC HG IN PR

(For MCC Injector Failure)

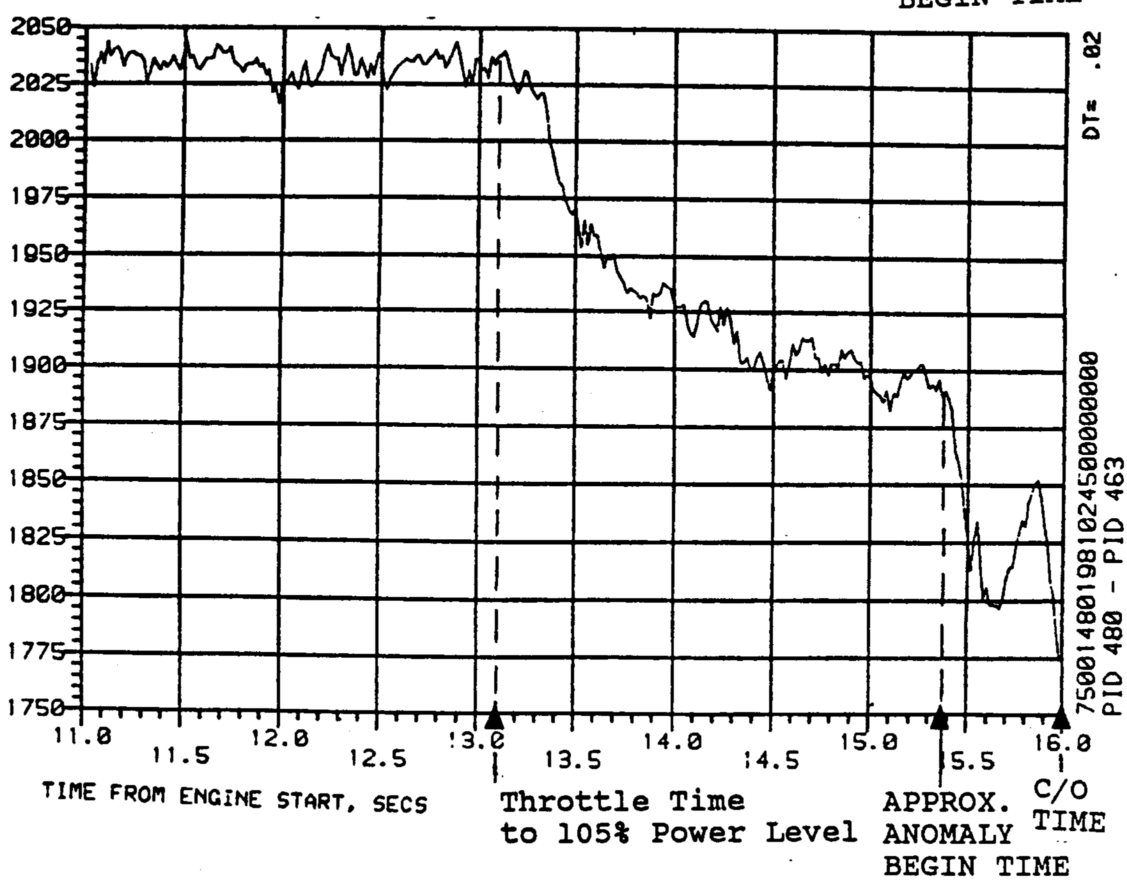


Table-IIA-1: Failure Mode Qualitative Characteristics (cont.) --Injector Failure Type (MCC and FPB)

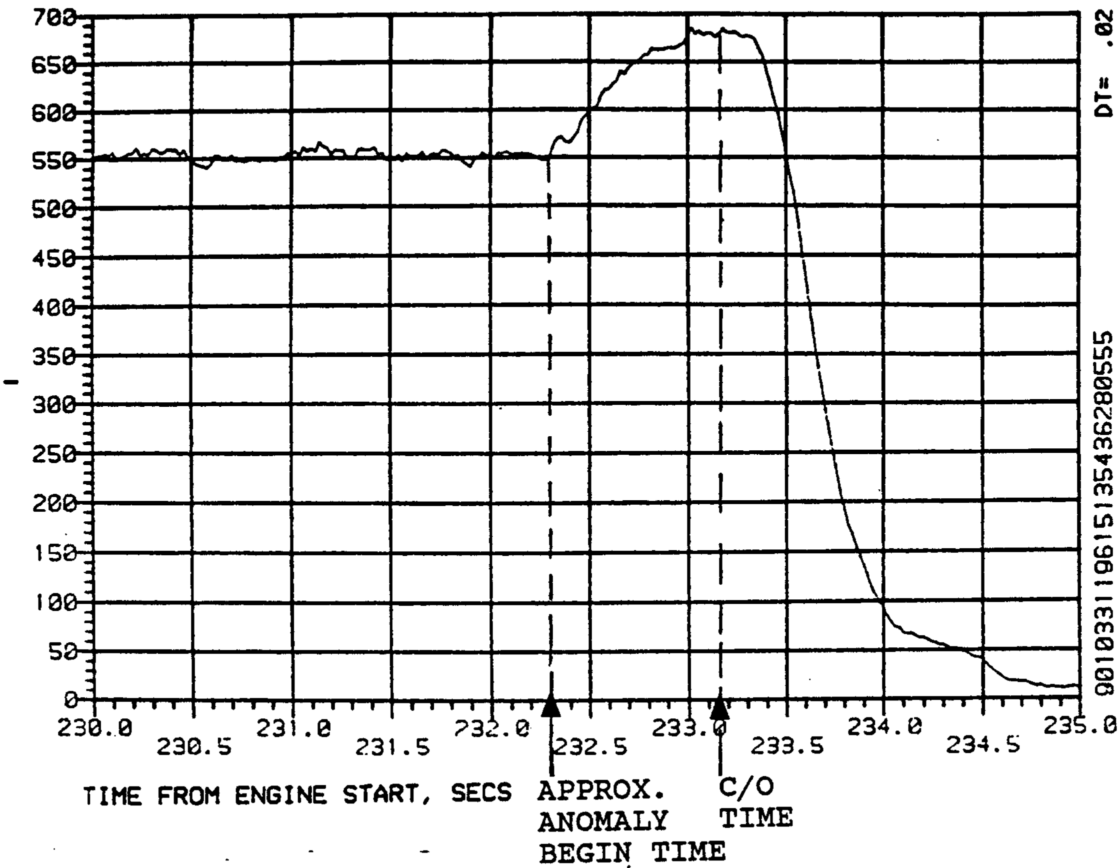
MCC Injector Anomaly

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

MCC OX Inlet Ps - MCC PC

(For MCC Injector Failure)



HPFP Disch Ps - MCC PC

(For MCC Injector Failure)

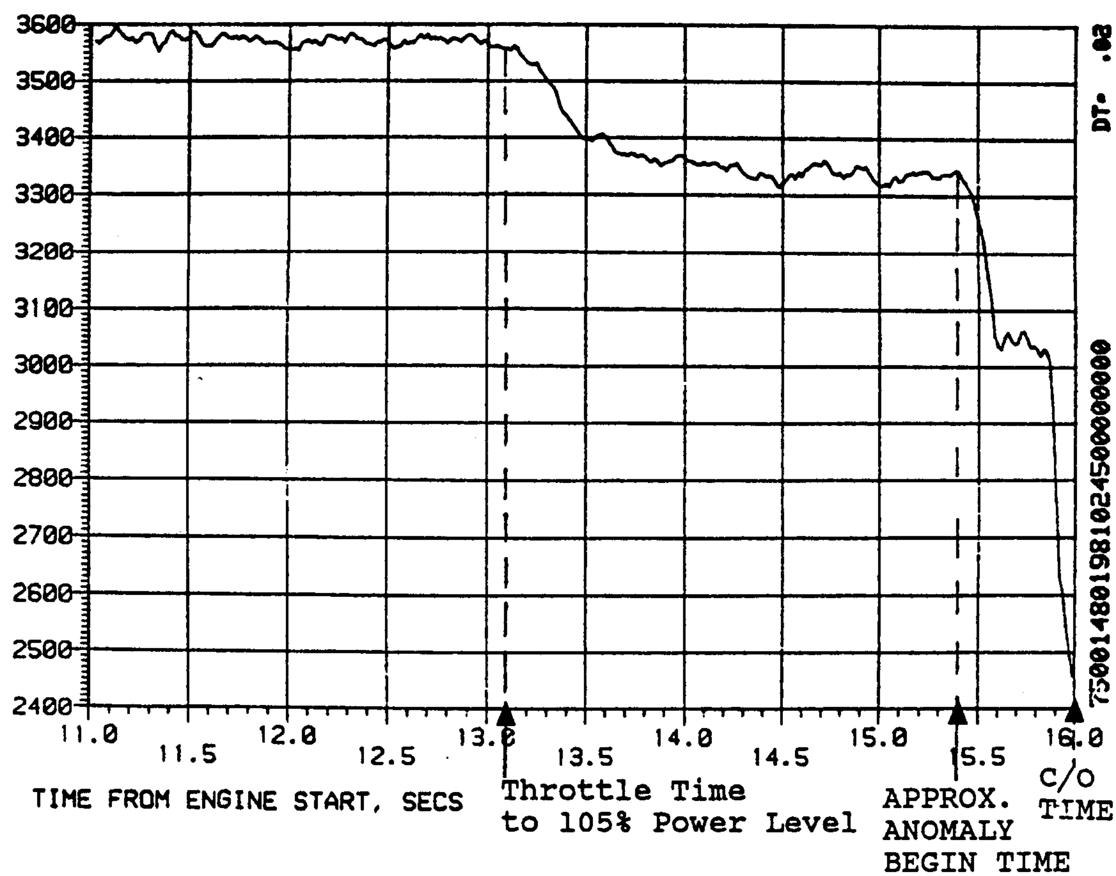


Table-IIA-1: (cont.) Failure Mode Qualitative Characteristics --Injector Failure Type (MCC and FPB)

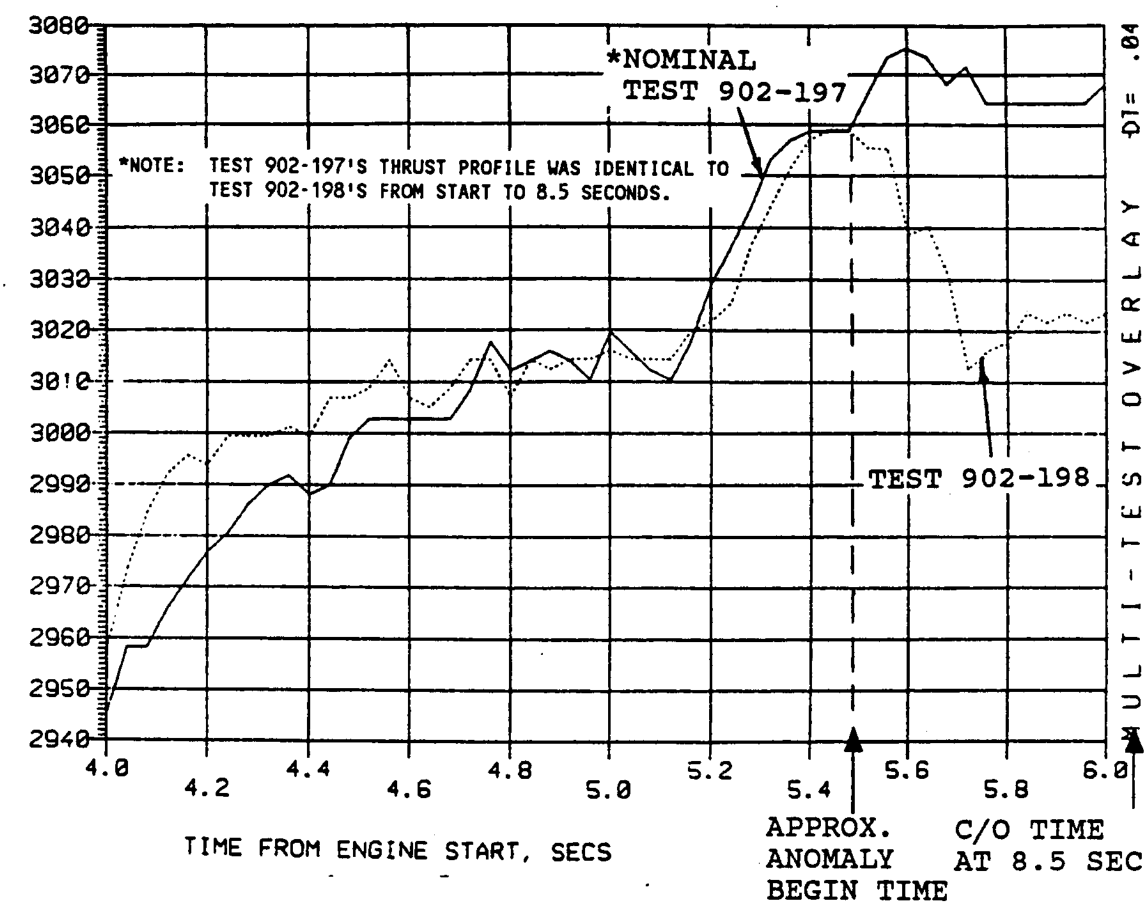
MCC Injector Anomaly

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

MCC PC

(For MCC Injector Failure)



MCC CL DS T

(For MCC Injector Failure)

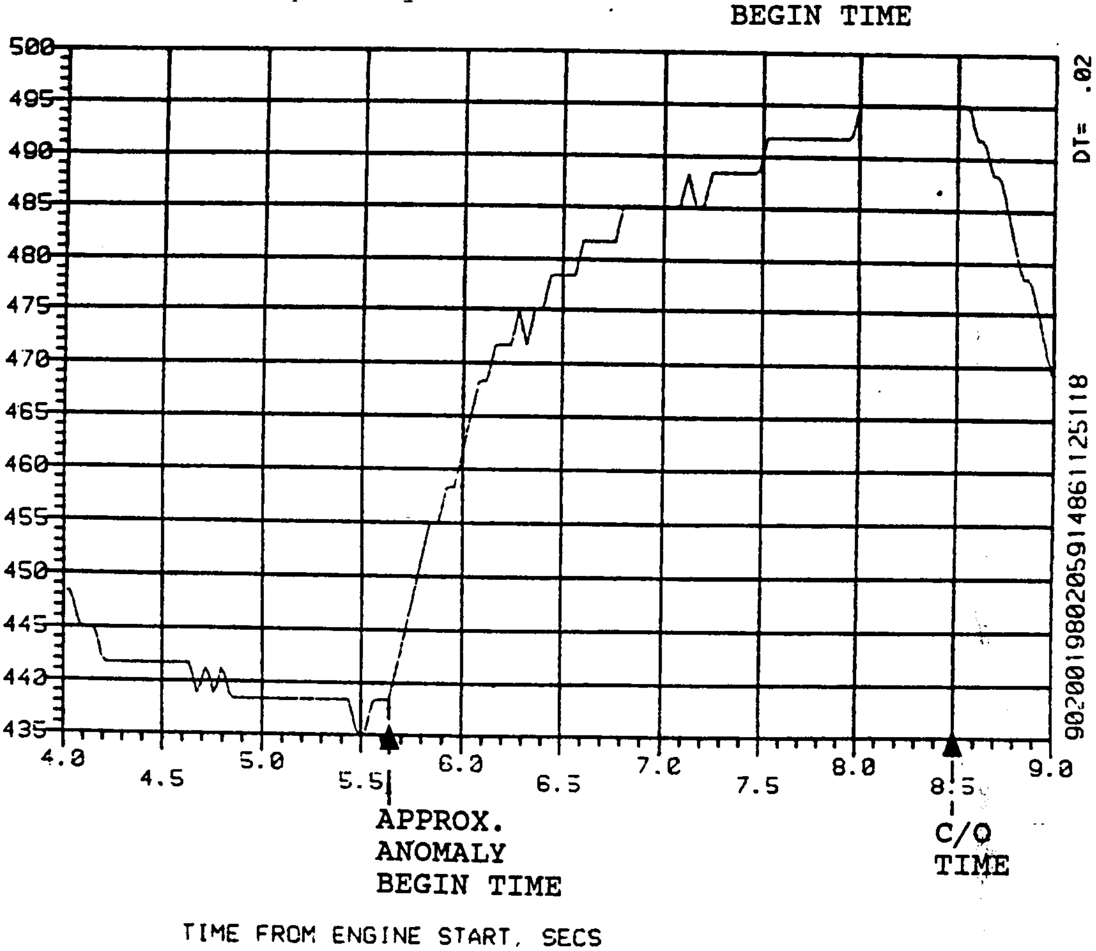


Table-IIA-1: (cont.) Failure Mode Qualitative Characteristics --Injector Failure Type (MCC and FPB)

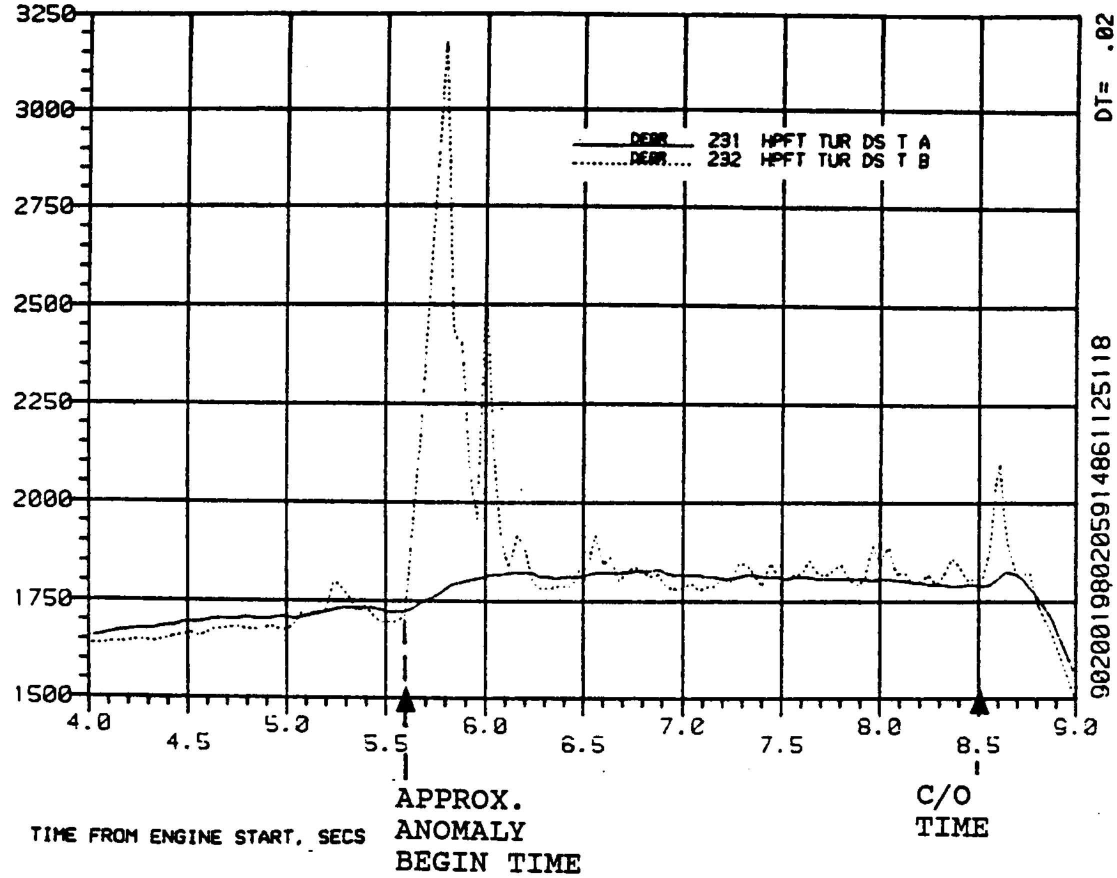
MCC Injector Anomaly

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

HPFT DS Temp

(For MCC Injector Failure)



HPOT DS Temp

(For MCC Injector Failure)

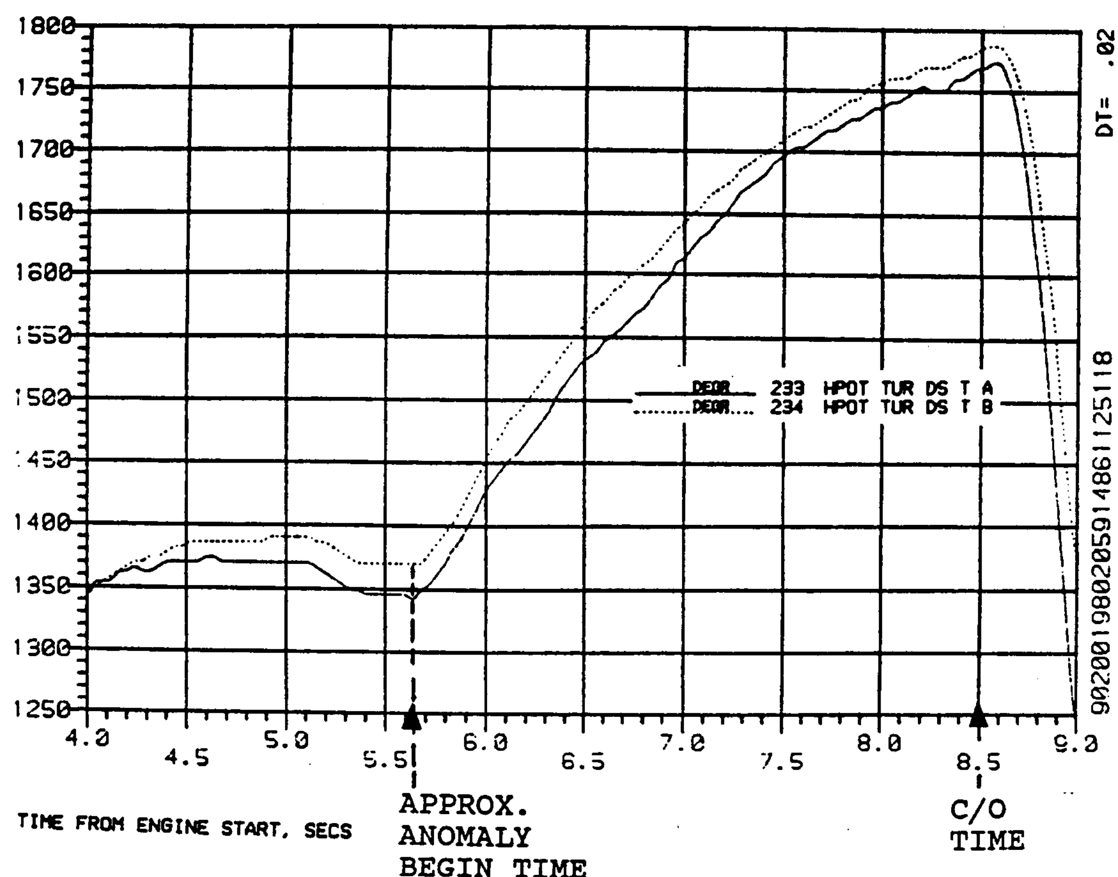


Table-IIA-1: Failure Mode Qualitative Characteristics
(cont.) --Injector Failure Type (MCC and FPB)

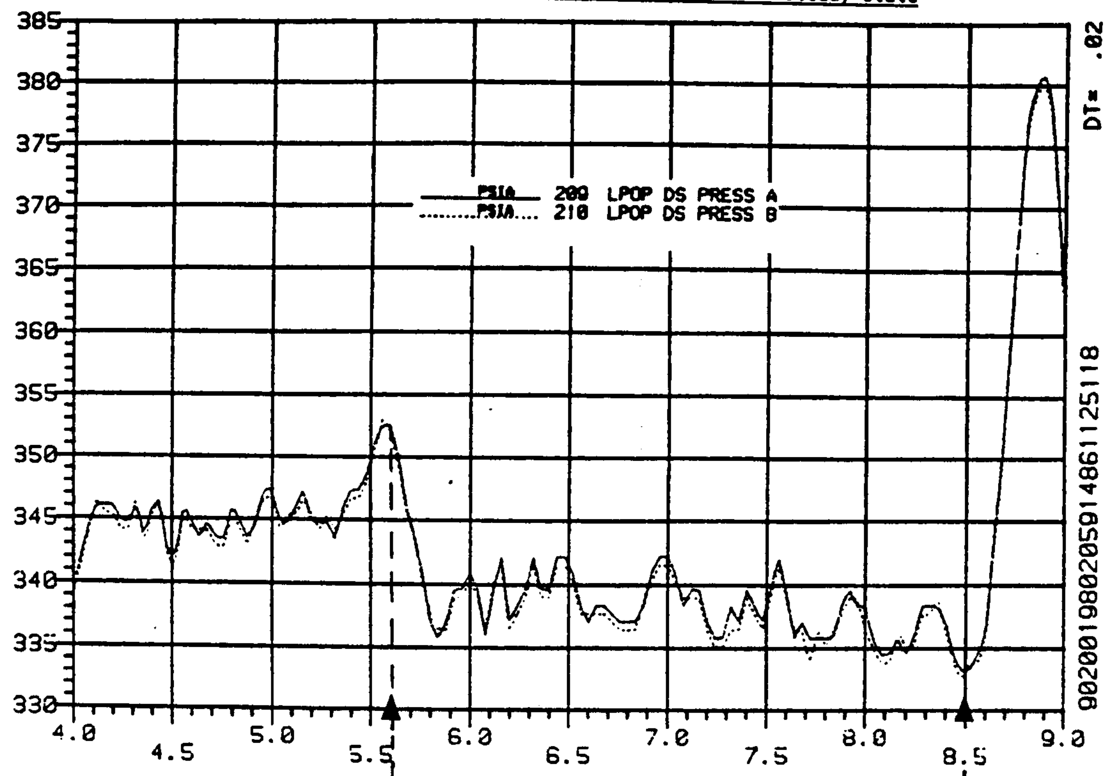
MCC Injector Anomaly/ FPB Injector Anomaly

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

LPOP DS PR

(For MCC Injector Failure)



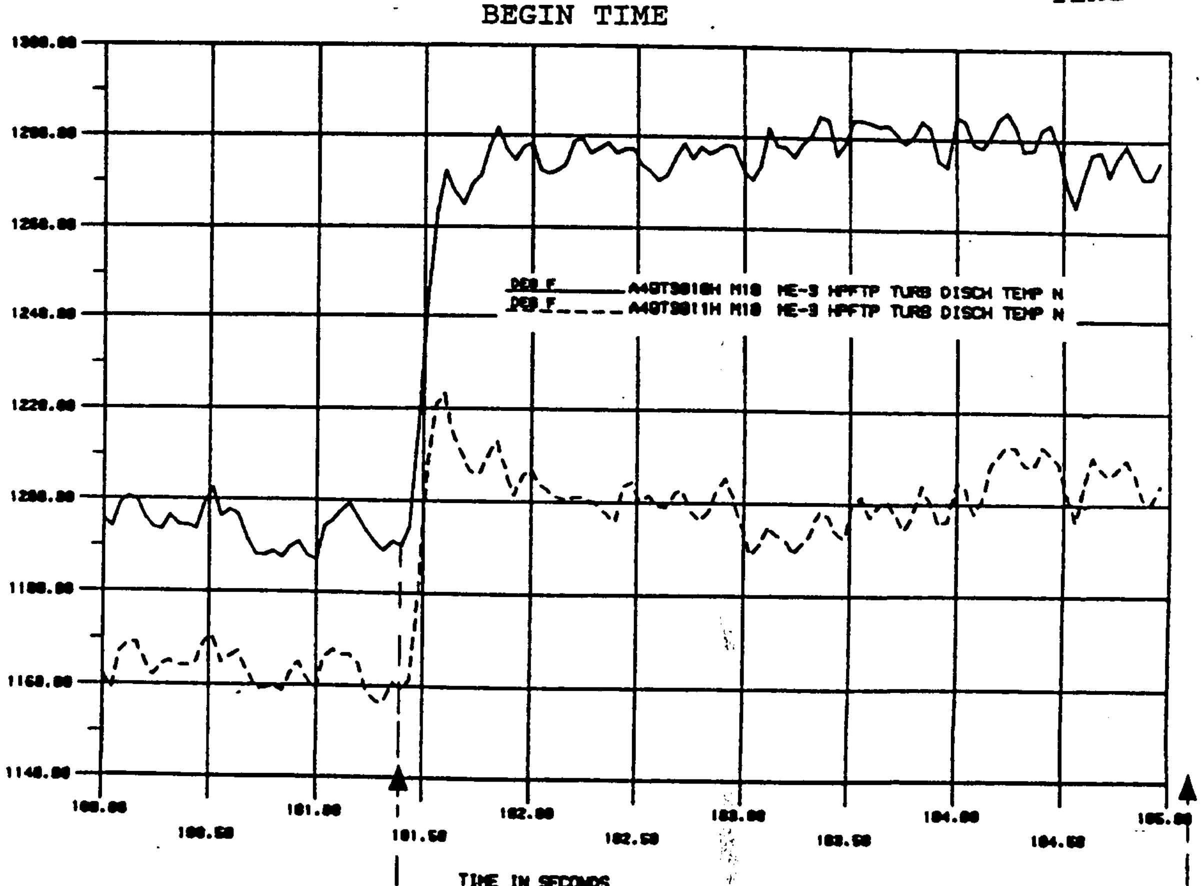
TIME FROM ENGINE START, SECS

APPROX. ANOMALY BEGIN TIME

C/O TIME

HPFT DS Temp

(For FPB Injector Failure)



APPROX. ANOMALY BEGIN TIME

c/o AT 106.6 SEC

Table-IIA-1: (cont.) Failure Mode Qualitative Characteristics --Injector Failure Type (MCC and FPB).

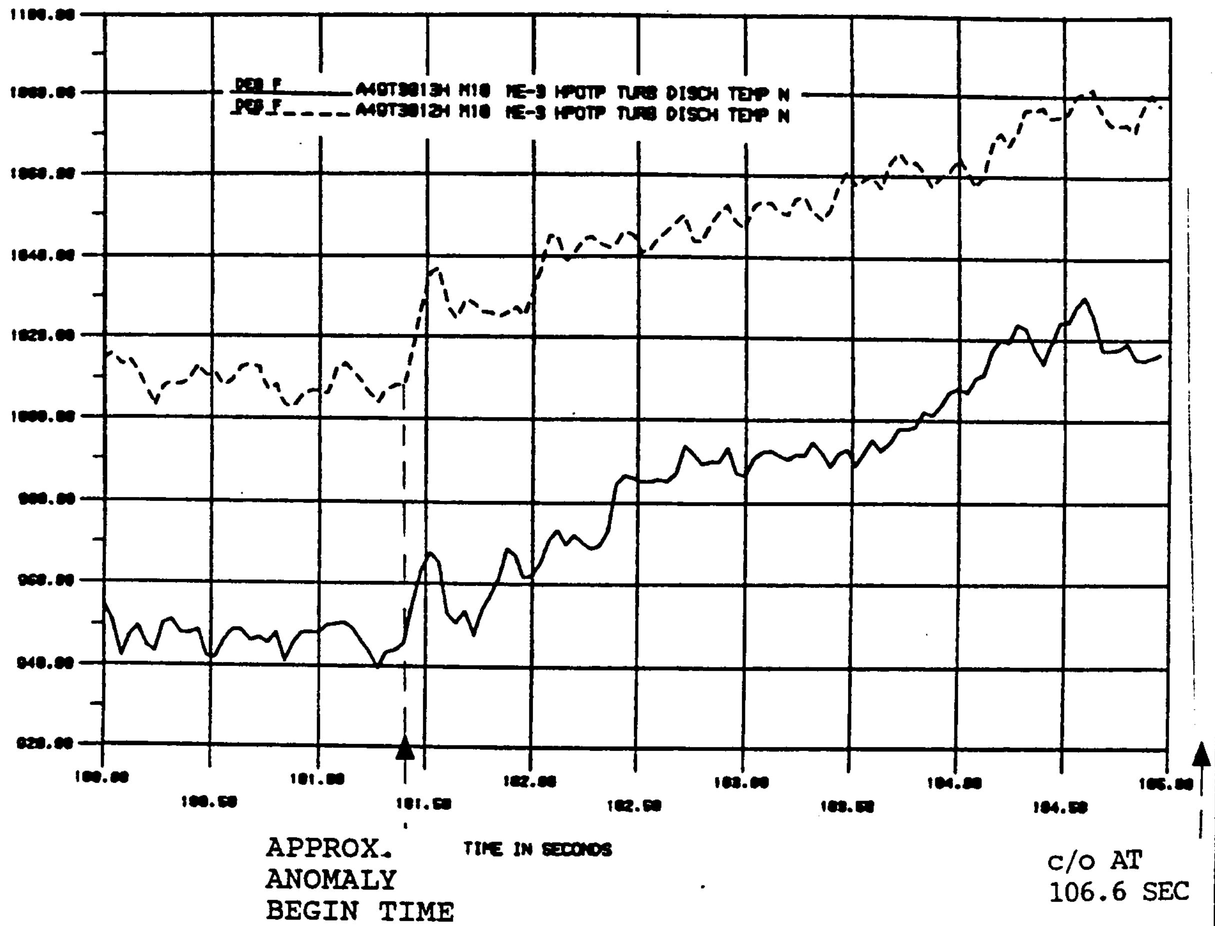
FPB Injector Anomaly

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

HPOT Ds Temp

(For FPB Injector Failure)



OPOV ACT POS

(For FPB Injector Failure)

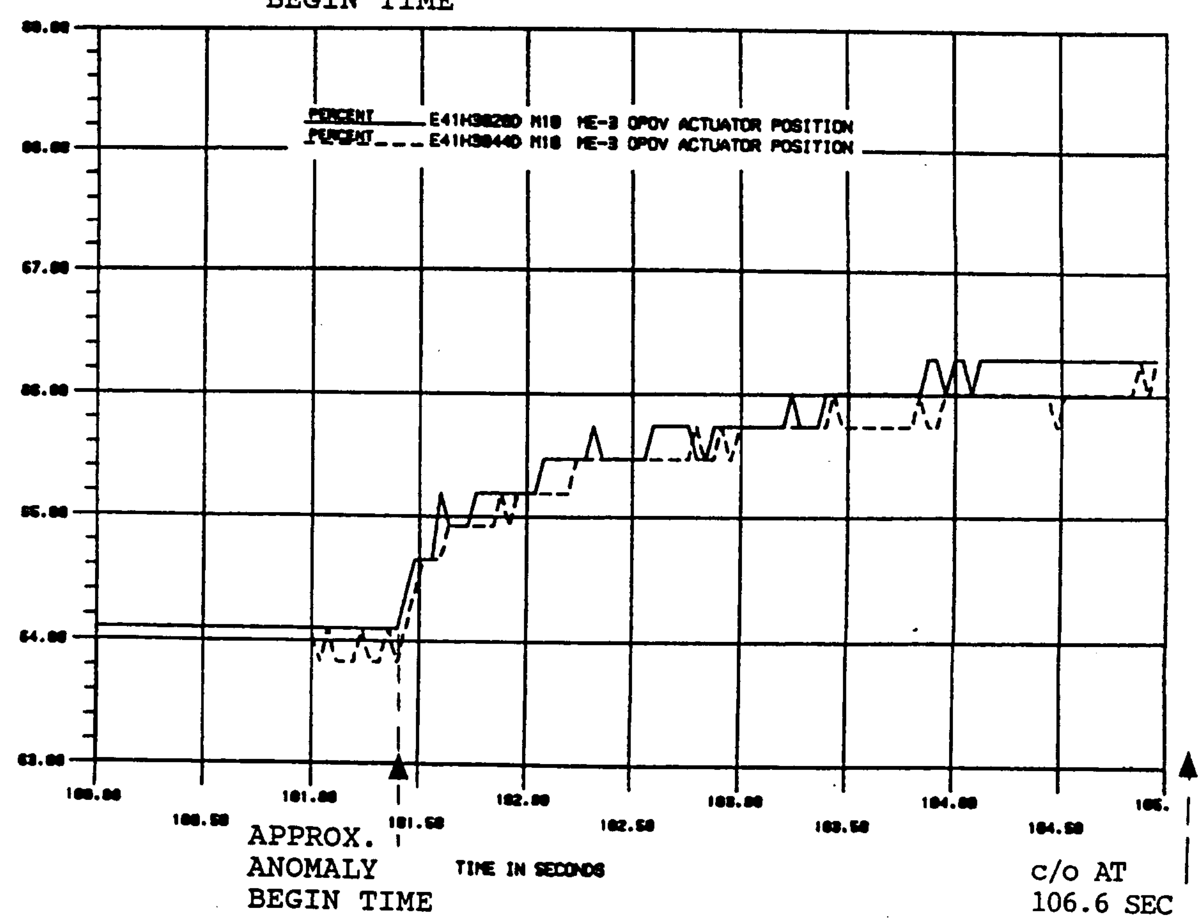


Table-IIA-1: (cont.) Failure Mode Qualitative Characteristics --Injector Failure Type (MCC and FPB)

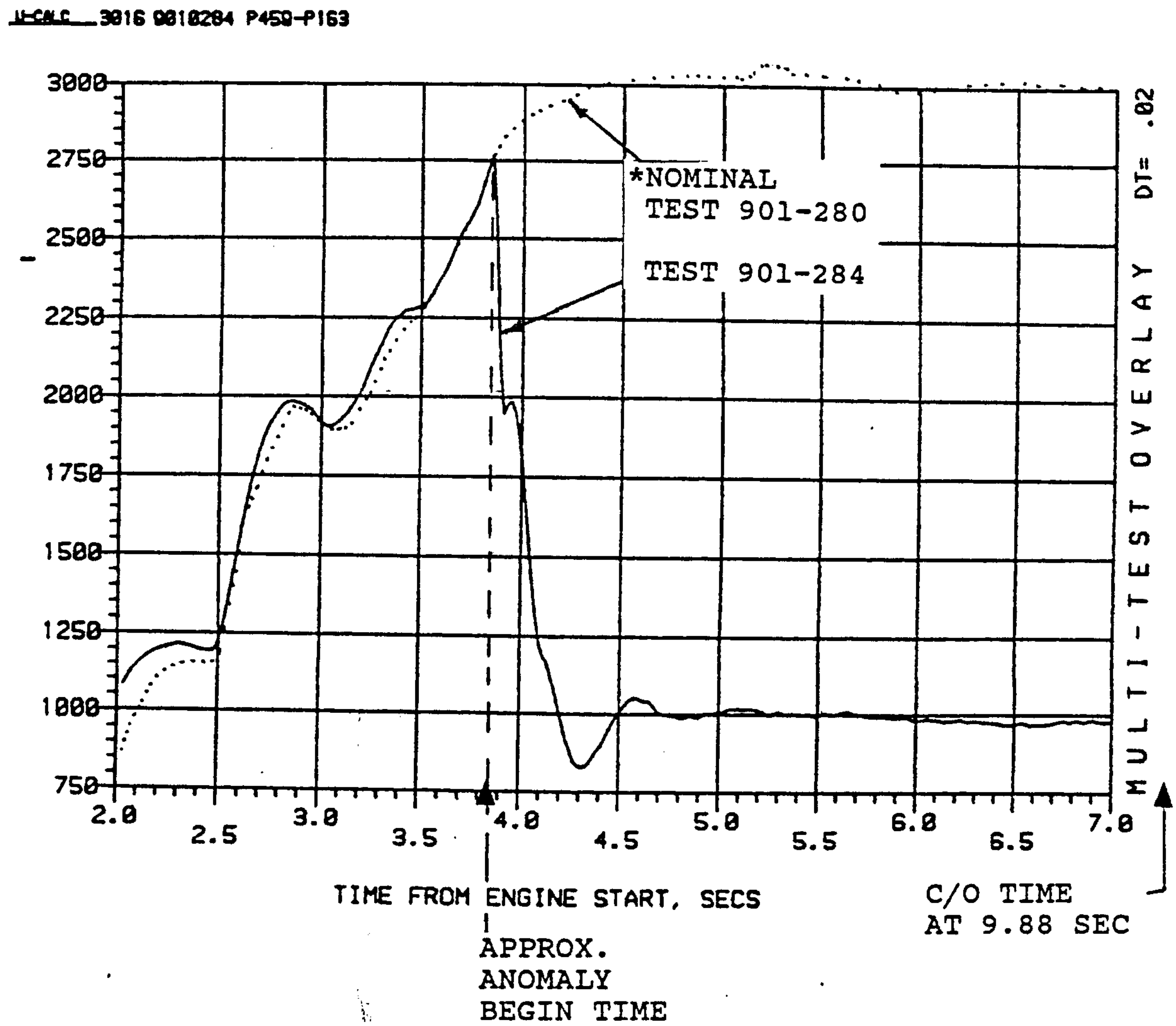
FAILURE MODE QUALITATIVE CHARACTERISTICS:

Type of Incident	Generic Description of Incident Type and Sample Indicative Parameters:
Control Failure (Erroneous Sensor, Lee Jet)	The miscontrolled chamber pressure anomaly observed in one test can be characterized as being based on proper operation of the engine Controller under the two circumstances below. 1. The loss of redundance in chamber pressure sensing. 2. The malfunction of the remaining Controller sensor on chamber pressure. Operating under errorenous sensor data the Controller causes certain SSME components to exceed their designed tolerances (all sensor measurements reflect large changes from nominal conditions).

Sample Indicative Parameters — CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPFP Disch Ps - MCC PC

(For Control Failure)



*NOTE: TEST 901-280'S START AND THRUST PROFILE WAS IDENTICAL TO TEST 901-284'S FROM START TO 9.88 SECONDS.

Table-IIA-2: Failure Mode Qualitative Characteristics --Control Failure Type

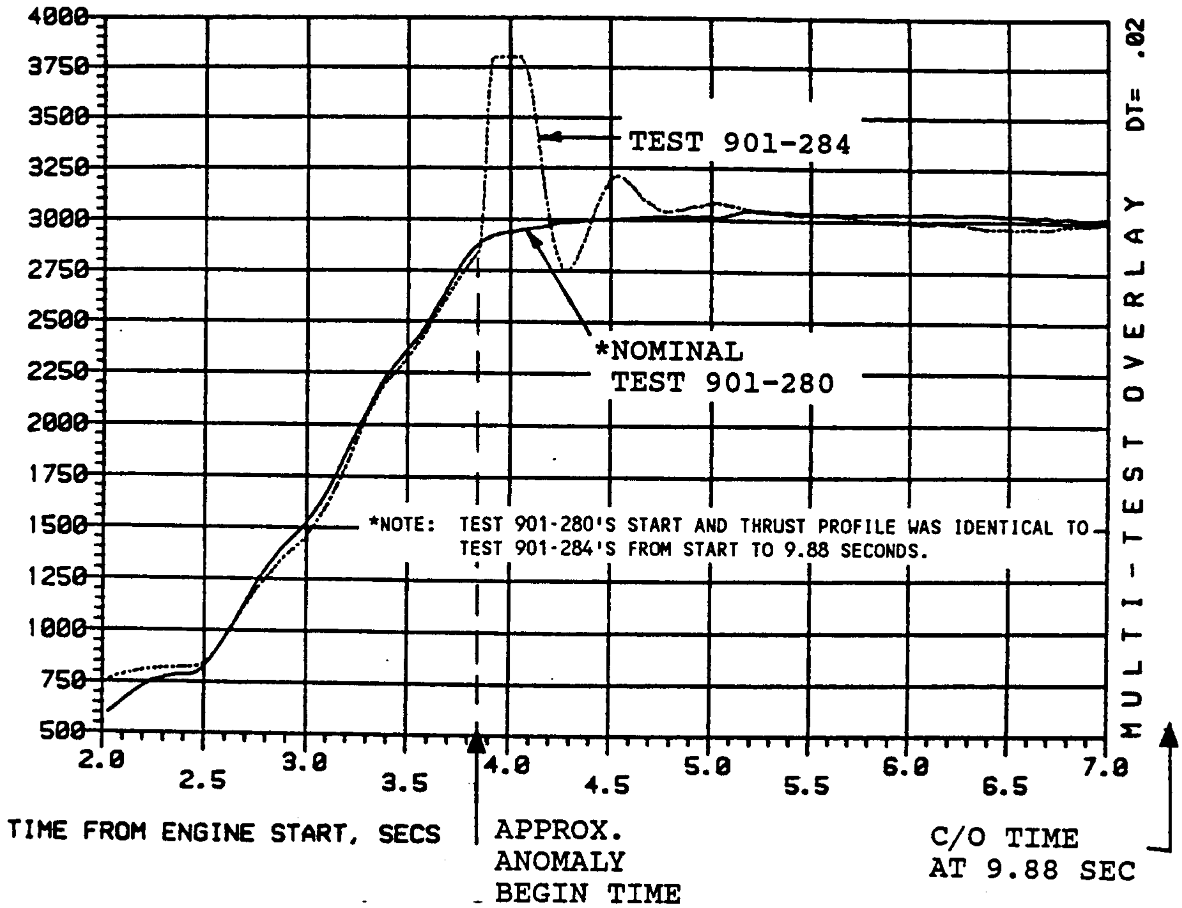
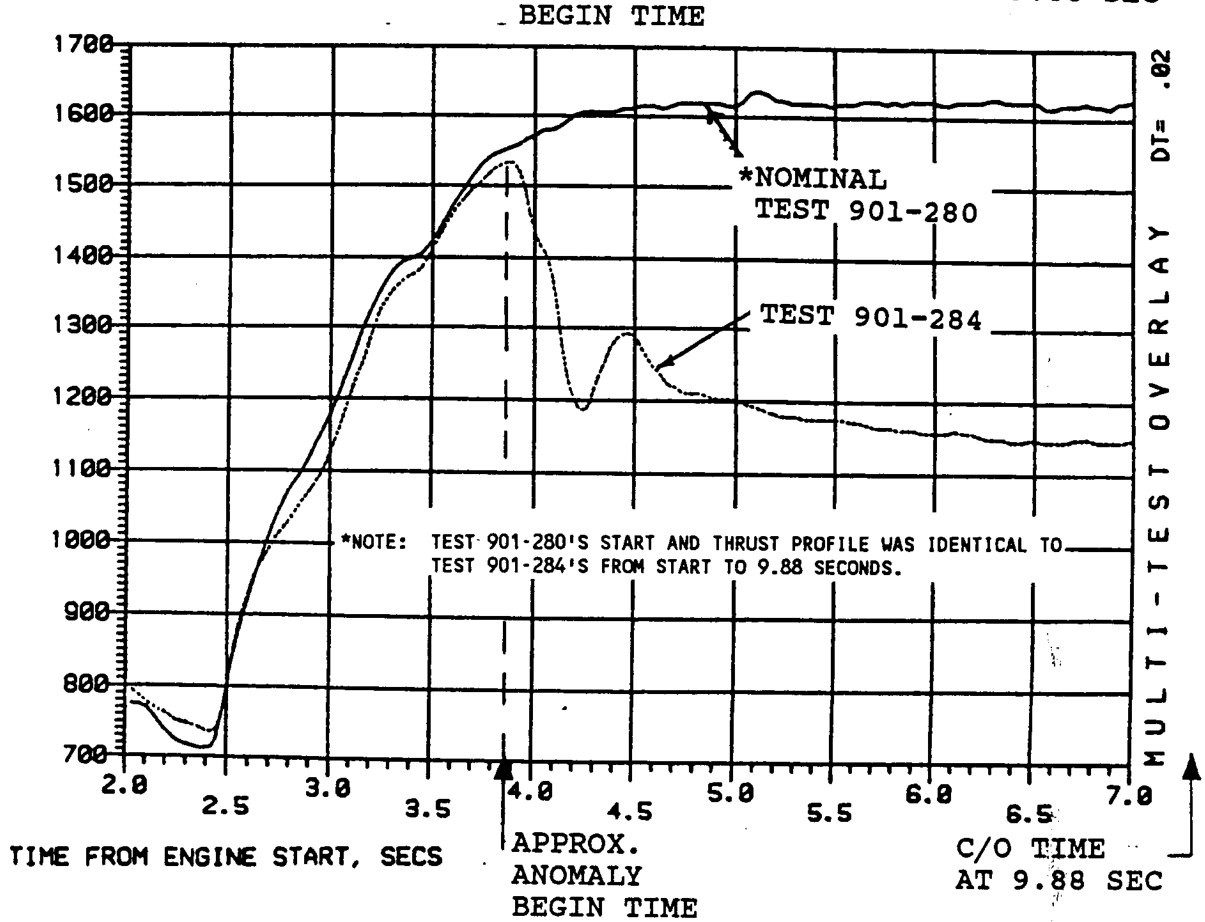
Sample Indicative Parameters	CRT Example of the Indicative Parameter's Anomaly Change from Steady State
MCC PC (For Control Failure)	
HPFT DS Temp (For Control Failure)	

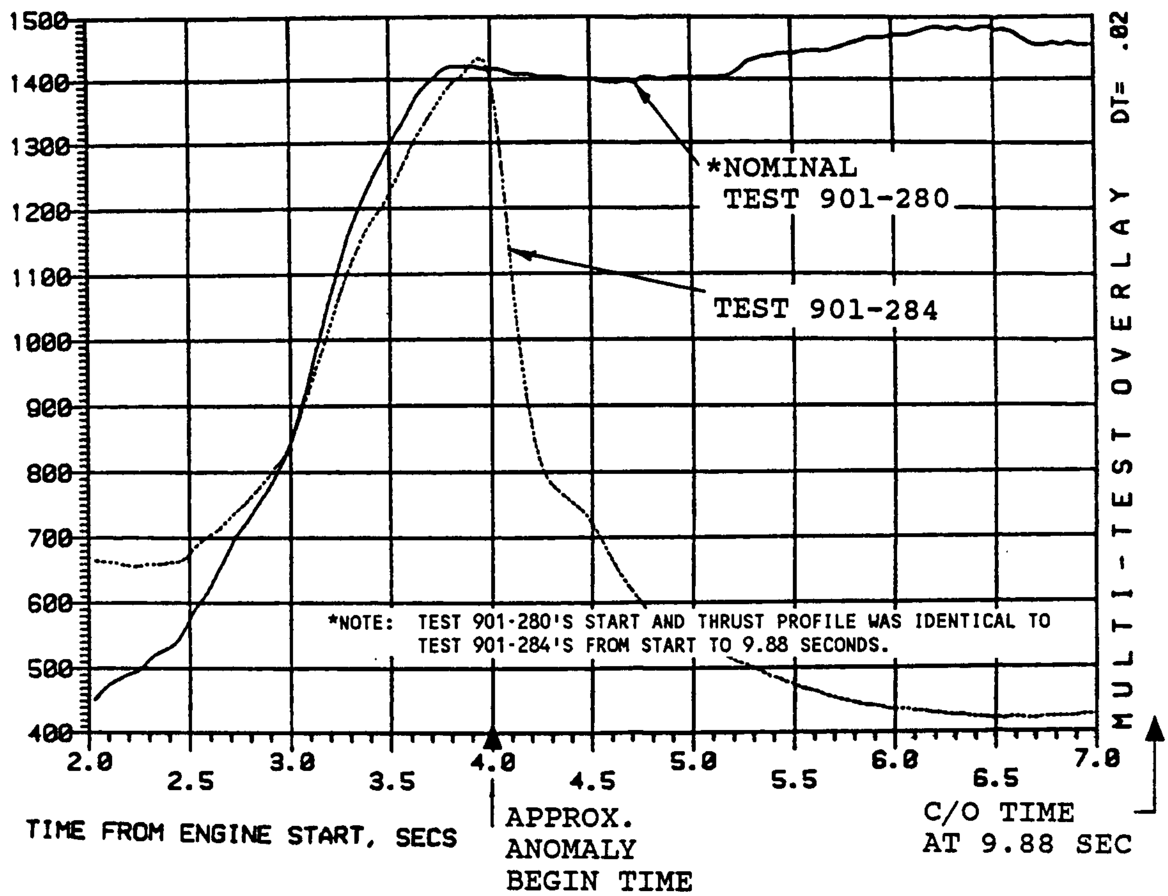
Table-IIA-2: Failure Mode Qualitative Characteristics
(cont.) --Control Failure Type

Sample
Indicative
Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State

HPOT DS Temp

(For
Control
Failure)



LPOP DS PR

(For
Control
Failure)

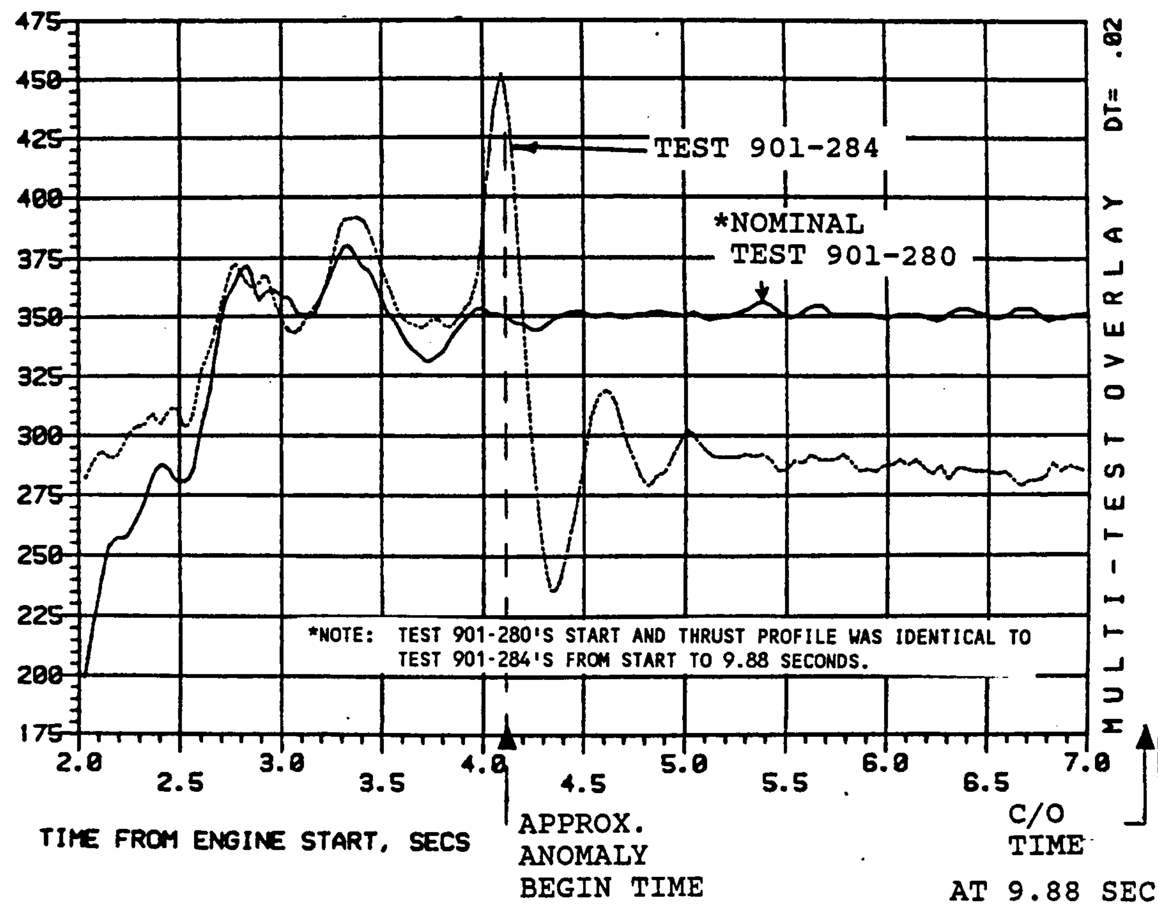
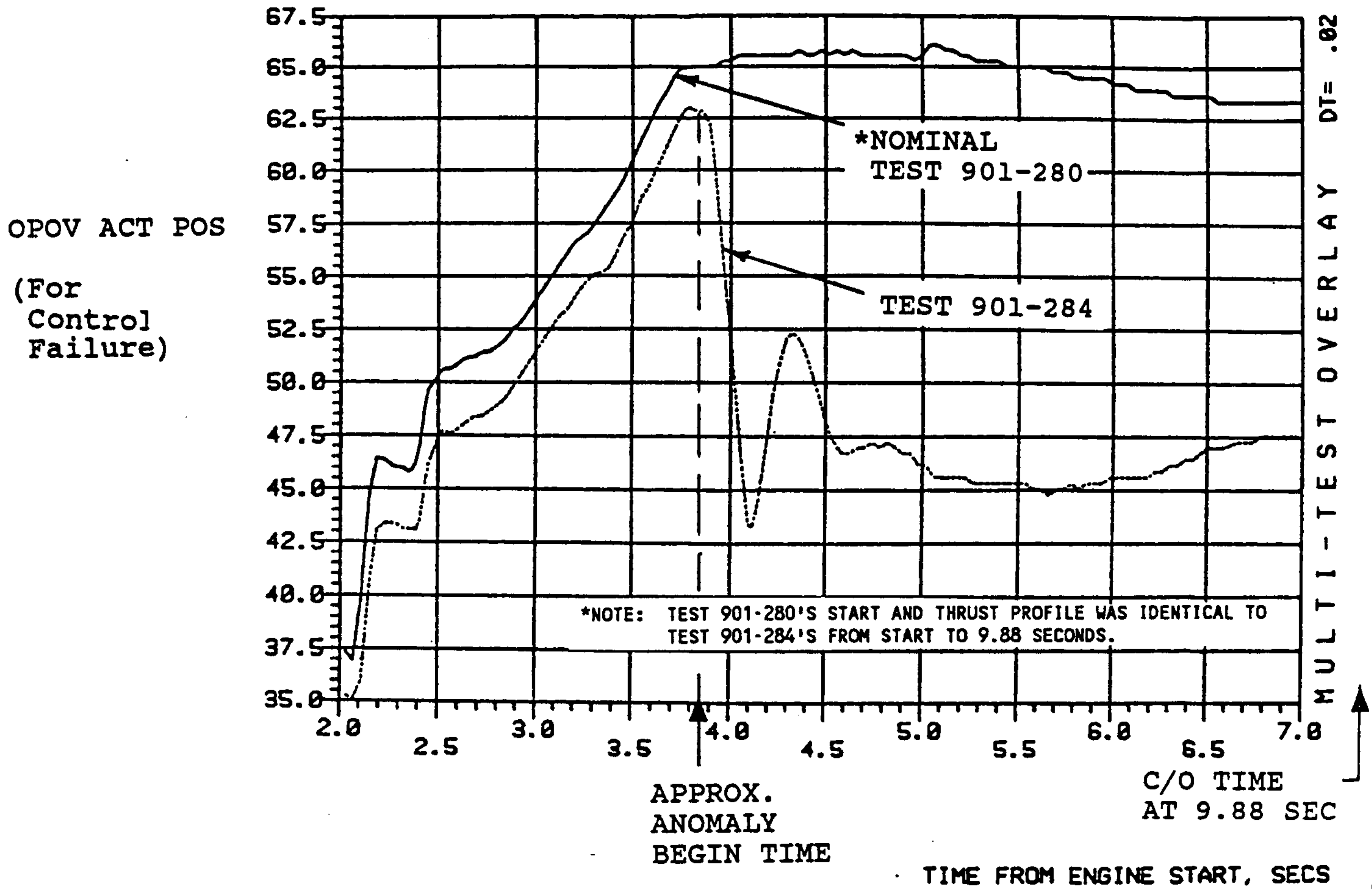


Table-IIA-2: Failure Mode Qualitative Characteristics
(cont.) --Control Failure Type

Sample
Indicative
Parameters

CRT Example of the Indicative Parameter's Anomaly Change From Steady State



C-2

Table-IIA-2: (cont.) Failure Mode Qualitative Characteristics --Control Failure Type

FAILURE MODE QUALITATIVE CHARACTERISTICS:

Type of Incident	Generic Description of Incident Type and Sample Indicative Parameters:
Duct, Manifold, r Heat xchange Failure	The duct, manifold, or heat exchanger anomalies observed in four previous SSME tests can be characterized as being initiated from a leakage or restriction of fluid through either of the three components. The extent and/or rate of damage to other components is dependent on their response to: (1) the amount of fluid leaked or restricted and (2) the existence or absence of redundancy for the failed duct, manifold, or heat exchanger.

A leakage of one of several nozzle cooling tubes in Test 901-485 caused little damage to other components; the test shutdown when the HPOT (High Pressure Oxidizer Turbine) temperature reached its redline temperature. The temperature rose 3.9% from its steady state condition before the cutoff time in 8.06 seconds. Six days after the test the damage was repaired to the cooling tube and a 520 second program duration test was completed.

A rupture or blockage of a one-of-a-kind duct/manifold have caused major damage to other components (for three of three tests where these types of failure have occurred). After the initial duct/manifold failure the sequence below is generally followed:

1. One or more pumps are rapidly driven to extreme off-design conditions, e.g. an increase of 27.7% pump speed from the nominal and cavitation (within .14 and .55 seconds), and/or increased vibrations in less than .1 seconds.

2. During the drive to pump off-design conditions, other related components are damaged.

3. Subsequent to the above, either the pump(s) and/or the engine system separate from the test stand (for the cases of an initiating duct or manifold leak).

Sample Indicative Parameters — CRT Example of the Indicative Parameter's Anomaly Change from Steady State

MCC OX Inlet Ps - MCC PC

(Duct, Manifold, or Heat Exchanger Failure)

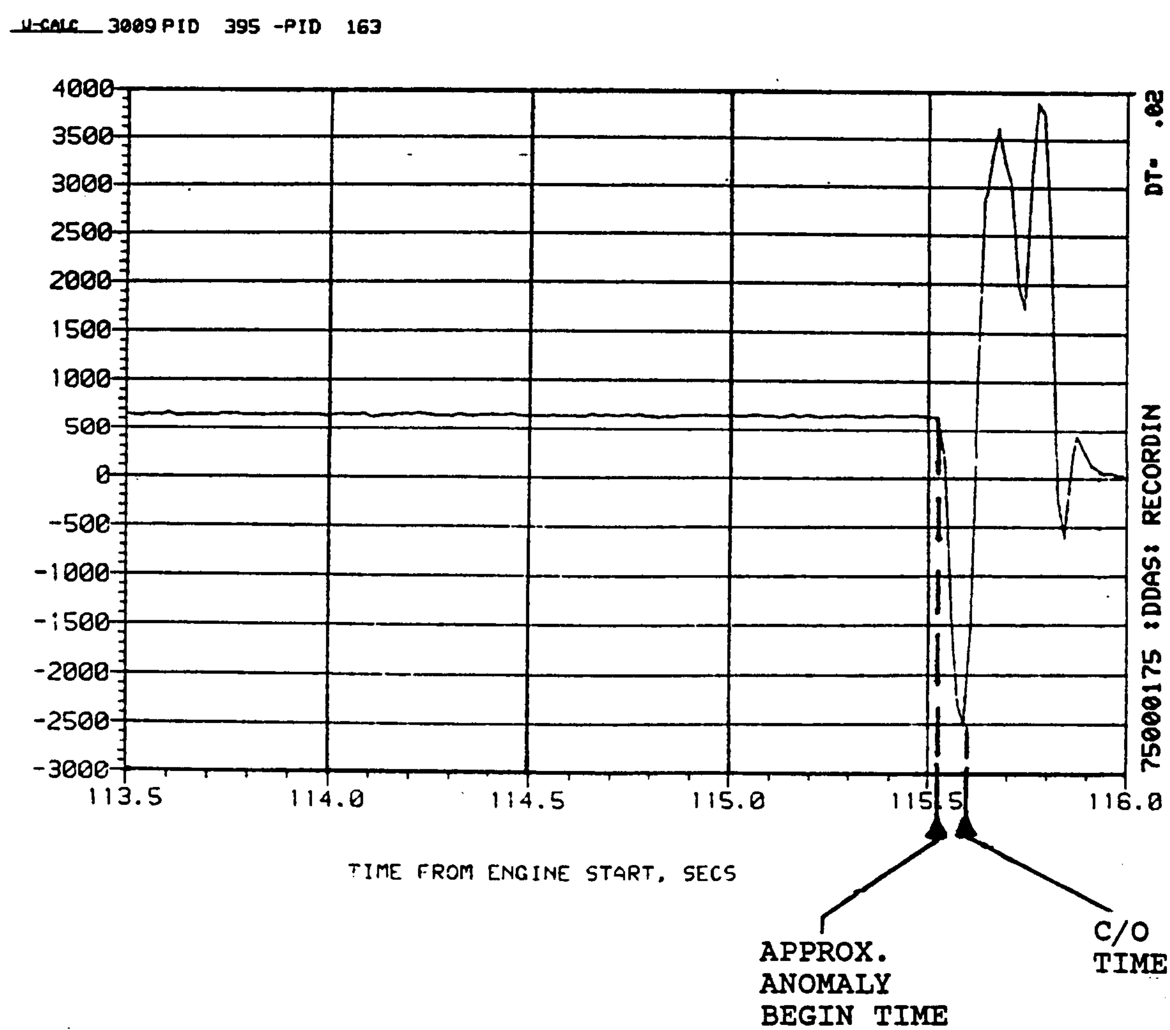


Table IIA-3: Failure Mode Qualitative Characteristics --Duct, Manifold, or Heat Exchanger Failure

Duct, Manifold, or Heat Exchanger Failure

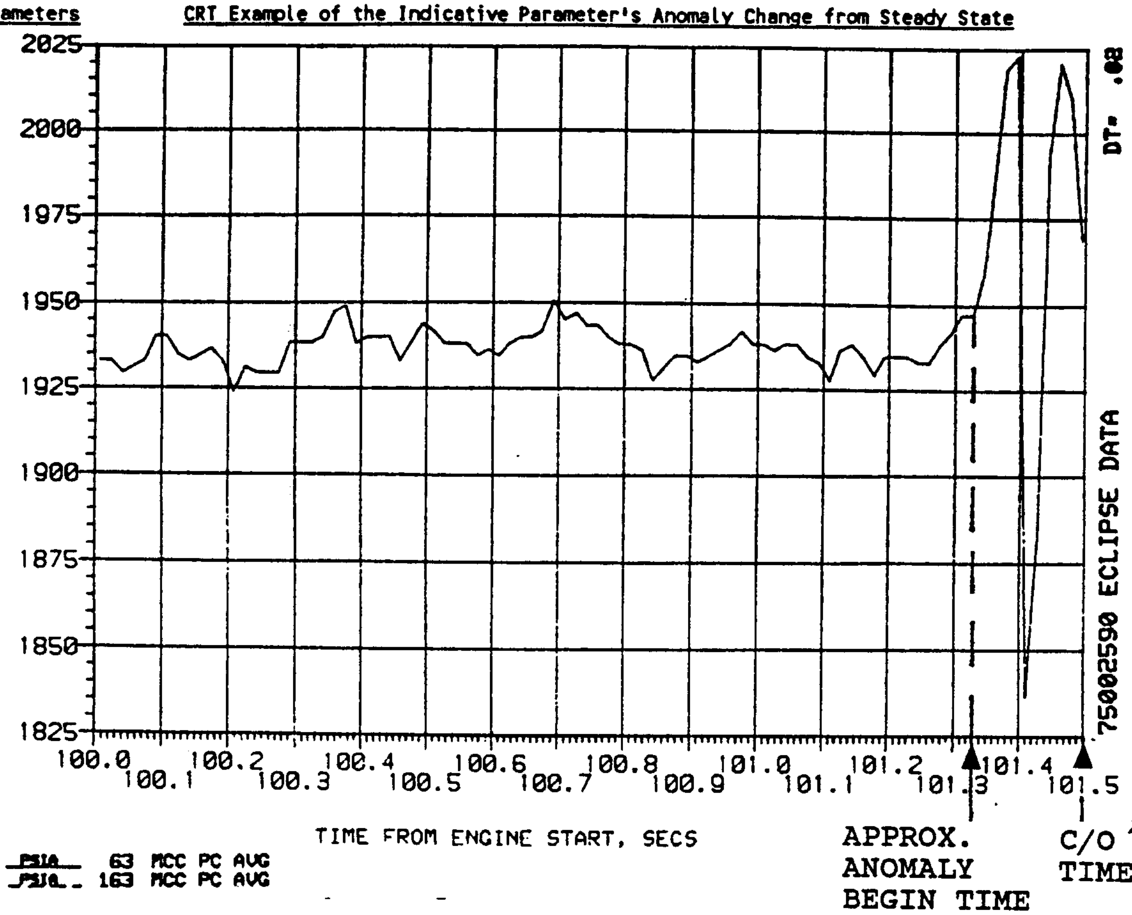
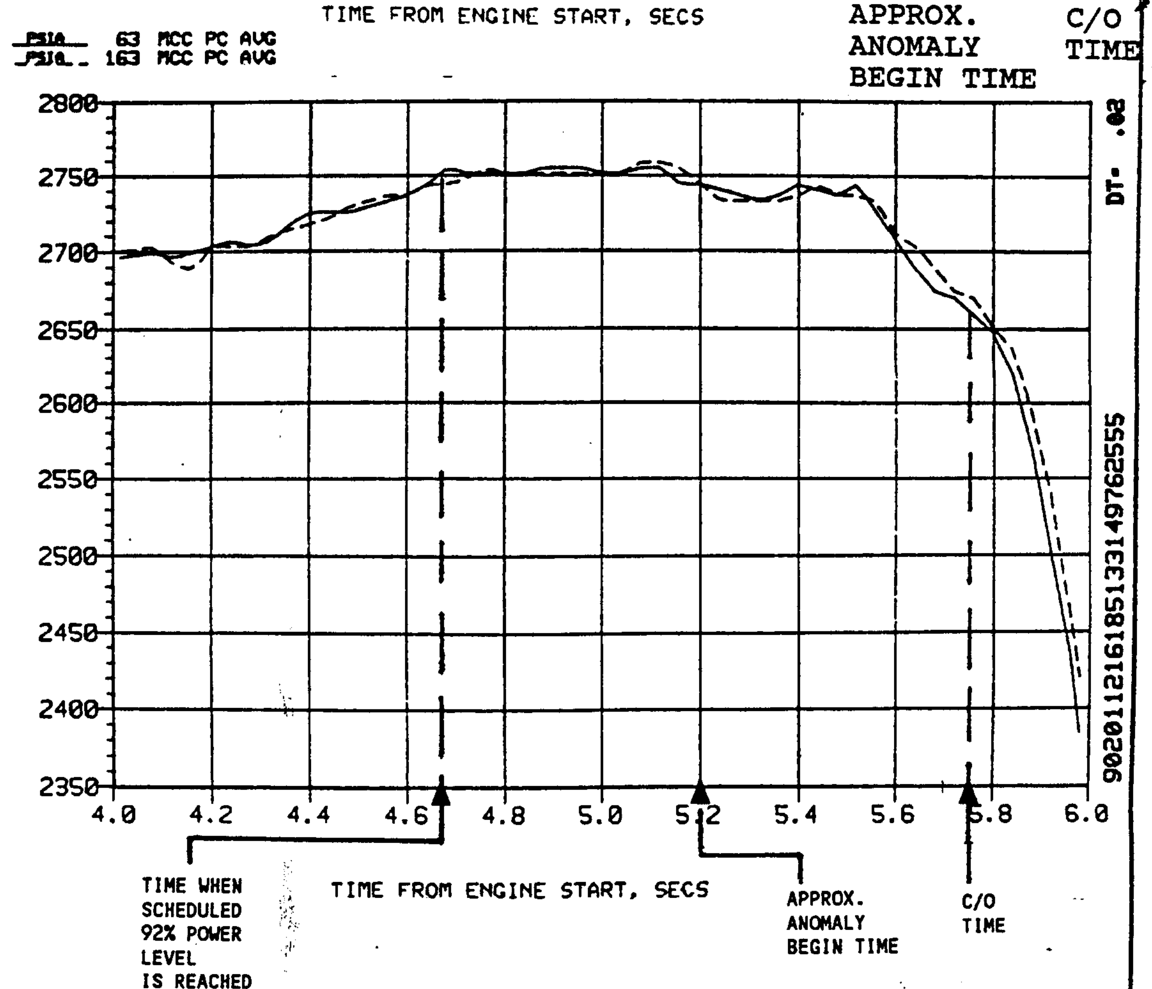
Sample Indicative Parameters	CRT Example of the Indicative Parameter's Anomaly Change from Steady State
FPB PC - MCC HG IN PR (Duct, Manifold, or Heat Exchanger Failure)	
MCC PC (Duct, Manifold, or Heat Exchanger Failure)	

Table IIA-3: (cont.) Failure Mode Qualitative Characteristics --Duct, Manifold, or Heat Exchanger Failure

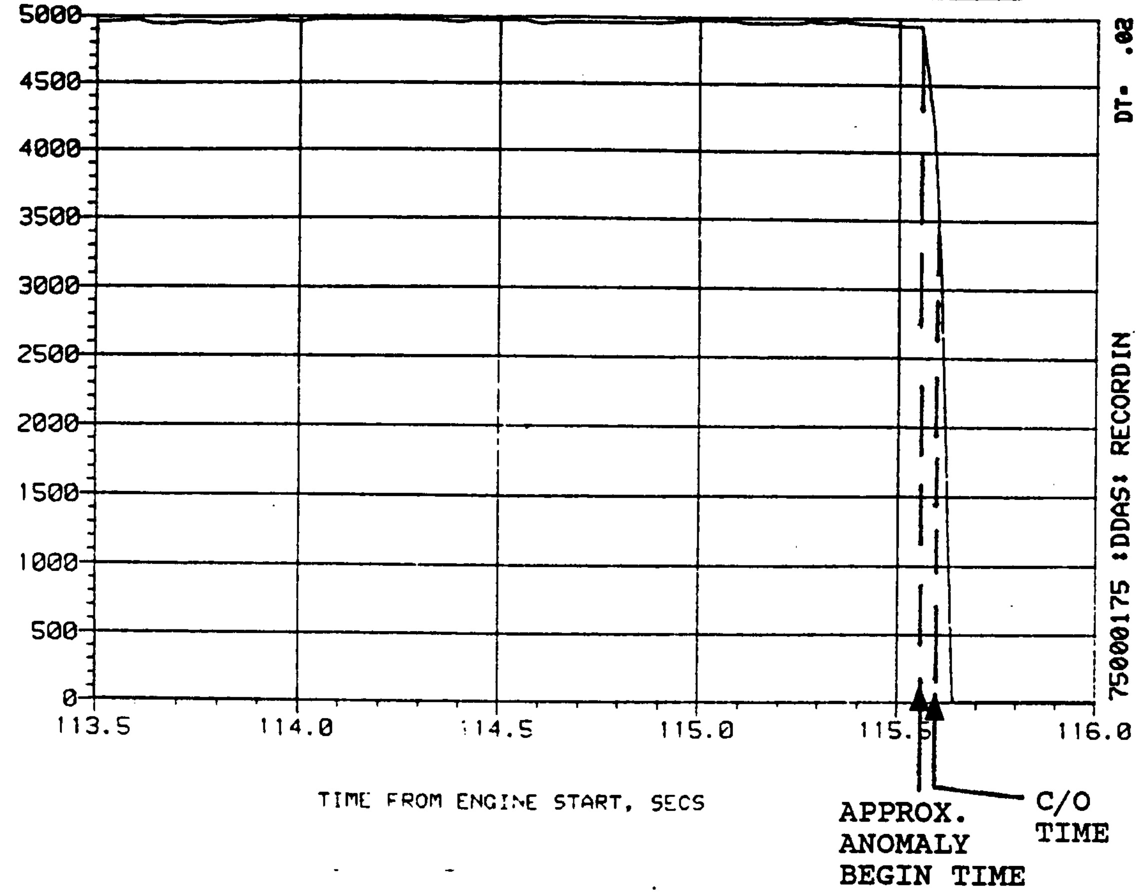
Duct, Manifold, or Heat Exchanger Failure

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change from Steady State

MCC CL DS T

(Duct, Manifold, or Heat Exchanger Failure)



HPFP SPEED

(Duct, Manifold, or Heat Exchanger Failure)

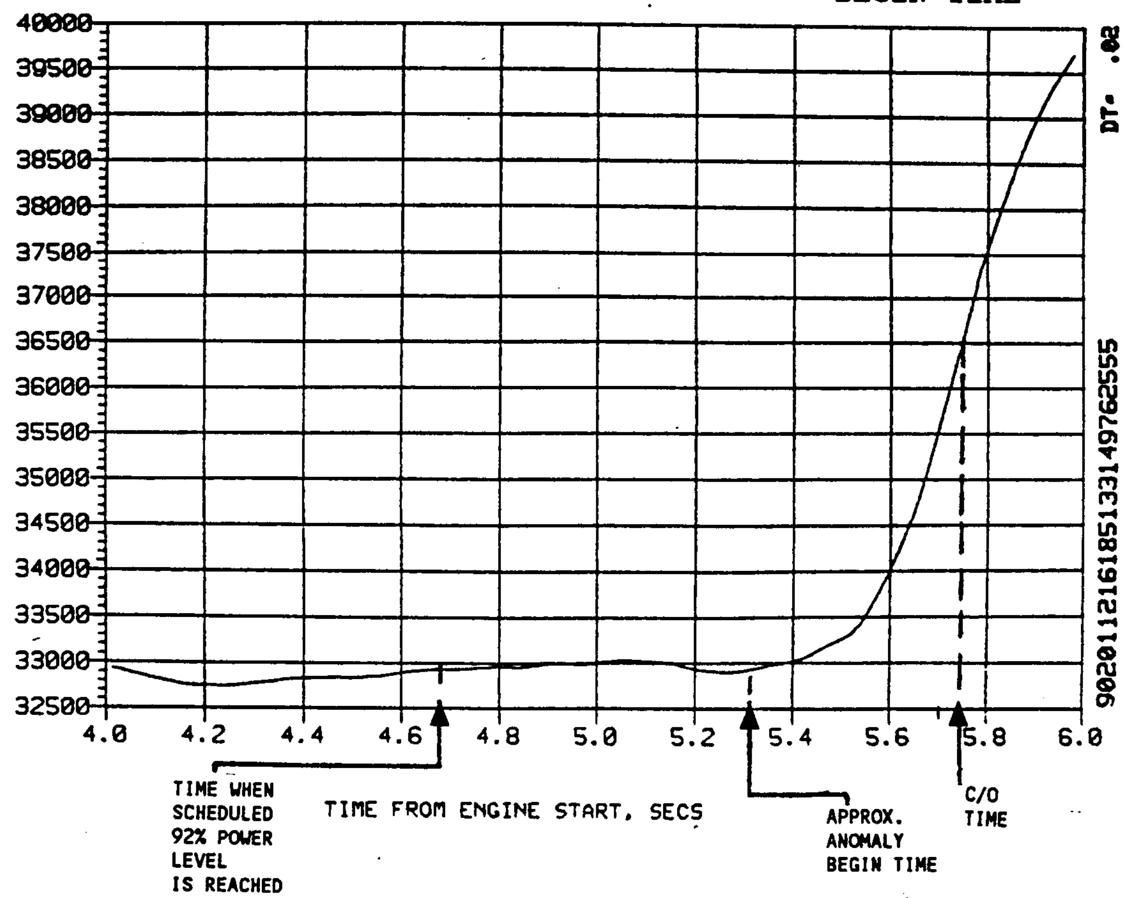


Table IIA-3: (cont.) Failure Mode Qualitative Characteristics --Duct, Manifold, or Heat Exchanger Failure

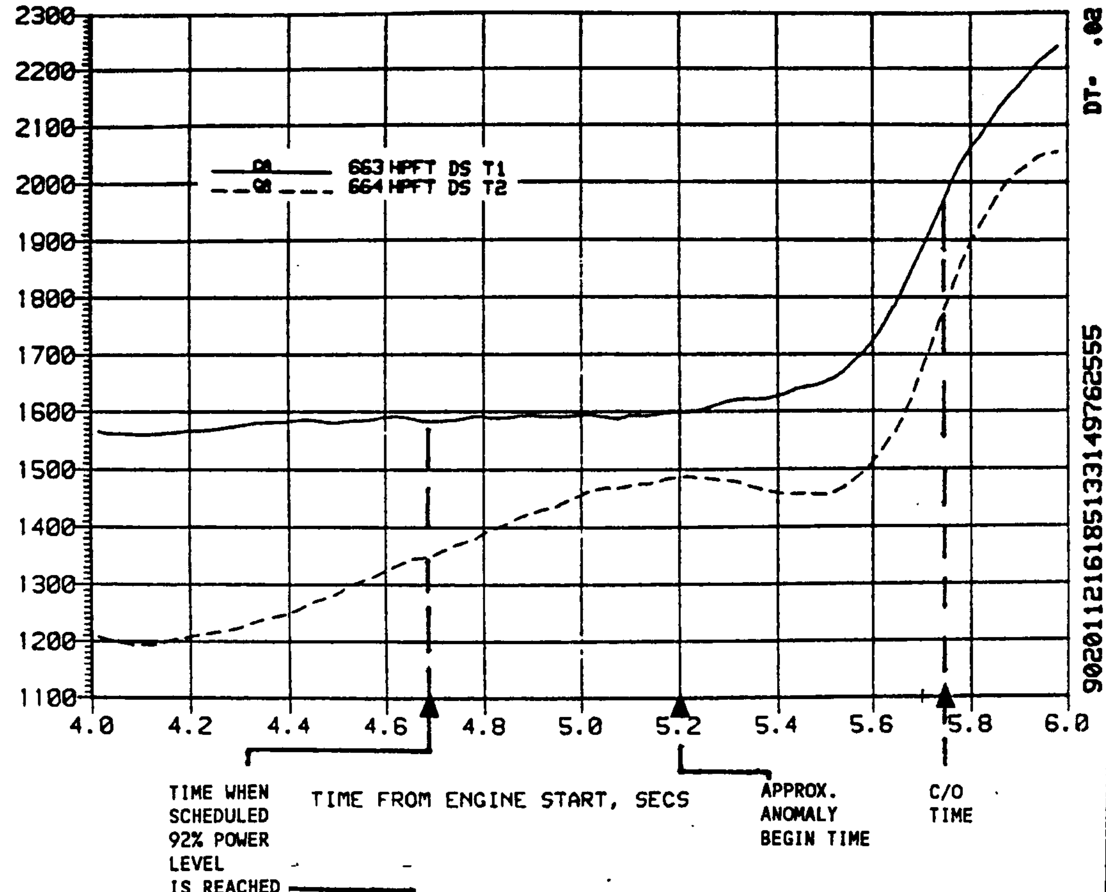
Duct, Manifold, or Heat Exchanger Failure

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPFT DS TEMP

(Duct, Manifold or Heat Exchanger Failure)



HPOT DS TEMP

(Duct, Manifold, or Heat Exchanger Failure)

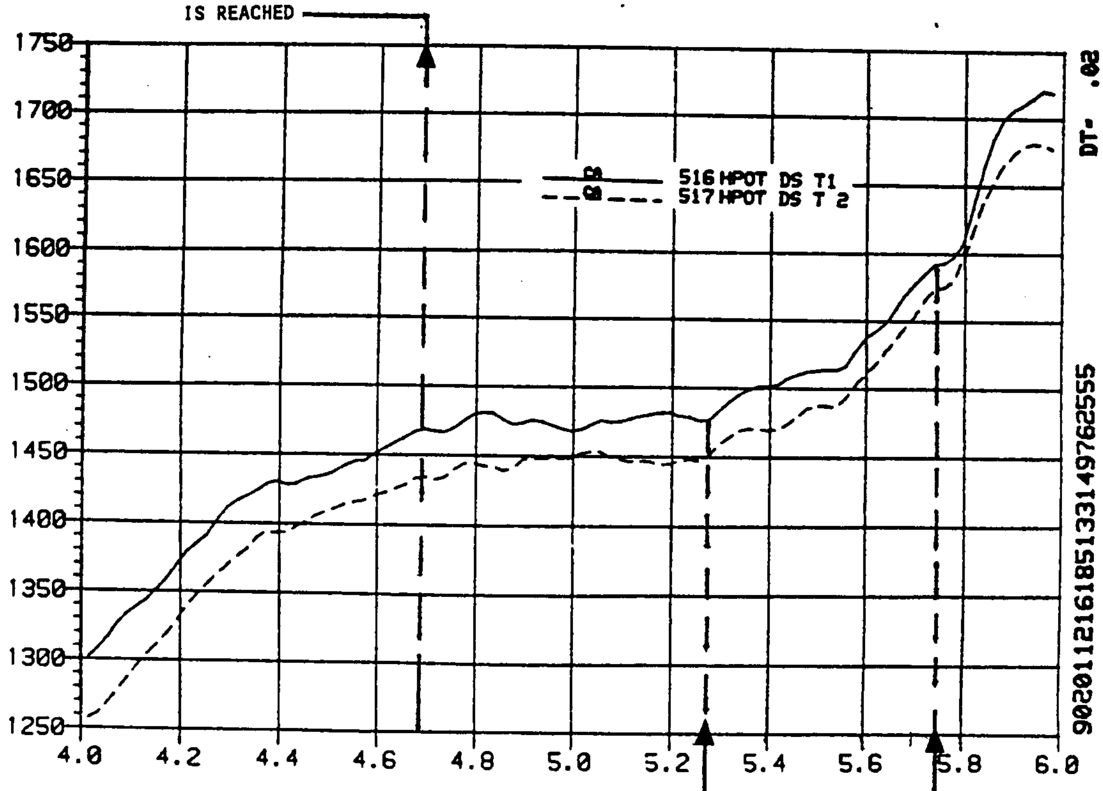


Table IIA-3: (cont.) Failure Mode Qualitative Characteristics --Duct, Manifold, or Heat Exchanger Failure

Duct, Manifold, or Heat Exchanger Failure

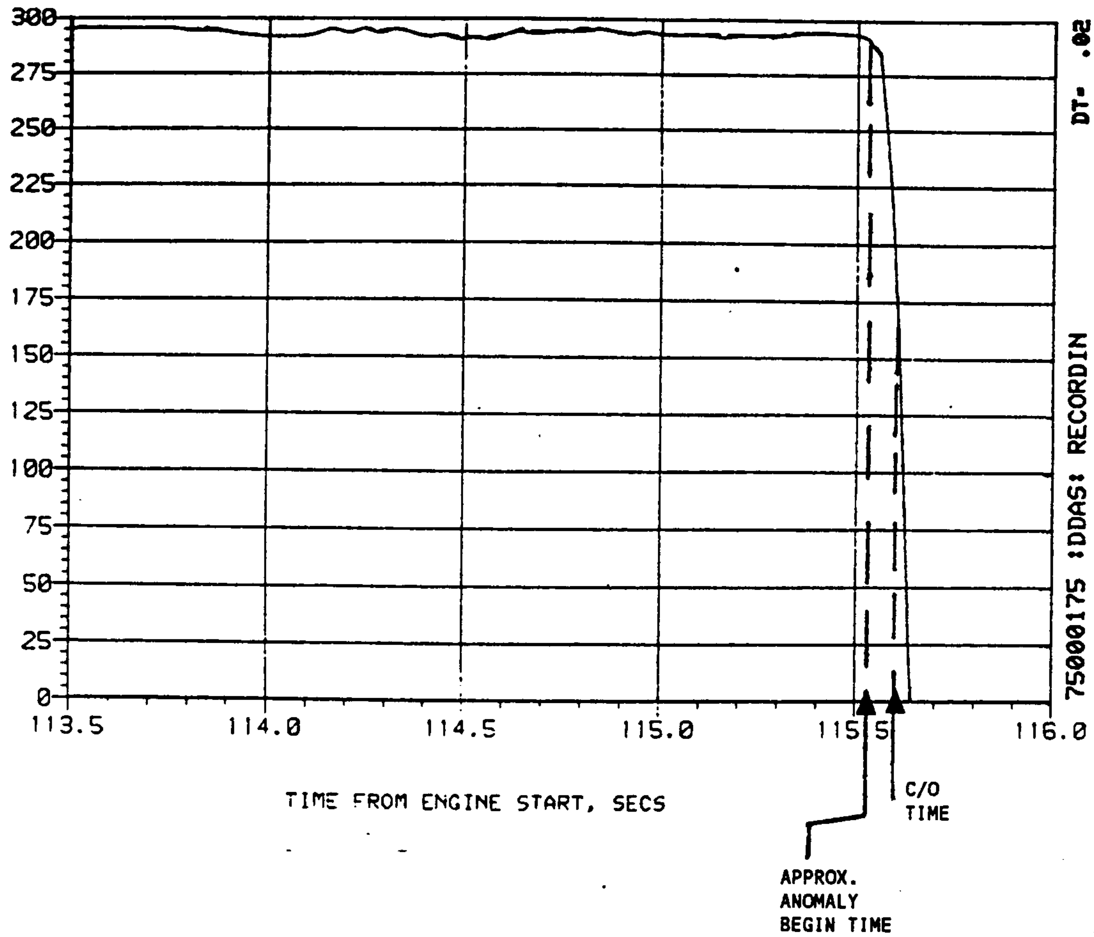
Sample Indicative Parameters	CRT Example of the Indicative Parameter's Anomaly Change from Steady State
LPOP DS PR (Duct, Manifold, or Heat Exchanger Failure)	

Table IIA-3: (cont.) Failure Mode Qualitative Characteristics --Duct, Manifold, or Heat Exchanger Failure

FAILURE MODE QUALITATIVE CHARACTERISTICS:

Type of Incident	Generic Description of Incident Type and Sample Indicative Parameters:
Valve Failure	The valve anomalies in two previous SSME tests can be characterized as being initiated from a failure of the main propellant valves (the main fuel or oxidizer valves). In both cases the failure resulted in:

1. The HPFT (High Pressure Fuel Turbine) discharge temperature rising to its redline limit in less than .1 seconds.
2. Damage to other related engine components.
3. And a fire damaging further system components.

Sample Indicative Parameters	CRT Example of the Indicative Parameter's Anomaly Change from Steady State

MCC PC

(Valve Failure)

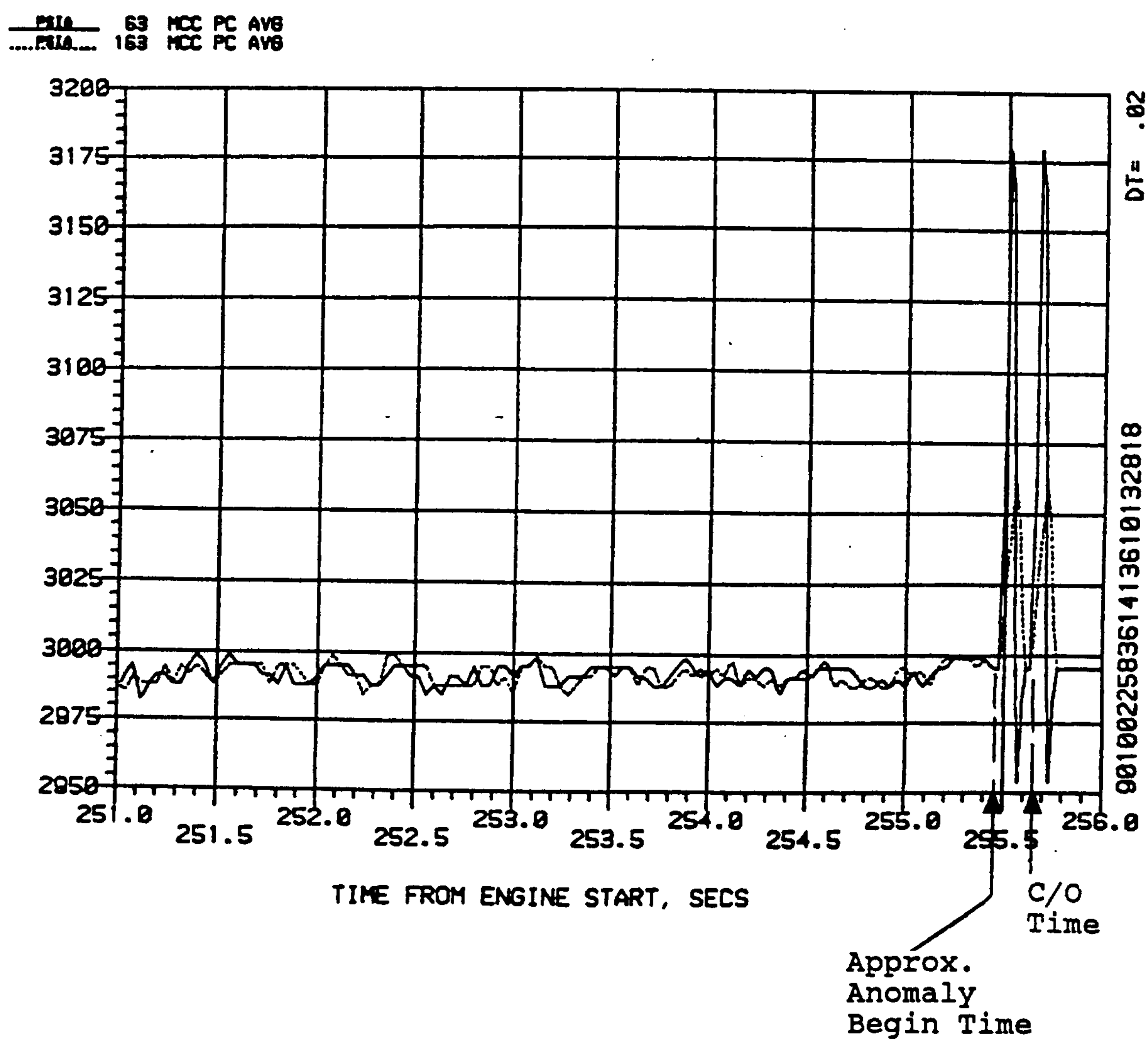


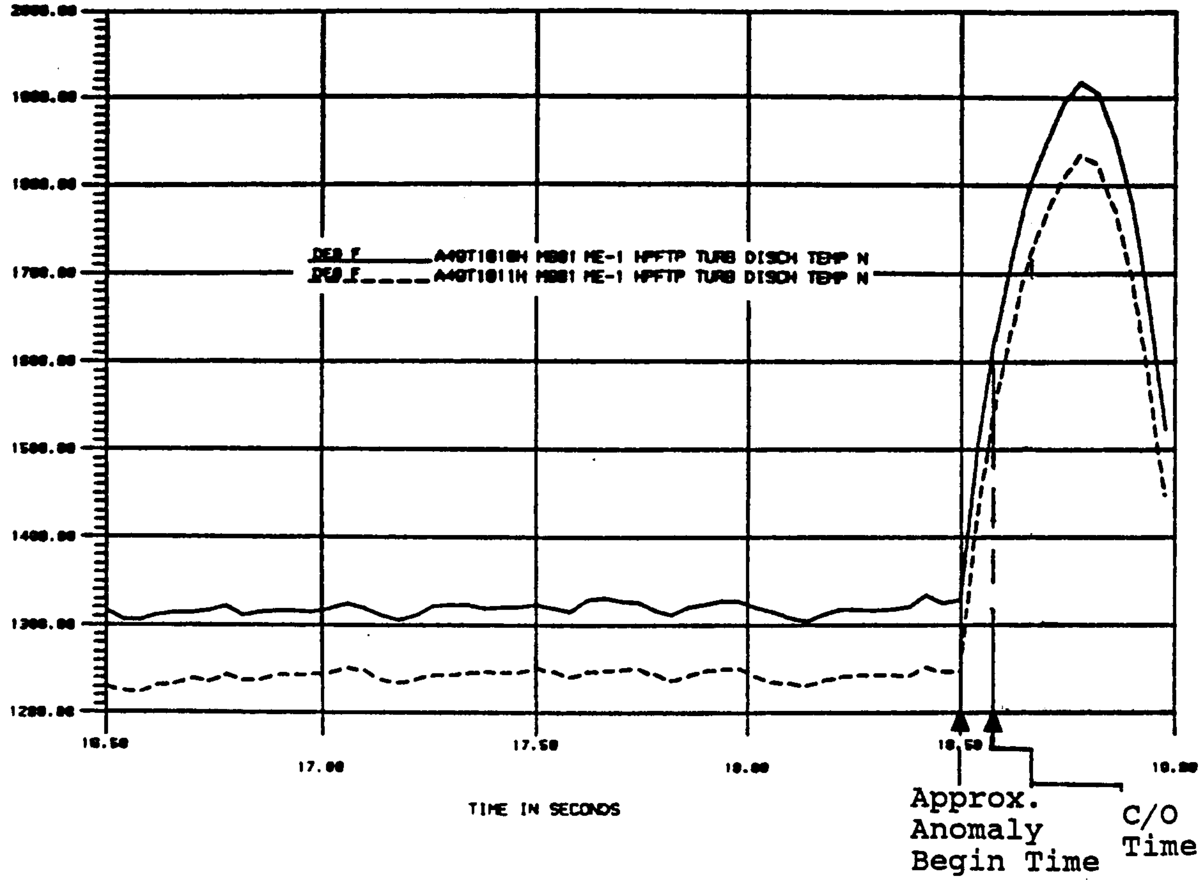
Table IIA-4: Failure Mode Qualitative Characteristics --Valve Failure

Sample
Indicative
Parameters

CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPFT DS TEMP

(Valve
Failure)



HPOT DS TEMP

(Valve
Failure)

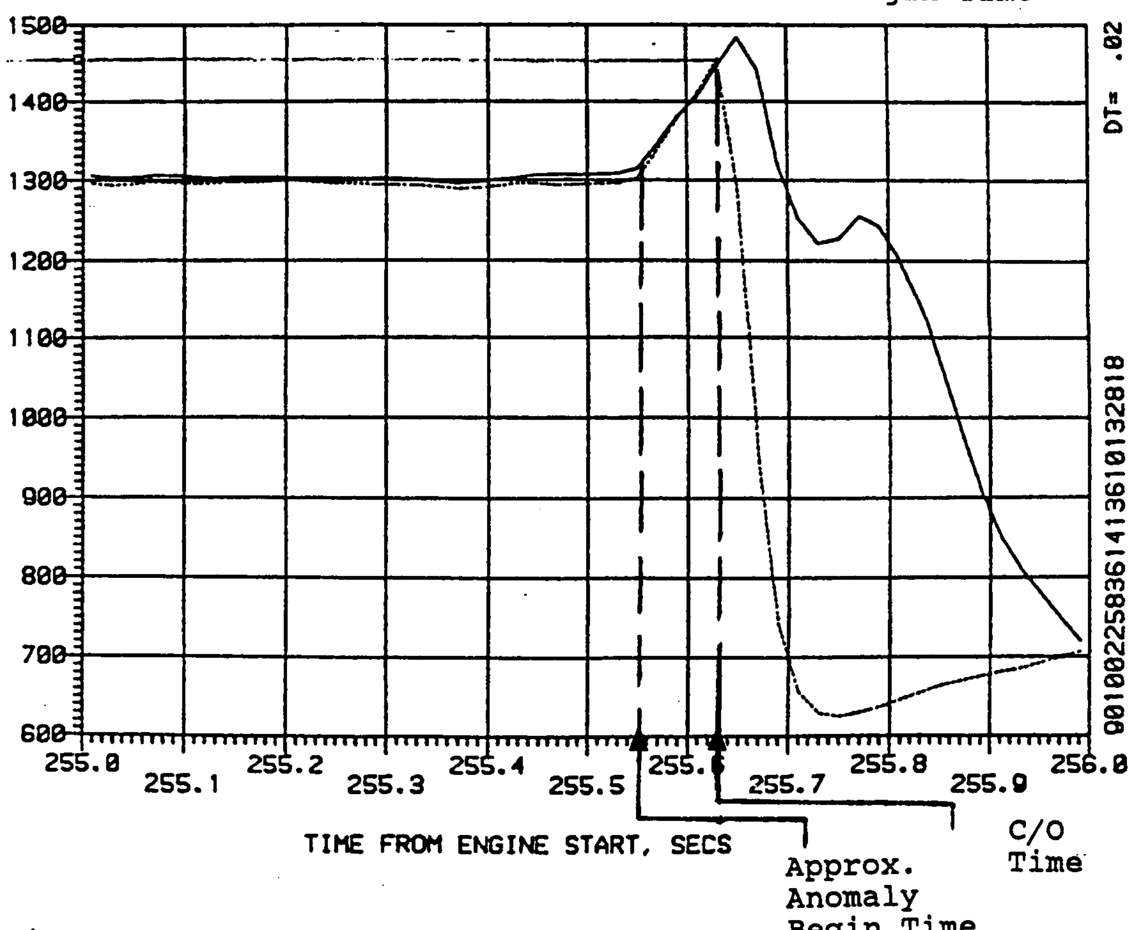


Table IIA-4: (Cont.) Failure Mode Qualitative Characteristics --Valve Failure

FAILURE MODE QUALITATIVE CHARACTERISTICS:

Type of Incident	Generic Description of Incident Type and Sample Indicative Parameters:
HPOTP Failure	The HPOTP (High Pressure Oxidizer Turbopump) anomalies in three previous SSME tests can be characterized as being initiated from either a rubbing, interference, or structural failure of one or more components of the HPOTP. The latter failure results in LOX (liquid oxygen) ignition within .02 to 25. seconds from cutoff (dependent on the failured component's location).

Sample Indicative Parameters — CRT Example of the Indicative Parameter's Anomaly Change from Steady State

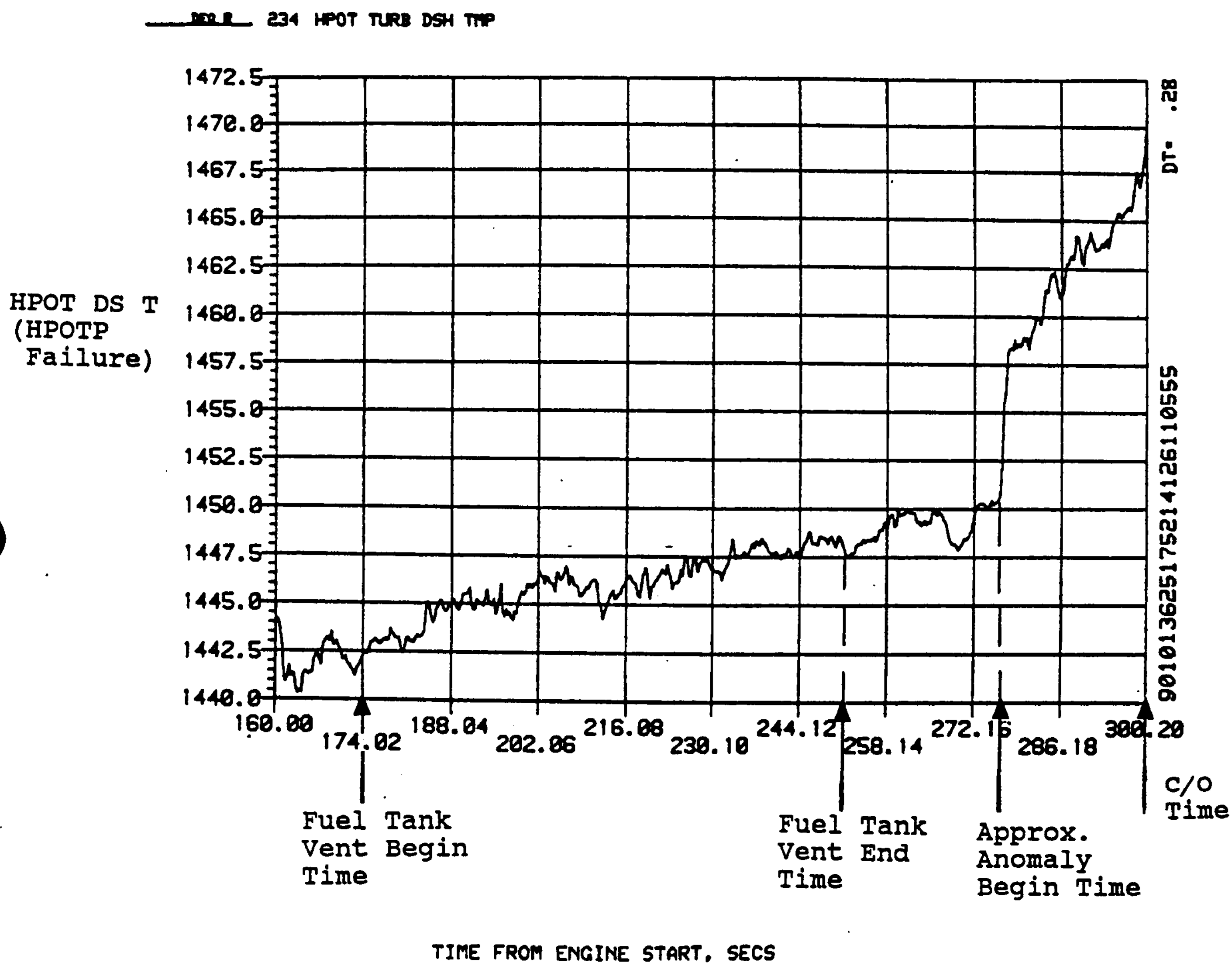


Table IIA-5: Failure Mode Qualitative Characteristics --HPOTP Failure

Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPOT PRSL DR T (HPOTP Failure)

OPOV ACT POS (HPOTP Failure)

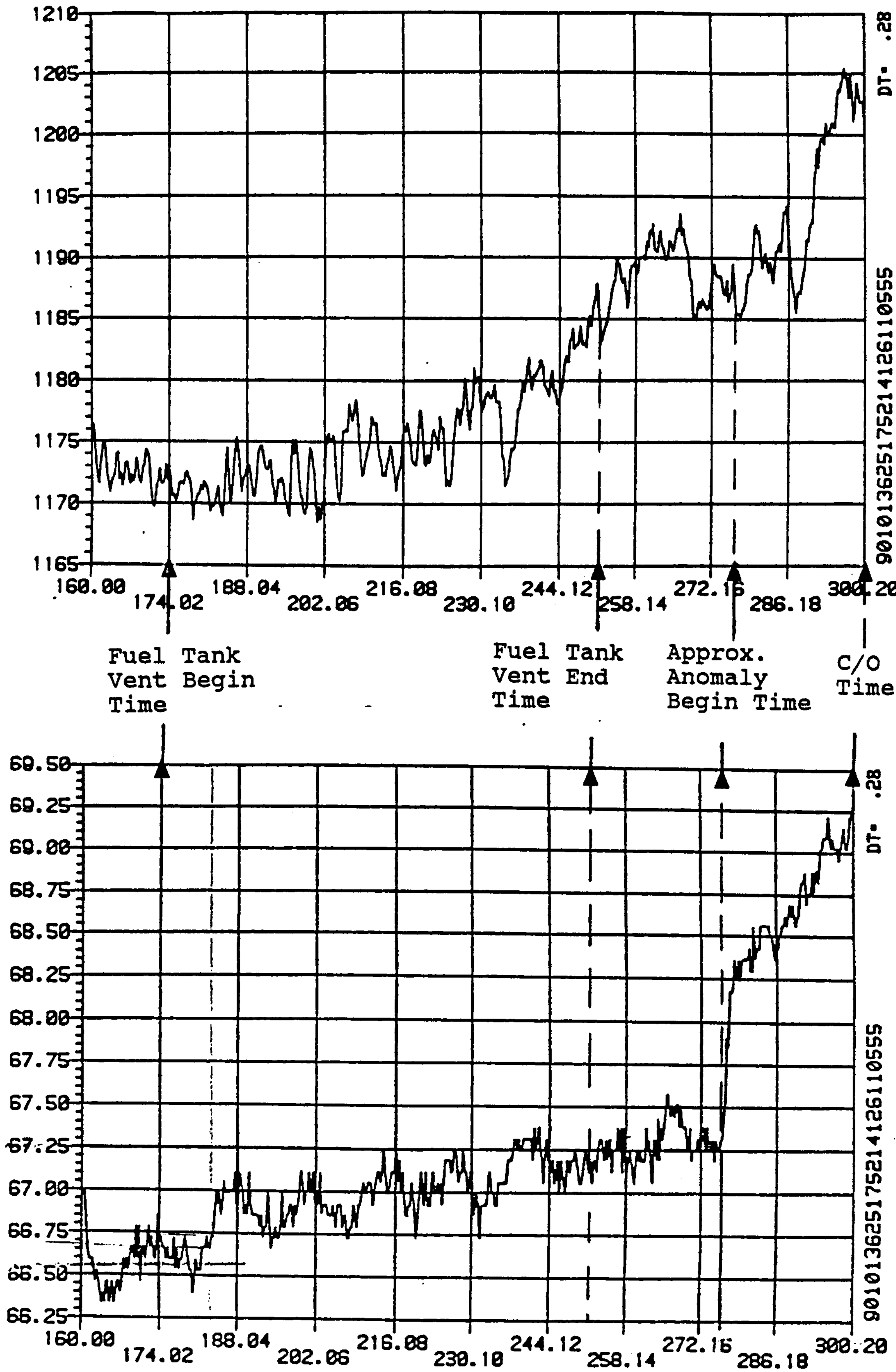


Table IIA-5: (cont.) Failure Mode Qualitative Characteristics --HPOTP Failure

FAILURE MODE QUALITATIVE CHARACTERISTICS:

Type of Incident	Generic Description of Incident Type and Sample Indicative Parameters:
HPFTP Failure	The HPFTP (High Pressure Fuel Turbopump) anomalies in eleven (11) previous SSME tests can be characterized as being initiated by failure of one component of the HPFTP. Subsequent to this failure one of the following occurs:

1. The engine system rebalances itself (to maintain the thrust level) in response to the initial HPFTP failure. This new balance lasts between 1.1 to several hundreds of seconds until other related HPFTP components fail. The engine system again responses by rebalancing itself. This second new balance lasts from .24 seconds to hundreds of seconds until other engine components suffer damage and redline cutoff is initiated. The tests which follow this sequence of events are: 901-340, 901-364, 901-436, 902-118, and 902-249.

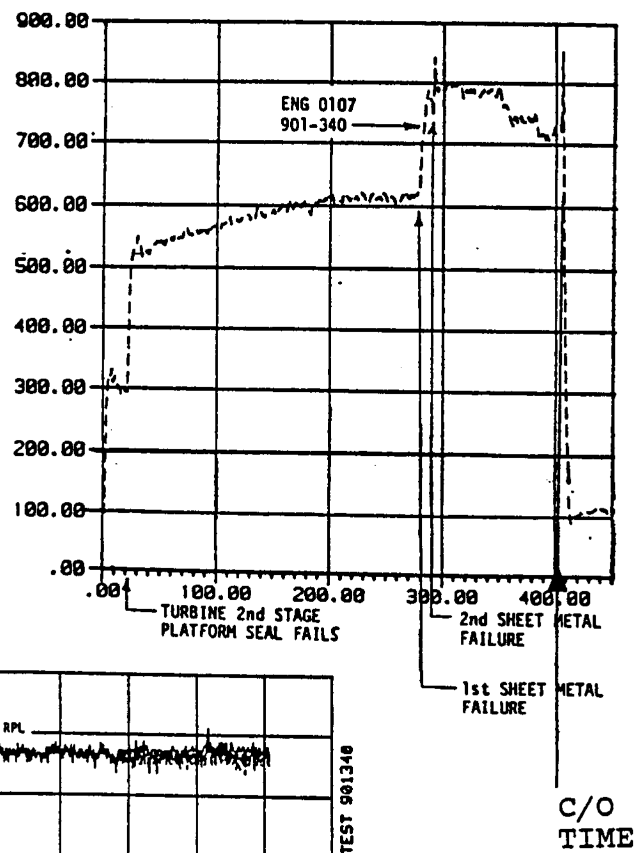
2. The engine system rebalances itself (to maintain the thrust level) in response to either the initial HPFTP failure or a combination of the initial failure and subsequent failures to other engine components. The new balance does not cause redline limits to be exceeded and lasts several hundreds of seconds until scheduled cutoff. The tests which follow this sequence of events are: 901-362, 901-363, 901-346, 901-410, and 902-209.

3. The engine system rebalances itself (to maintain the thrust level) in response to a combination of the initial HPFTP failure and subsequent failure of other engine components. The new balance exceeds redline limits and cutoff is initiated. Test 902-095 follows this sequence of events.

Sample Indicative Parameters	CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPFP CL LNR PR-
MCC HG IN PR
(Coolant Liner
Delta-P)

(HPFTP Failure)



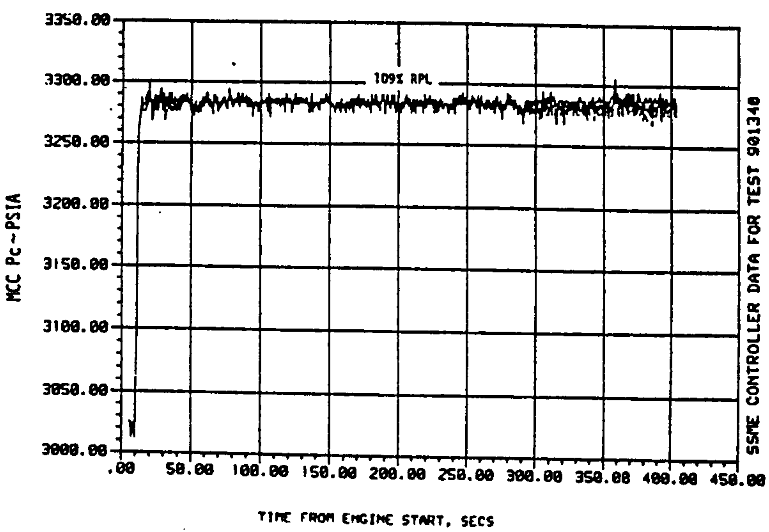
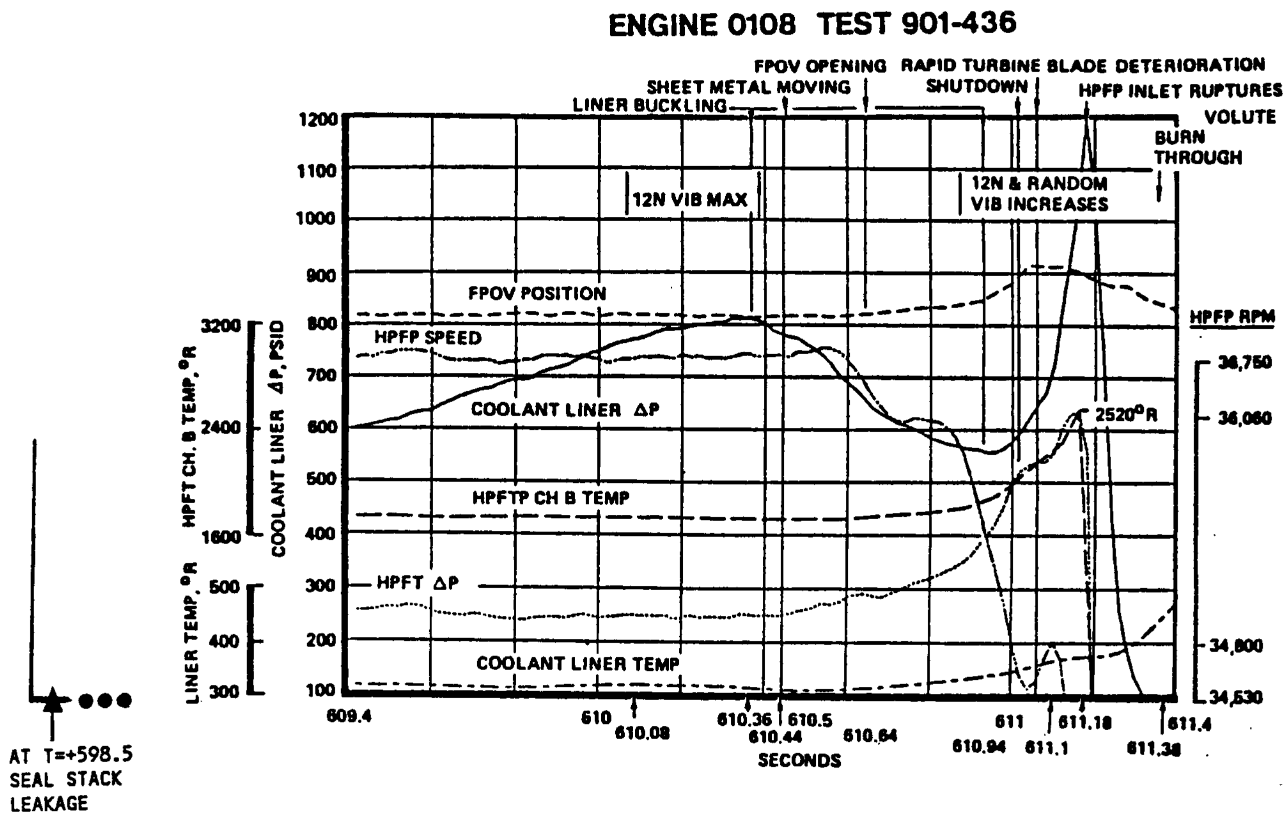


Table IIA-6: Failure Mode Qualitative Characterisitcs --HPFTP Failure

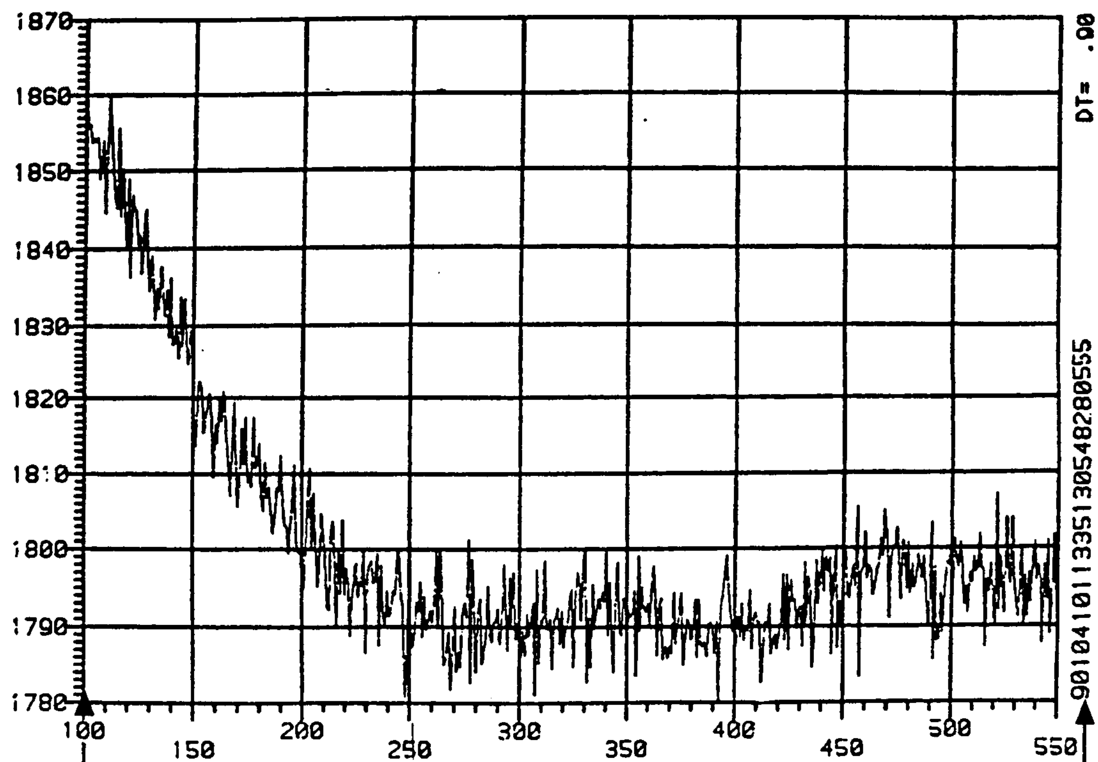
Sample Indicative Parameters

CRT Example of the Indicative Parameter's Anomaly Change from Steady State



HPFT Delta-P

(HPFTP Failure)



C/O Time at 595 sec.

APPROX.
ANOMALY
BEGIN TIME

Table IIA-6: (cont.) Failure Mode Qualitative Characteristics --HPFTP Failure

Sample
Indicative
Parameters

CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPOT Delta-P

(HPFTP Failure)

HPFT DS Temp

(HPFTP Failure

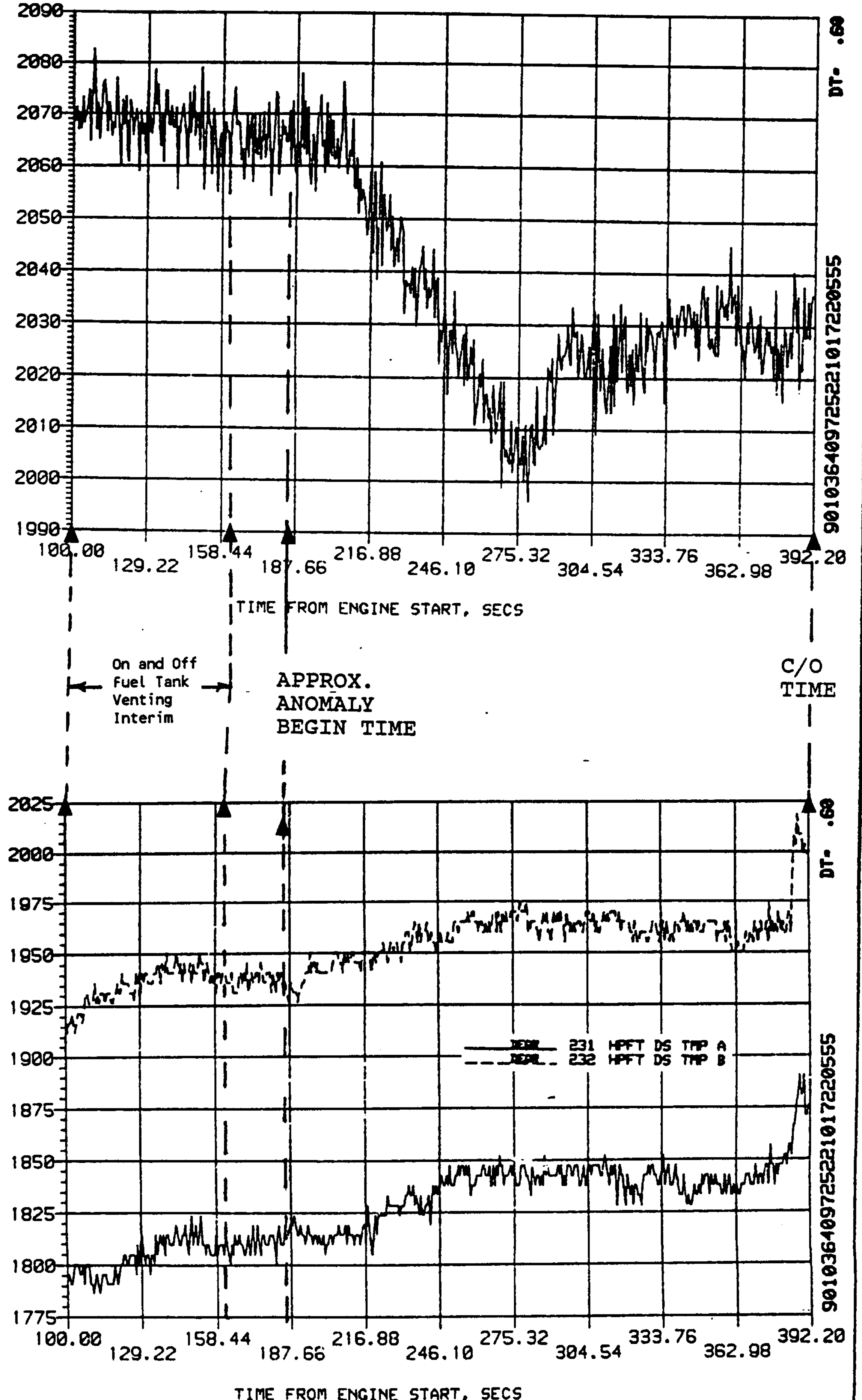


Table IIA-6: Failure Mode Qualitative Characteristics
(cont.) --HPFTP Failure

Sample
Indicative
Parameters

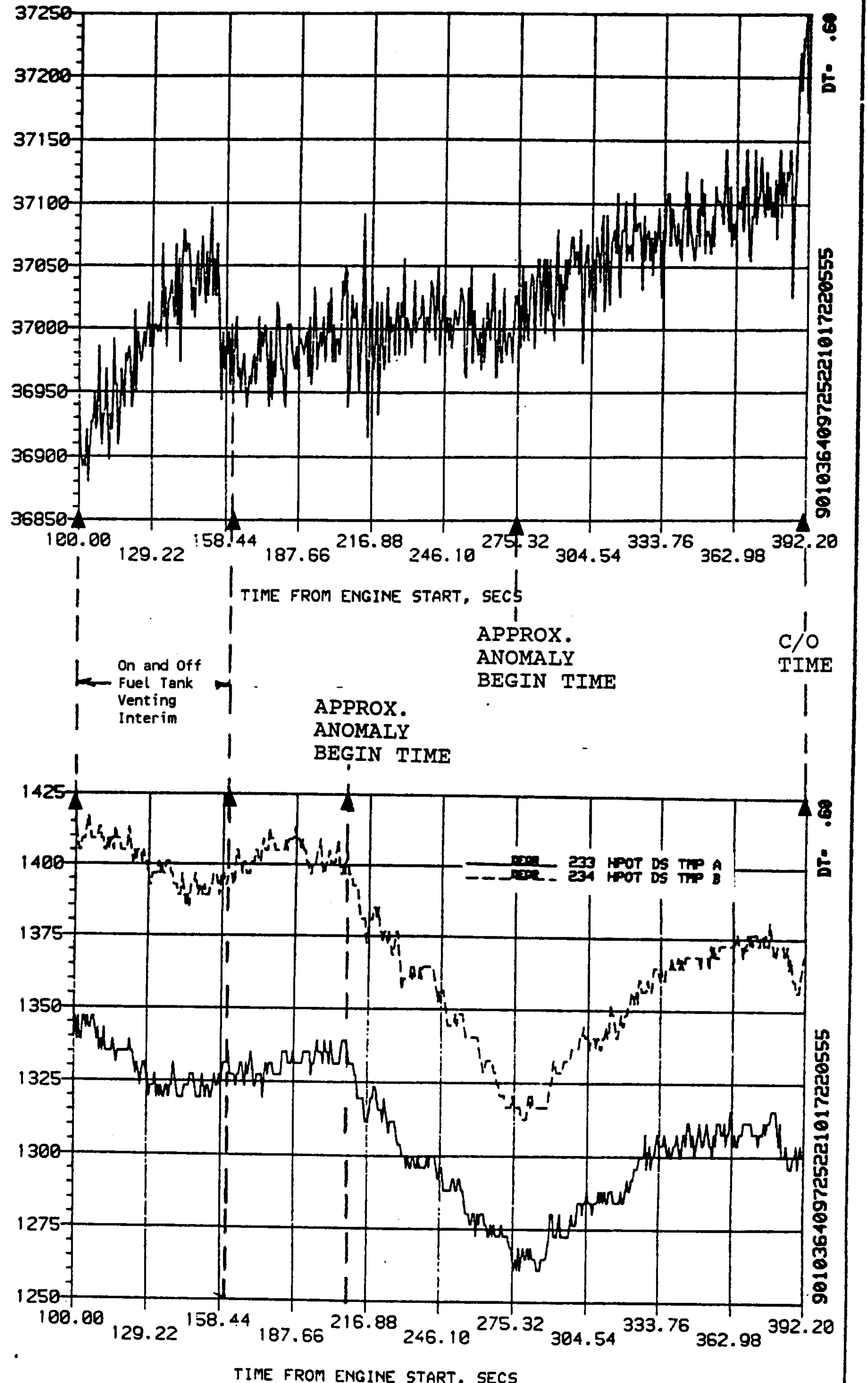
CRT Example of the Indicative Parameter's Anomaly Change from Steady State

HPFP SPEED

(HPFTP Failure)

HPOT DS TEMP

(HPFTP Failure)



Sample Indicative Parameters

FPOV ACT POS

(HPFTP Failure)

CRT Example of the Indicative Parameter's Anomaly Change from Steady State

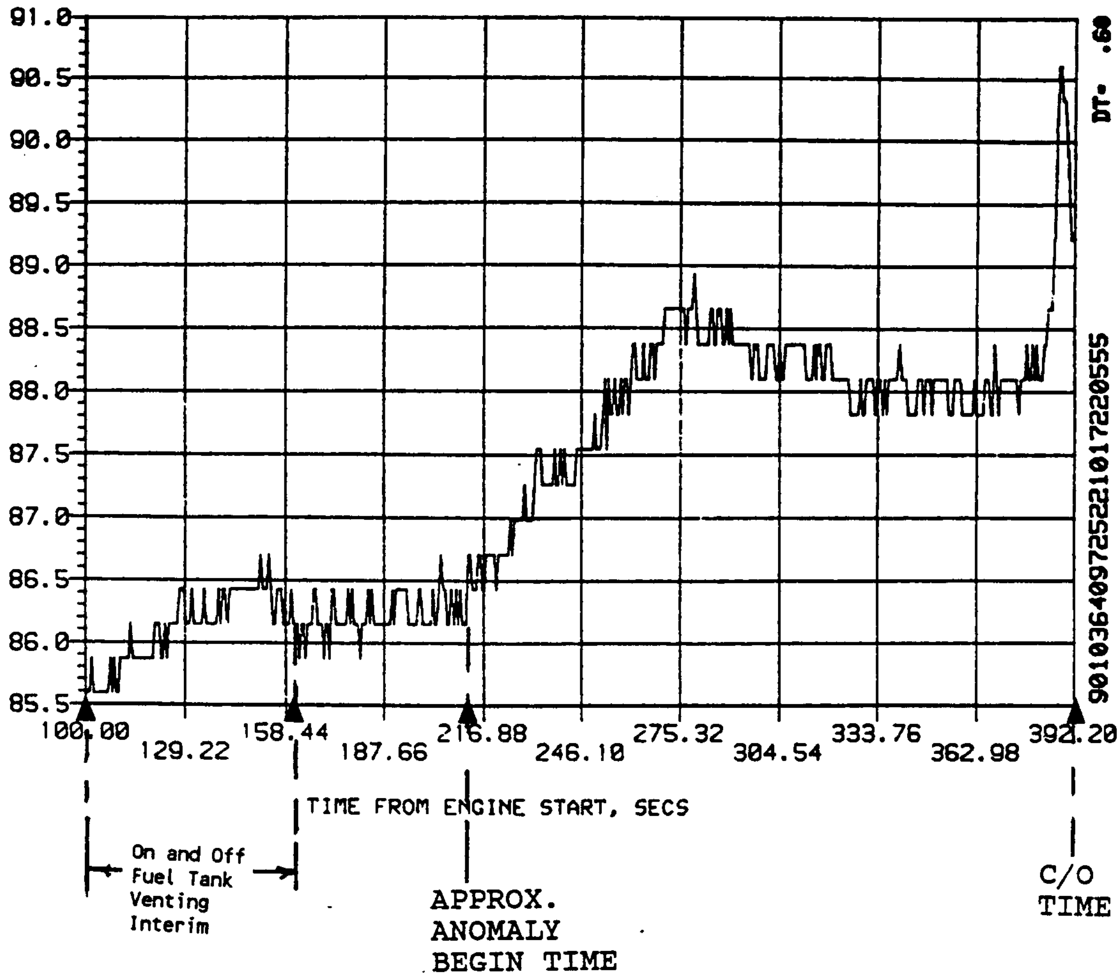
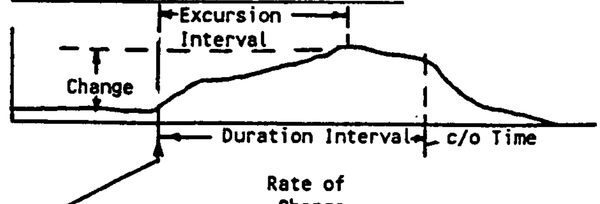


Table IIA-6: (cont.) Failure Mode Qualitative Characteristics --HPFTP Failure

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (MCC)	901-173 (Engine 0002)	Incident: During stable operation at 92% of rated power level, LOX post 10, row-13 cracked through at the tip radius between the primary and secondary faceplates. Hotgas flow into the LOX post ignited and burned out the post. LOX pouring into the face coolant manifold caused burn through of the primary and secondary faceplates, dumping face coolant into the hotgas manifold. Ejection of burned debris caused severe nozzle tube rupture (46-tubes). Fuel loss to the preburners coupled with engine control reactions to maintain MCC PC caused the HPFT discharge temperature to exceed its redline, producing a premature cutoff at 201.16 seconds from start time. (Test conducted on 4 April 1978)

Damage:
- Primary and secondary faceplates burned through. Primary faceplate burned away in a 2.5in by 1.5in area. 18-elements were burned away to within 1/8in above the secondary faceplate. Numerous high cycle fatigue cracks were found in LOX post threads in the outer rows.
- MCC showed flame spray and erosion at one acoustic cavity and upstream, adjacent to the main injector at the burned out area.
- Nozzle damage included 46-tube ruptures, primarily from impact damage, and numerous impact dents.

- A schematic of the primary faceplate damage is illustrated below.

References:
- Rocketdyne data room records.
- Rocketdyne internal letter, #IL-78-CD-3135, Engine 0002 Main Injector Failure Data Review, 4 April 1978.

Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
200.5...	OPB PC - MCC HG IN PR	- 90.9	.66	.66
200.68..	Secondary faceplate delta-P	-212.5	.48	.48
200.68..	Hotgas injector delta-P	+ 93.8	.16	.48
200.68..	MCC PC	-250.0	.48	.48
200.68..	Primary faceplate delta-P	-282.3	.48	.48
200.79..	FPB PC- MCC HG IN PR	+216.2	.37	.37
200.8...	HPFP DS PR- MCC PC	-500.0	.36	.36
200.8...	HPFT DS T1 A	+388.9	.36	.36
200.8...	HPFT DS T1 B	+388.9	.36	.36
200.8...	HPOT DS T1	+236.1	.36	.36
200.8...	HPOT DS T2	+111.1	.36	.36
200.8...	LPOP DS PR	- 34.7	.36	.36
201.06..	MCC OX IN PR- MCC PC	-350.0	.1	.1
...	MCC CLNT DS T	(Sensor does not exist)		

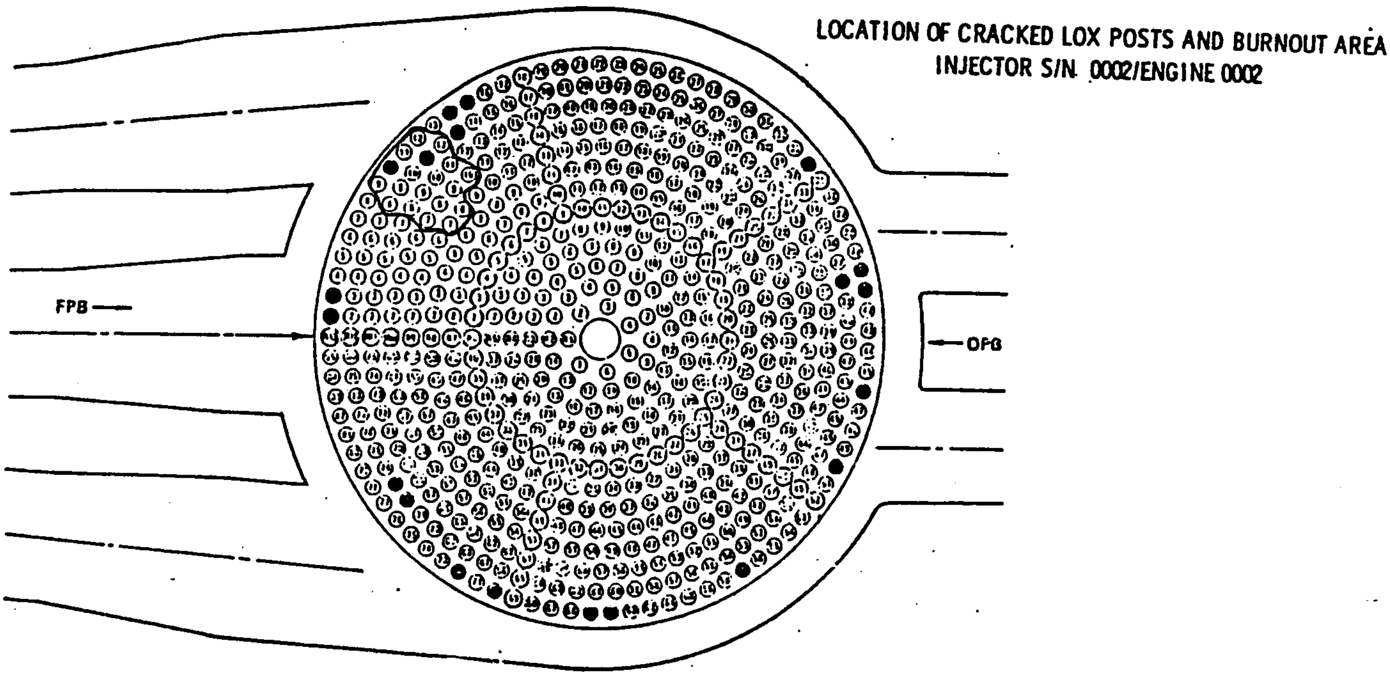
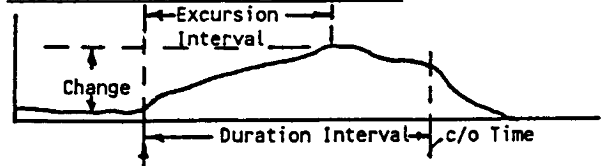


Table IIB-1: Failure Investigation Summary for Each Test (Test 901-173)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (MCC)	901-331 (Engine 2108)	See below

Incident: During stable operation at 100% of rated power level, LOX post 79, row-13 failed in the 316L material at the inertial weld (which joins a 316L post to an INCO718 interporpellant plate stub). Test data analysis reveals that the LOX post failure occurred first, and subsequently did major damage to the injector. Once the injector was damaged, a loss in C-star efficiency resulted and caused a reduction in MCC PC. The engine control system responded by increasing the OPOV (Oxidizer Preburner Oxidizer Valve) open position. The increased LOX flowrate necessary to maintain the 100% rated power level caused the HPOT discharge temperature to exceed its redline (1760 deg-R). The test was thus cutoff prematurely at 233.14 seconds from start time. (Test conducted on 15 July 1981).

Damage:
- Primary and secondary faceplates burned through. 169 LOX posts were either eroded off above the secondary faceplate, or eroded into or part of the inter-propellant faceplate.
- MCC acoustic cavity suffered erosion damage. The MCC liner had 10 gouges from 1/8in to 3/4in long and had minor slag on 15% of the convergent section.
- Nozzle damage included approximately 60-tubes from shrapnel.
- HPOT sheet metal burned through and inlet (struts burned white).

- A schematic of some of the above cited damage is illustrated below.

References:
- Rocketdyne data room records.
- NASA Marshall Investigation Board Report #2108 Main Injector Failure, Test Stand A1, Part I, 15 July 1981.

Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
232.19..	Secondary faceplate delta-P	-625.0	.12	.95
232.2...	Primary faceplate delta-P	-146.7	.15	.94
232.2...	Hotgas injector delta-P	+375.0	.12	.94
232.25..	HPFP DS PR-MCC PC	-500.0	.1	.89
232.25..	OPB PC - MCC HG IN PR	-1000.0	.1	.89
232.25..	LPOP DS PR	+170.0	.1	.89
232.28..	MCC CLNT DS T	+ 89.3	.56	.86
232.29..	FPB PC - MCC HG IN PR	-600.0	.1	.85
232.3...	MCC OX IN PR-MCC PC	+200.0	.7	.84
232.3...	HPFT DS T1 A	+566.7	.3	.84
232.3...	HPFT DS T1 B	+583.3	.3	.84
232.32..	MCC PC	-1000.0	.11	.82
232.39..	HPOT DS T2	+706.7	.75	.75
232.40..	HPOT DS T1	+743.2	.74	.74

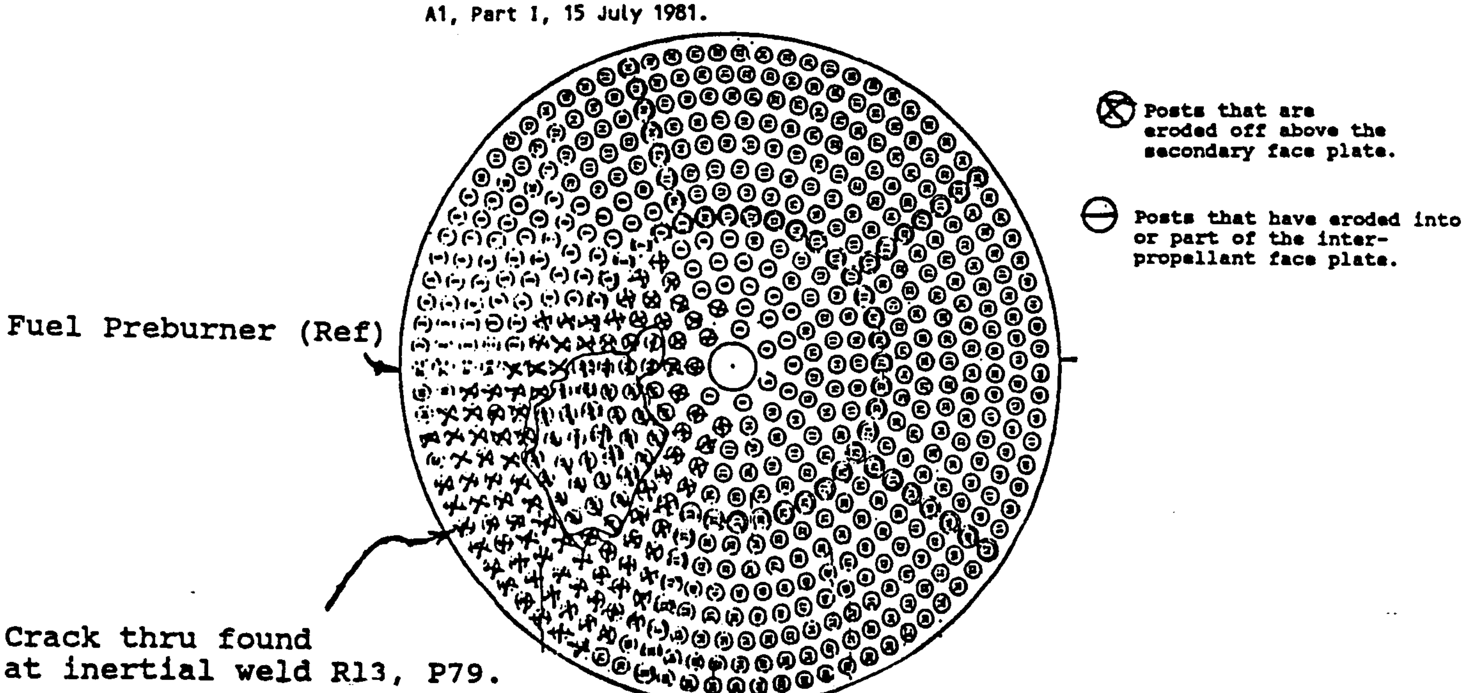
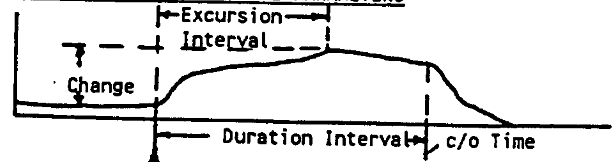


Table IIB-2: Failure Investigation Summary for Each Test (Test 901-331)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (MCC)	750--148 (Engine 0110)	Incident: During stable operation at 105% of rated power level, LOX post 12, row-13 failed at the inertial weld. Test data analysis reveals that the LOX post failure occurred first, and subsequently did major damage to the injector. The loss in combustion efficiency (due to damage in the injector area), combined with a sudden loss of fuel from many nozzle tube ruptures (due to injector debris) caused the controller to command the OPOV open to the limit value in an attempt to maintain the required chamber pressure. The OPOV opening with the fuel loss to the oxidizer preburner, caused the HPOTP turbine discharge temperature to exceed its redline value at 16 seconds from start time. (Test conducted on 2 September 1981). Damage: -Primary and secondary faceplates burned through. 149 LOX posts burned through. Erosion evident in the interpropellant plate, severe erosion in MCC injector. -MCC erosion downstream of one acoustic cavity, 1-three channel wide erosion through the hotgas wall in the convergent section, 50-dings or nicks, slag deposits. -Nozzle damage included approximately 150 tube ruptures.

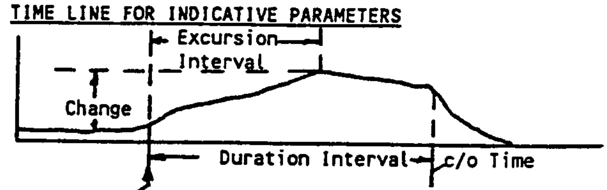
Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
15.37..	OPB PC - MCC HG IN PR	-533.3	.15	.63
15.4...	HPFP DS PR- MCC PC	-1500.0	.2	.6
15.4...	FPB PC - MCC HG IN PR	-750.0	.1	.6
15.4...	LPOP DS PR	+72.2	.18	.6
15.42..	Hotgas injector delta-P	+562.5	.08	.58
15.45..	Secondary injector delta-P	-666.7	.18	.55
15.45..	Primary injector delta-P	-589.3	.28	.55
15.48..	MCC CLNT DS T	+101.9	.52	.52
15.5...	MCC OX IN PR- MCC PC	-862.5	.08	.5
15.5...	HPFT DS T1 A	+1000.0	.5	.5
15.52..	MCC PC	-425.0	.48	.48
15.54..	HPOT DS T1	+978.0	.46	.46
15.54..	HPOT DS T2	+1169.6	.46	.46
...	HPFT DS T1 B	(Sensor malfunction)		

References: -Rocketdyne data room records.
-NASA Marshall Investigation Board Report SSME 0110 Main Injector Failure Test Stand A-3, Part I, 2 September 1981.

Table IIB-3: Failure Investigation Summary for Each Test (Test 750-148)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (MCC)	901-183 (Engine 0005)	Incident: During stable operation at 92% of rated power level, LOX post 76, row-13 had a thread root fatigue crack (due to high cycle fatigue). The condition appears to have limited itself; cutoff was initiated by an erroneous HPFP radial accelerameter redline at 51.1 seconds from start time. (Test conducted on 5 June 1978). Damage: -Primary faceplate burned through. 15-LOX posts eroded back to the secondary faceplate; secondary faceplate has not burned through. -MCC hotgas wall received minor scalding. -Nozzle had a failed saddle patch at tube #246. -A schematic of some of the above cited damage is illustrated below. Reference: -Rocketdyne data room records.

Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
24.0...	Secondary faceplate delta-P	-5.7	4.80	27.1
24.1...	HPFP DS PR-MCC PC	-33.3	.60	27.0
24.2...	MCC OX IN PR-MCC PC	+3.9	2.20	26.9
24.21..	MCC PC	-39.5	.19	26.89
24.3...	Primary injector delta-P	-8.4	3.50	26.8
24.5...	HPFT DS T1 A	+260.0	.10	26.6
24.5...	HPFT DS T1 B	+146.7	.15	26.6
24.5...	HPOT DS T1	+24.0	.25	26.6
24.5...	HPOT DS T2	+12.0	.25	26.6
24.6...	Hotgas injector delta-P	-10.3	.68	26.5
24.6...	MCC CLNT DS T	+1.5	3.20	26.5
...	FPB PC - MCC HG IN PR	(No change is strikingly indicated)		
...	OPB PC - MCC HG IN PR	(No change is strikingly indicated)		
...	LPOP DS PR	(No change is strikingly indicated)		

LOCATION OF CRACKED LOX POSTS AND BURNOUT AREA
INJECTOR S/N 2003/ENGINE 0005

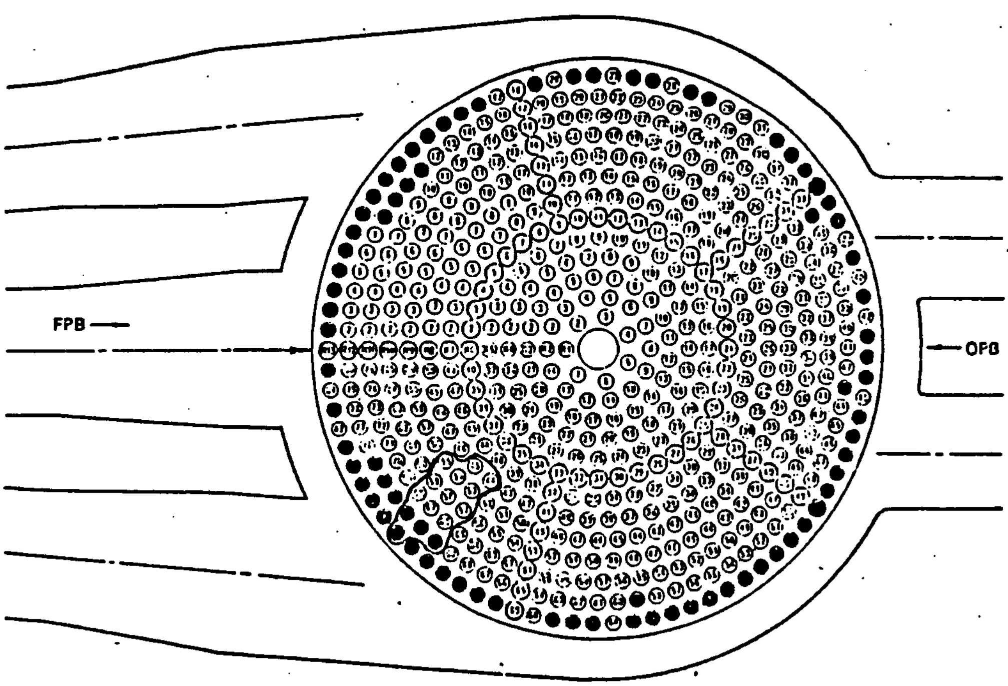
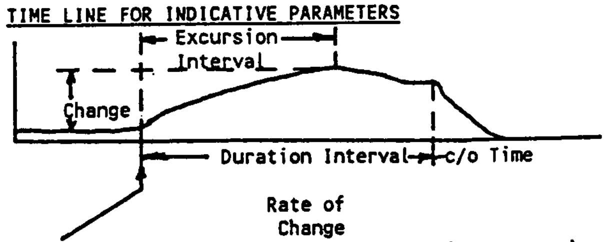


Table IIB-4: Failure Investigation Summary for Each Test
(Test 901-183)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (MCC)	902-198 (Engine 2004)	Incident: During stable operation at 102% of rated power level, LOX post 61, row-12 cracked through between the primary and secondary faceplates. Test data analysis reveals that the LOX post failure occurred first, and subsequently did major damage to the injector. The loss of fuel through the primary faceplate and from the ruptured nozzle tubes resulted in a oxidizer rich condition in the oxidizer preburner and led to a HPOT discharge temperature redline cutoff at 8.5 seconds from start time. (Test conducted on 23 July 1980).

Damage:
- Primary faceplate burned through between rows 5 and 13. Minor erosion of the secondary faceplate; burn through of 56-LOX posts; the interpropellant plate and most of the basic injector reusable.
- MCC minor erosion in acoustic cavity and to coolant channels.
- Nozzle damage included 38 tube damage from injector shrapnel; holes found in 11 tubes and dents in 27 tubes.

Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
5.5...	Secondary faceplate delta-P	-200.0	.25	3.0
5.5...	Primary faceplate delta-P	-266.0	.30	3.0
5.5...	HPFP DS PR-MCC PC	-300.0	.20	3.0
5.5...	OPB PC - MCC HG IN PR	+92.3	1.30	3.0
5.5...	MCC PC	-213.6	.22	3.0
5.5...	HPOT DS T1	+1620.0	.25	3.0
5.5...	HPOT DS T2	+1560.0	.25	3.0
5.6...	HPFT DS T1 A	+3625.0	.40	2.9
5.6...	HPFT DS T1 B	+237.5	.40	2.9
5.6...	LPOP DS PR	-66.8	.25	2.9
5.66..	MCC CLNT DS T	+23.5	2.34	2.84
5.7...	Hotgas injector delta-P	-44.1	1.45	2.8
5.75..	FPB PC - MCC HG IN PR	+120.0	.5	2.75
...	MCC OX IN PR-MCC PC	(Sensor does not exist)		

- A schematic of some of the above cited damage is illustrated below.

References:
- Rocketdyne data room records.
- NASA Marshall Investigation Board Report SSME #2004 Main Combustion Chamber Failure Test Stand A-2, National Space Technology Laboratory, 22 August 1980.

Fuel Preburner (Ref)

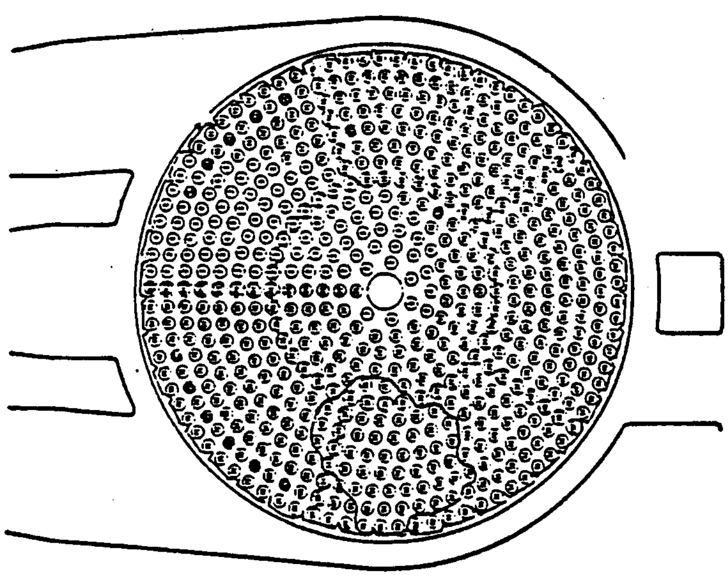


Table IIB-5: Failure Investigation Summary for Each Test (Test 902-198)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

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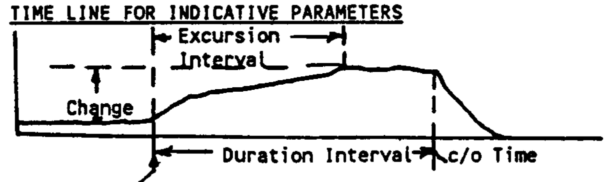


Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (FPB)	901-307 (Engine 0009)	Incident: This test was one of several designed to determine the minimum LOX level upstream of the LPOP (i.e. minimum NPSH) with which the pump could operate without overspeed. The test terminated as designed with a redline cutoff at the elevation-J level of the LPOP inlet duct. During operation at 109% rated power level a High Cycle Fatigue (HCF) through crack developed at the fuel preburner's injector LOX post/element C-8. The fuel mixed with the LOX through this crack, ignited and burned the LOX post tip. Additional damage followed to the fuel sleeve and faceplate. After cutoff initiation, the GH2 backflowed and ignited the residual LOX within the dome, causing the remaining damage. (Test conducted on 28 January 1981)

Time of Change	Indicative Parameter	Rate of Change (psi/sec, pos/sec, or deg/sec)	Excursion Interval	Duration Interval
31.03..	HPFT DS T1 B	-1.10	44.0	44.0
38.03..	OPOV ACT POS	-.20	9.0	37.0
44.03..	LPOP DS PR	-.71	31.0	31.0
47.03..	MCC OX IN PR-MCC PC	-.89	28.0	28.0
47.03..	HPOT DS T2	-1.75	28.0	28.0
49.03..	HPOT DS T1	-1.80	26.0	26.0
54.73..	HPFP CL L PR-MCC HG IN PR	-60.00	.5	20.3
61.03..	HPFT DS T1 A	-17.40	3.5	14.0

Damage:
- Fuel preburner injector had an eroded area from number-1 baffle out past number 5, and from row B thru row G. The average depth of the erosion was .02 inches with 4-holes burned through the fuel sleeve. There was severe face and post damage. Only one LOX post/element had crack damage. Slag buildup was found on the inside diameter of the LOX posts (40 of 250 posts).
- HPFT inlet burned completely through at the 1 o'clock position; most 1st stage turbine blades had heavy spalling and appeared to have cracks at the root; turbine seals had moderate erosion.

- The schematic below illustrates one area of damage described above.

References:
- Rocketdyne data room records.
- Rocketdyne's Fuel Turbomachinery Post Test Report, Engine 0009, 29 January 1981.
- Unsatisfactory Condition Report (UCR), FPB Injector Assy, 29 January 1981.
- Rocketdyne report RSS-8595-24, SSME Accident/Incident Report, Engine 0009/0204, 22 December 1981, NAS8-27980.

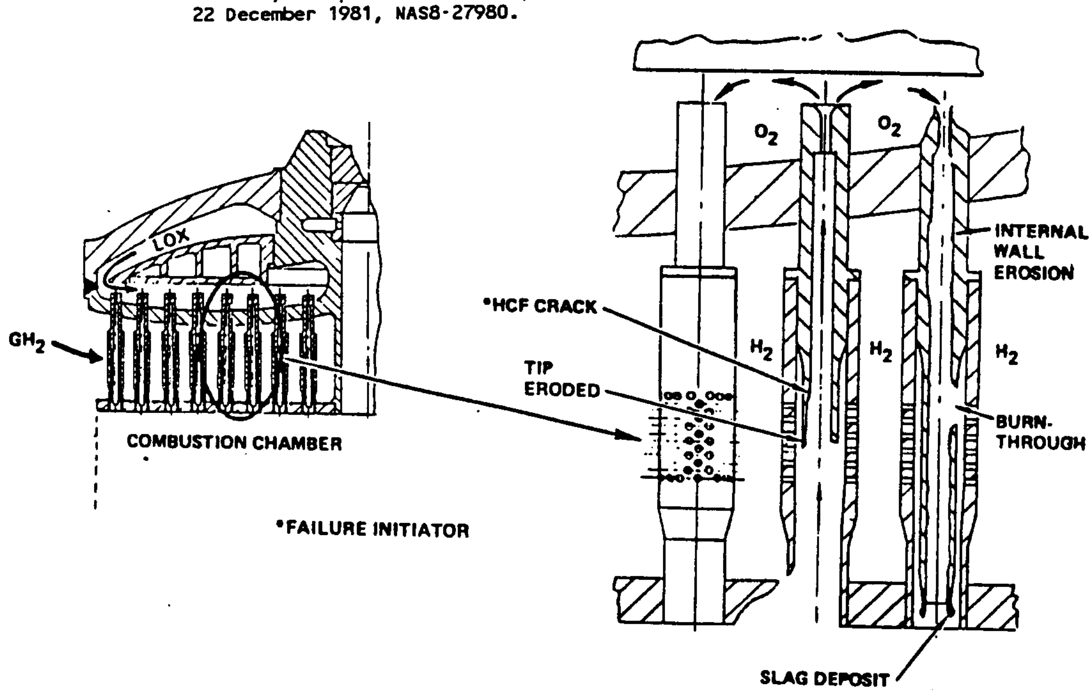
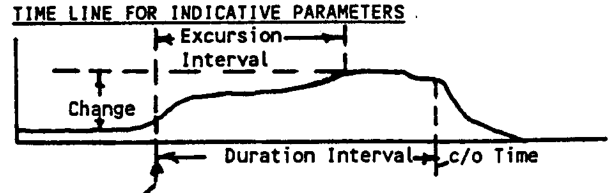


Table IIB-6: Failure Investigation Summary for Each Test (Test 901-307)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



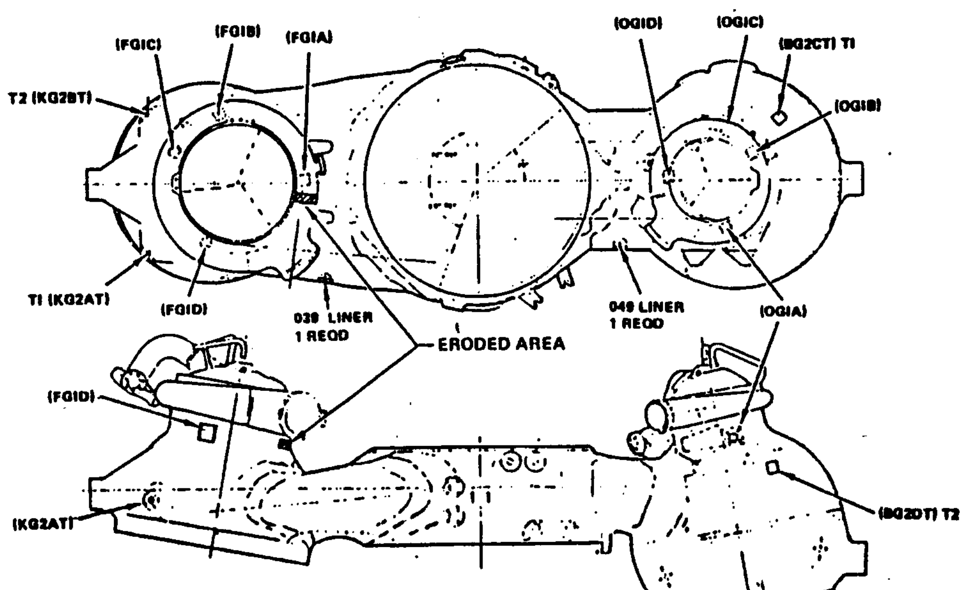
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Injector (FPB)	SF10-01 (Engine 0006)	Incident: During 102% rated power level operation this test terminated when fire detectors and hazardous gas detectors triggered in the aft fuselage. Based on a review of the movie films, the digital data, pre-test and post-test hardware inspections, and on previous experience the most probable cause of the failure was an erosion of the fuel preburner injector element H-13 during the start transient followed by slag deposits in the fuel annulus in the sector adjacent to the liner wall. The resultant higher mixture ratio in the outer zone in combination with the large (.042 to .045 inches) liner end cap gap for this preburner (allowing hot combustion gas to flow behind the liner diluting the coolant gas), then caused the burnthrough of the liner and subsequently the preburner body. Whether or not contamination played a role in the initiation of the erosion has to be conjectured. However, the deflection of the faceplate created a fuel annulus gap which was smaller than the fuel element orifices (.018in) designed to protect the annulus from contamination.

Time of Change	Indicative Parameter	Rate of Change (psi/sec pos/sec, or deg/sec)	Excursion Interval	Duration Interval
101.4...	HPOT DS T1	+25.00	3.20	5.20
101.4...	HPOT DS T2	+26.60	3.20	5.20
101.4...	OPOV ACT POS	+.88	2.50	5.20
101.45..	HPFT DS T1 A	+324.00	.25	5.15
101.45..	HPFT DS T1 B	+413.00	.15	5.15
...	HPFP CL L PR - MCC HG IN PR	(Sensor does not exist)		
...	MCC OX IN PR - MCC PC	(Sensor does not exist)		
...	LPOP DS PR	(Sensor does not exist)		

Damage:
- Fuel preburner had an eroded hole through the liner and outer wall approximately 1.5" x .5", located 2" below the fuel manifold; outboard side of one injector element (13) eroded--some melting of tip, eroded faceplate area around #12, 13, & 14 elements.
- HPFT blades had moderate to heavy spalling Zr costing.

- A schematic of some of the damage cited above is illustrated below.

References:
- Rocketdyne data room records.
- NASA Marshall Investigation Board Report, SSME Engine 0006, MPTA Test Stand, 12 July 1980, Part II.



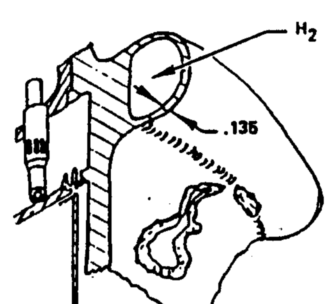
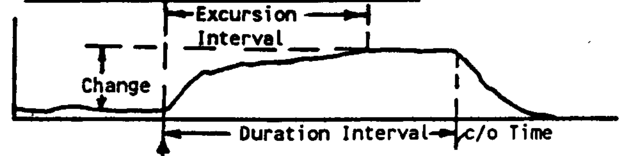


Table IIB-7: Failure Investigation Summary for Each Test (SF10-01)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (psi/sec, pos/sec, or deg/sec)	Excursion Interval	Duration Interval
Control Failure (Erroneous Sensor, Lee Jet)	901-284 (Engine 0010)	Incident: Near the close of a nominal start the following major events occurred:	3.85...	HPFP DS PR-MCC PC delta-P	-2961.5	.65	6.03
		1. Channel B of the Controller cut itself off at 3.25 seconds (under launch conditions this would have resulted in engine shutdown due to "Major Component Fail"). The Channel B shutdown was caused by a failure of electronic components in the facility power supply.	3.85...	MCC PC	+18000.0	.05	6.03
			3.85...	OPOV ACT POS	-71.4	.28	6.03
			3.87...	HPFT DS T1 A	-394.65	.35	6.01
			4.00...	HPOT DS T1	-495.0	2.0	5.88
			4.12...	LPOP DS PR	+500.0	.2	5.76

2. At approximately 3.9 seconds the Lee Jet orifice (used to purge the Channel A PC transducer passage) became dislodged and caused the PC transducer to sense the MCC coolant flow pressure instead of chamber pressure (see the schematic below). This erroneous reading (3800 psi) caused the Controller to close the OPOV to reduce PC to the desired 3012 psi level. A few milliseconds later, the Controller calculated a mixture ratio of 9.0 and commanded the FPOV full open in an attempt to reduce the mixture ratio to 6.0.

   a. The immediate result of the Controller's actions (based on an erroneous PC) was operation in an abnormal mode, characterized by high fuel flow and low turbine inlet temperatures of the oxidizer and fuel preburner. In fact, the oxidizer preburner turbine inlet temperature fell quickly to about 440 deg-R which assured freezing of the water which makes up about 10% of the total flowrate of 40 lbs/sec.

   b. The ultimate result of the Controller's actions was a fire in the HPOTP at about 9.7 seconds due to rubbing in the area of the LOX primary seal slinger. The rubbing was caused by a high axial load which displaced the rotor assembly toward the pump end of the HPOTP housing. This high axial load was caused by ice formation in the cavity between the housing and the second stage turbine wheel which resulted in reduction in the cavity pressure from about 2500 psi to near ambient. This reduced pressure on one side of the turbine wheel caused an estimated increase in rotor axial force of about 31000 lbs which far exceeded the control capability of the balance pistons to control the position of the rotor.

3. At 9.88 seconds the test was terminated when the high pressure oxidizer preburner pump radial accelerometer exceeded the 10g redline. (Test conducted on 30 July 1980).

Damage: Post test inspection of the facility and the engine revealed extensive fire damage to the high pressure oxidizer turbopump (HPOTP), the engine Controller, and harnesses and ducting in the vicinity of the HPOTP. The major facility damage was limited to instrumentation, electrical cables, and photo equipment.

References: -Rocketdyne Incident Report (RSS-8595-22), Engine 0010 Test 901-284, dated 15 January 1981.
-NASA Failure Investigation Team Report SSME 0010, Test 901-284, Part I & II, 30 July 1980.

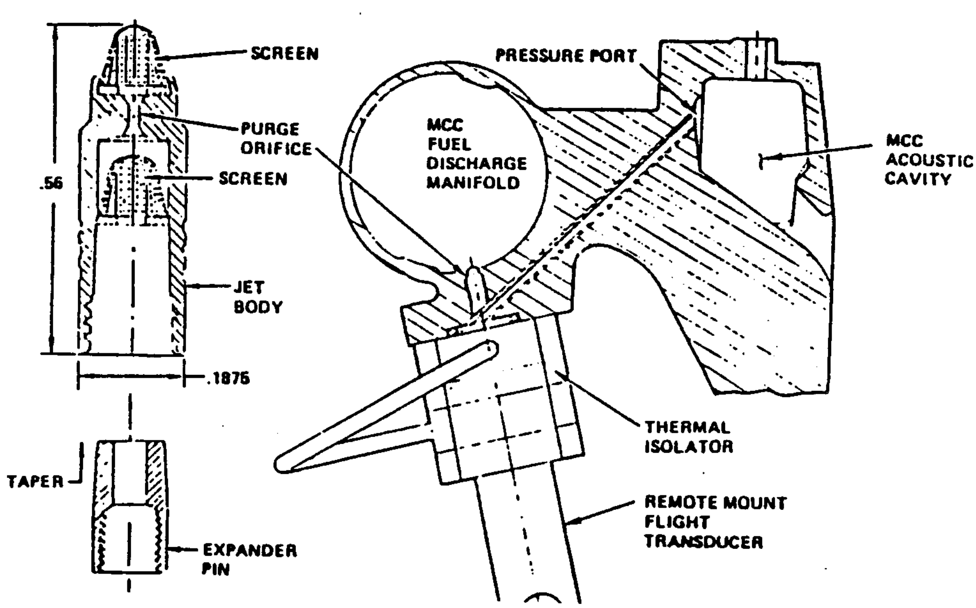
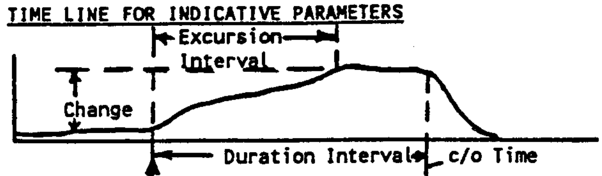


Table IIB-8: Failure Investigation Summary for Each Test (Test 901-284)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

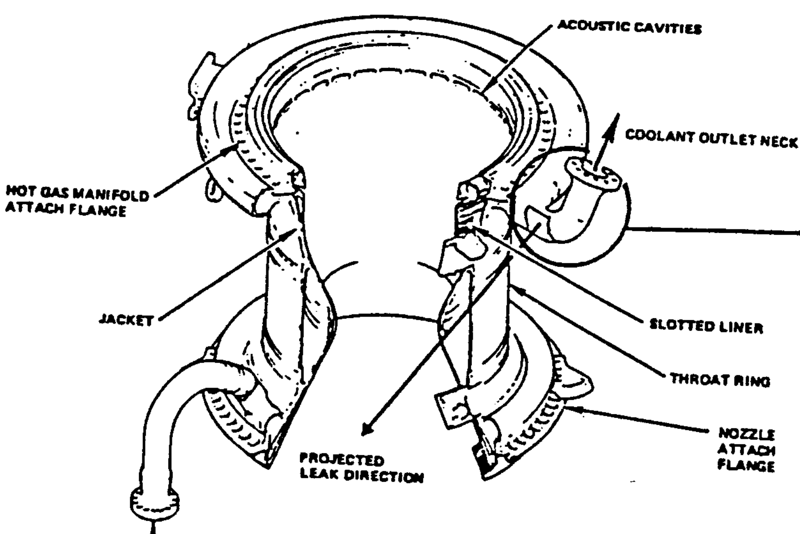
TIME LINE FOR INDICATIVE PARAMETERS



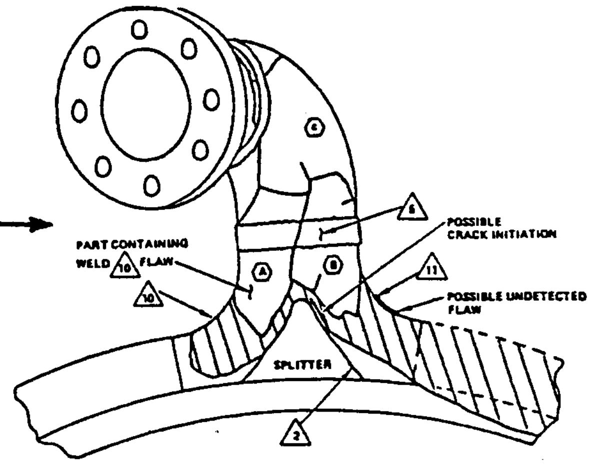
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
Duct, Manifold, or Heat Exchange Failure (MCC Outlet Manifold Neck Failure)	750-259 (Engine 2308)	Incident: During stable operation at 109% of rated power level a small fuel leak developed in the MCC outlet neck as determined by film review. The leak caused less than .25% change in nominal values for e.g. the LPFP speed, discharge pressure and OPOV position. The fuel leak remained essentially constant until approximately 200 milliseconds prior to cutoff at which time a major fuel leak occurred at apparently the same location based on both data and film review. In response to the rupture, the LPFP rapidly decayed in speed. This speed drop reduced the pump's discharge pressure and the high pressure fuel pump (HPFP) went into deep cavitation. As a consequence, the HPFP speed (PID-261) exceeded its nominal speed by approximately 10000 rpm. The off-nominal condition led the pump to exceed its vibration redline and led to a cutoff command. Following cutoff, the fuel caviation condition resulted in: reduced engine fuel flow, a severe oxygen-rich condition, burnout of the turbines, burn-through of the hotgas manifold, severe erosion of the gimbal bearing, and eventual separation of the engine below the low pressure pumps. (Test conducted on 27 March 1985, c/o time- 101.5 sec.)	101.28..	FPB PC - MCC HG IN PR	+888.9	.09	.22
			101.31..	MCC PC	-673.7	.19	.19
			101.31..	MCC CL DS T	-15714.	.07	.19
			101.31..	HPFT DS T1 A	-6714.3	.07	.19
			101.31..	HPOT DS T1	-3888.9	.09	.19
			101.31..	LPOP DS PR	-1000.0	.19	.19
			101.34..	MCC HG IN PR- MCC PC	-4281.3	.16	.16
			101.34..	MCC OX IN PR- MCC PC	-3625.0	.16	.16
			101.34..	OPB PC- MCC HG IN PR	+3833.3	.03	.16
			101.36..	HPFP SPEED	+66420.0	.14	.14
			101.38..	HPFT DS T1 B	+2000.0	.12	.12
			101.40..	HPOT DS T2	+600.0	.10	.10

Damage: The engine sustained extensive internal and external damage as a result of the failure and subsequent impact with the flame deflector and spillway.

References: -Rocketdyne data room records.
-Rocketdyne SSME Accident/Incident Report, SSFL Test 750-259, Engine 2308, MCC Outlet Manifold Neck Failure, 25 July 1985.



Main Combustion Chamber

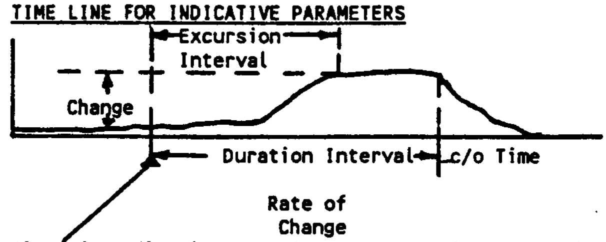


Engine 2308 MCC Outlet Flange Aft View

Table IIB-9: Failure Investigation Summary for Each Test (Test 750-259)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS

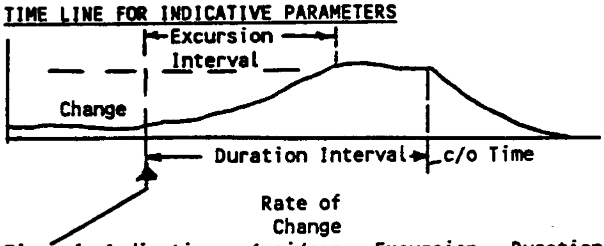


Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
Duct, Manifold, or Heat Exchanger Failure (Nozzle Tube Rupture)	901-485 (Engine 2105)	Incident: During stable operation at 109% of rated power level nozzle tube number 99 was ruptured on the hot-wall side. The rupture caused the high pressure oxidizer turbine HPOT to exceed its redline value. This led to a cutoff at 28.56 seconds from start. The test was conducted on 24 July 1985; six days later the damage was repaired (MRD #290206) and a 520 second program duration test was completed. Damage: The rupture was l/4 in. long x l/8 in. wide, located l4.5 in. aft of G15. A Class II and Class I nozzle cold-wall side leakage were noted (and also repaired). References: ·Rocketdyne Test 901-486 Pretest Readiness Review, Engine 2105, 26 July 1985, Briefing Charts, 5 August 1985. ·Material Review Disposition (MRD) No. 290206, Nozzle Assembly, 6 pp.	20.5...	HPOT DS T1	+7.0	8.06	8.06
			20.56..	HPOT DS T2	+6.25	8.00	8.00
			...	FPB PC - MCC HG IN PR	(No change is strikingly indicated)		
			...	MCC PC	(No change is strikingly indicated)		
			...	MCC CL DS T	(No change is strikingly indicated)		
			...	HPFT DS T1 A	(No change is strikingly indicated)		
			...	HPFT DS T1 B	(No change is strikingly indicated)		
			...	LPOP DS PR	(No change is strikingly indicated)		
			...	MCC HG IN PR-MCC PC	(Sensor does not exist)		
			...	MCC OX IN PR-MCC PC	(No change is strikingly indicated)		
			...	OPB PC - MCC HG IN PR	(No change is strikingly indicated)		
			...	HPFP Speed	(No change is strikingly indicated)		

Table IIB-10: Failure Investigation Summary for Each Test (Test 901-485)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Duct, Manifold, or Heat Exchange Failure (Catastropic Structural: High Cycle Fatigue in High Pressure Oxidizer Duct)	750-175 (Engine 2208)	Incident: During stable operation at 111% of rated power level a specially developed high pressure oxidizer duct failed. The system location of the duct is shown below. The special development consisted of ten ultrasonic flow transducer blocks mounted on the duct exterior. The failure initiated by a 2.5 inch long High-Cycle Fatigue (HCF) crack adjacent to ultrasonic flowmeter block No. 9-10. The HCF crack was caused by a combination of thinning the duct wall to install the transducer blocks, physically adding the block masses to the duct, and the increased local stresses brought about by brazing the blocks to the duct wall. The ruptured duct e.g. resulted in a drop in system ~~pressures and~~ increase in vibrations in less than 100 msec. (Test conducted on 27 August 1982, c/o time- 115.6 sec due to a preburner oxidizer pump accelerometer redline). Damage: The preburner oxidizer pump separated from the engine, and the oxidizer preburner section of the hot-gas manifold and the oxidizer system were damaged extensively. The first-stage turbine disk failured. Both the engine and the facility test stand (A-3) sustained damage. References: -Rocketdyne data room records. -Rocketdyne SSME Accident/Incident Report, SSFL Test 750-175, 27 August 1982, Engine 2208, High Pressure Oxidizer Duct Failure, 15 December 1983.

Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
115.53..	MCC OX IN PR-MCC PC	-45000.	.07	.07
115.54..	HPFP SPEED	-66667.	.03	.06
115.55..	MCC CL DS T	-2300.	.05	.05
115.55..	HPFT DS T1 A	-47000.	.05	.05
115.55..	HPFT DS T1 B	-11800.	.05	.05
115.55..	LPOP DS PR	-2800.	.05	.05
115.57..	HPOT DS T1	-16667.	.03	.03
115.57..	HPOT DS T2	-16667.	.03	.03
..	MCC HG IN PR-MCC PC	(Sensor does not exist)		
..	FPB PC - MCC HG IN PR	(Sensor does not exist)		
..	OPB PC - MCC HG IN PR	(Sensor does not exist)		
..	MCC PC	(No change is strikingly indicated)		

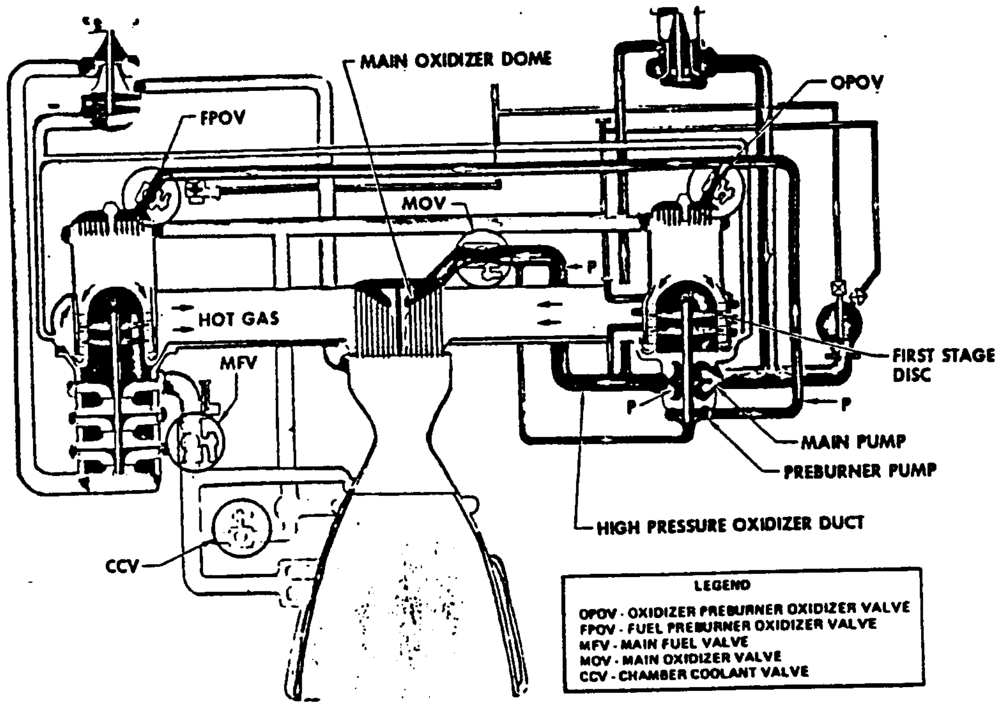
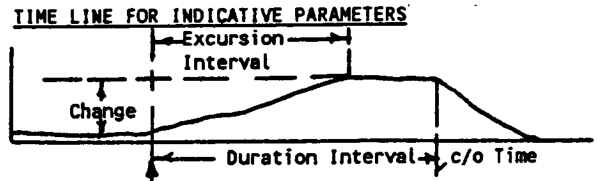


Table IIB-11: Failure Investigation Summary for Each Test (Test 750-175)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



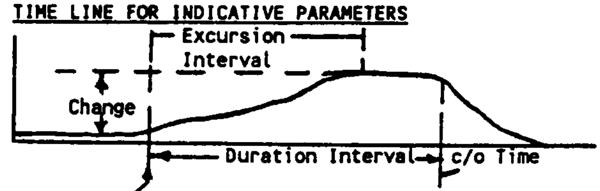
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Duct, Manifold, or Heat Exchange Failure (Solidified Nitrogen Blockage of Fuel Pump Inlet)	902-112 (Engine 0101)	Incident: During stable operation at 92% of rated power level cutoff was initiated by the High Pressure Fuel Turbopump (HPFTP) speed when the values exceeded the maximum redline setting (at 5.75 seconds from start time). The incident was caused when the facility fuel inlet Frantz-screen was partially blocked by solidified nitrogen. Nitrogen was inadvertently introduced into the tank during chill. Cavitation of both the high and low pressure fuel pump occurred when the LPFP (low pressure fuel pump) inlet pressure dropped below zero psig. (Test conducted on 10 June 1978). Damage: As a consequence of the excessive pump speed and cavitation both the LPFP and high pressure fuel pump (HPFP) were damaged; the LPFP would not rotate; the HPFP shaft was stuck in the upward position, and the turbine tip seal separated. Damage also occurred in the HPOP (High Pressure Oxidizer Pump), it would not rotate. Seven (7) main injector baffle elements were eroded. References: -Rocketdyne data room records. -Rocketdyne SSME Accident/Incident Report, Test 902-112 Fuel Inlet Blocked by Nitrogen, RSS-8595-14, June 1978.

Time of Change	Indicative Parameter	Rate of Change (psi/sec, or deg/sec)	Excursion Interval	Duration Interval
5.20..	MCC PC	-163.6	.55	.55
5.20..	HPFT DS T1 A	+690.9	.55	.55
5.25..	FPB PC - MCC HG IN PR	+200.0	.50	.50
5.28..	HPOT DS T1	+234.0	.47	.47
5.28..	HPOT DS T2	+382.9	.47	.47
5.30..	HPFP SPEED	+8000.0	.45	.45
5.58..	HPFT DS T1 B	+1882.4	.17	.17
5.58..	LPOP DS PR	-97.1	.17	.17
..	MCC HG IN PR-MCC PC	(No change is strikingly indicated)		
..	MCC OX IN PR-MCC PC	(No change is strikingly indicated)		
..	OPB PC - MCC HG IN PR	(Sensor does not exist)		
..	MCC CL DS T	(Sensor does not exist)		

Table IIB-12: Failure Investigation Summary for Each Test (Test 902-112)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS

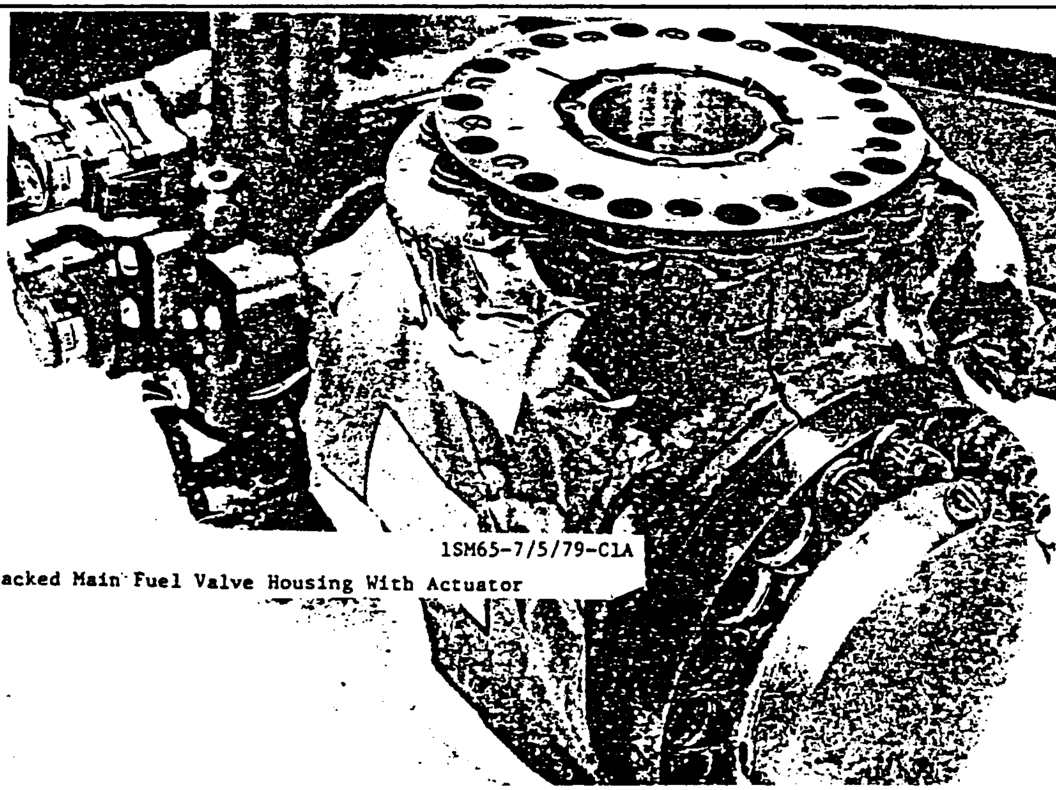


Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Valve Failure (Main Fuel Valve: Structural, Fuel Leak)	SF6-01 (Engine 2002, ME-1)	Incident: During stable operation at 100% of rated power level the Main Fuel Valve (MFV) on Main Engine-1 (ME-1), engine 2002 developed a cracked housing (see the photo below) allowing hydrogen to leak into the boattail area. The loss of hydrogen caused the high pressure fuel turbine discharge temperature to rise above its redline and a shutdown was initiated. The failure occurred due to fatigue, initiating at small surface defects caused by either salt stress corrosion, surface oxidation, or hydrogen embrittlement. (Test conducted on 2 July 1979, c/o time- 18.58 seconds).

Time of Change	Indicative Parameter	Rate of Change (psi/sec, rpm/sec, or deg/sec)	Excursion Interval	Duration Interval
18.46...	MCC PC	-3750	.04	.12
18.50...	HPFT DS T1 A	+4875	.08	.08
18.50...	HPFT DS T1 B	+4500	.08	.08
18.50...	HPOT DS T1	+4000	.08	.08
18.50...	HPOT DS T2	+4000	.08	.08
...	HPFP SPEED	(Sensor not sufficiently settled to steady state)		
...	Primary faceplate delta-P	(Sensor does not exist)		
...	MCC OX IN PR-MCC PC	(Sensor does not exist)		

Damage: -Gasification of liquid hydrogen in the boattail area caused an over pressure condition which blew off heat shields from the test article and resulted in major structural damage to the aft section of the MPTA (Main Propulsion Test Article). Fire external to the boattail ensued causing minor damage to external equipment, primarily instrumentation wiring. There was no fire damage inside the boattail area.

References: -Rocketdyne SSME Accident/Incident Report, MPTA Static Firing Test SF6-01, MFV Failure, 7 January 1981.
-NASA Marshall Investigation Board Report, SSME S/N 2002, MPTA Test Stand, NSTL, 2 July 1979.



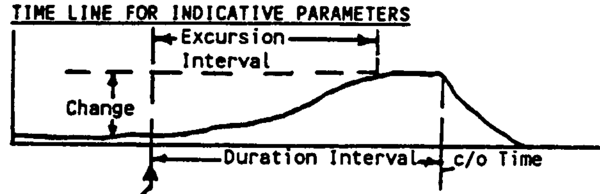
1SM65-7/5/79-C1A

Cracked Main Fuel Valve Housing With Actuator

Table IIB-13: Failure Investigation Summary for Each Test (Test SF6-01)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (psi/sec, rpm/sec, or deg/sec)	Excursion Interval	Duration Interval
Valve Failure (Main Oxidizer Valve: Heat Addition to Liquid Oxygen (LOX))	901-225 (Engine 2001)	Incident: During stable operation at 100% of rated power level the Voting Logic Cutoff Device initiated a shutdown when the High Pressure Fuel Turbine (HPFT) discharge temperature redline was exceeded. Failure analysis indicates the incident was caused by fretting at the main oxidizer valve (MOV) inlet sleeve-to-bellows flanged joint which resulted in the initiation of a fire within the MOV. Flow oscillations at four times the high pressure oxidizer turbopump speed caused sufficient excitation of the MOV sleeve to overcome the retention screw preload and allowed fretting between the bellows mating surfaces and shims (see the schematic below). The heat generated by fretting produced ignition of the LOX environment. Metal combustion of the MOV caused an over pressure at the valve which increased the initial LOX flow to the main injector and raised the back pressure to the high pressure oxidizer turbopump (HPOTP). The back pressure increase uprated the HPOTP turbine power and resulted in an increase of LOX to the fuel preburner causing the HPFT discharge temperature to exceed its redline. (Test conducted on 27 December 1978, c/o time- 255.63 seconds.)	255.49..	MCC PC	+9000	.02	.14
			255.53..	HPFT DS T1 A	+2750	.10	.10
			255.53..	HPFT DS T1 B	+2750	.10	.10
			255.53..	Primary faceplate delta-P	-1000	.04	.10
			255.53..	MCC OX IN PR-MCC PC	+7000	.04	.10
			255.55..	HPOT DS T1	+2000	.08	.08
			255.55..	HPOT DS T2	+2000	.08	.08
			255.58..	HPFP SPEED	+30000	.05	.05

Damage: The heat and overpressure generated by the fire caused failure of the high pressure oxidizer duct (see Table IIB-11 for a schematic), the low pressure oxidizer turbopump, main injector oxidizer inlet, and other extensive engine and electrical facility damage.

References:
- Rocketdyne SSME Accident/Incident Report, SSME Test 901-225, MOV Fire, RSS-8595-18, 1 August 1979.
- NASA Marshall Investigation Board Report, SSME S/N 2001 Oxygen System Fire, Test Stand A-1, NSTL, 27 December 27, 1978, Part I.

Identification No.	Nomenclature
1	Inlet Sleeve to Bellows
2	Inlet Sleeve Screw
3	Inlet Sleeve to Bellows Shim
4	CAM Follower to Bellows Interface
5	CAM Follower to Housing Interface
6	CAM Follower Guide
7	Bellows Guide
8	Downstream Sleeve Screws
9	Downstream Sleeve Shim
10	Sleeve to Housing Interface
11	Inlet Sleeve
12	Bellows Stop
13	Shaft Axial Adjustment Shim
14	Seal Plate
15	Seal Plate Screw

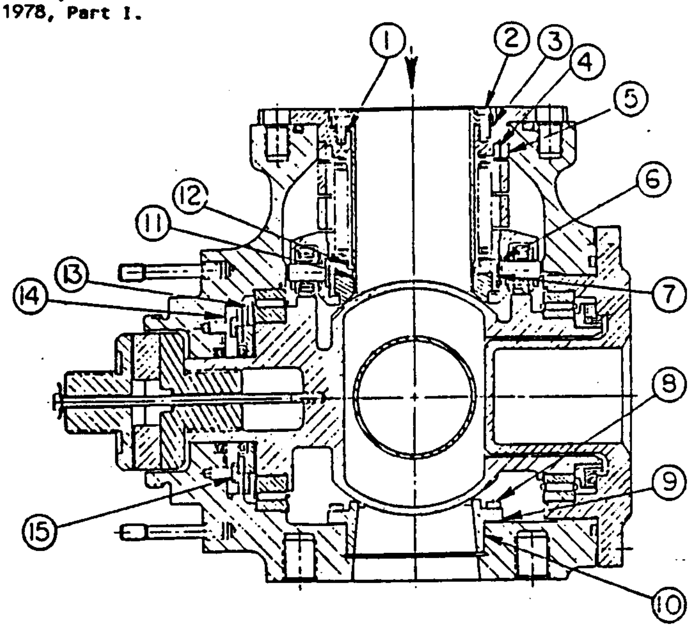
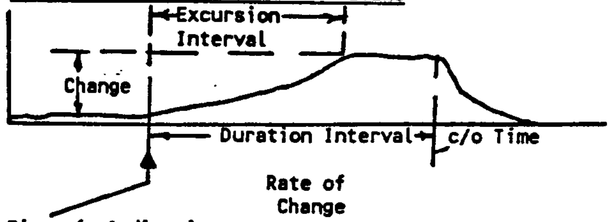


Table IIB-14: Failure Investigation Summary for Each Test (Test 901-225)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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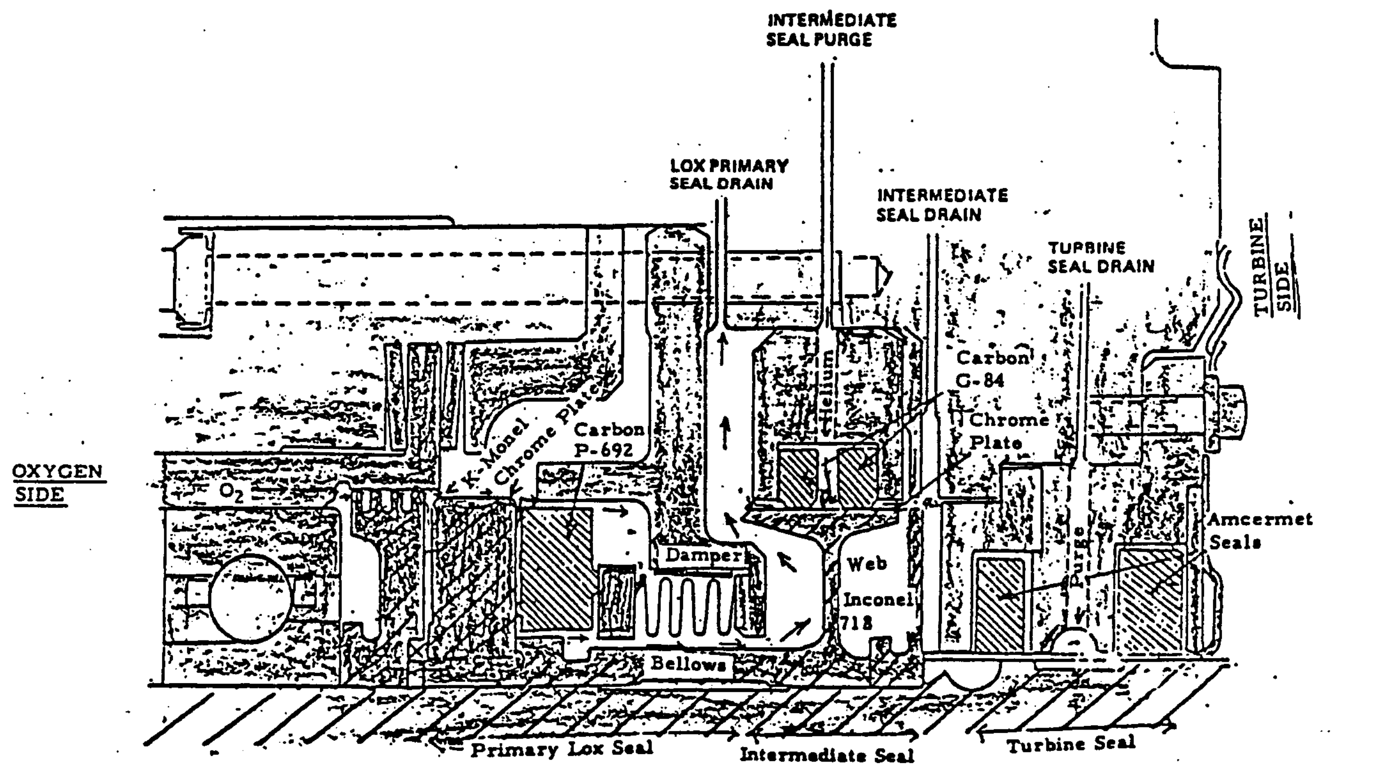
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, or deg/sec)	Excursion Interval	Duration Interval
HPOTP Failure (Rotor/ Seal Support: Heat Addition to Liquid Oxygen (LOX))	901-110 (Engine 0003)	Incident: During stable operation at 75% of rated power level, the engine controller issued a cutoff command when a fire occurred in the High Pressure Oxidizer Turbopump (HPOTP). The fire started in the LOX primary seal drain cavity. The exact cause of the fire could not be positively determined, however nine sources were determined to have the potential of causing the ignition. These are listed below:	55.5...	OPOV ACT POS	+.21	1.4	18.5
			56.2...	HPOT PRSL DR T (PID #1186)	-370.	1.0	17.8
			57.7...	HPOT DS T1	+31.4	.7	16.3
			57.7...	HPOT DS T2	+28.6	.7	16.3

1. Loss of hydrodynamic lift resulting in rubbing of the primary oxidizer seal against the mating ring, creating enough heat to initiate burning.
2. Primary oxidizer seal bellows weld failure allowing oxygen leakage.
3. Ignition at the interface of the bellows and its vibration damper as a result of friction.
4. Contamination in the primary oxidizer seal area.
5. Rubbing of the primary oxidizer seal due to changing phase (liquid to gas).
6. Effects of hotgas leakage past the intermediate seal into the primary oxidizer seal cavity.
7. Rubbing of the primary oxidizer seal against the mating rating due to mating ring vibration.
8. Leakage of hotgas containing hydrogen past the intermediate seal into the primary oxidizer seal cavity creating a combustible mixture.
9. Other leak paths allowing communication between the drain systems.

(Test conducted on 24 March 1977, cutoff time- 74 seconds).

Damage: Major damage occurred in the HPOTP, low pressure oxidizer turbopump discharge duct, engine controller simulator and control harnesses, main combustion chamber fuel inlet manifold, fuel system insulation, and the facility instrumentation systems.

References: -Rocketdyne SSME Accident/Incident Report, Test 901-110 High Pressure Oxidizer Turbopump Fire, (24 March 1977), RSS-8595-11, dated 30 June 1977.
-NASA Marshall Investigation Report SSME 0003 Oxygen Fire on Test Stand A-1, NSTL 24 March 1977, Part I and II, dated 17 May 1977.



HPOTP SEAL PACKAGE

Table IIB-15: Failure Investigation Summary for Each Test (Test 901-110)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

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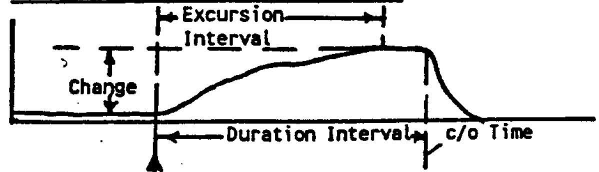
TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Time of Change	Indicative Parameter	Rate of Change (pos/sec, or deg/sec)	Excursion Interval	Duration Interval
HPOTP Failure (Rotor/ Seal Support)	901-136 (Engine 0004)	275.2...	HPOT DS T1	+2.27	10.98	25.
		275.2...	HPOT DS T2	+2.73	10.98	25.
		275.2...	OPOV ACT POS	+.08	25.00	25.
		286.2...	HPOT PRSL DR T	+1.46	10.30	14.

Incident and Damage Description (Comments, if applicable)

Incident: During stable operation at 90% of rated power level the engine controller initiated a shutdown because of loss of engine elctrical control. Simultaneously, a fire was observed in the area of the High Pressure Oxidizer Turbopump (HPOTP) due to bearing failure. The failure resulted from three root causes acting in combination: poor load sharing of pump-end and turbine-end bearings, insufficient cooling of the turbine-end bearings, and large unbalance of the rotor-excessive bearing loads. The most probable failure sequence is as follows:

1. The coolant flow at the pump-end bearings caused pressure induced loads that were sufficient to radially clamp and axially unload the No. 1 bearing (BRG) and increase the axial load on the No. 2 bearing (BRG) which was forced to carry 90% or more of the rotor radial loads. This, combined with the small length/diameter ratio cartridge pilot, allowed considerable radial motion and nutation of the bearing carrier, and resulted in the effective spring rate of the preburner bearing package to deteriorate. The increased radial motion increased the effective rotor unbalance which resulted in increased radial loads on both the pump end and turbine end bearings and increased overhung rotor deflections at the turbine seal.

2. The coolant flow at the turbine-end bearings was insufficient to prevent bearing degradation with the increased radial loads and heat generation. Coolant flow induced axial loads on the turbine end bearings and cartridge, decreased the axial preload on the No. 4 bearing and increased the axial preload on the No. 3 bearing, causing the No. 3 bearing to carry most of the rotor radial loads.

3. As loads at the bearings built up, shaft deflections increased until there was interference and a fire.

Internal rubbing apparently began during fuel tank venting (at t= +185 seconds). Approximately 24-seconds after venting was complete (i.e. at t= +275.2 seconds) analysis indicates the HPOTP began to loose its performance, pump vibration increased, and LOX heating due to internal rubbing increased. (Test conducted on 8 September 1977, c/o time- 300.2 seconds).

Damage: The HPOTP was extensively damaged, the following ducts were eroded: the preburner supply and discharge duct, HPOTP drain lines, LPOTP turbine drive duct, fuel and oxidizer preburner supply line, head exchanger supply and discharge lines. The oxidizer preburner LOX supply inlet duct ruptured downstream of the OPOV (oxidizer preburner oxidizer valve). The controller simulator, and facility instrmentation received extensive fire damage.

References: -Rocketdyne SSME Accident/Incident Report, Test 901-136 High Pressure Oxidizer Turbopump Fire, (8 September 1977), RSS-8595-13, 20 March 1978.
-NASA Marshall Board of Investigation Report, SSME 0004 Oxygen Fire on Test Stand A-1, NSTL, 8 September 1977, dated 14 November 1977.

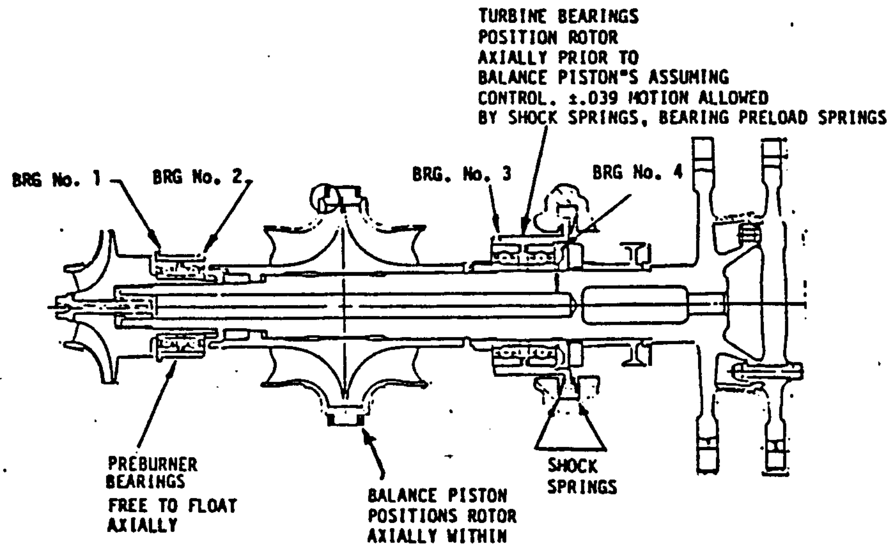
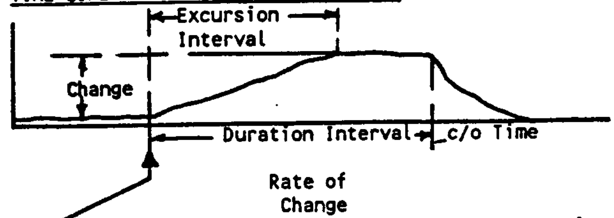


Table IIB-16: Failure Investigation Summary for Each Test (Test 901-136)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, or deg/sec)	Excursion Interval	Duration Interval
HPOTP Failure (Heat Addition to LOX)	902-120 (Engine 0101)	Incident: During stable operation at 100% of rated power level the test was prematurely shutdown by a High Pressure Oxidizer Turbopump (HPOTP) radial accelerometer redline, almost simultaneously the engine was partially enveloped in an external fire. The failure centered around a capacitance device which was designed to determined HPOTP shaft, bearing, and bearing cartridge movement. Analysis and damage evidence indicates heat addition to LOX was due to rubbing, interference, or structural failure of the stationary capacitance device pick-off plates and the rotating speed nut. (Test conducted on 18 July 1978, c/o time- 41.81 seconds).	41.79...	OPOV ACT POS	+100.	.02	.02
				..HPOT DS T1	(No change is strikingly indicated)		
				..HPOT DS T2	(No change is strikingly indicated)		
				..HPOT PRSL DR T	(No change is strikingly indicated)		

Damage: As a result of the fire, major damage occurred in the following areas:

1. HPOTP - severe erosion.
2. Low-Pressure Oxidizer Turbopump (LPOTP)- housing broken.
3. LPOTP discharge duct broken.
4. Engine controller simulator and control harnesses- erosion.
5. Facility instrumentation systems- burned.

References:
- Rocketdyne SSME Accident/Incident Report, Test 902-120 High Pressure Oxidizer Turbopump Fire, (18 July 1978), RSS-8595-15, 12 February 1979.
- NASA Marshall Board of Investigation Report, SSME 0101 Oxygen Fire on Test Stand A-2, NSTL, 18 July 1978, dated 31 August 1978, Part I and II.

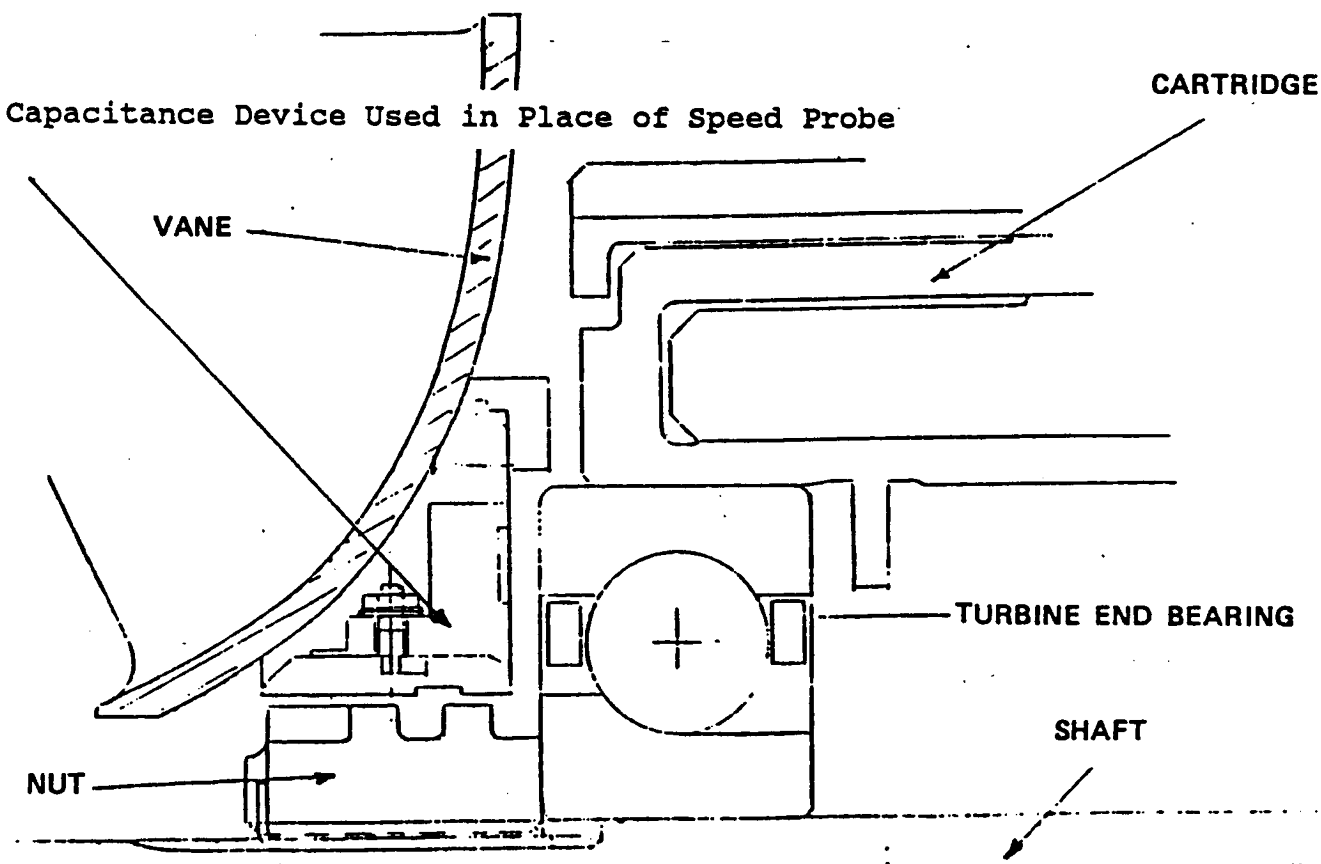
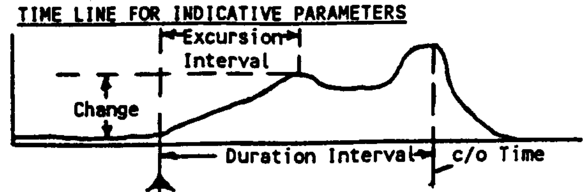


Table IIB-17: Failure Investigation Summary for Each Test (Test 902-120)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:



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Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Turn Around Duct Cracked/ Torn)	901-340 (Engine 0107)	Incident: During stable operation at 109% of rated power level the following series of events occurred within the High Pressure Fuel Turbopump (HPFTP): (1) the 2nd rotor platform seal and the T/A (Turn Around) duct inner wall fractures at t=+20.6 seconds from start, (2) the nut erodes, the 2nd rotor exit straightening vane breaks out and the T/A duct inner wall fractures propagate at t= +277 seconds, (3) the washer lodges on the nozzle vane and T/A duct sheet metal deflects at t= +280 seconds, (4) major ruptures occur in the T/A duct at t= +290 seconds. and (5) the T/A duct sheet metal flap breaks loose at t= +357 seconds. At t= +405.5 seconds the test was shutdown due to a High Pressure Fuel Turbine (HPFT) discharge temperature redline. (Test conducted on 15 October 1981).	20.6	HPFP CL LNR PR - MCC HG IN PR	+27.7	9.5	384.9
			20.6	HPFT DS T1 A	-1300.	.1	384.9
			20.6	HPFT DS T1 B	+16.7	3.6	384.9
			279.0	FPOV ACT POS	+.29	5.5	126.5
			280.6	HPOT DS T1	-6.1	12.1	124.9
			282.5	HPOT DS T2	-6.8	9.5	123.0
			290.0	HPFT Delta-P	+150.	.7	115.5
			290.0	HPOT Delta-P	+100.	.7	115.5
			290.0	HPFP SPEED	-2525.	.2	115.5

Damage: HPFTP damages are summarized in the below schematic. Damage to other engine components are as follows: main injector- dent in post 76/77 flow shield, erosion of six face nuts, 21 hot gas filters broken, nozzle- damage to nozzle belly band and jacket, and fuel preburner- -movement in 59 LOX post pin elements.

References: -Rocketdyne data room records.

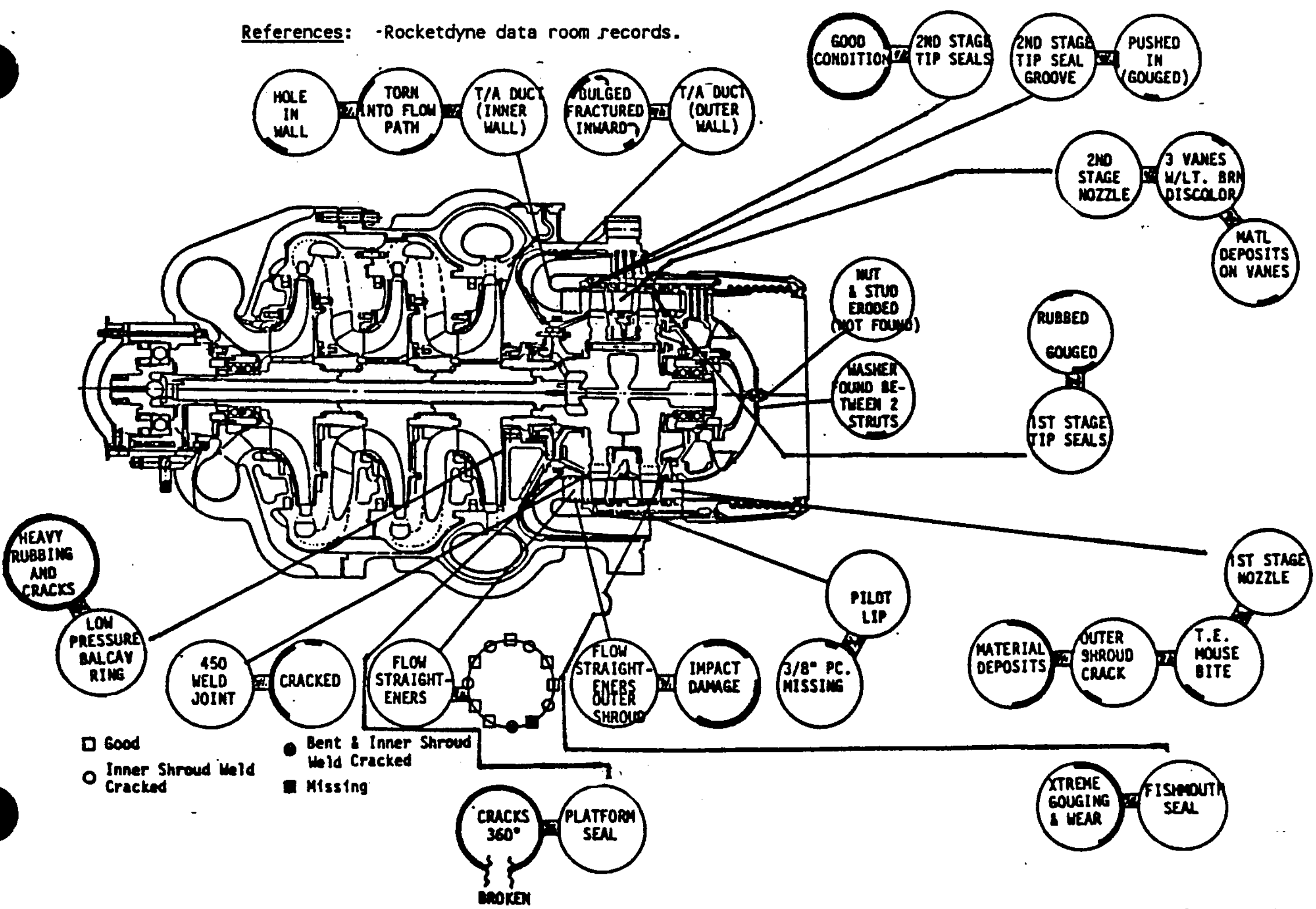
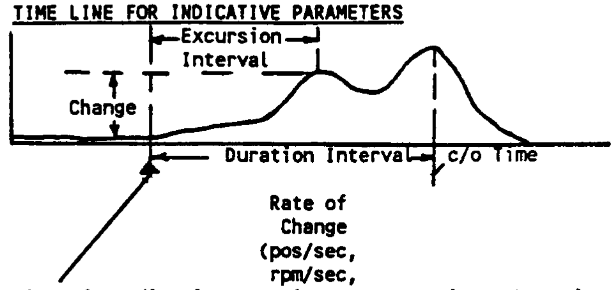


Table IIB-18: Failure Investigation Summary for Each Test (Test 901-340)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS

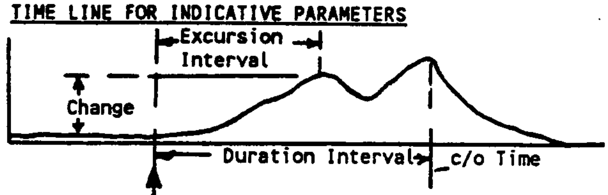


Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Turn Around Duct Cracked/ Torn)	901-363 (Engine 2013)	Incident: At the conclusion of this program duration test (250 seconds) fourteen (14) cracks were found in the HPFTP (Hight Pressure Fuel Turbopump) turn around duct sheet metal. The location of the turn around (T/A) duct is presented in Table IIB-18's schematic. (Test conducted on 30 March 1982; a week later Test 901-364 was conducted). Damage: Engine damage was confined to the area cited above. Reference: Rocketdyne data room records.	85.0....	HPFP CL LNR PR - MCC HG IN PR	+2.0	15.0	165.0
			85.0....	HPFT DS T1 A	+1.25	20.0	165.0
			135.5....	HPOT Delta-P	+17.1	1.4	114.5
			135.5....	HPFP SPEED	+110.0	1.0	114.5
			136.2....	FPOV ACT POS	-.77	1.1	113.8
			136.4....	HPFT DS T1 B	-4.92	7.1	113.6
			136.7....	HPOT DS T1	+11.4	.7	113.3
			137.3....	HPFT Delta-P	-16.0	1.0	112.7
			137.4....	HPOT DS T2	+11.7	.9	112.6

Table IIB-19: Failure Investigation Summary for Each Test (Test 901-363)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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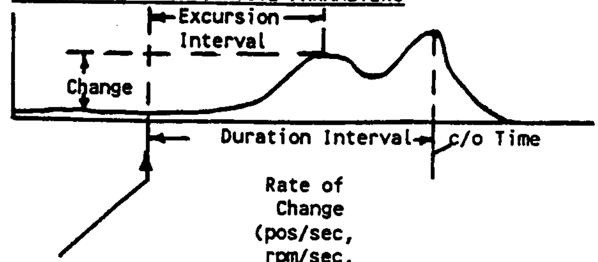
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Turn Around Duct Cracked/ Torn)	902-118 (Engine 0101)	Incident: During stable operation at 92% of rated power level the following series of events occurred within the High Pressure Fuel Turbopump (HPFTP): (1) the coolant liner buckles at approximately t= +5.5 seconds from start and (2) the T/A (Turn Around) duct sheet metal partially collapses at t= +6.6 seconds. The location of the T/A duct may be seen in Table IIB-18. At t= +6.84 seconds the test was shutdown due to a High Pressure Fuel Turbine (HPFT) discharge temperature redline. (Test conducted on 21 July 1978). Damage: HPFTP T/A duct damages included five (5) major bulges in both the inner and outer diameter sheet metal and an approximate 1.5 inch tear in the inner diameter sheet metal. MCC damages included twenty-six (26) heat shield retainers either missing or partially failed. References: -Rocketdyne data room records.	5.0....	HPFT DS T1 A	+130.4	1.84	1.84
			5.0....	HPFT DS T1 B	+108.7	1.84	1.84
			5.5....	HPFT Delta-P	+108.3	1.20	1.34
			5.5....	HPOT Delta-P	+58.3	1.20	1.34
			5.5....	HPOT DS T1	-22.4	1.34	1.34
			5.5....	HPOT DS T2	-22.4	1.34	1.34
			5.5....	HPFP CL LNR PR - MCC HG IN PR	+54.5	1.10	1.34
			6.12...	FPOV ACT POS	+4.4	.50	.72
			6.65...	HPFP SPEED	-2000.0	.15	.19

Table IIB-20: Failure Investigation Summary for Each Test (Test 902-118)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Coolant Liner Buckle)	901-436 (Engine 0108)	Incident: During stable operation at 109% of rated power level the following series of events occurred within the High Pressure Fuel Turbopump (HPFTP): (1) pieces from the interstage seal pass through the 2nd stage platform gap, decreasing the 2nd disc cavity pressure and increasing the seal stack leakage into the coolant liner at approximately t= +598.5 seconds from start, (2) an interstage seal piece lodges in the 2nd stage shank increasing the 2nd platform seal gap and exciting 12 stiffener vanes per revolution at t= +607 seconds, (3) the coolant liner begins to buckle at t= +610.36 seconds, and (4) the T/A (turn around) sheet metal begins movement, reducing the flow area at t= +610.44 seconds. The location of some of the above components are presented in Table IIB-18's schematic. At t= +611.06 seconds the test was shutdown due to a High Pressure Fuel Turbine (HPFT) discharge temperature redline. (Test conducted on 14 February 1984).	598.5....	HPFP CL LNR PR - MCC HG IN PR	+55.5	4.50	12.56
			610.44...	HPFT Delta-P	+467.7	.62	.62
			610.44...	HPOT Delta-P	+161.3	.62	.62
			610.55...	HPFT DS T1 A	+686.3	.51	.51
			610.55...	HPFT DS T1 B	+764.7	.51	.51
			610.55...	FPOV ACT POS	+19.0	.51	.51
			610.59...	HPFP SPEED	-4255.3	.47	.47
			610.90...	HPOT DS T1	+237.5	.16	.16
			610.95...	HPOT DS T2	+200.0	.11	.11

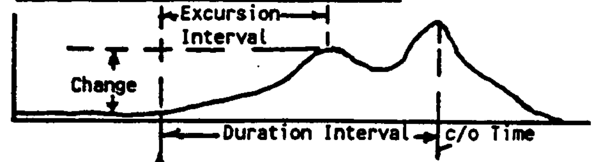
Damage: The HPFTP was massively damaged. The engine was totally gutted due to a oxidizer rich shutdown; the high pressure fuel pump inlet duct failed (due to over pressure caused by turbine erosion and the HPFTP seizure). The engine was retired.

References:
- Rocketdyne data room records.
- Rocketdyne Internal Letter #525-107, SSME-84-0787, Engine 0108 Failure Investigation-Engine Systems Contribution to Final Report, 5 June 1984.

Table IIB-21: Failure Investigation Summary for Each Test (Test 901-436)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



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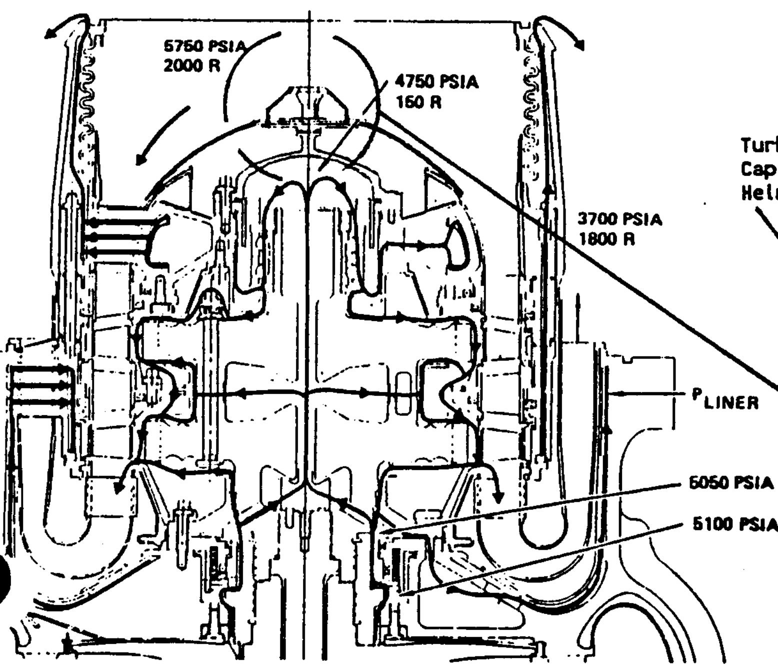
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Hotgas Intrusion to Rotor Cooling)	901-364 (Engine 2013)	Incident: During stable operation at 109% of rated power level the test shutdown prematurely due to a LOX (Liquid Oxygen) preburner pump radial accelerometer redline. The probable cause of the failure was a new HPFTP (High Pressure Fuel Turbopump) thermal shield retainer nut assembly used for the first time on this test, see the schematic below. The geometry of the nut allowed a direct leak path through the heat shield for the high temperature ASI gas which produced two jets impinging directly on the turbine end cap (Kaiser helmet) and reducing material properties in the impingement zone. The sequence of failure follows:	205.95...	HPFP CL LNR PR - MCC HG IN PR	-.50	40.15	186.20
			205.95...	HPOT Delta-P	-.91	69.32	186.20
			207.95...	HPOT DS T1	-1.04	67.32	184.20
			207.95...	HPOT DS T2	-1.30	67.32	184.20
			209.95...	FPOV ACT POS	+.04	65.32	182.20
			275.15...	HPFT Delta-P	+1.00	87.66	117.00
			384.95...	HPFT DS T1 A	+112.50	.40	7.20
			384.95...	HPFT DS T1 B	+145.00	.40	7.20
			384.95...	HPFP SPEED	+375.00	.40	7.20

1. A breach in the Kaiser helmet occurs from a combination of heat shield-vibration-induced loads, pressure differential across the thickness of the Kaiser helmet and material degradation and fatigue.
2. The hot gas interrupts coolant flow to and heats the turbine end bearings.
3. Heating produces an increase in bearing stiffness which causes increasing synchronous vibrations.
4. Synchronous vibration continues to build up until bearing failure occurs followed by large rotor displacement, severe blade rubbing and eventual blade breakage, turbine seizing, fuel flow stoppage, rupture of the pump inlet volute, and finally a severe fire caused by the resulting LOX-rich shutdown.

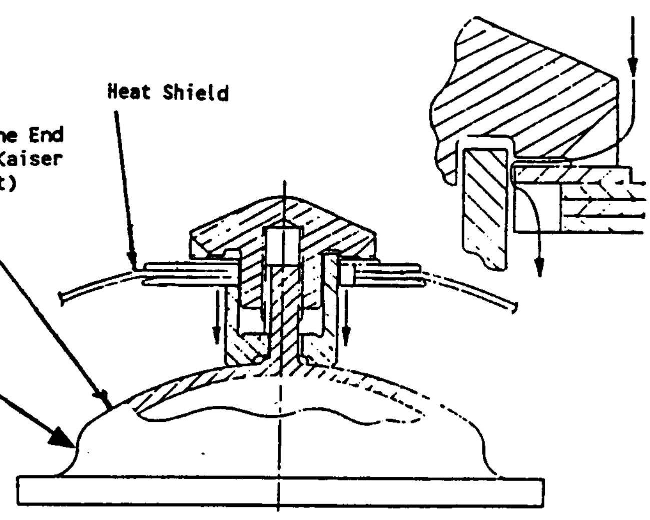
(Test conducted on 7 April 1982, c/o time- 392.15 seconds)

Damage: During the failure most of the engine separated from the test stand and broke apart; the major engine parts came to rest on the concrete spillway; the engine was retired. Damage to the facility was light to moderate.

References: -Rocketdyne SSME Accident/Incident Report, RSS-8595-28, NSTL Test 901-364, 7 April 1982, Engine 2013, High Pressure Fuel Turbopump Kaiser Helmet Failure, dated 14 July 1982.
-NASA Marshall Investigation Board Report, Certification Engine Failure, 7 April 1982, SSME S/N 2013, Test Stand A-1, Test 901-364, NSTL, Part I & II, 1 July 1982.



HPFTP Turbine Operating Conditions Coolant Circuit

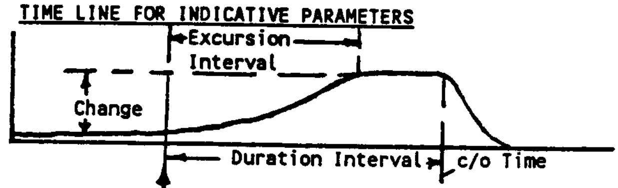


Kaiser Hat Nut Hot-Gas Leak Path

Table IIB-22: Failure Investigation Summary for Each Test (Test 901-364)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
HPFTP Failure (Hotgas Intrusion to Rotor Cooling)	902-209 (Engine 2008)	Incident: At the conclusion of this program duration test (823 seconds) the nut of the turbine end dome and lock tab was found missing in the HPFT (High Pressure Fuel Turbine) and minor inner baffle tip erosion discovered in the fuel preburner injector. (Test conducted on 16 November 1980). Damage: Engine damage was confined to the areas cited above. Reference: Rocketdyne data room.

Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
619.9....	HPFP SPEED	-.097	1.6	203.1
619.9....	HPOT DS T1	+9.33	3.0	203.1
620.0....	HPFT DS T1 A	+.78	25.0	203.0
620.0....	HPOT DS T2	+7.32	3.0	203.0
621.0....	FPOV ACT POS	+.09	3.0	202.0
...	HPFP CL LNR PR-MCC HG IN PR	(Sensor does not exist)		
...	HPFT Delta-P	(Sensor does not eixst)		
...	HPOT Delta-P	(Sensor does not exist)		
...	HPFT DS T1 B	(Sensor malfunction)		

Table IIB-23: Failure Investigation Summary for Each Test (Test 902-209)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

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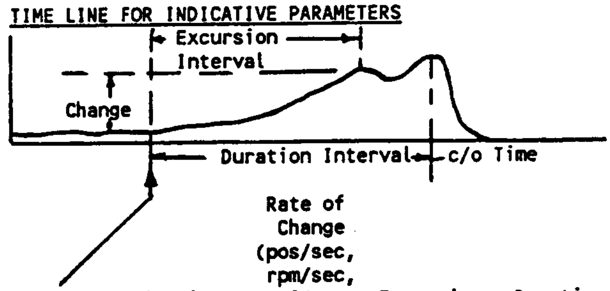
TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number
HPFTP Failure (Power Transfer Failure, Turbine Blades)	902-249 (Engine 0204)

Incident and Damage Description (Comments, if applicable)

Incident: During stable operation at 109% of rated power level the test shutdown prematurely due to a HPFTP accelerometer redline and associated massive failure of the HPFT (High Pressure Fuel Turbine) first stage turbine blade. The sequence of events leading to the blade failure follows:

1. Initial turbine damage at t= +3.0 seconds. The FPB (Fuel Preburner) injector's nonuniform flow condition experienced in at least two previous tests may have persisted (despite rework) and worsened.
2. Engine fuel inlet temperature increases and the high pressure fuel pump begins to cavitate at t= 108.0 seconds. The temperature increase was brought about by propellant transfer. The increase lowers the fuel density causing an increase in HPFP volumetric flowrate, speed, and power necessary to hold thrust constant. As the flow and speed increase, the HPFP approaches the conditions at which the sunction capability of the hardware is exceeded and cavitation starts. Once cavitation is initiated the efficiency of the pump degrades, causing speed to increase to maintain pump output to hold thrust constant, causing worsening cavitation conditions and causing an increase in HPFT inlet temperature.
3. Kel-F rub ring flexes and melts at t= +374 seconds. The released Kel-F particles plug nozzle tubes causing them to rupture, contributing to the HPFT inlet temperature increase.
4. The first stage turbine blade failures at t= +450.52 seconds.

(Test conducted on 21 September 1981, c/o time- 450.58 seconds)

Damage: Post firing inspection of the facility and engine revealed severe damage to the main combustion chamber including the injector and side-walls, extensive burn through damage to the nozzle, substantial damage to the HPFTP first and second stage turbines, and an approximately 12 inch long section of the HPFP inlet volute missing. This "blown out" portion of the inlet volute caused a loss of fuel to the engine precipitating an oxygen rich engine shutdown condition. There was no significant damage to the facility.

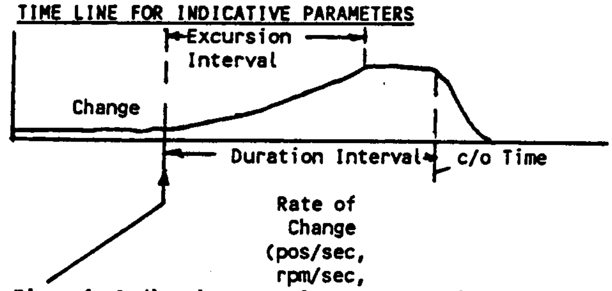
Refereces: -Rocketdyne data room records.
-NASA Marshall Investigation Board Report SSME S/N 0204, Test Stand A-2 NSTL, Part I and II, 14 December 1981.

Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
320.0...	HPFT DS T1 A	+2.22	130.6	130.6
320.0...	HPFT DS T1 B	+1.00	90.0	130.6
320.0...	HPFP SPEED	+8.37	130.6	130.6
349.6...	FPOV ACT POS	+.07	92.0	101.0
375.0...	HPOT DS T1	+1.75	40.0	75.58
375.0...	HPOT DS T2	+1.50	40.0	75.58
...	HPFP CL LNR PR-MCC HG IN PR	(Sensor does not exist)		
...	HPFT Delta-P	(Sensor does not exist)		
...	HPOT Delta-P	(Sensor does not exist)		

Table IIB-24: Failure Investigation Summary for Each Test (Test 902-249)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS

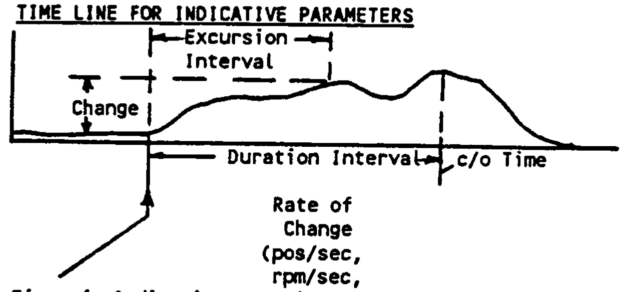


Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Power Transfer Failure, Turbine Blades)	902-095 (Engine 0002)	Incident: During stable operation at 95% rated power level, the test was shutdown prematurely due to a preburner pump radial accelerometer redline. (Test conducted on 17 November 1977, c/o time- 51.09 seconds) Damage: Post-test hardware inspection revealed: extensive turbine damage, eight (8) main injector LOX posts eroded and 15- MCC face nuts eroded. Reference: Rocketdyne data room records.	...	HPFP SPEED	(No change indicated)		
			...	HPOT DS T1	(No change indicated)		
			...	HPFT DS T1 A	(No change indicated)		
			...	HPOT DS T2	(No change indicated)		
			...	FPOV ACT POS	(No change indicated)		
			...	HPFP CL LNR PR-MCC HG IN PR	(Sensor does not exist)		
			...	HPFT Delta-P	(No change indicated)		
			...	HPOT Delta-P	(No change indicated)		
			...	HPFT DS T1 B	(Sensor malfunction)		

Table IIB-25: Failure Investigation Summary for Each Test (Test 902-095)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



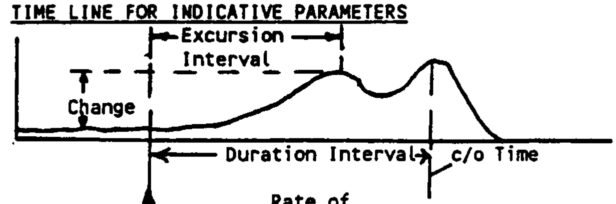
Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
HPFTP Failure (Localized: Turbine Blades)	901-346 (Engine 0107)	Incident: At the conclusion of this program duration test (500 seconds), damage was found in the HPFT (High Pressure Fuel Turbine) and MCC liner. (Test conducted on 19 November 1981) Damage: Engine damage was confined to the areas cited above, to be specific: HPFT-fishmouth seal dropped 1/16 inch, 180 deg around, the first stage turbine blade had shanks under cut approximately .02 inches; MCC liner had a new crack at element 85. Reference: Rocketdyne data room records.

Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
100....	HPFP CL LNR PR- MCC HG IN PR	-23.00	222.	400.
100....	HPFP SPEED	+.50	400.	400.
300....	HPOT DS T1	+.42	190.	200.
300....	HPOT DS T2	+.18	190.	200.
375....	HPFT DS T1 A	-.82	45.	125.
375....	HPFT DS T1 B	-1.33	45.	125.
380....	FPOV ACT POS	-.11	30.	120.
...	HPFT Delta-P	(No change indicated)		
...	HPOT Delta-P	(No change indicated)		

Table IIB-26: Failure Investigation Summary for Each Test (Test 901-346)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS

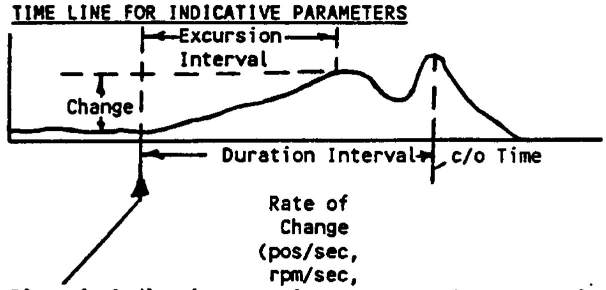


Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Power Transfer Failure)	901-362 (Engine 2013)	Incident: At the conclusion of this program duration test (500 seconds) the following damage was noted: HPOT- first stage blade, outer shroud leading edge was broken off, HPFT- the savereisen was gone out of the bull nose nut. (Test conducted on 27 March 1982)	234.0....	HPFT DS T1 A	+5.30	4.3	266.0
			239.5....	HPFP SPEED	+240.00	.5	260.5
			240.0....	HPFT Delta-P	-.59	92.0	260.0
		Damage: Engine damage was confined to the areas cited above.	240.0....	FPOV ACT POS	-.47	1.8	260.0
			241.5....	HPFT DS T1 B	-10.00	1.5	258.5
		Reference: Rocketdyne data room records.	...	HPFP CL LNR PR-MCC HG IN PR	(Sensor does not exist)		
			...	HPOT Delta-P	(No change indicated)		
			...	HPOT DS T1	(No change indicated)		
			...	HPOT DS T2	(No change indicated)		

Table IIB-27: Failure Investigation Summary for Each Test (Test 901-362)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

TIME LINE FOR INDICATIVE PARAMETERS



Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	Time of Change	Indicative Parameter	Rate of Change (pos/sec, rpm/sec, psi/sec, or deg/sec)	Excursion Interval	Duration Interval
HPFTP Failure (Power Transfer Failure)	901-410 (Engine 2014)	Incident: At the conclusion of this program duration test (595 seconds) one damper was found missing from the 2nd stage turbine, impact damage was evident to the 1st stage blades/tip seals, and the HPFP (High Pressure Fuel Pump) disc scroll had a .75 sq. inch area missing, 12 inches from F4. (Test conducted 20 May 1983) Damage: Engine damage was confined to the areas cited above. Reference: Rocketdyne data room records.	100.0....	HPFT DS T1 A	+.17	200.	495.
			100.0....	HPFT Delta-P	-.53	200.	495.
			110.0....	HPFP SPEED	+.47	340.	485.0
			110.0....	HPOT DS T1	-.17	140.	485.0
			110.0....	HPOT DS T2	-.22	140.	485.0
			250.0....	FPOV ACT POS	+.003	200.	345.0
			250.0....	HPOT DS T2	+.08	210.	345.0
			505.0....	HPFP CL LR PR-MCC HG IN PR	+4.6	27.	90.0
			....	HPOT Delta-P	(No change indicated)		

Table IIB-28: Failure Investigation Summary for Each Test (Test 901-410)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Incident Occurring During A Transient:		
Duct, Manifold, or Heat Exchanger Failure (Heat Exchanger, Weld)	901-222 (Engine 0007)	Incident: At the close of engine start the test was terminated (4.34 seconds) by the heat exchanger outlet pressure minimum redline. It was concluded from the test data that the incident was caused by a leak in the heat exchanger coil. The leak occurred prior to or during the early part of the start, as evidenced by the excessive coil pressure drop. The high pressure drop indicates increased mass flow. The coil failure was located near the heat exchanger inlet and and discharge area, as shown by the hardware damage. Oxygen from the leak became entrained in the fuel-rich preburner combustion gas. The mixed gases were ignited when the turbine discharge gas reached a high enough temperature during the thrust build-up ramp. The radial accelerometer spike at 3.54 seconds indicates that ignition occurred as a detonation, and was near the heat exchanger inlet/outlet area. The resulting continued combustion of the hydrogen-rich preburner combustion products and leaking oxygen caused burning of the coil; the change in nozzle flame pattern at 3.58 seconds shows evidence of metal burning. The heat exchanger coil pressure decayed to below the hot-gas manifold pressure at 3.71 seconds, indicating that the heat exchanger coils were completely severed, with extensive communication occurring between the coil and hot-gas. Hot-gas flowing into the discharge end of the severed coil combusted in the discharge line, with oxygen from the bypass system. The discharge line burned through (4.185 seconds in the motion pictures) causing a rapid decay in discharge pressure at 4.212 seconds. (Data entries for this anomaly should be determined in another study) Possible causes: 1. Undetected internal mechanical damage to the heat exchanger inlet tube may have occurred during reaming of the inlet for removal of weld drop-through. The damage may have been aggravated by a later readjustment of the inlet tube position. 2. Damage to the heat exchanger may have occurred during an arc-welding rework operation on a coil support bracket. (Test conducted on 6 December 1978) Damage: Extensive damage occurred to the heat exchanger coil, oxidizer turbine discharge area of the hot-gas manifold, main injector and heat exchanger discharge line. References: -Rocketdyne accident/incident report, Test 901-222 Engine 0007, Heat Exchanger Fire, RSS-8595-17, October 1979. -NASA Investigation Board Report, Part II.

Table IIB-29: Failure Investigation Summary for Each Test (Test 901-222)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	
Incident Occurring During A Transient:			
Control Failure (MOV Mis-Indexed)	902-132 (Engine 0006)	Incident: During the start transient the HPFP (High Pressure Fuel Pump) and LPFP (Low Pressure Fuel Pump) boiled out, resulting in a LOX (Liquid Oxygen) rich cutoff. The LPFP and HPFP boil out was attributed to the late HPFTP break away (.07 seconds) and an early main LOX dome prime (approximately 1.5 seconds). The early prime was caused by a mis-clocking of the MOV (Main Oxidizer Valve) resulting in the MOV being 3.5% more open than indicated. Cutoff was initiated at 2.36 seconds from start time by low main combustion chamber pressure at ignition confirm and high pressure fuel turbine discharge temperature redline. (Test conducted on 3 October 1978). Damage: High pressure oxidizer and fuel turbine erosion; 136 main injector elements eroded between faceplates; and the hot-gas manifold liner eroded on the fuel preburner side. Reference: Rocketdyne data room records.	(Data entries for this anomaly should be determined in another study)

Table IIB-30: Failure Investigation Summary for Each Test (Test 902-132)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)
Incident Occurring During A Transient:		
Injector Failure (Fuel Blockage)	750-160 (Engine 0110F)	Incident: The test was prematurely terminated at 3.16 seconds (from start time) by a HPFT (High Pressure Fuel Turbine) discharge temperature redline. Data analysis, hardware condition and supporting laboratory tests identified the cause of the incident as EDM (Electrical Discharge Machining) water contamination of the fuel system upstream of the fuel preburner. The formation of ice during engine start resulted in fuel flow restriction in some fuel preburner elements. This restriction produced one or more abnormal high temperature combustion gas zones which caused turbine blade erosion and/or failure. The resulting decay in fuel flow to the engine produced excessive combustion gas mixture ratio and subsequent erosion damage. (Test conducted on 12 February 1982.) Damage: Post-test hardware inspection revealed severe erosion damage to the high pressure fuel and oxidizer turbines, main injector, main combustion chamber, nozzle, and hot-gas manifold. References: -Rocketdyne SSME Accident/Incident Report, Engine 0110F, Fuel Preburner Ice Incident, Test 750-160, RSS-8595-27, 17 May 1982. -NASA Investigation Report, SSME S/N 0110F, Part I, 23 July 1982. (Data entries for this anomaly should be determined in another study)

Table IIB-31: Failure Investigation Summary for Each Test (Test 750-160)

FAILURE INVESTIGATION SUMMARY FOR EACH TEST:

Type of Incident	Test Number	Incident and Damage Description (Comments, if applicable)	
Incident Occurring During A Transient:			
HPFTP Failure (Power Transfer Failure)	901-147 (Engine 0103)	Incident: During throttle up from 70% rated power level (RPL) to 95% RPL, the HPFTP seized, causing speed and discharge pressure drops, and high pressure fuel and oxidizer turbine temperature rises. Cutoff was initiated due to a preburner boost pump accelerometer redline, at 31.36 seconds from start time. (Test conducted on 1 December 1977). Damage: Extensive engine damage due to LOX rich shutdown; the main combustion chamber, main injector, and nozzle were eroded. Reference: Rocketdyne data room records.	(Data entries for this anomaly should be determined in another study)

Table IIB-32: Failure Investigation Summary for Each Test (Test 901-147)

Summary of Sensor Standard Deviations:

LEGEND:

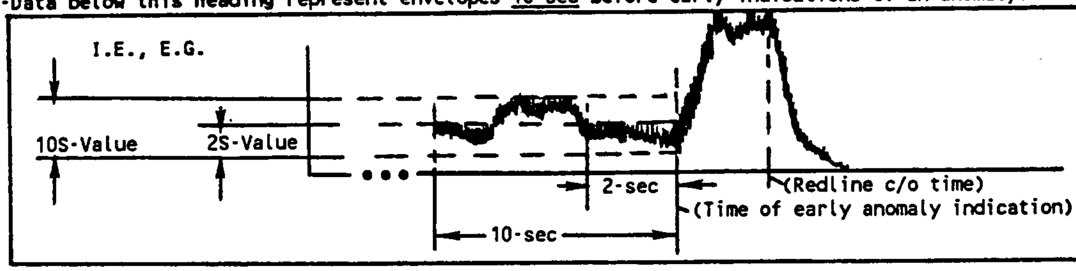
STD1------Standard Deviation of envelopes (test-to-test) measured 2-sec before the anomaly (See Table III-2 for envelopes)
STD2------Standard Deviation of envelopes (test-to-test) measured 10-sec before the anomaly (See Table III-2 for envelopes)
STD3------Standard Deviation of data from average steady state value (See Table III-3).
ID------Insufficient data for complete derivation.
*------Value could be larger if more test data is added to the appropriate data base.

PID NO.(S)	PARAMETER	STD1	STD2	STD3
366-371	(INJ CLNT PR) -(MCC HG IN PR)	2.48	2.24	1.08
366-383	(INJ CLNT PR) -(MCC PC)	4.48	6.25	.632
371-383	(MCC HG IN PR) -(MCC PC)	7.86	10.10	1.08
395-383	(MCC OX INJ PR) -(MCC PC)	5.13	6.16	3.28
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	6.00	(ID)	.640
459-383	(HPFP DS PR) -(MCC PC)	7.06	11.29	7.75
412-371	(FPB PC) -(MCC HG IN PR)	5.78	8.81	4.73
480-371	(OPB PC) -(MCC HG IN PR)	10.37	10.04	3.2
63, 163	MCC PC	4.43	3.89	3.25
200	MCC PC AVG	4.43	3.91	2.13
436	MCC CLNT DS PR	14.87	14.91	7.72
566	MCC CLNT DS T	1.35	1.75	1.05
24	MCC FU INJ PR	9.89	9.66	8.20
1951, 1956	MCC LN CAV P	(ID)	(ID)	(ID)
595	MCC OX INJ TEMP	.324	.460	.072
86	HPFP IN PR	2.02	2.70	1.01
459	HPFP DS PR	10.72	12.79	10.50
659	HPFP DS T	.068	.106	.082
457	HPFP BAL CAV PR	17.67	25.92	10.15
52, 764	HPFP SPD	31.51	44.42	30.70
53, 940	HPFP CL LNR PR	4.97	3.40	5.59
650	HPFP CL LNR T	1.84	.5	2.48
657	HPFP DR PR	.01	0.	.012
658	HPFP DR TEMP	.05	(ID)	.157
663	HPFT DS T1 A	14.10	14.29	3.56
664	HPFT DS T1 B	8.47	8.16	3.74
754	LPFP SPD	433.8	469.45	17.35
436	LPFT IN PR	4.09	6.39	6.56
1205, 1206	FAC FU FL	32.80	31.78	2.10
1207, 1209	FAC FU FL CT	(Sensor Trace Not Applicable)		
722	ENG FU FLOW	23.60	26.68	23.84
1722	ENG FU FLOW CT	(Sensor Trace Not Applicable)		
233	HPOT DS T1	4.83	5.89	0.
234	HPOT DS T2	6.84	13.71	1.44
1190	HPOT PRSL DR T	1.36	1.77	2.72
1071	OX BLD INT T	2.47	3.45	.224
1054	OX FAC FM DS T	.319	.315	.029
854	FAC OX FM DS PR	2.41	2.28	.462
1214	FAC OX FLOW CT	(Sensor trace is not applicable)		
1212, 1213	FAC OX FLOW	18.02	27.31	16.94
858, 860	ENG OX IN PR	.83	1.39	.773
1058	ENG OX IN TEMP	.11	.191	.046
338	HPOP DS PR	12.04	19.93	7.25
325, 326	HPOP BALCAV PR	12.00	12.81	4.06
30, 734	LPOP SPD	18.45	28.35	4.21
302	LPOP DS PR	1.60	2.55	3.49
93, 94	PBP DS TMP	.684	1.02	.268
341	PBP DS PR	23.95	26.33	16.1
412	FPB PC	14.04	14.85	7.64
480	OPB PC	7.46	19.03	8.02
878	HX INT PR	7.78	7.33	4.29
879	HX INT T	.81	3.71	1.68
881	HX VENT IN PR	1.47	1.41	.31
882	HX VENT IN T	.943	2.16	.083
883	HX VENT DP	.269	.282	.305
40	OPOV ACT POS	.397	.226	.112
42	FPOV ACT POS	.122	.124	.202

Table III-1: Summary of Sensor Standard Deviations

TEST-TO TEST ENVELOPE Data Base

Legend: 2S---Data below this heading represent envelopes 2-sec before early indications of an anomaly.
10S---Data below this heading represent envelopes 10-sec before early indications of an anomaly.



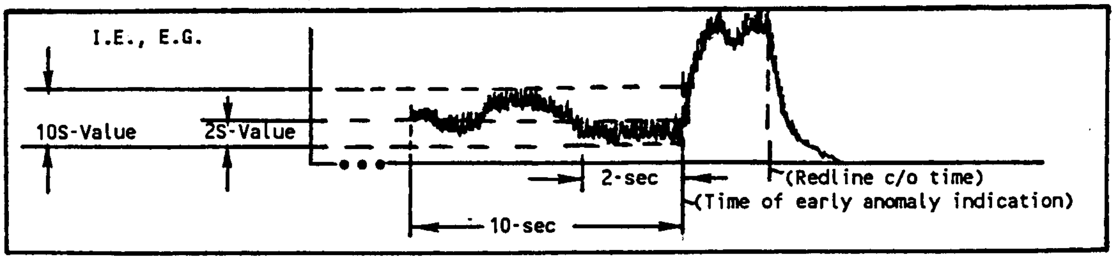
X---Parameter does not exist for the test number.
M---Parameter malfunction.
NA---Envelope not applicable for parameter.
NS---Sensor has not settled adequately to steady state conditions.
UA---Data is unavailable for 10-seconds prior to early indications of an anomaly.
*---No early indication of an anomaly from parameter, the envelope value is before cutoff time.

		Test Numbers:									
		901-173		901-183		901-331		901-307		901-485	
PID NO.(S)	PARAMETER	2S	10S	2S	10S	2S	10S	2S	10S	2S	10S
366-371	(INJ CLNT PR) -(MCC HG IN PR)	7	8	9.5	10	X	X	X	X	X	X
366-383	(INJ CLNT PR) -(MCC PC)	2	4	3.5	3.5	X	X	X	X	10.8*	16*
371-383	(MCC HG IN PR) -(MCC PC)	10	10	9.5	11	13	15	6.5*	17*	X	X
395-383	(MCC OX INJ PR) -(MCC PC)	10	17.5	20.5	25.5	20	27.5	11.9	14.5	19.3*	30*
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	X	X	X	X	X	X	8	15	X	X
459-383	(HPFP DS PR) -(MCC PC)	26	28	25	32.5	28.5	37.1	12*	16*	31*	50*
412-371	(FPB PC) -(MCC HG IN PR)	15	20	10*	10*	19.3	26.5	NS	NS	21.5*	30*
480-371	(OPB PC) -(MCC HG IN PR)	20	27	15*	15*	14.5	25.5	NS	NS	24*	30*
63, 163	MCC PC	22	22	10.8	17	10	14.8	6.5	15	13.3*	20*
200	MCC PC AVG	22	22	10.8	17	10	14.8	6.5	14.8	13.3*	20*
436	MCC CLNT DS PR	25	33	20	25	18	21.5	NS	NS	30*	45*
566	MCC CLNT DS T	X	X	1	1.7	2	3.3	0	3	3.25*	7*
24	MCC FU INJ PR	11	22	NS	NS	10	20	0	8	15*	25*
1951, 1956	MCC LN CAV P	X	X	X	X	M	M	X	X	M	M
595	MCC OX INJ TEMP	X	X	X	X	.06	.06	.03*	.034*	.5*	UA
86	HPFP IN PR	4	4.6	NS	NS	4	6.5	9.5*	13*	7.1*	7.1*
459	HPFP DS PR	40	45	18	41	41	62	13*	22*	42*	42*
659	HPFP DS T	.3	.46	.34	.34	.3	.32	.3*	.5*	.3*	.4*
457	HPFP BAL CAV PR	30	33	65	98	25.5	34.5	10*	20*	30*	30*
52, 764	HPFP SPD	114	160	100	100	115	130	42*	90*	109*	109*
53, 940	HPFP CL LNR PR	X	X	X	X	X	X	X	X	28*	28*
650	HPFP CL LNR T	X	X	X	X	X	X	X	X	7.6*	12*
657	HPFP DR PR	X	X	X	X	X	X	X	X	.05*	.08*
658	HPFP DR TEMP	X	X	X	X	X	X	X	X	1	UA
663	HPFT DS T1 A	55	55	32	34	15	29	X	X	8.9*	8.9*
664	HPFT DS T1 B	30	37	22	30	18	29	6	12	4.5*	12*
754	LPFP SPD	1500	1500	40	UA	33	58	70*	100*	61.5*	100*
436	LPFT IN PR	25	33	20	25	18	21.5	X	X	22*	27*
1205, 1206	FAC FU FL	70	105	80	109	54	87	25*	50*	122*	135*
1207, 1209	FAC FU FL CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
722	ENG FU FLOW	100	115	105	106	127	127	70*	70*	90*	120*
1722	ENG FU FLOW CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
233	HPOT DS T1	12	22	11	17	8	16	0	11	X	X
234	HPOT DS T2	28	54	13	16	8	16	7	10	X	X
1190	HPOT PRSL DR T	3.5	7.5	NS	NS	4	UA	1*	3*	2*	UA
1071	OX BLD INT T	X	X	NS	NS	.9	1.5	6	9	NS	NS
1054	OX FAC FM DS T	.02	.04	.01*	.013*	.04*	.07*	1*	1*	NS	NS
854	FAC OX FM DS PR	1.2*	1.8*	2.8*	3.2*	9*	9*	.22*	.45*	2.6*	2.6*
1214	FAC OX FLOW CT	NA	NA	NA	NA	NA	NA	M	M	NA	NA
1212, 1213	FAC OX FLOW	50	75	50	50	34	66	M	M	90*	90*
858, 860	ENG OX IN PR	1.9*	1.95*	1.7	2.5	2	2.7	2*	3*	4.2*	4.2*
1058	ENG OX IN TEMP	.033	.045	.047*	.08*	.09	.37	NS	NS	X	X
338	HPOP DS PR	30	47	35	50	45	45	16	29	45*	70*
325, 326	HPOP BALCAV PR	35	35	18	20	9.5	22	7.8	11	10.8*	16.5*
30, 734	LPOP SPD	20	20	22*	120*	22	52	18	25	57*	70*
302	LPOP DS PS	5	7.6	7	11.7	5	6.5	2	4	5.3*	5.3*
93, 94	PBP DS TMP	X	X	X	X	.09	.09	NS	NS	NS	NS
341	PBP DS PR	80	80	76	79	M	M	35	50	62*	72
412	FPB PC	5	6	30.5	31	18.3	25	16	18	26*	27.5*
480	OPB PC	22	33	16.5	32	16.5	27.5	15	18	23*	86*
878	HX INT PR	15	29.5	NS	NS	7.8	17.2	11	15	X	X
879	HX INT T	1.4	3.9	NS	NS	2	3.8	4	13	NS	NS
881	HX VENT IN PR	2	2	NS	NS	2	2	.8*	1.8*	0*	0*
882	HX VENT IN T	.2	1.8	NS	NS	.9	.9	.5	1	NS	NS
883	HX VENT DP	.55	1.1	NS	NS	.19	.61	.4*	.78*	X	X
40	OPOV ACT POS	.25	UA	0	.78	.27	.54	.24	.5	.25	UA
42	FPOV ACT POS	.5	.9	.5	.71	.27	.54	.55	.55	.28*	.74*

Table III-2: Test-to-Test Envelope Data Base Definition

TEST-TO TEST ENVELOPE Data Base (Continued)

Legend: 2S---Data below this heading represent envelopes 2-sec before early indications of an anomaly.
10S---Data below this heading represent envelopes 10-sec before early indications of an anomaly.



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X---Parameter does not exist for the test number.
M---Parameter malfunction.
NA---Envelope not applicable for parameter.
NS---Sensor has not settled adequately to steady state conditions.
UA---Data is unavailable for 10-seconds prior to early indications of an anomaly.
*---No early indication of an anomaly from parameter, the envelope value is before cutoff time.

		Test Numbers: 901-110		901-136		901-340		901-363		901-436	
PID NO.(S)	PARAMETER	2S	10S	2S	10S	2S	10S	2S	10S	2S	10S
366-371	(INJ CLNT PR) -(MCC HG IN PR)	6*	6*	2.6	4	X	X	X	X	X	X
366-383	(INJ CLNT PR) -(MCC PC)	5*	9.4*	1	2	X	X	13	18	NS	NS
371-383	(MCC HG IN PR) -(MCC PC)	6.9*	7.4*	1	3.6	28	37	X	X	X	X
395-383	(MCC OX INJ PR) -(MCC PC)	8.5*	17.5*	18	22	25	33.5	21.5	28	15	17
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	X	X	X	X	20	UA	X	X	X	X
459-383	(HPFP DS PR) -(MCC PC)	20*	45*	8.8	14	20	UA	20	27	30	35
412-371	(FPB PC) -(MCC HG IN PR)	19*	27*	9	11	25	UA	X	X	25	35
480-371	(OPB PC) -(MCC HG IN PR)	43*	43*	6	19	20	UA	X	X	29	43
63, 163	MCC PC	14.5*	14.5*	6	10	14	UA	15	22.5	15	20
200	MCC PC AVG	14.5*	14.5*	6	10	14	UA	15	22.5	15	20
436	MCC CLNT DS PR	40*	53*	23	35.5	30	UA	70	70	30	48
566	MCC CLNT DS T	.5*	.8*	NS	1.7	3.3	UA	M	M	3.5	3.5
24	MCC FU INJ PR	26.5	UA	NS	NS	19	30	29	29	30	42
1951, 1956	MCC LN CAV P	X	X	X	X	NS	NS	M	M	M	M
595	MCC OX INJ TEMP	.8*	1.2*	X	X	.9	UA	.68	.9	.29	.45
86	HPFP IN PR	3.5*	5*	NS	NS	3.1	UA	4.6	5.7	5	5
459	HPFP DS PR	30*	60*	35	49	20	UA	41	61	42.5	62.5
659	HPFP DS T	.18*	.47*	.1	.15	.27	UA	.27	.27	.3	.3
457	HPFP BAL CAV PR	M	M	7	18	37	UA	4.8*	5.9*	35	39
52, 764	HPFP SPD	100*	150*	65	110	110	195	95	122	20	20
53, 940	HPFP CL LNR PR	X	X	X	X	20	UA	14	22	20	20
650	HPFP CL LNR T	X	X	X	X	X	UA	12	UA	9	11
657	HPFP DR PR	X	X	X	X	X	X	X	X	.07*	.08*
658	HPFP DR TEMP	X	X	X	X	X	X	X	X	.9*	3.4*
663	HPFT DS T1 A	19*	24*	15	22	15	UA	9	13	10	10
664	HPFT DS T1 B	13*	19*	13	20	22	30	5	20	5	15
754	LPFP SPD	33*	80*	115	115	55	UA	32	55	65	65
436	LPFT IN PR	12*	40*	14	19	23	UA	19	29	23	33
1205, 1206	FAC FU FL	130*	163*	72	75	82	UA	75	120	25	125
1207, 1209	FAC FU FL CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
722	ENG FU FLOW	100*	150*	55	100	85	UA	133	143	70	70
1722	ENG FU FLOW CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
233	HPOT DS T1	16	UA	.5	1	8	8	8	12.4	8.6	12.6
234	HPOT DS T2	11	UA	13	16	4	8	8	12.4	4.5	16.3
1190	HPOT PRSL DR T	X	X	5.5	6.5	2.5	4	NS	NS	3.5	3.5
1071	OX BLD INT T	NS	NS	X	X	.62*	1.9*	NS	NS	NS	NS
1054	OX FAC FM DS T	.11*	.14*	.01	.01	.48	UA	.03*	.31*	.03*	.05*
854	FAC OX FM DS PR	3*	4*	.65*	1.8*	5*	5.9*	3.4	3.5	1.9*	3.7*
1214	FAC OX FLOW CT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1212, 1213	FAC OX FLOW	40*	72*	47	67	80	UA	58	87	38	147
858, 860	ENG OX IN PR	2*	3*	1.2*	1.9*	3*	6*	2.45*	2.6*	3.2	5.7
1058	ENG OX IN TEMP	.04*	.04*	NS	NS	.29	.51	.29*	.48*	.16*	.18*
338	HPOP DS PR	50*	70*	20	54	53*	106*	30	55	45	45
325, 326	HPOP BALCAV PR	49*	57*	20	20	17	UA	16	30	20	22
30, 734	LPOP SPD	77*	77*	36	86	50*	50*	50*	80*	41*	51*
302	LPOP DS PS	7*	10*	3	5.4	5.3	UA	4.2	8.1	7	11
93, 94	PBP DS TMP	X	X	X	X	.3	UA	1.8	2.4	.31*	.43*
341	PBP DS PR	120*	140*	X	X	87	UA	80	80	104	104
412	FPB PC	57*	57*	10.5	19.5	X	X	22.5	43	24	45
480	OPB PC	38*	38*	14	20	20.4	UA	27	43	32	44
878	HX INT PR	NS	NS	5	11	13	UA	16	20	31*	31*
879	HX INT T	X	X	2	2.7	2	2	NS	NS	2.4	3.6
881	HX VENT IN PR	X	X	.2	.7	2	3	1.4	1.6	5*	5*
882	HX VENT IN T	.X	X	.5	1.1	3	7	NS	NS	1.5*	1.5*
883	HX VENT DP	.1*	.2*	.17	.95	1	UA	.5	.7	.38*	.43*
40	OPOV ACT POS	.25	UA	.1	.28	1.5	UA	.25	.25	.25	.85
42	FPOV ACT POS	.5	UA	.33	.8	.6	UA	.57	.57	.6	.6

Table III-2: Test-to-Test Envelope Data Base Definition
(cont.)

TEST TO TEST ENVELOPE Data Base (Continued)

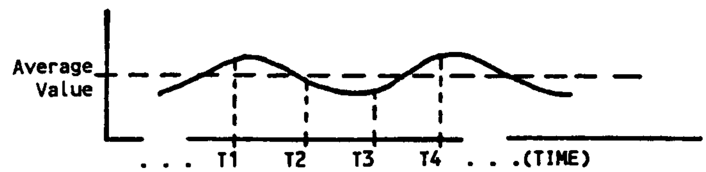
Legend: AVG1---Data below this heading represent average envelope values 2-sec before early indications of an anomaly.
AVG2---Data below this heading represent average envelope values 10-sec before early indications of an anomaly.
STD1---Data below this heading represent the standard deviation derived from the respective average envelope value AVG1 and the test-to-test envelopes of Table III-2. The STD1 data list are used in Table III-1.
STD2---Data below this heading represent the standard deviation derived from the respective average envelope value AVG2 and the test-to-test envelopes of Table III-2. The STD2 data list are used in Table III-1.
ID-----Insufficient data for derivations.

PID NO.(S)	PARAMETER	AVG1	AVG2	STD1	STD2
366-371	(INJ CLNT PR) -(MCC HG IN PR)	6.28	7.	2.48	2.24
366-383	(INJ CLNT PR) -(MCC PC)	5.88	8.82	4.48	6.25
371-383	(MCC HG IN PR) -(MCC PC)	10.70	14.43	7.86	10.10
395-383	(MCC OX INJ PR) -(MCC PC)	16.97	23.3	5.13	6.16
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	14.	(ID)	6.00	(ID)
459-383	(HPFP DS PR) -(MCC PC)	22.13	31.62	7.06	11.29
412-371	(FPB PC) -(MCC HG IN PR)	17.98	22.79	5.78	8.81
480-371	(OPB PC) -(MCC HG IN PR)	21.44	28.93	10.37	10.04
63, 163	MCC PC	12.71	17.31	4.43	3.89
200	MCC PC AVG	12.71	17.29	4.43	3.91
436	MCC CLNT DS PR	31.78	41.38	14.87	14.91
566	MCC CLNT DS T	1.94	3.04	1.35	1.75
24	MCC FU INJ PR	17.56	25.14	9.89	9.66
1951, 1956	MCC LN CAV P	(ID)	(ID)	(ID)	(ID)
595	MCC OX INJ TEMP	.466	.529	.324	.460
86	HPFP IN PR	5.1	6.7	2.02	2.70
459	HPFP DS PR	32.25	49.39	10.72	12.79
659	HPFP DS T	.266	.357	.068	.106
457	HPFP BAL CAV PR	27.14	34.8	17.67	25.92
52, 764	HPFP SPD	87.	118.60	31.51	44.42
53, 940	HPFP CL LNR PR	20.5	23.33	4.97	3.40
650	HPFP CL LNR T	9.53	11.5	1.84	.5
657	HPFP DR PR	.06	.08	.01	0.
658	HPFP DR TEMP	.95	(ID)	.05	(ID)
663	HPFT DS T1 A	19.88	24.49	14.10	14.29
664	HPFT DS T1 B	13.85	22.4	8.47	8.16
754	LPFP SPD	200.5	259.13	433.8	469.45
436	LPFT IN PR	19.56	28.44	4.09	6.39
1205, 1206	FAC FU FL	73.50	107.67	32.80	31.78
1207, 1209	FAC FU FL CT	(Sensor trace not applicable)			
722	ENG FU FLOW	93.50	111.22	23.60	26.68
1722	ENG FU FLOW CT	(Sensor trace not applicable)			
233	HPOT DS T1	8.01	12.5	4.83	5.89
234	HPOT DS T2	10.72	18.59	6.84	13.71
1190	HPOT PRSL DR T	3.14	4.9	1.36	1.77
1071	OX BLD INT T	2.51	4.13	2.47	3.45
1054	OX FAC FM DS T	.192	.204	.319	.315
854	FAC OX FM DS PR	2.98	3.60	2.41	2.28
1214	FAC OX FLOW CT	(Sensor trace is not applicable)			
1212, 1213	FAC OX FLOW	54.11	81.75	18.02	27.31
858, 860	ENG OX IN PR	2.37	3.36	.83	1.39
1058	ENG OX IN TEMP	.136	.244	.11	.191
338	HPOP DS PR	36.9	57.1	12.04	19.93
325, 326	HPOP BALCAV PR	20.3	25.94	12.00	12.81
30, 734	LPOP SPD	39.3	63.1	18.45	28.35
302	LPOP DS PR	5.08	7.73	1.60	2.55
93, 94	PBP DS TMP	.625	.973	.684	1.02
341	PBP DS PR	80.5	86.43	23.95	26.33
412	FPB PC	23.31	30.22	14.04	14.85
480	OPB PC	22.44	37.94	7.46	19.03
878	HX INT PR	14.11	20.62	7.78	7.33
879	HX INT T	2.30	4.83	.81	3.71
881	HX VENT IN PR	1.68	2.01	1.47	1.41
882	HX VENT IN T	1.1	2.22	.943	2.16
883	HX VENT DP	.411	.681	.269	.282
40	OPOV ACT POS	.336	.533	.397	.226
42	FPOV ACT POS	.470	.676	.122	.124

Table III-2: Test-to-Test Envelope Data Base Definition (cont.)

Data base for time sliced value deviations from the average steady-state sensor value

I.E. E.G.



Legend: DEV1---Data below this heading represent the standard deviation for values taken every 20 msec over a 5-sec interval. These data were taken from Test 901-484 and derived from NTI (New Technology Inc.) of Huntsville Alabama.

DEV2---Data below this heading represent the standard deviation for values taken every 100 msec over a 1-sec interval. These data were taken from Test 901-436, 901-307, and 901-173.

STD3---Data below this heading represent the data summarized in Table III-1
STD3= DEV1, If DEV1 is unavailable, STD3= DEV2.

UNAV---Data is unavailable.

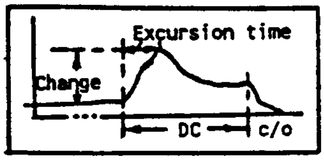
PID NO.(S)	PARAMETER		DEV2	DEV1	STD3
366-371	(INJ CLNT PR)	-(MCC HG IN PR)	1.08	UNAV	1.08
366-383	(INJ CLNT PR)	-(MCC PC)	.632	UNAV	.632
371-383	(MCC HG IN PR)	-(MCC PC)	1.08	UNAV	1.08
395-383	(MCC OX INJ PR)	-(MCC PC)	3.28	UNAV	3.28
940-371	(HPFP CL LNR PR)	-(MCC HG IN PR)	.640	UNAV	.640
459-383	(HPFP DS PR)	-(MCC PC)	7.75	UNAV	7.75
412-371	(FPB PC)	-(MCC HG IN PR)	4.73	UNAV	4.73
480-371	(OPB PC)	-(MCC HG IN PR)	3.2	UNAV	3.2
63, 163	MCC PC		3.25	UNAV	3.25
200	MCC PC AVG		3.13	UNAV	2.13
436	MCC CLNT DS PR		7.72	UNAV	7.72
566	MCC CLNT DS T		1.05	UNAV	1.05
24	MCC FU INJ PR		8.20	UNAV	8.20
1951, 1956	MCC LN CAV P		UNAV	UNAV	UNAV
595	MCC OX INJ TEMP		.06	.072	.072
86	HPFP IN PR		1.01	1.01	1.01
459	HPFP DS PR		10.25	10.50	10.50
659	HPFP DS T		.081	.082	.082
457	HPFP BAL CAV PR		8.43	10.15	10.15
52, 764	HPFP SPD		5.64	30.70	30.70
53, 940	HPFP CL LNR PR		5.59	UNAV	5.59
650	HPFP CL LNR T		1.97	2.48	2.48
657	HPFP DR PR		.012	.012	.012
658	HPFP DR TEMP		.157	UNAV	.157
663	HPFT DS T1 A		3.56	UNAV	3.56
664	HPFT DS T1 B		3.74	UNAV	3.74
754	LPFP SPD		12.71	17.35	17.35
436	LPFT IN PR		4.24	6.56	6.56
1205, 1206	FAC FU FL		2.11	2.10	2.10
1207, 1209	FAC FU FL CT		(Sensor trace is not applicable)		
722	ENG FU FLOW		21.96	23.84	23.84
1722	ENG FU FLOW CT		(Sensor trace is not applicable)		
233	HPOT DS T1		0.	UNAV	0.
234	HPOT DS T2		1.44	UNAV	1.44
1190	HPOT PRSL DR T		.855	2.72	2.72
1071	OX BLD INT T		.224	UNAV	.224
1054	OX FAC FM DS T		.0064	.029	.029
854	FAC OX FM DS PR		.293	.462	.462
1214	FAC OX FLOW CT		(Sensor trace is not applicable)		
1212, 1213	FAC OX FLOW		6.78	16.94	16.94
858, 860	ENG OX IN PR		.590	.773	.773
1058	ENG OX IN TEMP		.0329	.046	.046
338	HPOP DS PR		7.25	UNAV	7.25
325, 326	HPOP BALCAV PR		2.68	4.06	4.06
30, 734	LPOP SPD		6.43	4.21	4.21
302	LPOP DS PR		3.49	UNAV	3.49
93, 94	PBP DS TMP		.268	UNAV	.268
341	PBP DS PR		19.65	16.1	16.1
412	FPB PC		6.43	7.64	7.64
480	OPB PC		5.70	8.02	8.02
878	HX INT PR		4.68	4.29	4.29
879	HX INT T		5.99	1.68	1.68
881	HX VENT IN PR		.31	UNAV	.31
882	HX VENT IN T		.083	UNAV	.083
883	HX VENT DP		.305	UNAV	.305
40	OPOV ACT POS		.112	UNAV	.112
42	FPOV ACT POS		.202	UNAV	.202

Table III-3: Data Base for Time Sliced Value Deviations from the Average Steady State Sensor Measurement

Data Base for Early Parameter Indicators of Test Classification: Injector Failure

-Test 901-173 (LOX Post Fractures, Erosion-MCC) conducted 31 March 1978 for Engine 0002.
---Cutoff Time= 201.16 sec due to a HPFT discharge temperature redline.
---Early indications occur near 92% PL.
---Damage: Main injector (burnouts of secondary and primary faceplate, 18-LOX posts), MCC (burnout at one acoustic cavity and adjacent to injector burnout area), and nozzle (46 tube ruptures).
---Impact: Unavailable.

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVEL A + B	DC	LEVEL-C
366-372	*(INJ CLNT PR) -(MCC HG IN PR)	124.4	1.	259.1	1.	2.0	.48	0.
366-383	*(INJ CLNT PR) -(MCC PC)	30.(1.)	1.(.3)	63.(.1)	1.(.1)	2.0(.4)	.48(28.5)	0.(1.)
372-383	(MCC HG IN PR) -(MCC PC)	4.1(1.)	1.(.3)	26.(.1)	1.(.1)	2.0(.4)	.48(28.5)	0.(1.)
395-383	*(MCC OX INJ PR) -(MCC PC)	5.6	1.	56.	1.	2.0	.1	0.
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	*(HPFP DS PR) -(MCC PC)	6.7(.4)	1.(.1)	19.(.1)	1.(.1)	2.0(.2)	.36(23.)	0.(1.)
412-372	*(FPB PC) -(MCC HG IN PR)	5.3(.3)	1.(.1)	14.(.1)	1.(.1)	2.0(.2)	.37(21.)	0.(1.)
480-372	*(OPB PC) -(MCC HG IN PR)	3.9	1.	5.9	.5	1.5	.66	.3
63, 163	*MCC PC	4.4	1.	7.85	.5	1.5	.48	.3
200	*MCC PC AVG	4.4	1.	7.85	.5	1.5	.48	.3
436	*MCC CLNT DS PR	5.6	1.	12.1	1.	2.0	.46	0.
18	*MCC CLNT DS T	(Sensor does not exist)						
24	*MCC FU INJ PR	4.4(1.)	1.(.3)	9.5(.1)	.5(.1)	1.5(.4)	.46(22.5)	0.(1.)
1951, 1956	*MCC LN CAV P	(Sensor does not exist)						
595	*MCC OX INJ TEMP	(Sensor does not exist)						
86	*HPFP IN PR	2.76	.7	8.92	.5	1.2	.32	0.
459	*HPFP DS PR	4.63	1.	12.2	1.	2.0	.38	0.
659	*HPFP DS T	2.6	.7	10.03	1.	1.7	.26	0.
457	*HPFP BAL CAV PR	4.87	1.	15.7	1.	2.0	.31	0.
52, 764	*HPFP SPD	1.5	.3	4.17	.5	.8	.36	0.
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
663	*HPFT DS T1 A	7.45	1.	20.7	1.	2.0	.36	0.
664	*HPFT DS T1 B	7.45	1.	20.7	1.	2.0	.36	0.
754	LPFP SPD	12.2	1.	3.1	.3	1.3	29.1	1.
436	*LPFT IN PR	5.6	1.	12.1	1.	2.0	.46	0.
1205, 1206	FAC FU FL	1.8	.3	6.	.5	.8	.3	0.
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	*ENG FU FLOW	2.74	.7	7.62	.5	1.2	.36	0.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	*HPOT DS T1	4.87	1.	13.53	1.	2.0	.36	0.
519	*HPOT DS T2	2.96	.7	8.23	.5	1.2	.36	0.
1190	HPOT PRSL DR T	.63	.1	.69	.1	.2	3.86	.7
1071	OX BLD INT T	(Sensor does not exist)						
1054	OX FAC FM DS T	.009	.1	.007	.1	.2	3.16	.7
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1214	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	.8	.1	1.6	.3	.4	.66	.3
858	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	.006	.1	.0063	.1	.2	.96	.3
338	*HPOP DS PR	5.91	1.	16.4	1.	2.0	.36	0.
325, 326	*HPOP BALCAV PR	3.39	1.	9.4	.5	1.5	.36	0.
734	*LPOP SPD	2.7	.7	7.5	.5	1.2	.36	0.
302	LPOP DS PR	3.4	1.	9.6	.5	1.5	.36	0.
93, 94	*PBP DS TMP	(Sensor does not exist)						
59, 159	*PBP DS PR	3.2	1.	8.88	.5	1.5	.36	0.
412	*FPB PC	1.1(.4)	.3(.1)	7.(.02)	.5(.1)	.8(.2)	.16(22.8)	0.(1.)
480	*OPB PC	3.8(.3)	1.(.1)	11.(.1)	1.(.1)	2.0(.2)	.36(23.)	0.(1.)
878	*HX INT PR	.94	.1	1.57	.3	.4	.26	0.
879	*HX INT T	.36	.1	.33	.1	.2	2.76	.7
881	*HX VENT IN PR	1.43	.3	3.98	.3	.6	.36	0.
882	*HX VENT IN T	.06(.3)	.1(.1)	.2(.02)	.1(.1)	.2(.2)	.26(21.)	0.(1.)
883	*HX VENT DP	1.12	.3	4.35	.3	.6	.26	0.
40	*OPOV ACT POS	4.2(3.7)	1.(1.)	9.1(1.)	.5(.5)	1.5(1.5)	.46(28.5)	0.(1.)
42	*FPOV ACT POS	1.83	.3	5.08	.5	.8	.36	0.

Table III-4: 901-173 Data Base

Data Base for Early Parameter Indicators of Test Classification: Injector Failure

-Test 901-331 (LOX Post Fractures, Erosion-MCC) conducted 15 July 1981 for Engine 2108.

---Cutoff Time= 233.14 sec. due to a HPOT discharage temperature redline.

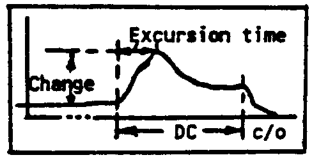
---Early indications occur near 100% PL.

---Damage: Main injector (burn through of primary and secondary faceplate, 169 LOX posts), MCC (minor erosion in acoustic cavity), and nozzle (60 tubes damaged).

---Impact: $4.1M, Delay Time- 24 weeks.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
835-371	(INJ CLNT PR)	-(MCC HG IN PR)	125.	1.	1042.	1.	2.0	.95	.3
835-383	(INJ CLNT PR)	-(MCC PC)	7.2	1.	48.1	1.	2.0	.93	.3
371-383	(MCC HG IN PR)	-(MCC PC)	17.6	1.	147.1	1.	2.0	.94	.3
395-383	(MCC OX INJ PR)	-(MCC PC)	25.5	1.	36.4	1.	2.0	.84	.3
940-371	(HPFP CL LNR PR)	-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR)	-(MCC PC)	1.59	.3	15.9	1.	1.3	.89	.3
412-371	(FPB PC)	-(MCC HG IN PR)	3.22	1.	32.2	1.	2.0	.85	.3
480-371	(OPB PC)	-(MCC HG IN PR)	5.55	1.	55.5	1.	2.0	.89	.3
63, 163	MCC PC		3.6(.8)	1.(.1)	33.(8.)	1.(.5)	2.0(.6)	.82(.94)	.3(.3)
200	MCC PC AVG		3.6(.8)	1.(.1)	33.(8.)	1.(.5)	2.0(.6)	.82(.94)	.3(.3)
17	MCC CLNT DS PR		4.78	1.	22.4	1.	2.0	.88	.3
18	*MCC CLNT DS T		10.2	1.	18.2	1.	2.0	.86	.3
24	MCC FU INJ PR		5.32	1.	44.3	1.	2.0	.82	.3
1951, 1956	MCC LN CAV P		(Sensor malfunction)						
595	MCC OX INJ TEMP		.5	.1	.98	.1	.2	.69	.3
86	HPFP IN PR		5.	1.	6.	.5	1.5	.94	.3
459	HPFP DS PR		2.79	.7	14.7	1.	1.7	.86	.3
659	HPFP DS T		.93	.1	5.78	.5	.6	.84	.3
457	HPFP BAL CAV PR		2.69	.7	14.93	1.	1.7	.84	.3
52, 764	HPFP SPD		1.2	.3	8.58	.5	.8	.88	.3
53, 940	HPFP CL LNR PR		(Sensors do not exist)						
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
663	HPFT DS T1 A		10.12	1.	33.73	1.	2.0	.84	.3
664	HPFT DS T1 B		10.74	1.	35.79	1.	2.0	.84	.3
754	LPFP SPD		5.21	1.	11.08	1.	2.0	.76	.3
436	LPFT IN PR		4.13	1.	27.52	1.	2.0	.79	.3
1205, 1207	FAC FU FL		9.2	1.	15.4	1.	2.0	.79	.3
1207, 1209	FAC FU FL CT		(Sensor malfunction)						
722	ENG FU FLOW		11.4	1.	27.14	1.	2.0	.79	.3
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	*HPOT DS T1		41.	1.	55.5	1.	2.0	.74	.3
234	*HPOT DS T2		40.	1.	53.1	1.	2.0	.75	.3
1190	HPOT PRSL DR T		3.04	1.	4.89	.3	1.3	.36	0.
1071	OX BLD INT T		.93	.1	4.43	.3	.4	.43	0.
1054, 1056	OX FAC FM DS T		(No change is strikingly indicated)						
854	FAC OX FM DS PR		(No change is strikingly indicated)						
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212	FAC OX FLOW		9.64	1.	18.5	1.	2.0	.64	.3
858, 860	ENG OX IN PR		9.7(4.)	1.(1.)	97.(17)	1.(1.)	2.0(2.)	.82(.94)	.3(.3)
1058	ENG OX IN TEMP		.14	.1	2.26	.3	1.3	.4	0.
90	HPOP DS PR		4.06	1.	8.83	.5	1.5	.76	.3
325, 326	HPOP BALCAV PR		2.74	.7	5.96	.5	1.2	.69	.3
30, 734	LPOP SPD		2.06	.7	7.11	.5	1.2	.75	.3
209, 210	LPOP DS PR		5.76	1.	57.6	1.	2.0	.89	.3
93, 94	PBP DS TMP		(No change is strikingly indicated)						
59, 159	PBP DS PR		(Sensor malfunction)						
412	FPB PC		2.54	.7	21.2	1.	1.7	.77	.3
480	OPB PC		2.46	.7	12.3	1.	1.7	.86	.3
878	HX INT PR		4.71	1.	10.02	1.	2.0	.64	.3
879	*HX INT T		7.16	1.	10.23	1.	2.0	.44	0.
881	*HX VENT IN PR		4.26	1.	8.69	.5	1.5	.57	.3
882	HX VENT IN T		.42	.1	.698	.1	.2	.34	0.
883	HX VENT DP		4.31	1.	8.3	.5	1.5	.61	.3
40	*OPOV ACT POS		7.17	1.	9.96	.5	1.5	.86	.3
42	*FPOV ACT POS		6.55	1.	9.5	.5	1.5	.77	.3

Table III-5: 901-331 Data Base

Data Base for Early Parameter Indicators of Test Classification: Injector Failure

-Test 750-148 (LOX Post Fractures, Erosion-MCC) conducted 2 September 1981 for Engine 0110.

---Cutoff Time= 16. sec due to a HPOT discharge temperature redline.

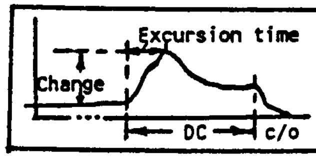
---Early indications occur near 105% PL.

---Damage: Main injector (burn thru of primary and secondary faceplate, 149 LOX posts), MCC (erosion in one acoustic cavity), nozzle (150 tubes ruptured).

---Impact: $7.0M, Delay Time- 8 weeks.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVEL A + B	DC	LEVEL-C
437-463	(INJ CLNT PR) -(MCC HG IN PR)	30.	1.	167.	1.	2.0	.55	.3
437-63	(INJ CLNT PR) -(MCC PC)	50.7	1.	181.	1.	2.0	.55	.3
463-63	(MCC HG IN PR) -(MCC PC)	10.6	1.	132.4	1.	2.0	.58	.3
395-383	(MCC OX INJ PR) -(MCC PC)	9.9	1.	12.3	1.	2.0	.5	.3
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	9.	1.	45.	1.	2.0	.6	.3
411-463	(FPB PC) -(MCC HG IN PR)	4.2	1.	42.	1.	2.0	.6	.3
480-463	(OPB PC) -(MCC HG IN PR)	4.2	1.	28.	1.	2.0	.63	.3
63, 163	MCC PC	6.43	1.	13.4	1.	2.0	.48	0.
200	MCC PC AVG	6.43	1.	13.4	1.	2.0	.48	0.
436	*MCC CLNT DS PR	13.6	1.	25.7	1.	2.0	.53	.3
18	*MCC CLNT DS T	10.6	1.	20.5	1.	2.0	.52	.3
24	MCC FU INJ PR	(Sensor malfunction)						
1951, 1956	MCC LN CAV P	(Sensor malfunction)						
595	MCC OX INJ TEMP	.1	.1	.58	.1	.2	.56	.3
86	HPFP IN PR	4.2	1.	42.	1.	2.0	.58	.3
459	HPFP DS PR	7.2	1.	31.2	1.	2.0	.55	.3
659	HPFP DS T	2.8	.7	9.3	.5	1.2	.56	.3
457	*HPFP BAL CAV PR	15.9	1.	31.8	1.	2.0	.5	.3
52, 764	HPFP SPD	1.47	.3	7.	.5	.8	.58	.3
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
663	*HPFT DS T1 A	30.9	1.	61.8	1.	2.0	.5	.3
232	HPFT DS T1 B	(Sensor malfunction)						
754	LPFP SPD	.9	.1	1.5	.3	.4	.48	0.
436	LPFT IN PR	13.6	1.	25.7	1.	2.0	.53	.3
1205, 1206	FAC FU FL	(Sensor does not exist)						
1207, 1209	FAC FU FL CT	(Sensor does not exist)						
722	ENG FU FLOW	2.17	.7	21.	1.	2.0	.55	.3
1722	ENG FU FLOW CT	(Sensor does not exist)						
518	*HPOT DS T1	32.6	1.	65.2	1.	2.0	.46	0.
519	*HPOT DS T2	37.6	1.	81.7	1.	2.0	.46	0.
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	*OX BLD INT T	.9	.1	2.23	.3	.4	.4	0.
1054	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	4.7(1.)	1.(.3)	15.(14)	1.(1.)	2.0(1.3)	.62(.72)	.3(.3)
1214	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	3.38	1.	7.68	.5	1.5	.64	.3
858	ENG OX IN PR	8.6(2.)	1.(.7)	35.(14)	1.(1.)	2.0(1.7)	.68(.83)	.3(.3)
1058	ENG OX IN TEMP	(Sensor does not exist)						
338	HPOP DS PR	4.7	1.	20.5	1.	2.0	.54	.3
325, 326	HPOP BALCAV PR	5.5	1.	28.9	1.	2.0	.5	.3
734	LPOP SPD	2.31	.7	9.2	.5	1.2	.54	.3
302	LPOP DS PR	3.83	1.	38.3	1.	2.0	.6	.3
93, 94	PBP DS TMP	.8	.1	3.0	.3	.4	.54	.3
59, 159	PBP DS PR	4.47	1.	13.5	1.	2.0	.65	.3
412	FPB PC	5.9	1.	24.7	1.	2.0	.56	.3
480	OPB PC	6.0	1.	26.2	1.	2.0	.56	.3
878	HX INT PR	3.4	1.	8.4	.5	1.5	.5	.3
879	*HX INT T	.7	.1	2.3	.3	.4	.3	.3
881	*HX VENT IN PR	2.6	.7	5.8	.5	1.2	.44	0.
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	(Sensor has not settled adequately to steady state conditions)						
40	OPOV ACT POS	8.0(1.3)	1.(.3)	24.(1.)	1.(.3)	2.0(.6)	.45(1.4)	0.(.7)
42	FPOV ACT POS	2.2	.7	7.35	.5	1.2	.6	.3

Table III-6: 750-148 Data Base

Data Base for Early Parameter Indicators of Test Classification: Injector Failure

·Test 901-183 (LOX Post Fractures, Erosion-MCC) conducted 5 June 1978 for Engine 0005.

---Cutoff Time= 51.1 sec. due to an erroneous HPFP radial accelerameter redline.

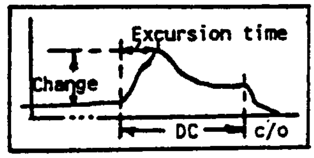
---Early indications occur near 92% PL.

---Damage: Main injector (burn thru of primary faceplate only, 15-LOX posts), MCC (minor scalding), and nozzle (a failed saddle patch at tube #246.).

---Impact: Unavailable.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR)	-(MCC HG IN PR)	157.1	1.	32.7	1.	2.0	27.1	1.
366-383	(INJ CLNT PR)	-(MCC PC)	9.74	1.	2.78	.3	1.3	26.8	1.
371-383	(MCC HG IN PR)	-(MCC PC)	2.44	.7	3.6	.3	1.3	26.5	1.
395-383	(MCC OX INJ PR)	-(MCC PC)	1.44	.3	.3	.1	.4	26.9	1.
940-371	(HPFP CL LNR PR)	-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR)	-(MCC PC)	.77	.1	1.19	.3	.4	27.	1.
412-371	(FPB PC)	-(MCC HG IN PR)	(No change is strikingly indicated)						
480-371	(OPB PC)	-(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC		.27	.1	1.43	.3	.4	26.89	1.
200	MCC PC AVG		.27	.1	1.43	.3	.4	26.89	1.
436	MCC CLNT DS PR		.52	.1	1.3	.3	.4	26.85	1.
566	MCC CLNT DS T		1.04	.3	.32	.1	.4	26.6	1.
24	MCC FU INJ PR		(Sensor has not settled adequately to steady state conditions)						
1951, 1956	MCC LN CAV P		(Sensor does not exist)						
595	MCC OX INJ TEMP		(Sensor does not exist)						
86	HPFP IN PR		(Sensor has not settled adequately to steady state conditions)						
459	HPFP DS PR		.49	.1	1.35	.3	.4	26.88	1.
659	HPFP DS T		.19	.1	.16	.1	.2	28.	1.
457	HPFP BAL CAV PR		3.39	1.	.89	.1	1.1	30.9	1.
52, 764	HPFP SPD		(No change is strikingly indicated)						
53, 940	HPFP CL LNR PR		(Sensors do not exist)						
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
663	HPFT DS T1 A		1.597	.3	15.97	1.	1.3	26.6	1.
664	HPFT DS T1 B		1.38	.3	9.2	.5	.8	26.6	1.
754	LPFP SPD		.69	.1	.06	.1	.2	38.	1.
436	LPFT IN PR		.52	.1	1.3	.3	.4	26.85	1.
1205, 1206	FAC FU FL		.69	.1	1.69	.3	.4	26.5	1.
1207, 1209	FAC FU FL CT		(No change is strikingly indicated)						
722	ENG FU FLOW		.51	.1	2.32	.3	.4	26.52	1.
1722	ENG FU FLOW CT		(Sensor malfunction)						
233	HPOT DS T1		.53	.1	2.11	.3	.4	26.6	1.
234	HPOT DS T2		.28	.1	1.19	.3	.4	26.6	1.
1190	HPOT PRSL DR T		(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T		(Sensor has not settled adequately to steady state conditions)						
1054	OX FAC FM DS T		(No change is strikingly indicated)						
854	FAC OX FM DS PR		(No change is strikingly indicated)						
1214	FAC OX FLOW CT		(Sensor malfunction)						
1212, 1213	FAC OX FLOW		.29	.1	.37	.1	.2	26.7	1.
858, 860	ENG OX IN PR		(No change is strikingly indicated)						
1058	ENG OX IN TEMP		(No change is strikingly indicated)						
338	HPOP DS PR		.2	.1	1.13	.3	.4	26.88	1.
325, 326	HPOP BALCAV PR		.11	.1	.51	.1	.2	26.61	1.
30, 734	LPOP SPD		(No change is strikingly indicated)						
209, 210	LPOP DS PR		(No change is strikingly indicated)						
93, 94	PBP DS TMP		(Sensor does not exist)						
341	PBP DS PR		.48	.1	2.4	.3	.4	26.7	1.
412	FPB PC		.30	.1	.41	.1	.2	27.4	1.
480	OPB PC		.31	.1	1.54	.3	.4	26.9	1.
878	HX INT PR		(Sensor has not settled adequately to steady state conditions)						
879	HX INT T		.234	.1	.17	.1	.2	27.5	1.
881	HX VENT IN PR		(Sensor has not settled adequately to steady state conditions)						
882	HX VENT IN T		(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP		(No change is strikingly indicated)						
40	OPOV ACT POS		1.1	.3	.734	.1	.4	26.75	1.
42	FPOV ACT POS		.39	.1	1.95	.3	.4	25.8	1.

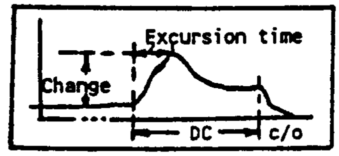
Table III-7: 901-183 Data Base

Data Base for Early Parameter Indicators of Test Classification: Injector Failure

- Test 902-198 (LOX Post Fractures, Erosion-MCC) conducted 23 July 1980 for Engine 2004.
  - ---Cutoff Time= 8.5 sec. due to a HPOT discharge temperature redline.
  - ---Early indications occur near 102% PL.
  - ---Damage: Main injector (burn thru of primary faceplate only, 56 LOX posts), MCC (minor erosion in acoustic cavity and to coolant channels), nozzle (11 tubes ruptured, 27 w/dents)
  - ---Impact: $1M (for repair/replacement only), Delay Time- 12 weeks.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

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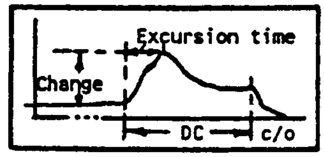
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
17-24	(INJ CLNT PR) -(MCC HG IN PR)	4.17	1.	16.7	1.	2.0	3.	.7
17-163	(INJ CLNT PR) -(MCC PC)	5.33	1.	17.7	1.	2.0	3.	.7
24-163	(MCC HG IN PR) -(MCC PC)	21.77	1.	15.	1.	2.0	2.8	.7
395-383	(MCC OX INJ PR) -(MCC PC)	(Sensor does not exist)						
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	1.91	.3	9.55	.5	.8	3.	.7
411-24	(FPB PC) -(MCC HG IN PR)	3.35	1.	6.7	.5	1.5	2.75	.7
480-24	(OPB PC) -(MCC HG IN PR)	6.63	1.	5.1	.5	1.5	3.	.7
63, 163	MCC PC	1.54	.3	6.98	.5	.8	3.	.7
200	MCC PC AVG	1.54	.3	6.98	.5	.8	3.	.7
17	MCC CLNT DS PR	1.98	.3	10.98	1.	1.3	2.98	.7
18	*MCC CLNT DS T	12.5	1.	5.34	.5	1.5	2.84	.7
24	MCC FU INJ PR	1.76	.3	7.98	.5	.8	3.01	.7
1951, 1956	MCC LN CAV P	(Sensor malfunction)						
595	*MCC OX INJ TEMP	1.63	.3	.77	.1	.4	2.6	.7
86	HPFP IN PR	9.89	1.	7.27	.5	1.5	3.1	.7
459	HPFP DS PR	1.63	.3	7.45	.5	.8	3.0	.7
659	HPFP DS T	.69	.3	3.13	.3	.6	3.01	.7
457	HPFP BAL CAV PR	2.08	.7	10.4	1.	1.7	2.92	.7
52, 764	HPFP SPD	.43	.1	3.92	.3	.4	3.01	.7
53, 940	HPFP CL LNR PR	1.449	.3	9.66	.5	.8	2.9	.7
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	84.1	1.	210.	1.	2.0	2.9	.7
232	HPFT DS T1 B	5.5	1.	13.8	1.	2.0	2.9	.7
754	LPFP SPD	3.33	1.	4.44	.3	1.3	3.0	.7
436	LPFT IN PR	2.19	.7	9.9	.5	1.2	3.0	.7
1205, 1206	FAC FU FL	3.58	1.	5.1	.5	1.5	2.85	.7
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	2.64	.7	7.57	.5	1.2	2.85	.7
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	*HPOT DS T1	30.11	1.	12.04	1.	2.0	3.0	.7
234	*HPOT DS T2	28.5	1.	11.39	1.	2.0	3.0	.7
1190	*HPOT PRSL DR T	29.9	1.	11.96	1.	2.0	3.0	.7
1071	OX BLD INT T	4.99	1.	4.54	.3	1.3	3.1	.7
1054	*OX FAC FM DS T	.05	.1	.02	.1	.2	3.0	.7
854	*FAC OX FM DS PR	3.66	1.	1.47	.3	1.3	3.0	.7
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	*FAC OX FLOW	5.79	1.	2.32	.3	1.3	3.0	.7
858	*ENG OX IN PR	3.44	1.	1.38	.3	1.3	3.0	.7
1058	ENG OX IN TEMP	.76	.1	1.41	.3	.4	1.81	.7
338	HPOP DS PR	4.21	1.	2.45	.3	1.3	2.72	.7
325, 326	HPOP BALCAV PR	4.64	1.	2.32	.3	1.3	3.0	.7
734	LPOP SPD	2.17	.7	1.21	.3	1.0	3.0	.7
209,210	LPOP DS PR	4.73	1.	18.95	1.	2.0	2.9	.7
93, 94	PBP DS TMP	2.05	.7	.93	.1	.8	2.7	.7
59, 159	PBP DS PR	6.03	1.	3.55	.3	1.3	2.72	.7
412	FPB PC	1.17	.3	4.86	.3	.6	3.0	.7
480	OPB PC	2.24	.7	1.32	.3	1.0	2.84	.7
878	HX INT PR	4.51	1.	2.48	.3	1.3	2.7	.7
879	*HX INT T	15.44	1.	7.72	.5	1.5	2.5	.7
881	HX VENT IN PR	1.61	.3	1.08	.3	.6	2.88	.7
882	HX VENT IN T	(No change is strikingly indicated)						
883	HX VENT DP	1.85	.3	1.48	.3	.6	2.75	.7
40	OPOV ACT POS	5.00	1.	2.17	.3	1.3	3.0	.7
42	*FPOV ACT POS	2.29	.7	.93	.1	.8	2.74	.7

Table III-8: 902-198 Data Base

Data Base for Early Parameter Indicators of Test Classification: Injector Failure
-Test 901-307 (LOX-Post Fractures, Erosion-FPB), conducted 28 January 1981 for Engine 0009.
---Cutoff Time= 75.025 sec due to an Elevation-J pressure redline.
---Early indications occur near 65% PL
---Damage: FPB injector (severe face erosion, 4-LOX posts and fuel sleeves eroded back into fuel manifold), HPFTP (most 1st-stage turbines with heavy spalling & appear with cracks at root)
---Impact: Unavailable

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-163	(MCC HG IN PR) -(MCC PC)	(No change is strikingly indicated)						
395-163	(MCC OX INJ PR) -(MCC PC)	8.01	1.	.29	.1	1.1	28.	1.
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	25.(21)	1.(1.)	50.(3.4)	1.(.3)	2.0(1.3)	20.3(53)	1.(1.)
459-383	(HPFP DS PR) -(MCC PC)	(No change is strikingly indicated)						
410-371	(FPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
480-371	(OPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC	.38	.1	.11	.1	.2	38.5	1.
200	MCC PC AVG	.61	.1	.01	.1	.2	40.5	1.
17	MCC CLNT DS PR	(Sensor has not settled adequately to steady state conditions)						
18	MCC CLNT DS T	(No change is strikingly indicated)						
24	*MCC FU INJ PR	3.4	1.	.15	.1	1.1	23.	1.
1951	MCC LN CAV P	(Sensor does not exist)						
21	MCC OX INJ TEMP	(No change is strikingly indicated)						
86	HPFP IN PR	(No change is strikingly indicated)						
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	(No change is strikingly indicated)						
457	HPFP BAL CAV PR	(No change is strikingly indicated)						
52, 764	HPFP SPD	(No change is strikingly indicated)						
940	HPFP CL LNR PR	1.2(1.1)	.3(.3)	2.48(.2)	.3(.1)	.6(.4)	26.(57)	1.(1.)
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	4.(3.1)	1.(1.)	1.2(2.1)	.3(.3)	1.3(1.3)	14.(54.5)	1.
232	*HPFT DS T1 B	4.6	1.	.1	.1	1.1	44.	1.
754	LPFP SPD	(No change is strikingly indicated)						
436	LPFT IN PR	(Sensor does not exist)						
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	(No change is strikingly indicated)						
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	*HPOT DS T1	4.4	1.	.17	.1	1.1	26.	1.
234	*HPOT DS T2	4.5	1.	.16	.1	1.1	28.	1.
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T	21.2	1.	4.25	.3	1.3	49.	1.
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(Sensor malfunction)						
1212, 1213	FAC OX FLOW	(Sensor malfunction)						
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
762	ENG OX IN TEMP	(Sensor has not settled adequately to steady state conditions)						
90	*HPOP DS PR	1.26	.3	.04	.1	.4	28.5	1.
328	*HPOP BALCAV PR	1.14	.3	.04	.1	.4	27.5	1.
30, 734	LPOP SPD	.26	.1	.07	.1	.2	28.5	1.
209	*LPOP DS PR	9.2	1.	.3	.1	1.1	31.0	1.
93, 94	PBP DS TMP	(Sensor has not settled adequately to steady state conditions)						
59, 159	PBP DS PR	1.69	.3	.11	.1	.4	27.5	1.
410	*FPB PC	1.01	.3	.04	.1	.4	28.0	1.
480	*OPB PC	.82	.1	.03	.1	.2	28.0	1.
878	*HX INT PR	1.5	.3	.05	.1	.4	28.0	1.
879	HX INT T	3.8	1.	.15	.1	1.1	24.5	1.
881	HX VENT IN PR	(No change is strikingly indicated)						
882	*HX VENT IN T	.98	.1	.04	.1	.2	26.0	1.
883	HX VENT DP	(No change is strikingly indicated)						
40	OPOV ACT POS	3.41	1.	.4	.1	1.1	37.0	1.
42	FPOV ACT POS	1.26	.3	1.1	.3	.6	29.5	1.

Table III-9: 901-307 Data Base

Data Base for Early Parameter Indicators of Test Classification: Injector Failure

-SF10-01 (FPB Anomalies) conducted 12 July 1980 for Engine 0006.

---Cutoff Time= 106.6 sec due to a fire detection observer.

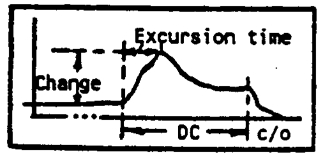
---Early indications occur near 102% PL

---Damage: FPB injector (eroded hole thru liner and outer wall, located 2" below fuel manifold), HPFTP (all turbine blades with moderate to heavy spalling of Zr coating)

---Impact: $1.5M, Delay Time- 16 weeks.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

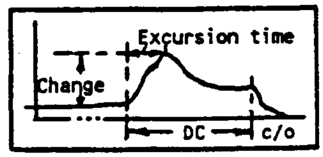
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-163	(MCC HG IN PR) -(MCC PC)	(Sensor does not exist)						
395-163	(MCC OX INJ PR) -(MCC PC)	(Sensor does not exist)						
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	(Sensor is unavailable)						
410-371	(FPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
480-371	(OPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
E41P3023D	MCC PC	1.77	.3	17.7	1.	1.3	5.2	1.
E41P3039D	MCC PC AVG	1.77	.3	17.7	1.	1.3	5.2	1.
E41P3067D	MCC CLNT DS PR	2.32	.7	15.5	1.	1.7	5.25	1.
E41T3070D	MCC CLNT DS T	3.98	1.	.184	.1	1.1	24.1	1.
24	MCC FU INJ PR	(Sensor does not exist)						
1921	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	HPFP IN PR	(Sensor is unavailable)						
E41P3029D	HPFP DS PR	2.92	.7	29.2	1.	1.7	5.25	1.
659	HPFP DS T	(Sensor does not exist)						
457	HPFP BAL CAV PR	(Sensor does not exist)						
52, 764	HPFP SPD	(No change is strikingly indicated)						
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
A49T3010H	HPFT DS T1 A	6.3	1.	25.4	1.	2.0	5.15	1.
A49T3011H	HPFT DS T1 B	5.3	1.	35.	1.	2.0	5.15	1.
E41R3072D	LPFP SPD	.84	.1	.84	.1	.2	5.2	1.
436	LPFT IN PR	(Sensor does not exist)						
1205, 1206	FAC FU FL	(Sensor does not exist)						
1207, 1209	FAC FU FL CT	(Sensor does not exist)						
E41R1034D	ENG FU FLOW	2.44	.7	24.4	1.	1.7	5.25	1.
1722	ENG FU FLOW CT	(Sensor does not exist)						
A49T3012H	*HPOT DS T1	8.0	1.	2.5	.3	1.3	5.2	1.
A49T3013H	*HPOT DS T2	9.0	1.	2.8	.3	1.3	5.2	1.
1190	HPOT PRSL DR T	(Sensor does not exist)						
1071	OX BLD INT T	(Sensor does not exist)						
1054, 1056	OX FAC FM DS T	(Sensor does not exist)						
854	FAC OX FM DS PR	(Sensor does not exist)						
1210	FAC OX FLOW CT	(Sensor does not exist)						
1212, 1213	FAC OX FLOW	(Sensor does not exist)						
858, 860	ENG OX IN PR	(Sensor does not exist)						
1058	ENG OX IN TEMP	(Sensor does not exist)						
90	HPOP DS PR	(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR	(Sensor does not exist)						
30, 734	LPOP SPD	(Sensor does not exist)						
209	LPOP DS PR	(Sensor does not exist)						
93, 94	PBP DS TMP	(Sensor does not exist)						
E41P3033D	PBP DS PR	2.3	.7	15.5	1.	1.7	5.2	1.
E41P3031D	FPB PC	2.94	.7	29.4	1.	1.7	5.25	1.
E41P3032D	OPB PC	2.15	.7	21.5	1.	1.7	5.25	1.
878	HX INT PR	(Sensor does not exist)						
879	HX INT T	(Sensor does not exist)						
881	HX VENT IN PR	(Sensor does not exist)						
882	HX VENT IN T	(Sensor does not exist)						
883	HX VENT DP	(Sensor does not exist)						
E41H3028D	OPOV ACT POS	3.43	1.	1.4	.3	1.3	5.2	1.
E41H1027D	FPOV ACT POS	2.2	.7	14.7	1.	1.7	5.25	1.

Table III-10: SF10-01 Data Base

Data Base for Early Parameter Indicators of Test Classification: Control Failure
Test 901-284 (Erroneous Sensor, Lee Jet) conducted 30 July 1980 for Engine 0010.

---Cutoff Time= 9.88 sec due to a PBP radial accelerometer redline
---Early indications occur near 100% PL
---Damage: Extensive engine damage when LPOP disch. duct ruptured, HPOTP (general gutting of pump end), POGO-system blown off with LPOP disch. duct, controller (severe fire damage)
---Impact: $9.2M, Delay Time- 16 weeks.

CRITERIA LEGEND: •Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

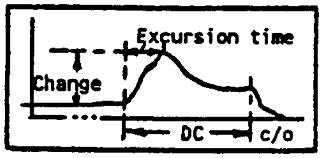
LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR)	-(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR)	-(MCC PC)	(Sensor does not exist)						
371-163	(MCC HG IN PR)	-(MCC PC)	(Sensor does not exist)						
395-163	(MCC OX INJ PR)	-(MCC PC)	270.8	1.	417.	1.	2.0	6.03	1.
940-371	(HPFP CL LNR PR)	-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR)	-(MCC PC)	70.	1.	107.7	1.	2.0	6.03	1.
410-371	(FPB PC)	-(MCC HG IN PR)	(Sensor does not exist)						
480-371	(OPB PC)	-(MCC HG IN PR)	(Sensor does not exist)						
63, 163	MCC PC		31.	1.	620.7	1.	2.0	6.03	1.
200	MCC PC AVG		31.	1.	620.7	1.	2.0	6.03	1.
17	MCC CLNT DS PR		37.9	1.	114.9	1.	2.0	5.96	1.
18	MCC CLNT DS T		79.8	1.	798.	1.	2.0	6.66	1.
24	MCC FU INJ PR		43.2	1.	134.9	1.	2.0	5.96	1.
1921	MCC LN CAV P		(Sensor malfunction)						
595	MCC OX INJ TEMP		5.38	1.	13.5	1.	2.0	5.48	1.
86	HPFP IN PR		20.5	1.	114.	1.	2.0	6.08	1.
52	HPFP DS PR		39.8	1.	120.7	1.	2.0	5.96	1.
659	HPFP DS T		19.8	1.	58.2	1.	2.0	5.92	1.
457	HPFP BAL CAV PR		16.7	1.	47.6	1.	2.0	5.93	1.
52, 764	HPFP SPD		19.4	1.	57.1	1.	2.0	5.96	1.
53, 940	HPFP CL LNR PR		(Sensors do not exist)						
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
231	HPFT DS T1 A		25.1	1.	71.7	1.	2.0	6.01	1.
232	HPFT DS T1 B		(Sensor malfunction)						
754	LPFP SPD		14.7	1.	40.7	1.	2.0	5.93	1.
436	LPFT IN PR		(Sensor does not exist)						
1205, 1206	FAC FU FL		20.97	1.	70.	1.	2.0	5.88	1.
1207, 1209	FAC FU FL CT		(Sensor does not exist)						
722	ENG FU FLOW		19.5	1.	52.6	1.	2.0	5.95	1.
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	HPOT DS T1		69.7	1.	34.9	1.	2.0	5.88	1.
234	HPOT DS T2		(Sensor malfunction)						
1190	HPOT PRSL DR T		26.7	1.	63.5	1.	2.0	6.03	1.
1071	OX BLD INT T		(Sensor does not exist)						
1054, 1056	OX FAC FM DS T		.52	.1	.89	.1	.2	6.46	1.
854	FAC OX FM DS PR		28.	1.	73.6	1.	2.0	5.96	1.
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW		63.6	1.	212.1	1.	2.0	5.88	1.
858, 860	ENG OX IN PR		51.6	1.	214.9	1.	2.0	5.9	1.
1058	ENG OX IN TEMP		.48	.1	1.66	.3	.4	4.43	.7
90	HPOP DS PR		49.3	1.	149.2	1.	2.0	5.96	1.
325, 326	HPOP BALCAV PR		52.2	1.	163.2	1.	2.0	5.96	1.
30, 734	LPOP SPD		29.3	1.	97.6	1.	2.0	5.88	1.
209	LPOP DS PR		28.6	1.	142.8	1.	2.0	5.76	1.
93, 94	PBP DS TMP		7.0	1.	13.5	1.	2.0	5.92	1.
59, 159	PBP DS PR		(Sensors malfunctioned)						
410	FPB PC		40.8	1.	110.3	1.	2.0	5.96	1.
480	OPB PC		47.5	1.	128.3	1.	2.0	5.96	1.
878	HX INT PR		53.5	1.	133.8	1.	2.0	5.83	1.
879	HX INT T		7.62	1.	11.7	1.	2.0	5.53	1.
881	HX VENT IN PR		53.7	1.	59.	1.	2.0	5.79	1.
882	HX VENT IN T		(No change is strikingly indicated)						
883	HX VENT DP		53.6	1.	59.5	1.	2.0	5.78	1.
40	OPOV ACT POS		31.7	1.	113.4	1.	2.0	6.03	1.
42	FPOV ACT POS		5.4	1.	27.	1.	2.0	6.08	1.

Table III-11: 901-284 Data Base

Data Base for Early Parameter Indicators of Test Classification: Duct, Manifold, or Heat Exchanger Failure
-Test 750-259 (MCC Outlet Manifold Neck Failure) conducted 25 March 1985 for Engine 2308.
---Cutoff Time= 101.5 sec due to a HPFP accelerameter redline.
---Early indications occur near 109% PL
---Damage: Engine sustained extensive internal and external damage as a result of the failure and subsequent impact with the flame deflector and spillway.
---Impact: Unavailable.

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-367	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
367-163	*(MCC HG IN PR) -(MCC PC)	100.	1.	1667.	1.	2.0	.16	0.
395-163	*(MCC OX INJ PR) -(MCC PC)	92.1	1.	575.	1.	2.0	.16	0.
940-367	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor is not available)						
459-383	(HPFP DS PR) -(MCC PC)	(Sensor is not available)						
410-367	(FPB PC) -(MCC HG IN PR)	4.1	1.	45.8	1.	2.0	.22	0.
480-367	(OPB PC) -(MCC HG IN PR)	5.7	1.	188.4	1.	2.0	.16	0.
63, 163	*MCC PC	3.9	1.	20.6	1.	2.0	.19	0.
200	MCC PC AVG	3.9	1.	20.6	1.	2.0	.19	0.
17	MCC CLNT DS PR	100.	1.	1667.	1.	2.0	.19	0.
18	MCC CLNT DS T	275.	1.	3930.	1.	2.0	.19	0.
24	*MCC FU INJ PR	56.3	1.	297.	1.	2.0	.19	0.
1921	MCC LN CAV P	(Sensor malfunction)						
595	MCC OX INJ TEMP	.25	.1	2.5	.3	.4	.16	0.
86	HPFP IN PR	32.9	1.	365.2	1.	2.0	.19	0.
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	(Sensor does not exist)						
457	*HPFP BAL CAV PR	36.4	1.	228.	1.	2.0	.16	0.
52, 764	HPFP SPD	100.	1.	3333.	1.	2.0	.16	0.
53	*HPFP CL LNR PR	56.	1.	295.	1.	2.0	.19	0.
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	410.	1.	13667.	1.	2.0	.17	0.
658	HPFP DR TEMP	(Sensor malfunction)						
231	HPFT DS T1 A	24.9	1.	355.	1.	2.0	.19	0.
232	*HPFT DS T1 B	14.	1.	116.	1.	2.0	.12	0.
754	LPFP SPD	61.9	1.	364.	1.	2.0	.17	0.
436	*LPFT IN PR	73.6	1.	1227.	1.	2.0	.17	0.
1205, 1206	*FAC FU FL	8.8	1.	88.	1.	2.0	.1	0.
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	*ENG FU FLOW	99.7	1.	623.	1.	2.0	.16	0.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	24(1.9)	1.(.3)	258(.5)	1.(.1)	2.0(.4)	.19(9.7)	0.
234	*HPOT DS T2	3.9(.6)	1.(.1)	39(3.2)	1.(.3)	2.0(.4)	.1(10.5)	0.
1190	HPOT PRSL DR T	75.3	1.	3765.	1.	2.0	.17	0.
1071	OX BLD INT T	(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(Sensor has not settled adequately to steady state conditions)						
858, 860	ENG OX IN PR	36.3	1.	908.3	1.	2.0	.15	0.
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
90	*HPOP DS PR	52.9	1.	278.6	1.	2.0	.19	0.
325, 326	*HPOP BALCAV PR	12.32	1.	77.	1.	2.0	.16	0.
30, 734	*LPOP SPD	5.7	1.	57.	1.	2.0	.1	0.
209	*LPOP DS PR	55.9	1.	294.1	1.	2.0	.19	0.
93, 94	*PBP DS TMP	6.2	1.	51.4	1.	2.0	.19	0.
59, 159	*PBP DS PR	4.1	1.	31.3	1.	2.0	.13	0.
410	*FPB PC	13.9	1.	86.7	1.	2.0	.16	0.
480	*OPB PC	14.0	1.	87.5	1.	2.0	.16	0.
878	*HX INT PR	.97	.1	8.07	.5	.6	.12	0.
879	*HX INT T	6.1	1.	202.7	1.	2.0	.16	0.
881	HX VENT IN PR	(No change is strikingly indicated)						
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	(Sensor does not exist)						
40	*OPOV ACT POS	1.8(.5)	.3(.1)	9.(.09)	.5(.1)	.8(.2)	.2(10.5)	0.
42	*FPOV ACT POS	5.7	1.	47.8	1.	2.0	.12	0.

Table III-12: 750-259 Data Base

Data Base for Early Parameter Indicators of Test Classification: Duct, Manifold, or Heat Exchanger Failure

·Test 901-485 (Nozzle Tube Rupture), conducted 24 July 1985 for Engine 2105.

---Cutoff Time= 28.56 sec due to HPOT discharge temperature redline.

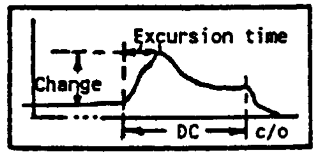
---Early indications occur near 109% PL

---Damage: HPFP turbine (borescope inspection indicated a suspected crack), nozzle (hot wall eyelid tube rupture 1/8in. by 1/4in., 14.5 inches from junction G15)

---Impact: Unavailable.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

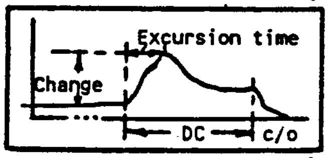
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(No change is strikingly indicated)						
371-163	(MCC HG IN PR) -(MCC PC)	(Sensor does not exist)						
395-163	(MCC OX INJ PR) -(MCC PC)	(No change is strikingly indicated)						
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	(No change is strikingly indicated)						
410-371	(FPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
480-371	(OPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
17	MCC CLNT DS PR	(No change is strikingly indicated)						
18	MCC CLNT DS T	(No change is strikingly indicated)						
24	MCC FU INJ PR	(No change is strikingly indicated)						
1921	MCC LN CAV P	(Sensor malfunction)						
595	MCC OX INJ TEMP	.4	.1	.07	.1	.2	8.06	1.
86	HPFP IN PR	(No change is strikingly indicated)						
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	(No change is strikingly indicated)						
457	HPFP BAL CAV PR	(No change is strikingly indicated)						
52, 764	HPFP SPD	(No change is strikingly indicated)						
53, 940	HPFP CL LNR PR	(No change is strikingly indicated)						
650	HPFP CL LNR T	(No change is strikingly indicated)						
657	HPFP DR PR	(No change is strikingly indicated)						
658	HPFP DR TEMP	2.23	.7	.4	.1	.8	7.76	1.
231	HPFT DS T1 A	(No change is strikingly indicated)						
232	HPFT DS T1 B	(No change is strikingly indicated)						
754	LPFP SPD	(No change is strikingly indicated)						
436	LPFT IN PR	(No change is strikingly indicated)						
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	(No change is strikingly indicated)						
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	*HPOT DS T1	3.97	1.	.98	.1	1.1	8.06	1.
234	HPOT DS T2	3.08	1.	.88	.1	1.1	8.06	1.
1190	HPOT PRSL DR T	.66	.1	.33	.1	1.1	4.56	.7
1071	OX BLD INT T	(Sensor has not settled adequately to steady state conditions)						
1054, 1056	OX FAC FM DS T	(Sensor has not settled adequately to steady state conditions)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	1.8	.3	.27	.1	.4	7.56	1.
90	HPOP DS PR	(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR	(No change is strikingly indicated)						
30, 734	LPOP SPD	(No change is strikingly indicated)						
209	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	(Sensor has not settled adequately to steady state conditions)						
59, 159	PBP DS PR	(No change is strikingly indicated)						
410	FPB PC	(No change is strikingly indicated)						
480	OPB PC	(No change is strikingly indicated)						
878	*HX INT PR	1.7	.3	.4	.1	.4	7.76	1.
879	HX INT T	(Sensor has not settled adequately to steady state conditions)						
881	HX VENT IN PR	(No change is strikingly indicated)						
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	1.79	.3	.24	.1	.4	7.76	1.
40	*OPOV ACT POS	.94	.1	.23	.1	.2	4.06	.7
42	FPOV ACT POS	(No change is strikingly indicated)						

Table III-13: 901-485 Data Base

Data Base for Early Parameter Indicators of Test Classification: Duct, Manifold, or Heat Exchanger Failure
Test 750-175 (High Cycle Fatigue in High Pressure Oxidizer Duct) conducted 27 August 1982 for Engine 2208.

---Cutoff Time= 115.6 sec due to a preburner oxidizer pump redline accelerometer
---Early indications occur near 111% PL
---Damage: Preburner oxidizer pump speparated from the engine, oxidizer preburner section of the hotgas manifold and the oxidizer system were damaged extensively.
---Impact: Not Available

CRITERIA LEGEND:
- •Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100
- •Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- •Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

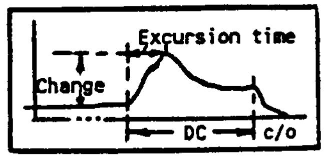
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-163	(MCC HG IN PR) -(MCC PC)	(Sensor does not exist)						
395-163	*(MCC OX INJ PR) -(MCC PC)	484.6	1.	6923.	1.	2.0	.07	0.
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	37.1	1.	530.6	1.	2.0	.07	0.
410-371	(FPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
480-371	(OPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
63,163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
436	*MCC CLNT DS PR	50.	1.	1250.	1.	2.0	.04	0.
18	*MCC CLNT DS T	24.7	1.	494.6	1.	2.0	.05	0.
24	MCC FU INJ PR	(Sensor does not exist)						
1921	MCC LN CAV P	(Sensor does not exist)						
595	*MCC OX INJ TEMP	2.39	.7	34.3	1.	1.7	.07	0.
86	*HPFP IN PR	9.6	1.	240.4	1.	2.0	.04	0.
459	*HPFP DS PR	26.5	1.	661.8	1.	2.0	.04	0.
659	*HPFP DS T	6.0	1.	120.	1.	2.0	.05	0.
457	HPFP BAL CAV PR	19.	1.	475.	1.	2.0	.05	0.
52, 764	*HPFP SPD	5.4	1.	180.2	1.	2.0	.06	0.
53, 940	*HPFP CL LNR PR	42.5	1.	1062.5	1.	2.0	.06	0.
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(No change is strikingly indicated)						
658	HPFP DR TEMP	(No change is strikingly indicated)						
231	*HPFT DS T1 A	61.	1.	1220.8	1.	2.0	.05	0.
232	*HPFT DS T1 B	33.	1.	659.2	1.	2.0	.05	0.
754	*LPFP SPD	10.4	1.	172.8	1.	2.0	.06	0.
436	*LPFT IN PR	22.4	1.	448.9	1.	2.0	.05	0.
1205, 1206	*FAC FU FL	3.5	1.	70.6	1.	2.0	.05	0.
1207, 1209	FAC FU FL CT	(Sensor does not exist)						
722	ENG FU FLOW	(Sensor does not exist)						
1722	ENG FU FLOW CT	(Sensor does not exist)						
518	*HPOT DS T1	33.3	1.	1110.	1.	2.0	.03	0.
519	*HPOT DS T2	33.3	1.	1110.	1.	2.0	.03	0.
1190	HPOT PRSL DR T	(No change is strikingly indicated)						
1071	OX BLD INT T	(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T	(Sensor does not exist)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(Sensor does not exist)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	*ENG OX IN PR	181.3	1.	3020.8	1.	2.0	.06	0.
1058	ENG OX IN TEMP	(Sensor has not settled adequately to steady state conditions)						
90	*HPOP DS PR	88.6	1.	886.	1.	2.0	.1	0.
325, 326	*HPOP BALCAV PR	67.7	1.	112.9	1.	2.0	.06	0.
30, 734	LPOP SPD	(No change is strikingly indicated)						
209	*LPOP DS PR	48.3	1.	965.5	1.	2.0	.05	0.
93, 94	PBP DS TMP	(No change is strikingly indicated)						
59, 159	*PBP DS PR	38.3	1.	383.	1.	2.0	.1	0.
410	FPB PC	27.8	1.	927.5	1.	2.0	.06	0.
480	OPB PC	28.7	1.	956.5	1.	2.0	.06	0.
878	*HX INT PR	5.4	1.	108.1	1.	2.0	.05	0.
879	HX INT T	(No change is strikingly indicated)						
881	HX VENT IN PR	(No change is strikingly indicated)						
882	HX VENT IN T	(No change is strikingly indicated)						
883	HX VENT DP	(Sensor does not exist)						
40	*OPOV ACT POS	17.8	1.	1780.8	1.	2.0	.01	0.
42	*FPOV ACT POS	15.7	1.	783.1	1.	2.0	.02	0.

Table III-14: 750-175 Data Base

Data Base for Early Parameter Indicators of Test Classification: Duct, Manifold, or Heat Exchanger Failure
-Test 902-112 (Fuel Blockage: Solidified-N2 blockage of pump inlet) conducted 10 June 1978 for Engine 0101.

---Cutoff Time= 5.75 sec due to a HPFP speed redline.
---Early indications occur near 92% PL
---Damage: LPFP and HPOP (would not rotate), MCC injector (7-injector baffle elements eroded), nozzle (3-tube splits)
---Impact: Unavailable.

CRITERIA LEGEND: •Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

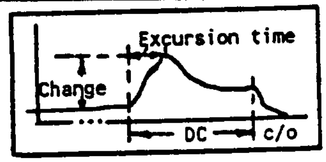
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-372	(INJ CLNT PR) -(MCC HG IN PR)	(No change is strikingly indicated)						
366-383	(INJ CLNT PR) -(MCC PC)	(No change is strikingly indicated)						
372-383	(MCC HG IN PR) -(MCC PC)	(No change is strikingly indicated)						
395-383	(MCC OX INJ PR) -(MCC PC)	(No change is strikingly indicated)						
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	4.3	1.	8.02	.5	1.5	.58	.3
410-372	*(FPB PC) -(MCC HG IN PR)	6.2	1.	12.3	1.	2.0	.5	.3
480-372	(OPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	*MCC PC	3.3	1.	5.96	.5	1.5	.55	.3
200	*MCC PC AVG	3.3	1.	6.0	.5	1.5	.55	.3
17	MCC CLNT DS PR	2.7	.7	5.4	.5	1.2	.57	.3
18	MCC CLNT DS T	(Sensor does not exist)						
24	MCC FU INJ PR	(Sensor does not exist)						
1921	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	*HPFP IN PR	47.	1.	62.6	1.	2.0	.75	.3
52	*HPFP DS PR	3.8	1.	6.7	.5	1.5	.57	.3
659	*HPFP DS T	23.6	1.	81.4	1.	2.0	.29	0.
457	*HPFP BAL CAV PR	7.4	1.	11.9	1.	2.0	.62	.3
52, 764	*HPFP SPD	10.9	1.	24.3	1.	2.0	.45	0.
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	*HPFT DS T1 A	23.8	1.	43.2	1.	2.0	.55	.3
232	*HPFT DS T1 B	21.6	1.	127.2	1.	2.0	.17	0.
754	*LPFP SPD	17.3	1.	49.5	1.	2.0	.35	0.
436	LPFT IN PR	2.8	.7	4.4	.3	1.0	.64	.3
1205, 1206	*FAC FU FL	29.	1.	44.6	1.	2.0	.65	.3
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	*ENG FU FLOW	12.8	1.	51.1	1.	2.0	.25	0.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	*HPOT DS T1	7.4	1.	15.8	1.	2.0	.47	0.
234	*HPOT DS T2	9.0	1.	19.1	1.	2.0	.47	0.
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T	(Sensor does not exist)						
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	*FAC OX FLOW	2.11	.7	4.32	.3	1.0	.49	0.
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(Sensor has not settled adequately to steady state conditions)						
338	*HPOP DS PR	1.97	.3	3.28	.3	.6	.6	.3
325, 326	HPOP BALCAV PR	(No change is strikingly indicated)						
30, 734	LPOP SPD	(No change is strikingly indicated)						
209	LPOP DS PR	4.4	1.	25.9	1.	2.0	.17	0.
93, 94	PBP DS TMP	(Sensor does not exist)						
59, 159	PBP DS PR	(Sensors malfunctioned)						
410	FPB PC	2.5	.7	17.9	1.	1.7	.19	0.
480	OPB PC	1.5	.3	10.8	1.	1.3	.14	0.
878	HX INT PR	1.5	.3	10.8	1.	1.3	.14	0.
879	HX INT T	(Sensor does not exist)						
881	HX VENT IN PR	(Sensor does not exist)						
882	HX VENT IN T	(Sensor does not exist)						
883	HX VENT DP	(Sensor does not exist)						
40	OPOV ACT POS	2.3	.7	4.9	.3	1.0	.48	0.
42	FPOV ACT POS	8.3	1.	17.2	1.	2.0	.48	0.

Table III-15: 902-112 Data Base

Data Base for Early Parameter Indicators of Test Classification: Valve Failure
SF6-01 (Main Fuel Valve: Structural, Fuel Leak) conducted 2 July 1979 for Engine 2002.

---Cutoff Time= 18.58 sec due to a HPFTP discharge temperature redline.
---Early indications occur near 100% PL
---Damage: MFV cracked housing, HPFT 1st and 2nd stage blade erosion, minor damage to controller, nozzle, electrical harness, nozzle, and facility.
---Impact: $8.3M, Delay Time- 14 weeks.

CRITERIA LEGEND: •Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

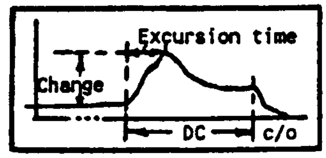
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-163	(MCC HG IN PR) -(MCC PC)	(Sensor does not exist)						
395-163	(MCC OX INJ PR) -(MCC PC)	(Sensor does not exist)						
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	(Sensor is unavailable)						
410-371	(FPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
480-371	(OPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
E41P1023D	MCC PC	5.02	1.	125.4	1.	2.0	.12	0.
E41P1039D	MCC PC AVG	5.02	1.	125.4	1.	2.0	.12	0.
E41P1067D	MCC CLNT DS PR	41.6	1.	1039.	1.	2.0	.12	0.
E41T1070D	MCC CLNT DS T	.86	.1	21.6	1.	1.1	.12	0.
24	MCC FU INJ PR	(Sensor does not exist)						
1921	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	HPFP IN PR	(Sensor is unavailable)						
E41P1029D	HPFP DS PR	74.6	1.	1864.4	1.	2.0	.12	0.
659	HPFP DS T	(Sensor does not exist)						
457	HPFP BAL CAV PR	(Sensor does not exist)						
E41R1006D	HPFP SPD	(Sensor has not settled adequately to steady state conditions)						
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
A49T1010H	HPFT DS T1 A	29.77	1.	372.1	1.	2.0	.08	0.
A49T1011H	HPFT DS T1 B	29.	1.	362.9	1.	2.0	.08	0.
E41R1072D	LPFP SPD	3.5	1.	86.5	1.	2.0	.12	0.
436	LPFT IN PR	(Sensor does not exist)						
1205, 1206	FAC FU FL	(Sensor does not exist)						
1207, 1209	FAC FU FL CT	(Sensor does not exist)						
E41R1034D	ENG FU FLOW	1.73	.3	43.2	1.	1.3	.12	0.
1722	ENG FU FLOW CT	(Sensor does not exist)						
A49T1012H	*HPOT DS T1	36.4	1.	454.5	1.	2.0	.08	0.
A49T1013H	*HPOT DS T2	36.4	1.	454.5	1.	2.0	.08	0.
1190	HPOT PRSL DR T	(Sensor does not exist)						
1071	OX BLD INT T	(Sensor does not exist)						
1054, 1056	OX FAC FM DS T	(Sensor does not exist)						
854	FAC OX FM DS PR	(Sensor does not exist)						
1210	FAC OX FLOW CT	(Sensor does not exist)						
1212, 1213	FAC OX FLOW	(Sensor does not exist)						
858, 860	ENG OX IN PR	(Sensor does not exist)						
1058	ENG OX IN TEMP	(Sensor does not exist)						
E41P1030D	HPOP DS PR	25.4	1.	634.3	1.	2.0	.12	0.
325, 326	HPOP BALCAV PR	(Sensor does not exist)						
30, 734	LPOP SPD	(Sensor does not exist)						
209	LPOP DS PR	(Sensor does not exist)						
93, 94	PBP DS TMP	(Sensor does not exist)						
E41P1033D	PBP DS PR	(Sensor not available)						
E41P1031D	FPB PC	51.5	1.	1287.1	1.	2.0	.12	0.
E41P1032D	OPB PC	8.2	1.	205.1	1.	2.0	.12	0.
878	HX INT PR	(Sensor does not exist)						
879	HX INT T	(Sensor does not exist)						
881	HX VENT IN PR	(Sensor does not exist)						
882	HX VENT IN T	(Sensor does not exist)						
883	HX VENT DP	(Sensor does not exist)						
E41H1028D	OPOV ACT POS	(Sensor has not settled adequately to steady state conditions)						
E41H1027D	FPOV ACT POS	.55	.1	13.8	1.	1.1	.12	0.

Table III-16: SF6-01 Data Base

Data Base for Early Parameter Indicators of Test Classification: Valve Failure
Test 901-225 (Main Oxidizer Valve: Heat Addition to LOX) conducted 12 December 1978 for Engine 2001.

---Cutoff Time= 255.63 sec. due to a HPFT discharge temperature redline.
---Early indications occur near 100% PL
---Damage: Extensive engine fire damage, MCC injector (LOX inlet elbow ruptured, many LOX posts burned out), HPOP (discharge duct ruptured)
---Impact: $10M, Delay Time- 4-6 weeks

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

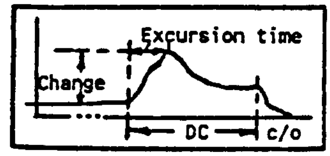
PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR)	-(MCC HG IN PR)	(Sensor malfunction)						
366-383	(INJ CLNT PR)	-(MCC PC)	12.9	1.	322.6	1.	2.0	.1	0.
371-383	(MCC HG IN PR)	-(MCC PC)	(Sensor malfunction)						
395-383	(MCC OX INJ PR)	-(MCC PC)	38.9	1.	972.2	1.	2.0	.1	0.
940-371	(HPFP CL LNR PR)	-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR)	-(MCC PC)	3.3	1.	166.7	1.	2.0	.07	0.
412-371	(FPB PC)	-(MCC HG IN PR)	(Sensor malfunction)						
480-371	(OPB PC)	-(MCC HG IN PR)	(Sensor malfunction)						
63, 163	MCC PC		6.01	1.	1202.	1.	2.0	.14	0.
200	MCC PC AVG		6.01	1.	1202.	1.	2.0	.14	0.
17	MCC CLNT DS PR		2.6	.7	36.9	1.	2.0	.15	0.
18	MCC CLNT DS T		(Sensor does not exist)						
24	MCC FU INJ PR		5.1	1.	128.7	1.	2.0	.16	0.
1921	MCC LN CAV P		(Sensor does not exist)						
595	MCC OX INJ TEMP		(Sensor does not exist)						
86	HPFP IN PR		2.9	.7	48.1	1.	2.0	.18	0.
52	HPFP DS PR		3.2	1.	39.8	1.	2.0	.16	0.
659	*HPFP DS T		3.1	1.	77.3	1.	2.0	.04	0.
457	*HPFP BAL CAV PR		5.3	1.	87.7	1.	2.0	.06	0.
52, 764	HPFP SPD		4.2	1.	83.3	1.	2.0	.05	0.
53, 940	HPFP CL LNR PR		(Sensor does not exist)						
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
231	*HPFT DS T1 A		15.1	1.	151.	1.	2.0	.1	0.
232	HPFT DS T1 B		15.1	1.	151.	1.	2.0	.1	0.
754	LPFP SPD		(No change is strikingly indicated)						
436	LPFT IN PR		(Sensor does not exist)						
1205, 1206	FAC FU FL		1.3	.3	33.3	1.	1.3	.07	0.
1207, 1209	FAC FU FL CT		(No change is strikingly indicated)						
722	ENG FU FLOW		3.1	1.	76.9	1.	2.0	.18.	0.
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	HPOT DS T1		12.3(4.)	1.(1.)	176(39)	1.(1.)	2.0(2.0)	.08(137.6)	0.(1.)
234	HPOT DS T2		12.3	1.	176.	1.	2.0	.08	0.
1190	HPOT PRSL DR T		(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T		(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T		(No change is strikingly indicated)						
854	*FAC OX FM DS PR		6.5	1.	107.5	1.	2.0	.06	0.
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212, 1213	*FAC OX FLOW		7.0	1.	140.4	1.	2.0	.05	0.
858, 860	*ENG OX IN PR		23.7	1.	295.7	1.	2.0	.08	0.
1058	ENG OX IN TEMP		.3	.1	.007	.1	.2	147.6	1.
90	HPOP DS PR		28.	1.	310.9	1.	2.0	.16	0.
325, 326	*HPOP BALCAV PR		31.3	1.	390.6	1.	2.0	.18	0.
30, 734	LPOP SPD		8.9	1.	127.3	1.	2.0	.15	0.
209	LPOP DS PR		45.8	1.	572.9	1.	2.0	.16	0.
93, 94	PBP DS TMP		(Sensor does not exist)						
59, 159	PBP DS PR		14.	1.	175.4	1.	2.0	.15	0.
412	*FPB PC		6.9	1.	86.6	1.	2.0	.08	0.
480	*OPB PC		6.	1.	75.	1.	2.0	.08	0.
878	*HX INT PR		5.1	1.	64.1	1.	2.0	.08	0.
879	HX INT T		(Sensor malfunction)						
881	HX VENT IN PR		2.4	.7	39.6	1.	1.7	.06	0.
882	HX VENT IN T		(Sensor has not settled adequately to steady state conditions)						
883	*HX VENT DP		2.2	.7	44.9	1.	1.7	.05	0..
40	OPOV ACT POS		(Sensor has not settled adequately to steady state conditions)						
42	FPOV ACT POS		.4	.1	3.04	.3	1.1(.8)	.55	.3

Table III-17: 901-225 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Oxidizer Turbopump (HPOTP) Failure
-Test 901-110 (Rotor/Seal Support, Heat Addition to LOX) conducted 24 March 1977 for Engine 0003.

---Cutoff Time= 74. sec due to a HPOP fire.
---Early indications occur near 75% PL
---Damage: Major damage in HPOTP and LPOP disch. duct, engine control simulator and control harnesses, fuel system insulation and facility instrumentation systems.
---Impact: $3.3M (for repair/replacement only), Delay Time- 6 weeks.

CRITERIA LEGEND: •Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-372	(INJ CLNT PR) -(MCC HG IN PR)	(No change is strikingly indicated)						
366-383	(INJ CLNT PR) -(MCC PC)	(No change is strikingly indicated)						
372-383	(MCC HG IN PR) -(MCC PC)	(No change is strikingly indicated)						
395-383	(MCC OX INJ PR) -(MCC PC)	(No change is strikingly indicated)						
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	(No change is strikingly indicated)						
412-372	(FPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
480-372	(OPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
17	MCC CLNT DS PR	(No change is strikingly indicated)						
18	MCC CLNT DS T	(No change is strikingly indicated)						
24	MCC FU INJ PR	1.36	.3	.16	.1	.1	16.3	1.
1951, 1956	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(No change is strikingly indicated)						
86	HPFP IN PR	(No change is strikingly indicated)						
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	(No change is strikingly indicated)						
457	HPFP BAL CAV PR	(Sensor malfunction)						
52, 764	HPFP SPD	(No change is strikingly indicated)						
53, 940	HPFP CL LNR PR	(Sensor does not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	(No change is strikingly indicated)						
232	HPFT DS T1 B	(No change is strikingly indicated)						
754	LPFP SPD	(No change is strikingly indicated)						
436	LPFT IN PR	(No change is strikingly indicated)						
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	(No change is strikingly indicated)						
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	1.67	.3	2.38	.3	.6	16.3	1.
234	HPOT DS T2	1.47	.3	2.1	.3	.6	16.3	1.
1190	*HPOT PRSL DR T	258(6.)	1.(1.)	860.(.7)	1.(.1)	2.(1.1)	.3(17.8)	0.(1.)
1071	OX BLD INT T	(Sensor has not settled adequately to steady state conditions)						
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
90	HPOP DS PR	(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR	(No change is strikingly indicated)						
30, 734	LPOP SPD	(No change is strikingly indicated)						
302	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	(Sensor does not exist)						
59, 159	PBP DS PR	(No change is strikingly indicated)						
410	FPB PC	(No change is strikingly indicated)						
480	OPB PC	(No change is strikingly indicated)						
878	HX INT PR	(Sensor has not settled adequately to steady state conditions)						
879	HX INT T	(Sensor does not exist)						
881	HX VENT IN PR	(Sensor does not exist)						
882	HX VENT IN T	(Sensor does not exist)						
883	HX VENT DP	(No change is strikingly indicated)						
40	OPOV ACT POS	.49	.1	.35	.1	.2	18.45	1.
42	FPOV ACT POS	.36	.1	.21	.1	.2	17.7	1.

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Table III-18: 901-110 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Oxidizer Turbopump (HPOTP) Failure

·Test 901-136 (Rotor Seal Support) conducted 8 September 1977 for Engine 0004.

---Cutoff Time= 300.2 sec. due to loss of electrical power and Engine Controller response.

---Early indications occur near 90% PL

---Damage: LOX feed system (erosion or severed), HPOTP (1st stage turbine blades damaged), MCC and nozzle (extensive slag coating), engine controller damaged, test facility ($.2M damage)

---Impact: $2.4M, Delay Time- 4 weeks.

CRITERIA LEGEND:

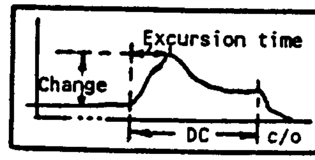
●Operating Level Anomaly Criteria (LC)

LC = (Absolute Change in Steady State Value/Steady State Value) x 100.

●Rate Criteria (RC) = LC/(Excursion time interval in seconds)

●Duration Criteria (DC)

DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier "LC" change for the parameter.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

**NOTE: Parameter changes where DC ranges between 49 to 115 seconds may or may not be from an anomaly, the fuel tank was vented (as scheduled) between an equivalent DC range of 49 to 128 seconds.

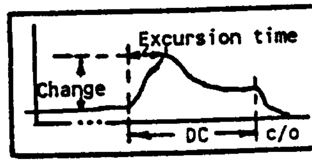
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A+B	DC	LEVEL-C
366-372	*(INJ CLNT PR) -(MCC HG IN PR)	3.26	1.	.03	.1	1.1	96.	1.
366-383	(INJ CLNT PR) -(MCC PC)	.84	.1	.07	.1	.2	116.	1.
372-383	*(MCC HG IN PR) -(MCC PC)	2.18	.7	.02	.1	.8	116.	1.
395-383	*(MCC OX INJ PR) -(MCC PC)	1.68	.3	.12	.1	.4	13.8	1.
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	.43	.1	.02	.1	.2	116.	1.
412-372	(FPB PC) -(MCC HG IN PR)	.18	.1	.02	.1	.2	112.	1.
480-372	*(OPB PC) -(MCC HG IN PR)	1.12	.3	.01	.1	.4	112.	1.
63, 163	MCC PC	.26	.1	.13	.1	.2	25.	1.
200	MCC PC AVG	.26	.1	.13	.1	.2	25.	1.
17	MCC CLNT DS PR	.33	.1	.02	.1	.2	112.	1.
18	MCC CLNT DS T	(Sensor has not settled adequately to steady state conditions)						
24	MCC FU INJ PR	(Sensor has not settled adequately to steady state conditions)						
1951, 1956	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	**HPFP IN PR	22.6	1.	.27	.1	1.1	126.	1.
52	*HPFP DS PR	.58	.1	.005	.1	.2	112.	1.
659	HPFP DS T	2.84	.7	.03	.1	.8	122.	1.
457	HPFP BAL CAV PR	1.18	.3	.01	.1	.4	126.	1.
764	HPFP SPD	1.09	.3	.01	.1	.4	122.	1.
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	1.47	.3	.02	.1	.4	112.	1.
232	HPFT DS T1 B	2.4(1.4)	.7(.3)	1.2(.02)	.3(.1)	1.0(.4)	112.	1.
754	LPFP SPD	.66	.1	.02	.1	.2	112.	1.
436	LPFT IN PR	.34	.1	.02	.1	.2	112.	1.
1205, 1206	FAC FU FL	.84	.1	.05	.1	.2	66.	1.
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	.74	.1	.009	.1	.2	112.	1.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	*HPOT DS T1	1.4(1.9)	.3(.3)	.1(.02)	.1(.1)	.4(.4)	25.(112.)	1.(1.)
234	HPOT DS T2	1.8(1.4)	.3(.3)	.04(.03)	.1(.1)	.4(.4)	25.(112.)	1.(1.)
1190	HPOT PRSL DR T	1.3(2.8)	.3(.7)	.09(.03)	.1(.1)	.4(.8)	13.8(98.)	1.(1.)
1071	OX BLD INT T	(Sensor does not exist)						
1054, 1056	OX FAC FM DS T	.004	.1	.0001	.1	.2	92.6	1.
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	.41	.1	.01	.1	.2	27.8	1.
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(Sensor has not settled adequately to steady state conditions)						
90	HPOP DS PR	2.42	.7	.02	.1	.8	112.	1.
325, 326	HPOP BALCAV PR	1.39	.3	.03	.1	.4	112.	1.
30, 734	*LPOP.SPD	1.24	.3	6.2	.5	.8	.2	0.
302	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	(Sensor doesn't exist)						
59, 159	PBP DS PR	(Sensor doesn't exist)						
412	FPB PC	.3	.1	.02	.1	.2	112.	1.
480	OPB PC	.33	.1	.02	.1	.2	112.	1.
878	HX INT PR	.79	.1	.03	.1	.2	27.8	1.
879	HX INT T	1.86	.3	.02	.1	.4	98.	1.
881	HX VENT IN PR	1.22	.3	.02	.1	.4	70.	1.
882	HX VENT IN T	1.38	.3	.07	.1	.4	73.	1.
883	HX VENT DP	.52	.1	.02	.1	.2	70.	1.
40	*OPOV ACT POS	3.(1.05)	.7(.3)	.12(.01	.1(.1)	.8(.4)	25.(116.)	1.(1.)
42	*FPOV ACT POS	1.78	.3	.02	.1	.4	112.	1.

Table III-19: 901-136 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Oxidizer Turbopump (HPOTP) Failure
Test 902-120 (Heat Addition to Liquid Oxygen (LOX)) conducted 18 July 1978 for Engine 0101.

---Cutoff Time= 41.81 sec due to a high-pressure oxidizer preburner pump axial vibration redline.
---Early indications occur near 100% PL
---Damage: Severe erosion to HPOP, controller simulator and control harnesses, broken LPOP housing, burned facility instrumentation system.
---Impact: $1.65M, Delay Time- 5 weeks

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

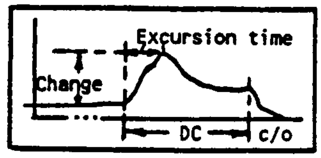
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-372	*(INJ CLNT PR) -(MCC HG IN PR)	54.5	1.	1363.6	1.	2.0	.04	0.
366-383	*(INJ CLNT PR) -(MCC PC)	11.9	1.	595.2	1.	2.0	.02	0.
372-383	*(MCC HG IN PR) -(MCC PC)	6.3	1.	211.6	1.	2.0	.03	0.
395-383	*(MCC OX INJ PR) -(MCC PC)	23.6	1.	589.2	1.	2.0	.04	0.
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	*(HPFP DS PR) -(MCC PC)	2.1	.7	51.7	1.	1.7	.04	0.
411-372	*(FPB PC) -(MCC HG IN PR)	2.8	.7	138.9	1.	1.7	.02	0.
480-372	*(OPB PC) -(MCC HG IN PR)	2.8	.7	138.9	1.	1.7	.02	0.
63, 163	*MCC PC	23.3	1.	333.3	1.	2.0	.07	0.
200	MCC PC AVG	(Sensor does not exist)						
17	MCC CLNT DS PR	(Sensor does not exist)						
18	MCC CLNT DS T	(Sensor does not exist)						
24	MCC FU INJ PR	(Sensor does not exist)						
1951, 1956	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	*HPFP IN PR	12.5	1.	178.6	1.	2.0	.07	0.
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	(Sensor does not exist)						
457	HPFP BAL CAV PR	(No change is strikingly indicated)						
52, 764	HPFP SPD	(No change is strikingly indicated)						
53, 940	HPFP CL LNR PR	(Sensor does not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	(No change is strikingly indicated)						
232	HPFT DS T1 B	(No change is strikingly indicated)						
754	LPFP SPD	(No change is strikingly indicated)						
436	LPFT IN PR	(No change is strikingly indicated)						
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	(No change is strikingly indicated)						
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	(No change is strikingly indicated)						
234	HPOT DS T2	(No change is strikingly indicated)						
1190	HPOT PRSL DR T	(No change is strikingly indicated)						
1071	OX BLD INT T	(Sensor does not exist)						
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	*ENG OX IN PR	9.3	1.	463.9	1.	2.0	.02	0.
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
90	HPOP DS PR	(No change is strikingly indicated)						
325, 326	*HPOP BALCAV PR	5.8	1.	289.9	1.	2.0	.02	0.
30, 734	*LPOP SPD	55.6	1.	793.3	1.	2.0	.07	0.
302	*LPOP DS PR	78.4	1.	784.	1.	2.0	.1	0.
93, 94	PBP DS TMP	(Sensor does not exist)						
59, 159	*PBP DS PR	61.8	1.	882.6	1.	2.0	.07	0.
410	*FPB PC	1.	.3	50.	1.	1.3	.02	0.
480	*OPB PC	1.	.3	50.	1.	1.3	.02	0.
878	HX INT PR	(Sensor does not exist)						
879	HX INT T	(Sensor does not exist)						
881	HX VENT IN PR	(Sensor does not exist)						
882	HX VENT IN T	(Sensor does not exist)						
883	HX VENT DP	(No change is strikingly indicated)						
40	*OPOV ACT POS	2.9	.7	142.9	1.	1.7	.02	0.
42	*FPOV ACT POS	2.5	.7	125.	1.	1.7	.02	0.

Table III-20: 902-120 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure
-Test 901-340 (Turn Around Duct Cracked/Torn) conducted on 15 October 1981 for Engine 0107.
---Cutoff Time= 405.5 sec due to a HPFT temperature redline.
---Early indications occur near 109% PL
---Damage: HPFT turnaround sheet metal cracked and bulged, HPFT bullnose nut and stud eroded away, nozzle belly band and jacket damaged.
---Impact: Unavailable.

CRITERIA LEGEND: •Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier "LC" change for the parameter.

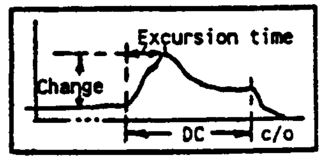
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-383	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-383	(MCC HG IN PR) -(MCC PC)	17.7	1.	117.8	1.	2.0	115.5	1.
395-163	(MCC OX INJ PR) -(MCC PC)	1.82	.3	.23	.1	.4	122.5	1.
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	31(89.)	1.(1.)	5.(9.5)	.5(.5)	1.5(1.5)	116(384.9)	1.(1.)
459-383	(HPFP DS PR) -(MCC PC)	1.9(.9)	.3(.1)	13(1.7)	1.(.3)	1.3(.4)	116(127.)	1.(1.)
411-371	(FPB PC) -(MCC HG IN PR)	4.8(1.1)	1.(.3)	7(.97)	.5(.1)	1.5(.4)	116(127.)	1.(1.)
480-371	(OPB PC) -(MCC HG IN PR)	3.3(1.3)	1.(.3)	4.7(3.)	.3(.3)	1.3(.6)	116(127.)	1.(1.)
63, 163	MCC PC	1.6(.3)	.3(.1)	11(1.5)	1.(.3)	1.3(.4)	116(127.)	1.(1.)
200	MCC PC AVG	1.6(.3)	.3(.1)	11(1.5)	1.(.3)	1.3(.4)	116(127.)	1.(1.)
17	MCC CLNT DS PR	1.6(.5)	.3(.1)	11(3.5)	1.(.3)	1.3(.4)	116(127.)	1.(1.)
18	MCC CLNT DS T	.7(.7)	.1(.1)	7(7.)	.5(.5)	.6(.6)	115(127.)	1.(1.)
24	MCC FU INJ PR	2.2	.7	14.6	1.	1.7	115.5	1.(1.)
1921	MCC LN CAV P	(Sensor has not settled adequately to steady state conditions)						
595	MCC OX INJ TEMP	.43(.2)	.1(.1)	.43(.2)	.1(.1)	.2(.2)	115(128.)	1.(1.)
86	HPFP IN PR	5.1(1.7)	1.(.3)	50(3.5)	1.(.3)	2.0(.6)	116(127.)	1.(1.)
52	HPFP DS PR	1.5(.4)	.3(.1)	15(2.5)	1.(.3)	1.3(.4)	116(127.)	1.(1.)
659	HPFP DS T	1.04(.2)	.3(.1)	5.2(.8)	.5(.1)	.8(.2)	116(127.)	1.(1.)
457	HPFP BAL CAV PR	2.3(.5)	.7(.1)	11(.97)	1.(.1)	1.7(.2)	116(127.)	1.(1.)
52, 764	HPFP SPD	1.37	.3	6.86	.5	.8	115.5	1.
53, 940	HPFP CL LNR PR	3.8(6.9)	1.(1.)	.72(1.1)	.1(.3)	1.1(1.3)	116(384.9)	1.(1.)
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
663	HPFT DS T1 A	6.4(7.)	1.(1.)	16(73.)	1.(1.)	2.0(2.)	116(384.9)	1.(1.)
664	HPFT DS T1 B	6.(3.6)	1.(1.)	14(1.)	1.(.3)	2.0(1.3)	116(384.9)	1.(1.)
754	LPFP SPD	1.2(.3)	.3(.1)	1.9(1.6)	.3(.3)	.6(.4)	116(127.)	1.(1.)
436	LPFT IN PR	1.3(.4)	.3(.1)	13(.8)	1.(.1)	1.3(.2)	116(127.)	1.(1.)
1205, 1206	FAC FU FL	2.5(.8)	.7(.1)	8.3(.8)	.5(.1)	1.2(.2)	115(127.)	1.(1.)
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	3.3(.6)	1.(.1)	27(3.2)	1.(.3)	2.0(.4)	116(127.)	1.(1.)
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	5.3	1.	.4	.1	1.1	124.9	1.
234	HPOT DS T2	4.55	1.	.48	.1	1.1	123.	1.
1190	HPOT PRSL DR T	2.2	.7	.17	.1	.8	124.5	1.
1071	OX BLD INT T	(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T	.01	.1	.02	.1	.2	126.5	1.
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	.5	.1	.97	.1	.2	126.5	1.
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
90	HPOP DS PR	(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR	1.2(.5)	.3(.1)	12(1.1)	1.(.3)	1.3(.4)	116(127.)	1.(1.)
30, 734	LPOP SPD	(No change is strikinglying indicated)						
209	LPOP DS PR	2.1	.7	11.6	1.	1.7	115.5	1.
93, 94	PBP DS TMP	.35(.24)	.1(.1)	1.8(.5)	.3(.1)	.4(.2)	116(127.)	1.(1.)
59, 159	PBP DS PR	.32(.63)	.1(.1)	1.6(1.3)	.3(.3)	.4(.4)	116(127.)	1.(1.)
410	FPB PC	(Sensor not available)						
480	OPB PC	1.2(.4)	.3(.1)	12(.9)	1.(.1)	1.3(.2)	116(127.)	1.(1.)
878	HX INT PR	.99(.5)	.1(.1)	2.8(.9)	.3(.1)	.4(.2)	116(127.)	1.(1.)
879	HX INT T	2.72	.7	.23	.1	.8	123.1	1.
881	HX VENT IN PR	.9	.1	4.5	.3	.4	115.5	1.
882	HX VENT IN T	1.48	.3	.12	.1	.4	123.1	1.
883	HX VENT DP	1.49(.3)	.3(.1)	4.97(.3)	.3(.1)	.6(.2)	116(127.)	1.(1.)
40	OPOV ACT POS	2.1(1.9)	.7(.3)	.75(.51)	.1(.1)	.8(.4)	118(127.)	1.(1.)
42	FPOV ACT POS	4.4(1.9)	1.(.3)	2.2(.2)	.3(.1)	1.3(.4)	116(127.)	1.(1.)

Table III-21: 901-340 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

-Test 901-363 (Turn Around Duct Cracked/Torn) conducted 30 March 1982 for Engine 2013.
---Cutoff Time= 250. sec, Program Duration.
---Early indications occur near 109% PL
---Damage: HPFT -14 turbine sheet metal cracks.
---Impact: Unavailable.

CRITERIA LEGEND: •Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier "LC" change for the parameter.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-367	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
367-163	(MCC HG IN PR) -(MCC PC)	2.	.7	1.54	.3	1.0	112.7	1.
395-163	(MCC OX INJ PR) -(MCC PC)	1.52	.3	.61	.1	.4	114.5	1.
940-367	(HPFP CL LNR PR)-(MCC HG IN PR)	30.2(25)	1.(1.)	34(1.6)	1.(.3)	2.0(1.3)	114(165)	1.(1.)
459-163	(HPFP DS PR) -(MCC PC)	1.01	.3	.92	.1	.4	114.6	1.
410-367	(FPB PC) -(MCC HG IN PR)	.81	.1	.81	.1	.2	112.7	1.
480-367	(OPB PC) -(MCC HG IN PR)	1.16	.3	.83	.1	.4	114.5	1.
63, 163	MCC PC	.49	.1	.288	.1	.2	114.5	1.
200	MCC PC AVG	.46	.1	.27	.1	.2	114.5	1.
17	MCC CLNT DS PR	.65	.1	.41	.1	.2	114.5	1.
18	MCC CLNT DS T	(Sensor malfunction)				.2		
24	MCC FU INJ PR	.56	.1	.61	.1	.2	114.5	1.
1951, 1956	MCC LN CAV P	(Sensor malfunction)						
595	MCC OX INJ TEMP	.3	.1	.32	.1	.2	113.7	1.
86	HPFP IN PR	1.03	.3	2.6	.3	.6	114.	1.
52	HPFP DS PR	.63	.1	2.09	.3	.4	114.	1.
659	HPFP DS T	.64	.1	.92	.1	.2	114.3	1.
457	HPFP BAL CAV PR	(No change is strikingly indicated)						
52, 764	HPFP SPD	.3	.1	.3	.1	.2	114.5	1.
53, 940	HPFP CL LNR PR	1.65(.8)	.3(.1)	.23(.1)	.1(.1)	.4(.2)	114(165)	1.(1.)
650	HPFP CL LNR T	19.7	1.0	19.7	1.0	2.0	120.4	1.
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	1.3(1.3)	.3(.3)	1.1(.1)	.3(.1)	.6(.4)	113(165)	1.(1.)
232	HPFT DS T1 B	1.85	.3	.26	.1	.4	113.6	1.
754	LPFP SPD	.44	.1	.49	.1	.2	114.6	1.
436	LPFT IN PR	.68	.1	.76	.1	.2	114.5	1.
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	(No change is strikingly indicated)						
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	.6	.1	.8	.1	.2	113.3	1.
234	HPOT DS T2	.73	.1	.81	.1	.2	112.6	1.
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T	(Sensor has not settled adequately to steady state conditions)						
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	.65	.1	.4	.1	.2	114.5	1.
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
90	HPOP DS PR	.58	.1	.38	.1	.2	114.6	1.
325, 326	HPOP BALCAV PR	.68	.1	.61	.1	.2	114.	1.
30, 734	LPOP SPD	(No change is strikingly indicated)						
302	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	.22	.1	.19	.1	.2	114.0	1.
59, 159	PBP DS PR	1.17	.3	1.31	.3	.6	113.8	1.
410	FPB PC	.45	.1	.5	.1	.2	114.5	1.
480	OPB PC	.84	.1	.76	.1	.2	113.9	1.
878	HX INT PR	.6	.1	.4	.1	.2	114.8	1.
879	HX INT T	(Sensor has not settled adequately to steady state conditions)						
881	HX VENT IN PR	.67	.1	.52	.1	.2	114.	1.
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	.62	.1	.89	.1	.2	114.	1.
40	OPOV ACT POS	3.11	1.	.65	.1	.2	114.	1.
42	FPOV ACT POS	1.01	.3	.918	.1	.4	113.8	1.

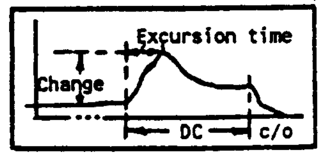
Table III-22: 901-363 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

- Test 902-118 (Turn Around Duct Cracked/Torn) conducted 12 July 1978 for Engine u101.
  - ---Cutoff Time= 6.84 sec. due a HPFT discharge temperature redline.
  - ---Early indications occur near 92% PL
  - ---Damage: HPFTP turnaround ducts (5-major bulges in both ID and OD sheet metal, 1.5 in. tears in ID sheet metal), MCC heat shield (26-retainers missing or partially failed)
  - ---Impact: Unavailable.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

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*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

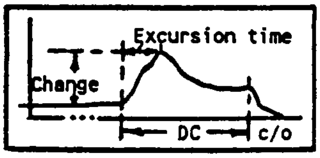
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-372	(INJ CLNT PR) -(MCC HG IN PR)	45.7	1.	76.2	1.	2.0	.74	.3
366-383	(INJ CLNT PR) -(MCC PC)	6.81	1.	3.7	.3	1.3	1.84	.7
372-383	(MCC HG IN PR) -(MCC PC)	6.88	1.	38.3	1.	2.0	.72	.3
395-383	(MCC OX INJ PR) -(MCC PC)	4.76	1.	5.67	.5	1.5	.84	.3
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	10.	1.	9.9	.5	1.5	1.34	.7
459-383	(HPFP DS PR) -(MCC PC)	2.08	.7	1.54	.3	1.0	1.34	.7
411-372	(FPB PC) -(MCC HG IN PR)	7.88	1.	6.57	.5	1.5	1.34	.7
480-371	(OPB PC) -(MCC HG IN PR)	4.49	1.	3.74	.3	1.3	1.34	.7
63, 163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
436	MCC CLNT DS PR	1.2	.3	4.01	.3	.6	.44	0.
18	MCC CLNT DS T	(Sensor does not exist)						
24	MCC FU INJ PR	(Sensor does not exist)						
1951, 1956	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	HPFP IN PR	10.3	1.	5.51	.5	1.5	1.95	.7
459	HPFP DS PR	.96	.1	.85	.1	.2	1.34	.7
659	HPFP DS T	1.06	.3	.88	.1	.4	1.2	.7
457	HPFP BAL CAV PR	1.2	.3	4.01	.3	.6	.44	0.
52, 764	HPFP SPD	.9	.1	6.	.5	.6	.19	0.
940	HPFP CL LNR PR	(Sensor measurement not available)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
663	*HPFT DS T1 A	13.88	1.	7.54	.5	1.5	1.84	.7
664	*HPFT DS T1 B	10.15	1.	5.51	.5	1.5	1.84	.7
754	LPFP SPD	1.63	.3	.84	.1	.4	2.06	.7
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
436	LPFT IN PR	1.2	.3	4.01	.3	.6	.44	0.
722	ENG FU FLOW	1.38	.3	6.27	.5	.8	.74	.3
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
516	HPOT DS T1	2.33	.7	1.17	.3	1.0	1.34	.7
517	HPOT DS T2	2.43	.7	1.23	.3	1.0	1.34	.7
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T	(Sensor does not exist)						
1054, 1056	*OX FAC FM DS T	.04	.1	.03	.1	.2	1.34	.7
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	.58	.1	.9	.1	.2	.64	.3
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(Sensor has not settled adquately to steady state conditions)						
338	*HPOP DS PR	2.67	.7	1.99	.3	1.0	1.34	.7
325, 326	*HPOP BALCAV PR	2.9	.7	1.36	.3	1.0	2.14	.7
30, 734	LPOP SPD	(No change is strikingly indicated)						
302	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	(Sensor does not exist)						
59, 159	PBP DS PR	1.18	.3	23.6	1.	.4	.24	0.
410	*FPB PC	1.7	.3	1.89	.3	.6	1.06	.7
480	*OPB PC	1.3	.3	4.35	.3	.6	.48	0.
878	HX INT PR	(Sensor does not exist)						
879	HX INT T	(Sensor does not exist)						
881	HX VENT IN PR	(Sensor does not exist)						
882	HX VENT IN T	(Sensor does not exist)						
883	HX VENT DP	(Sensor does not exist)						
40	OPOV ACT POS	(No change is strikingly indicated)						
42	FPOV ACT POS	2.75	.7	5.5	.5	1.2	.72	.3

Table III-23: 902-118 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure
·Test 901-436 (Coolant Liner Buckle) conducted 14 February 1984 for Engine 0108.

---Cutoff Time= 611.06 sec due to a high pressure fuel turbine discharge temperature redline.
---Early indications occur near 109% PL
---Damage: HPFTP (inlet volute blown off, 2nd stage disk w/blades 75-80% eroded), MCC injector (LOX posts eroded back to interpropellant plate), nozzle (3-areas of burn through), engine totally gutted due to LOX rich shutdown.
---Impact: Unavailable.

CRITERIA LEGEND:
•Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.
( )---Numbers within the parenthesis indicate an earlier "LC" change for the parameter

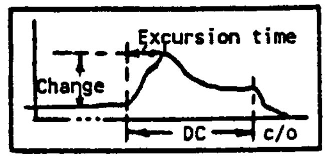
PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVEL A+B	DC	LEVEL-C
366-367	(INJ CLNT PR)	-(MCC HG IN PR)	(Sensor does not exist)						
366-383	(INJ CLNT PR)	-(MCC PC)	(Sensor has not settled adequately to steady state conditions)						
367-383	(MCC HG IN PR)	-(MCC PC)	(Sensor does not exist)						
395-383	*(MCC OX INJ PR)	-(MCC PC)	9.6	1.	19.6	1.	2.0	.49	0.
940-367	(HPFP CL LNR PR)	-(MCC HG IN PR)	825(60)	1.(1.)	208(13)	1.(1.)	2.0(2.0)	4(12.56)	.7(1.)
459-383	*(HPFP DS PR)	-(MCC PC)	4.2	1.	10.2	1.	2.0	.41	0.
410-367	(FPB PC)	-(MCC HG IN PR)	18.7	1.	30.2	1.	2.0	.62	.3
480-367	(OPB PC)	-(MCC HG IN PR)	5.95	1.	9.6	.5	1.5	.62	.3
63, 163	*MCC PC		3.86	1.	7.88	.5	1.5	.51	.3
200	*MCC PC AVG		3.86	1.	7.88	.5	1.5	.51	.3
17	*MCC CLNT DS PR		3.09	1.	7.03	.5	1.5	.51	.3
18	*MCC CLNT DS T		3.33	1.	9.26	.5	1.5	.36	0.
24	*MCC FU INJ PR		1.91	.3	6.37	.5	.8	.51	.3
1951, 1956	MCC LN CAV P		(Sensor malfunction)						
595	MCC OX INJ TEMP		(No change is strikingly indicated)						
86	*HPFP IN PR		29.8	1.	53.2	1.	2.0	.56	.3
52	*HPFP DS PR		4.41	1.	7.88	.5	1.5	.5	.3
659	HPFP DS T		1.5	.3	3.84	.3	.6	.5	.3
457	*HPFP BAL CAV PR		5.63	1.	12.24	1.	2.0	.46	0.
52, 764	*HPFP SPD		5.71	1.	13.93	1.	2.0	.47	0.
940	HPFP CL LNR PR		10.5(2)	1.(.3)	3.(.4)	.3(.1)	1.3(.4)	3.96(13)	.7(1.)
650	*HPFP CL LNR T		14.52	1.	36.2	1.	2.0	.4	0.
657	HPFP DR PR		(No change is strikingly indicated)						
658	HPFP DR TEMP		(No change is strikingly indicated)						
231	*HPFT DS T1 A		20.	1.	39.22	1.	2.0	.51	.3
232	*HPFT DS T1 B		22.8	1.	44.72	1.	2.0	.51	.3
754	*LPFP SPD		.61	.1	5.08	.5	.6	.12	0.
436	*LPFT IN PR		4.08	1.	8.87	.5	1.5	.46	0.
1205, 1206	*FAC FU FL		11.9	1.	25.8	1.	2.0	.46	0.
1207, 1209	FAC FU FL CT		(No change is strikingly indicated)						
722	*ENG FU FLOW		2.45	.7	12.27	1.	1.7	.5	.3
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	*HPOT DS T1		2.58	.7	16.1	1.	1.7	.16	0.
234	*HPOT DS T2		1.47	.3	13.4	1.	1.3	.11	0.
1193	HPOT PRSL DR T		.71	.1	.48	.1	.2	3.46	.7
1071	OX BLD INT T		(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T		(No change is strikingly indicated)						
854	FAC OX FM DS PR		(No change is strikingly indicated)						
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212, 1213	*FAC OX FLOW		1.22	.3	7.62	.5	.8	.16	0.
858, 860	*ENG OX IN PR		4.76	1.	43.2	1.	2.0	.11	0.
1058	ENG OX IN TEMP		(No change is strikingly indicated)						
90	HPOP DS PR		(No change is strikingly indicated)						
325, 326	*HPOP BALCAV PR		1.56	.3	4.34	.3	.6	.36	0.
30, 734	LPOP SPD		(No change is strikingly indicated)						
302	*LPOP DS PR		8.8	1.	31.6	1.	2.0	.28	0.
93, 94	PBP DS TMP		(No change is strikingly indicated)						
59, 159	PBP DS PR		(No change is strikingly indicated)						
410	*FPB PC		2.92	.7	5.2	.5	1.2	.56	.3
480	*OPB PC		.99	.1	2.17	.3	.4	.46	0.
878	HX INT PR		(No change is strikingly indicated)						
879	HX INT T		.35	.1	.122	.1	.2	3.46	.7
881	HX VENT IN PR		(No change is strikingly indicated)						
882	HX VENT IN T		(No change is strikingly indicated)						
883	HX VENT DP		(No change is strikingly indicated)						
40	OPOV ACT POS		3.62	1.	6.24	.5	1.5	.34	0.
42	FPOV ACT POS		11.9	1.	24.3	1.	2.0	.51	.3

Table III-24: 901-436 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

- Test 901-364 (Hotgas Intrusion to Rotor Cooling) conducted on 7 April 1982 for Engine 2013.
  - ---Cutoff Time= 392.15 sec due a PBP radial accelerameter redline.
  - ---Early indications occur near 109% PL
  - ---Damage: Engine sustained extensive internal and external damage as a result of the failure and subsequent impact with the spillway. The test facility showed light to moderate damage.
  - ---Impact: $26M, Delay Time- 8 weeks.

CRITERIA LEGEND:
- •Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- •Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- •Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.
**NOTE: Parameter changes where DC ranges between 233 to 292.2 seconds may or may not be from an anomaly; the fuel tank was vented on and off between these equivalent DC ranges.

PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A+B	DC	LEVEL-C
366-367	(INJ CLNT PR)	-(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR)	-(MCC PC)	(Sensor does not exist)						
367-163	*(MCC HG IN PR)	-(MCC PC)	11.9	1.	.05	.1	1.1	233.71	1.
395-163	(MCC OX INJ PR)	-(MCC PC)	(No change is strikingly indicated)						
940-367	*(HPFP CL LNR PR)	-(MCC HG IN PR)	21(8)	1.(1.)	.5(.2)	.1(.1)	1.1(1.1)	186.2(270)	1.
459-383	(HPFP DS PR)	-(MCC PC)	1.56(.6)	.3(.1)	.01(.02)	.1(.1)	.4(.2)	117(292.)	1.(1.)
410-367	(FPB PC)	-(MCC HG IN PR)	4.3(1.3)	1.(.3)	.05(.05)	.1(.1)	1.1(.4)	117(263.)	1.(1.)
480-367	(OPB PC)	-(MCC HG IN PR)	3.05	1.	.04	.1	1.1	186.2	1.
63, 163	MCC PC		.82	.1	1.03	.3	.4	6.45	1.
200	MCC PC AVG		.82	.1	1.03	.3	.4	6.45	1.
17	MCC CLNT DS PR		.82	.1	.01	.1	.2	292.2	1.
18	MCC CLNT DS T		1.44	.3	.04	.1	.4	117.	1.
436	MCC FU INJ PR		.73(.2)	.1(.1)	.01(.01)	.1(.1)	.2(.2)	117(292.)	1.(1.)
1921	MCC LN CAV P		(Sensor malfunction)						
595	MCC OX INJ TEMP		.7	.1	.01	.1	.2	186.2	1.
86	**HPFP IN PR		6.32	1.	.13	.1	1.1	292.2	1.
459	HPFP DS PR		.9(.93)	.1(.1)	.01(.03)	.1(.1)	.2(.2)	117(292.)	1.(1.)
59	*HPFP DS T		2.33	.7	.01	.1	.8	292.2	1.
57	HPFP BAL CAV PR		(Sensor malfunction)						
52, 764	HPFP SPD		.4(.4)	.1(.1)	1.(.3)	.3(.1)	.4(.2)	7.2(117)	1.(1.)
53, 940	HPFP CL LNR PR		.5(.14)	.1(.1)	.01(.004)	.1(.1)	.2(.2)	98.2(274)	1.(1.)
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
231	HPFT DS T1 A		2.4(2.8)	.7(.7)	6.1(.02)	.5(.1)	1.2(.8)	7.2(292.)	1.(1.)
232	HPFT DS T1 B		2.95(2.)	.7(.7)	7.4(.02)	.5(.1)	1.2(.8)	7.2(292.)	1.(1.)
754	LPFP SPD		.63(.4)	.1(.1)	.01(.01)	.1(.1)	.2(.2)	117(292.)	1.(1.)
436	LPFT IN PR		.52(.2)	.1(.1)	.004(.01)	.1(.1)	.2(.2)	117(292.)	1.(1.)
1205, 1206	FAC FU FL		1.33	.3	.005	.1	.4	292.2	1.
1207, 1209	FAC FU FL CT		(No change is strikingly indicated)						
722	ENG FU FLOW		.99	.1	.003	.1	.2	292.2	1.
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	HPOT DS T1		5.26	1.	.08	.1	1.1	184.2	1.
234	HPOT DS T2		6.25	1.	.09	.1	1.1	184.2	1.
1190	HPOT PRSL DR T		(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T		3.2	1.	.5	.1	1.1	188.2	1.
1054, 1056	OX FAC FM DS T		.24	.1	.003	.1	.2	204.5	1.
854	FAC OX FM DS PR		144.	1.	2.12	.3	1.3	189.2	1.
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW		(No change is strikingly indicated)						
858, 860	ENG OX IN PR		144.	1.	2.12	.3	1.3	189.2	1.
1058	ENG OX IN TEMP		.24	.1	.003	.1	.2	204.5	1.
90	HPOP DS PR		(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR		2.2	.7	.04	.1	.8	188.2	1.
30, 734	LPOP SPD		1.7	.3	.03	.1	.4	189.2	1.
209	LPOP DS PR		34.4	1.	.52	.1	1.1	188.2	1.
93, 94	PBP DS TMP		1.02	.3	.02	.1	.4	188.2	1.
59, 159	PBP DS PR		1.92	.3	.03	.1	.4	184.2	1.
410	FPB PC		.62(.4)	.1(.1)	.01(.01)	.1(.1)	.2(.2)	117(263.)	1.(1.)
480	OPB PC		1.1	.3	.02	.1	.4	182.2	1.
78	HX INT PR		.51	.1	.02	.1	.2	146.1	1.
79	HX INT T		4.7	1.	.07	.1	1.1	181.2	1.
881	HX VENT IN PR		(No change is strikingly indicated)						
882	HX VENT IN T		(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP		(Sensor has not settled adequately to steady state conditions)						
40	OPOV ACT POS		3.9(2.3)	1.(.7)	.05(.1)	.1(.1)	1.1(.8)	210(292.)	1.(1.)
42	FPOV ACT POS		2.9(.7)	.7(.1)	.04(.02)	.1(.1)	.8(.2)	182(292.)	1.(1.)

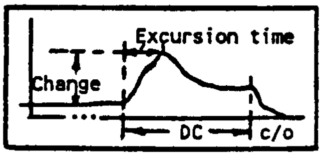
Table III-25: 901-364 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

- Test 902-209 (Hotgas Intrusion to Rotor Cooling) conducted 16 November 1980 for Engine 2008.
  - ---Cutoff Time= 823. sec., Program Duration.
  - ---Early indications occur near 90% PL
  - ---Damage: FPB injector (minor inner baffle tip erosion), HPFTP (nut found off turbine, dome and lock tab missing).
  - ---Impact: Unavailable.

CRITERIA LEGEND:

- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

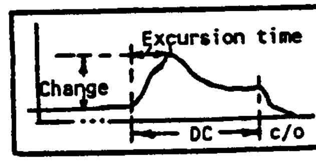
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-383	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-383	(MCC HG IN PR) -(MCC PC)	(Sensor does not exist)						
395-383	(MCC OX INJ PR) -(MCC PC)	(Sensor does not exist)						
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	.96	.1	.32	.1	.2	204.	1.
411-371	(FPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
480-371	(OPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
63, 163	MCC PC	.21	.1	.11	.1	.2	117.1	1.
200	MCC PC AVG	.14	.1	.11	.1	.2	176.2	1.
17	MCC CLNT DS PR	.24	.1	.4	.1	.2	203.5	1.
18	MCC CLNT DS T	(Sensor malfunction)						
24	MCC FU INJ PR	.46	.1	.04	.1	.2	173.	1.
1951, 1956	MCC LN CAV P	(Sensor malfunction)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	HPFP IN PR	1.13	.3	.11	.1	.4	213.	1.
52	HPFP DS PR	.42	.1	2.08	.3	.4	203.2	1.
659	HPFP DS T	.53	.1	.26	.1	.2	204.	1.
457	HPFP BAL CAV PR	.75	.1	.37	.1	.2	204.	1.
52, 764	HPFP SPD	.16	.1	.26	.1	.2	203.1	1.
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	1.16	.3	.05	.1	.4	203.	1.
232	HPFT DS T1 B	(Sensor malfunction)						
754	LPFP SPD	.33	.1	.6	.1	.2	203.1	1.
436	LPFT IN PR	.32	.1	.16	.1	.2	204.	1.
1205, 1206	FAC FU FL	(Sensor has not settled adequately to steady state conditions)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	.34	.1	.57	.1	.2	175.8	1.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	2.14	.7	.71	.1	.8	203.1	1.
234	HPOT DS T2	1.70	.3	.85	.1	.4	203.	1.
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T	(Sensor has not settled adequately to steady state conditions)						
1054, 1056	OX FAC FM DS T	(No change is strikingly indicated)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
90	HPOP DS PR	.44	.1	.15	.1	.2	176.	1.
325, 326	HPOP BALCAV PR	.38	.1	.13	.1	.2	176.	1.
30, 734	LPOP SPD	(No change is strikingly indicated)						
302	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	.1	.1	.025	.1	.2	177.	1.
59, 159	PBP DS PR	.72	.1	.18	.1	.2	177.	1.
414	FPB PC	.26	.1	.02	.1	.2	193.	1.
480	OPB PC	.31	.1	.08	.1	.2	177.	1.
878	HX INT PR	.52	.1	.17	.1	.2	178.	1.
879	HX INT T	1.03	.3	.09	.1	.4	203.	1.
881	HX VENT IN PR	1.31	.3	.26	.1	.4	208.	1.
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	1.47	.3	.06	.1	.4	208.	1.
40	OPOV ACT POS	.35	.1	1.75	.3	.4	203.2	1.
42	FPOV ACT POS	.36	.1	.12	.1	.2	202.	1.

Table III-26: 902-209 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

-Test 902-249 (Power Transfer Failure, Turbine Blades) conducted 21 September 1981 for Engine 0204.
---Cutoff Time= 450.58 sec due to HPFTP accelerometer redline.
---Early indications occur near 109% PL
---Damage: HPFTP (massive turbine damage, HPFP inlet ruptured), entire engine gutted due to LOX rich shutdown.
---Impact: $15.1M, Delay Time- 3 weeks.

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.
**NOTE: Parameter changes where DC ranges between 131.0 - 350.6 seconds may or may not be from an anomaly; propellant was transferred between these equivalent DC ranges.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A+B	DC	LEVEL-C
366-371	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-383	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
371-383	(MCC HG IN PR) -(MCC PC)	(Sensor does not exist)						
395-383	*(MCC OX INJ PR) -(MCC PC)	3.2	1.	.04	.1	1.1	90.6	1.
940-371	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	*(HPFP DS PR) -(MCC PC)	2.2	.7	.01	.1	.8	300.6	1.
410-371	(FPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
480-371	(OPB PC) -(MCC HG IN PR)	(Sensor does not exist)						
63, 163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
17	*MCC CLNT DS PR	1.04	.3	.003	.1	.4	350.6	1.
18	*MCC CLNT DS T	4.2	1.	.01	.1	1.1	326.6	1.
24	*MCC FU INJ PR	1.08	.3	.005	.1	.4	200.6	1.
1921	MCC LN CAV P	(Sensor malfunction)						
595	*MCC OX INJ TEMP	.25	.1	.001	.1	.2	275.6	1.
86	**HPFP IN PR	2.11	.7	.01	.1	.8	130.6	1.
52	HPFP DS PR	1.2	.3	.006	.1	.4	200.6	1.
659	*HPFP DS T	11.3	1.	.04	.1	1.1	350.6	1.
457	*HPFP BAL CAV PR	1.82	.3	.01	.1	.4	150.6	1.
52, 764	*HPFP SPD	2.9(1.3)	.7(.3)	.02(.01)	.1(.1)	.8(.4)	130.6(351)	1.(1.)
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	17.5(5)	1.(1.)	.13(.0002)	.1(.1)	1.1(1.1)	130.6(351)	1.(1.)
232	HPFT DS T1 B	5.3(3.6)	1.(1.)	.04(.0001)	.1(.1)	1.1(1.1)	130.6(351)	1.(1.)
754	LPFP SPD	1.2(.9)	.3(.1)	.01(.01)	.1(.1)	.4(.2)	121(351.)	1.(1.)
436	LPFT IN PR	.96	.1	.004	.1	.2	250.6	1.
1205, 1206	FAC FU FL	3.63	1.	.01	.1	1.1	350.6	1.
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	3.59	1.	.01	.1	1.1	350.6	1.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	5.3(7.1)	1.(1.)	.04(.1)	.1(.1)	1.1(1.1)	75.6(351)	1.(1.)
234	HPOT DS T2	4.5(6.9)	1.(1.)	.03(.1)	.1(.1)	1.1(1.1)	75.6(351)	1.(1.)
1190	HPOT PRSL DR T	4.6(4.7)	1.(1.)	.04(.07)	.1(.1)	1.1(1.1)	141(351.)	1.(1.)
1071	OX BLD INT T	5.95	1.	.11	.1	1.1	350.6	1.
1054, 1056	OX FAC FM DS T	1.53	.3	.004	.1	.4	350.6	1.
854	FAC OX FM DS PR	220.	1.	4.1	.3	1.3	350.6	1.
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	2.9	.7	.03	.1	.8	100.6	1.
858, 860	ENG OX IN PR	220.	1.	4.1	.3	1.3	350.6	1.
1058	ENG OX IN TEMP	1.53	.3	.004	.1	.4	350.6	1.
90	HPOP DS PR	1.22(.3)	.3(.1)	.01(.003)	.1(.1)	.4(.2)	151(351.)	1.(1.)
325, 326	HPOP BALCAV PR	.75(1.6)	.1(.3)	.01(.03)	.1(.1)	.2(.4)	101(351.)	1.(1.)
30, 734	LPOP SPD	.62(1.8)	.1(.3)	.004(.03)	.1(.1)	.2(.4)	151(351.)	1.(1.)
209	LPOP DS PR	1.7(20.)	.3(1.)	.03(.37)	.1(.1)	.4(1.1)	66.(351.)	1.(1.)
93, 94	PBP DS TMP	(Sensor has not settled adequately to steady state conditions)						
59, 159	PBP DS PR	1.1(2.8)	.3(.7)	.01(.05)	.1(.1)	.4(.8)	73.(351.)	1.(1.)
410	FPB PC	1.4	.3	.04	.1	.4	350.6	1.
480	OPB PC	1.8(1.1)	.3(.3)	.01(.02)	.1(.1)	.4(.4)	251(351.)	1.(1.)
878	HX INT PR	1.1	.3	.004	.1	.4	250.6	1.
879	HX INT T	4.2(4.9)	1.(1.)	.01(.01)	.1(.1)	1.1(1.1)	201(351.)	1.(1.)
881	HX VENT IN PR	4.5	1.	.045	.1	1.1	350.6	1.
882	HX VENT IN T	1.5(9.1)	.3(1.)	.02(.13)	.1(.1)	.4(1.1)	71.(351.)	1.(1.)
883	HX VENT DP	3.8	1.	.038	.1	1.1	350.6	1.
40	OPOV ACT POS	7(3.8)	1.(1.)	.03(.07)	.1(.1)	1.1(1.1)	226(351.)	1.(1.)
42	FPOV ACT POS	3.5(3.3)	1.(1.)	.04(.08)	.1(.1)	1.1(1.1)	101(351.)	1.(1.)

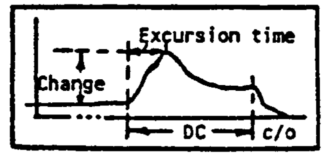
Table III-27: 902-249 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

- Test 902-095 (Power Transfer Failure, Turbine Blades) conducted on 17 November 1977 for Engine 0002.
  - ---Cutoff Time= 51.09 sec due to a PBP radial accelerometer redline.
  - ---Early indications occur near 95% PL
  - ---Damage: HPFTP (extensive turbine damage), MCC injector (8-LOX posts eroded, 15 MCC face nuts eroded)
  - ---Impact: Unavailable.

CRITERIA LEGEND:

- •Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- •Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- •Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.

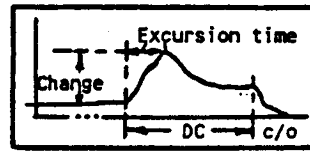
PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-372	(INJ CLNT PR) -(MCC HG IN PR)	(No change is strikingly indicated)						
366-383	(INJ CLNT PR) -(MCC PC)	.42	.1	.25	.1	.2	15.39	1.
372-383	(MCC HG IN PR) -(MCC PC)	.78	.1	.46	.1	.2	15.39	1.
395-383	(MCC OX INJ PR) -(MCC PC)	(No change is strikingly indicated)						
940-372	(HPFP CL LNR PR)-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR) -(MCC PC)	(No change is strikingly indicated)						
410-372	(FPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
480-372	(OPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
17	MCC CLNT DS PR	(No change is strikingly indicated)						
18	MCC CLNT DS T	(Sensor malfunction)						
24	*MCC FU INJ PR	.86	.1	.09	.1	.2	15.39	1.
1921	MCC LN CAV P	(Sensor does not exist)						
595	MCC OX INJ TEMP	(Sensor does not exist)						
86	HPFP IN PR	(Sensor has not settled adequately to steady state conditions)						
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	(No change is strikingly indicated)						
457	HPFP BAL CAV PR	(No change is strikingly indicated)						
52, 764	HPFP SPD	(No change is strikingly indicated)						
53, 940	HPFP CL LNR PR	(Sensors do not exist)						
650	HPFP CL LNR T	(Sensor does not exist)						
657	HPFP DR PR	(Sensor does not exist)						
658	HPFP DR TEMP	(Sensor does not exist)						
231	HPFT DS T1 A	(No change is strikingly indicated)						
232	HPFT DS T1 B	(Sensor malfunction)						
754	LPFP SPD	.43	.1	.06	.1	.2	15.39	1.
436	LPFT IN PR	(No change is strikingly indicated)						
1205, 1206	FAC FU FL	(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	(No change is strikingly indicated)						
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	(Sensor has not settled adequately to steady state conditions)						
234	HPOT DS T2	(Sensor has not settled adequately to steady state conditions)						
1190	HPOT PRSL DR T	(No change is strikingly indicated)						
1072	OX BLD INT T	(Sensor has not settled adequately to steady state conditions)						
1054, 1056	OX FAC FM DS T	(Sensor has not settled adequately to steady state conditions)						
854	*FAC OX FM DS PR	9.2	1.	.9	.1	1.1	10.29	1.
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	ENG OX IN PR	8.66	1.	.84	.1	1.1	10.29	1.
1058	ENG OX IN TEMP	(No change is strikingly indicated)						
338	HPOP DS PR	.34	.1	.2	.1	.2	10.29	1.
325, 326	HPOP BALCAV PR	(No change is strikingly indicated)						
30, 734	LPOP SPD	(No change is strikingly indicated)						
209	LPOP DS PR	2.12	.7	.25	.1	.8	8.59	1.
93, 94	PBP DS TMP	(Sensor does not exist)						
341	PBP DS PR	(No change is strikingly indicated)						
412	FPB PC	(No change is strikingly indicated)						
480	OPB PC	(No change is strikingly indicated)						
878	HX INT PR	1.13	.3	.14	.1	.4	17.1	1.
879	HX INT T	(Sensor has not settled adequately to steady state conditions)						
881	*HX VENT IN PR	1.76	.3	.15	.1	.4	12.	1.
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	(Sensor has not settled adequately to steady state conditions)						
40	*OPOV ACT POS	2.7	.7	.3	.1	.8	9.09	1.
42	FPOV ACT POS	(No change is strikingly indicated)						

Table III-28: 902-095 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure
Test 901-346 (Localized: Turbine Blades) conducted 19 November 1981 for Engine 0107.

---Cutoff Time= 500 sec, Program Duration.
---Early indications occur near 109% PL
---Damage: HPFTP (fishmouth seal dropped approx. 1/16 inches, 180-deg around; 1st stage blade shanks undercut approx. .02 inches)
---Impact: Unavailable

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.

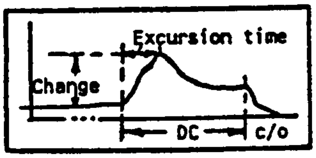
PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-371	(INJ CLNT PR)	-(MCC HG IN PR)	(Sensor does not exist)						
366-383	(INJ CLNT PR)	-(MCC PC)	(Sensor does not exist)						
371-383	(MCC HG IN PR)	-(MCC PC)	(No change is strikingly indicated)						
395-383	(MCC OX INJ PR)	-(MCC PC)	(No change is strikingly indicated)						
940-371	(HPFP CL LNR PR)	-(MCC HG IN PR)	18.9	1.	.08	.1	1.1	400.	1.
459-383	(HPFP DS PR)	-(MCC PC)	(No change is strikingly indicated)						
410-371	(FPB PC)	-(MCC HG IN PR)	(No change is strikingly indicated)						
480-371	(OPB PC)	-(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC		(No change is strikingly indicated)						
200	MCC PC AVG		(No change is strikingly indicated)						
17	MCC CLNT DS PR		.65	.1	.005	.1	.2	300.	1.
18	MCC CLNT DS T		3.3(1.3)	1.(.3)	.44(.01)	.1(.1)	1.1(.4)	15.5(350.)	1.
24	MCC FU INJ PR		8.24	1.	.03	.1	1.1	400.	1.
1921	MCC LN CAV P		(Sensor has not settled adequately to steady state conditions)						
595	MCC OX INJ TEMP		.27	.1	.01	.1	.2	200.	1.
86	HPFP IN PR		1.64	.3	1.64	.3	.6	200.	1.
52	HPFP DS PR		(No change is strikingly indicated)						
659	HPFP DS T		2.8	.7	.006	.1	.8	400.	1.
457	HPFP BAL CAV PR		(No change is strikingly indicated)						
52, 764	HPFP SPD		.54	.1	.001	.1	.2	400.	1.
53, 940	HPFP CL LNR PR		1.31	.3	.003	.1	.4	400.	1.
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
231	HPFT DS T1 A		3.2(1.2)	1.(.3)	.07(.01)	.1(.1)	1.1(.4)	125(400.)	1.
232	HPFT DS T1 B		3.3(.8)	1.(.1)	.07(.01)	.1(.1)	1.1(.2)	125(400.)	1.
754	LPFP SPD		.64(.4)	.1(.1)	.6(.003)	.1(.1)	.2(.2)	200(400.)	1.
436	LPFT IN PR		(No change is strikingly indicated)						
1205, 1206	FAC FU FL		.96	.1	.002	.1	.2	400.	1.
1207, 1209	FAC FU FL CT		(No change is strikingly indicated)						
722	ENG FU FLOW		1.47	.3	.003	.1	.4	400.	1.
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	HPOT DS T1		5.84	1.	.03	.1	1.1	200.	1.
234	HPOT DS T2		2.55	.7	.01	.1	.8	200.	1.
1190	HPOT PRSL DR T		.9	.1	.04	.1	.2	200.	1.
1071	OX BLD INT T		(Sensor has not settled adequately to steady state conditions)						
1054, 1056	OX FAC FM DS T		(Sensor has not settled adequately to steady state conditions)						
854	FAC OX FM DS PR		(No change is strikingly indicated)						
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW		(No change is strikingly indicated)						
858, 860	ENG OX IN PR		(No change is strikingly indicated)						
1058	ENG OX IN TEMP		.3	.1	.001	.1	.2	300.	1.
90	HPOP DS PR		(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR		(No change is strikingly indicated)						
30, 734	LPOP SPD		(No change is strikingly indicated)						
209	LPOP DS PR		(No change is strikingly indicated)						
93, 94	PBP DS TMP		.47	.1	.002	.1	.2	300.	1.
59, 159	PBP DS PR		(No change is strikingly indicated)						
410	FPB PC		(No change is strikingly indicated)						
480	OPB PC		(No change is strikingly indicated)						
878	HX INT PR		.96	.1	.003	.1	.2	400.	1.
879	HX INT T		5.81	1.	.02	.1	1.1	400.	1.
881	HX VENT IN PR		(No change is strikingly indicated)						
882	HX VENT IN T		(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP		1.69	.7	.004	.1	.8	400.	1.
40	OPOV ACT POS		3.1(1.9)	1.(.3)	.12(.1)	.1(.1)	1.1(.4)	135(350.)	1.
42	FPOV ACT POS		3.5(2.4)	1.(.7)	.11(.01)	.1(.1)	1.1(.8)	120(400.)	1.

Table III-29: 901-346 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure
-Test 901-362 (Power Transfer Failure) conducted 27 March 1982 for Engine 2013.

---Cutoff Time= 500 sec, Program Duration.
---Early indications occur near 109% PL
---Damage: HPOTP (1st stage turbine blade has corners chipped off), MCC (two old cracks have grown .125 inches)
---Impact: Unavailable.

CRITERIA LEGEND:
•Operating Level Anomaly Criteria (LC)
LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
•Rate Criteria (RC) = LC/(Excursion time interval in seconds)
•Duration Criteria (DC)
DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.

PID NO.(S)	PARAMETER		LC	LEVEL-A	RC	LEVEL-B	LEVELS A + B	DC	LEVEL-C
366-367	(INJ CLNT PR)	-(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR)	-(MCC PC)	(Sensor does not exist)						
367-163	(MCC HG IN PR)	-(MCC PC)	6.8	1.	.2	.1	1.1	175.	1.
395-163	(MCC OX INJ PR)	-(MCC PC)	(No change is strikingly indicated)						
940-367	(HPFP CL LNR PR)	-(MCC HG IN PR)	(Sensor does not exist)						
459-383	(HPFP DS PR)	-(MCC PC)	1.15	.3	.58	.1	.4	262.	1.
410-367	(FPB PC)	-(MCC HG IN PR)	2.8	.7	.03	.1	.8	260.	1.
480-367	(OPB PC)	-(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC		.41	.1	2.06	.3	.4	261.	1.
200	MCC PC AVG		.31	.1	3.1	.3	.4	260.	1.
17	MCC CLNT DS PR		.63	.1	6.3	.5	.6	260.	1.
18	MCC CLNT DS T		2.23	.7	.02	.1	.8	210.	1.
24	MCC FU INJ PR		(Sensor does not exist)						
1921	MCC LN CAV P		(Sensor malfunction)						
595	MCC OX INJ TEMP		(No change is strikingly indicated)						
86	HPFP IN PR		7.1(1.6)	1.(.3)	.2(1.6)	.1(.3)	1.1(.6)	175(261.)	1.
52	HPFP DS PR		.74	.1	1.48	.3	.4	260.5	1.
659	HPFP DS T		.53	.1	1.05	.3	.4	260.5	1.
457	HPFP BAL CAV PR		(No change is strikingly indicated)						
52, 764	HPFP SPD		.32	.1	.65	.1	.2	260.5	1.
53, 940	HPFP CL LNR PR		(Sensors do not exist)						
650	HPFP CL LNR T		(Sensor does not exist)						
657	HPFP DR PR		(Sensor does not exist)						
658	HPFP DR TEMP		(Sensor does not exist)						
231	HPFT DS T1 A		1.7(1.3)	.3(.3)	.04(.17)	.1(.1)	.4(.4)	160(266.)	1.
232	HPFT DS T1 B		1.6(.8)	.3(.1)	.03(.53)	.1(.1)	.4(.2)	175(258.5)	1.
754	LPFP SPD		.63(.6)	.1(.1)	.01(1.1)	.1(.3)	.2(.4)	210(261.)	1.
436	LPFT IN PR		.63(.6)	.1(.1)	.01(1.1)	.1(.3)	.2(.4)	200(261.)	1.
1205, 1206	FAC FU FL		(No change is strikingly indicated)						
1207, 1209	FAC FU FL CT		(No change is strikingly indicated)						
722	ENG FU FLOW		(No change is strikingly indicated)						
1722	ENG FU FLOW CT		(No change is strikingly indicated)						
233	HPOT DS T1		(No change is strikingly indicated)						
234	HPOT DS T2		(No change is strikingly indicated)						
1190	HPOT PRSL DR T		(No change is strikingly indicated)						
1071	OX BLD INT T		(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T		(Sensor has not settled adequately to steady state conditions)						
854	FAC OX FM DS PR		(No change is strikingly indicated)						
1210	FAC OX FLOW CT		(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW		(No change is strikingly indicated)						
858, 860	ENG OX IN PR		(No change is strikingly indicated)						
1058	ENG OX IN TEMP		(No change is strikingly indicated)						
90	HPOP DS PR		1.07	.3	2.14	.3	.6	258.5	1.
325, 326	HPOP BALCAV PR		1.35(.6)	.3(.1)	.01(2.9)	.1(.3)	.4(.4)	225(260.2)	1.
30, 734	LPOP SPD		.3	.1	1.43	.3	.4	260.1	1.
209	LPOP DS PR		(No change is strikingly indicated)						
93, 94	PBP DS TMP		.2	.1	.63	.1	.2	260.1	1.
59, 159	PBP DS PR		1.06	.3	1.06	.3	.6	260.2	1.
410	FPB PC		.62	.1	.09	.1	.2	260.2	1.
480	OPB PC		.76	.1	.38	.1	.2	260.2	1.
878	HX INT PR		.6	.1	.3	.1	.2	260.	1.
879	HX INT T		(Sensor has not settled adequately to steady state conditions)						
881	HX VENT IN PR		.7	.1	.4	.1	.2	260.	1.
882	HX VENT IN T		(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP		.7	.1	.4	.1	.2	260.	1.
40	OPOV ACT POS		1.8	.3	.9	.1	.4	260.	1.
42	FPOV ACT POS		.99	.1	.5	.1	.2	260.	1.

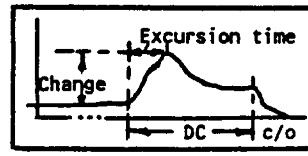
Table III-30: 901-362 Data Base

Data Base for Early Parameter Indicators of Test Classification: High Pressure Fuel Turbopump (HPFTP) Failure

-Test 901-410 (Power Transfer Failure, Turbine Blades) conducted 20 May 1983 for Engine 2014.

---Cutoff Time= 595. sec, Program Duration.
---Early indications occur near 104% PL
---Damage: HPFTP (2nd stage turbine damper missing, all locking tabs and pins missing, impact damage to 1st stage turbine blades and tip seals), HPFP has .75in**2 piece of scroll missing.
---Impact: Unavailable.

CRITERIA LEGEND:
- Operating Level Anomaly Criteria (LC)
  LC = (Absolute Change in Steady State Value/Steady State Value) x 100.
- Rate Criteria (RC) = LC/(Excursion time interval in seconds)
- Duration Criteria (DC)
  DC = Duration from the point of first failure indications to c/o time



WEIGHTED LEVEL VALUE ASSIGNMENT LEGEND:

LEVEL-A: Value of LC	A-Value	LEVEL-B: Value of RC	B-Value	LEVEL-C: Value of DC	C-Value
>3%.......	1.0	>10%/sec....	1.0	>5sec.......	1.0
>2%-3%.......	.7	>5 -10%/sec....	.5	>1 -5sec.......	.7
1%-2%.......	.3	1 - 5%/sec....	.3	.5 -1sec.......	.3
<1%.......	.1	<1%/sec....	.1	<.5sec.......	0.

( )---Numbers within the parenthesis indicate an earlier and more gradual "LC" change for the parameter.
*---Parameters prefixed with an asterisk indicate a change continues until cutoff time.
**NOTE: Parameter changes where DC ranges between 496 - 575 seconds may or may not be from an anomaly; the fuel tank was vented between the equivalent DC ranges.

PID NO.(S)	PARAMETER	LC	LEVEL-A	RC	LEVEL-B	LEVELS A+B	DC	LEVEL-C
366-367	(INJ CLNT PR) -(MCC HG IN PR)	(Sensor does not exist)						
366-163	(INJ CLNT PR) -(MCC PC)	(Sensor does not exist)						
367-163	(MCC HG IN PR) -(MCC PC)	4.	1.	.95	.1	1.1	465.	1.
395-163	(MCC OX INJ PR) -(MCC PC)	(No change is strikingly indicated)						
940-367	(HPFP CL LNR PR)-(MCC HG IN PR)	50.(16)	1.(1.)	1.9(2.)	.3(.3)	1.3(1.3)	90.(455.)	1.
459-163	(HPFP DS PR) -(MCC PC)	(No change is strikingly indicated)						
410-367	(FPB PC) -(MCC HG IN PR)	.6(5.5)	.1(1.)	.01(.03)	.1(.1)	.2(1.1)	185.(495)	1.(1.)
480-367	(OPB PC) -(MCC HG IN PR)	(No change is strikingly indicated)						
63, 163	MCC PC	(No change is strikingly indicated)						
200	MCC PC AVG	(No change is strikingly indicated)						
17	MCC CLNT DS PR	2.6	.7	.007	.1	.8	527.	1.
18	MCC CLNT DS T	(No change is strikingly indicated)						
24	MCC FU INJ PR	(No change is strikingly indicated)						
1951, 1956	MCC LN CAV P	(Sensor malfunction)						
595	MCC OX INJ TEMP	(Sensor malfunction)						
86	**HPFP IN PR	3.57	1.	.06	.1	1.1	535.	1.
52	HPFP DS PR	(No change is strikingly indicated)						
659	HPFP DS T	1.52	.3	.004	.1	.4	485.	1.
457	HPFP BAL CAV PR	(No change is strikingly indicated)						
52, 764	HPFP SPD	.45	.1	.001	.1	.2	485.	1.
53, 940	HPFP CL LNR PR	4.1(1.2)	1.(.3)	.2(.01)	.1(.1)	1.1(.4)	90.(455)	1.(1.)
650	HPFP CL LNR T	9.6(9.)	1.(1.)	.4(2.5)	.1(.3)	1.1(1.3)	80.(430.)	1.(1.)
657	HPFP DR PR	(No change is strikingly indicated)						
658	*HPFP DR TEMP	7.42	1.	.02	.1	.8	485.	1.
231	HPFT DS T1 A	2.03	.3	.01	.1	.2	495.	1.
232	HPFT DS T1 B	.92	.1	.004	.1	.2	345.	1.
754	LPFP SPD	.77	.1	.003	.1	.2	445.	1.
436	LPFT IN PR	.35	.1	.001	.1	.2	485.	1.
1205, 1206	FAC FU FL	.86	.1	.002	.1	.2	495.	1.
1207, 1209	FAC FU FL CT	(No change is strikingly indicated)						
722	ENG FU FLOW	.77	.1	.002	.1	.2	485.	1.
1722	ENG FU FLOW CT	(No change is strikingly indicated)						
233	HPOT DS T1	1.76	.3	.01	.1	.4	485.	1.
234	HPOT DS T2	2.28	.7	.02	.1	.8	485.	1.
1190	HPOT PRSL DR T	(Sensor has not settled adequately to steady state conditions)						
1071	OX BLD INT T	(No change is strikingly indicated)						
1054, 1056	OX FAC FM DS T	(Sensor has not settled adequately to steady state conditions)						
854	FAC OX FM DS PR	(No change is strikingly indicated)						
1210	FAC OX FLOW CT	(No change is strikingly indicated)						
1212, 1213	FAC OX FLOW	(No change is strikingly indicated)						
858, 860	ENG OX IN PR	(No change is strikingly indicated)						
1058	ENG OX IN TEMP	(Sensor has not settled adequately to steady state conditions)						
90	HPOP DS PR	(No change is strikingly indicated)						
325, 326	HPOP BALCAV PR	(No change is strikingly indicated)						
30, 734	LPOP SPD	(No change is strikingly indicated)						
302	LPOP DS PR	(No change is strikingly indicated)						
93, 94	PBP DS TMP	(Sensor has not settled adequately to steady state conditions)						
59, 159	PBP DS PR	.67	.1	.002	.1	.2	395.	1.
410	FPB PC	1.79	.3	.009	.1	.4	545.	1.
480	OPB PC	.24	.1	.001	.1	.2	370.	1.
878	HX INT PR	(No change is strikingly indicated)						
879	HX INT T	(Sensor has not settled adequately to steady state conditions)						
881	HX VENT IN PR	(No change is strikingly indicated)						
882	HX VENT IN T	(Sensor has not settled adequately to steady state conditions)						
883	HX VENT DP	(No change is strikingly indicated)						
40	OPOV ACT POS	3.17	1.	3.17	.3	1.3	579.	1.
42	FPOV ACT POS	.7(.33)	.1(.1)	.004(.03)	.1(.1)	.2(.2)	345.(555)	1.(1.)

Table III-31: 901-410 Data Base

6.0 PHASE II AND III DESIGN PLANS

6.1 INTRODUCTION

The Phase II and III plans relate directly to the original statement of work submitted to NASA MSFC in the original proposal effort. The efforts in both phases will lead to a preliminary definition of efforts required including added hardware, software, and system integration requirements for a prototype SAFD system.

6.2 PHASE II: DEVELOPMENT

In this phase, chosen failure detection algorithms and the development of failure simulations will be accomplished to quantify system requirements for the proposed failure detection system. Phase II includes five tasks necessary to develop the prototype failure detection algorithm. A schedule is defined in Figure 6-1.

<u>Task 7</u>: <u>Develop Failure Simulation Models</u>

Based on the rating scheme developed in Task 2, the chosen failure detection algorithms will be implemented and tested for their ability to detect the selected failure modes, the robustness to false detection, and for their ability to detect different classes of failures. The process of choosing the methods will be iterative in nature with the goal of choosing the proper combination of algorithms that best detects the maximum number of failures. Five (5) tests approved by NASA MSFC will be used. These tests are: 901-173, 901-284, 901-364, 901-340, and 901-225.

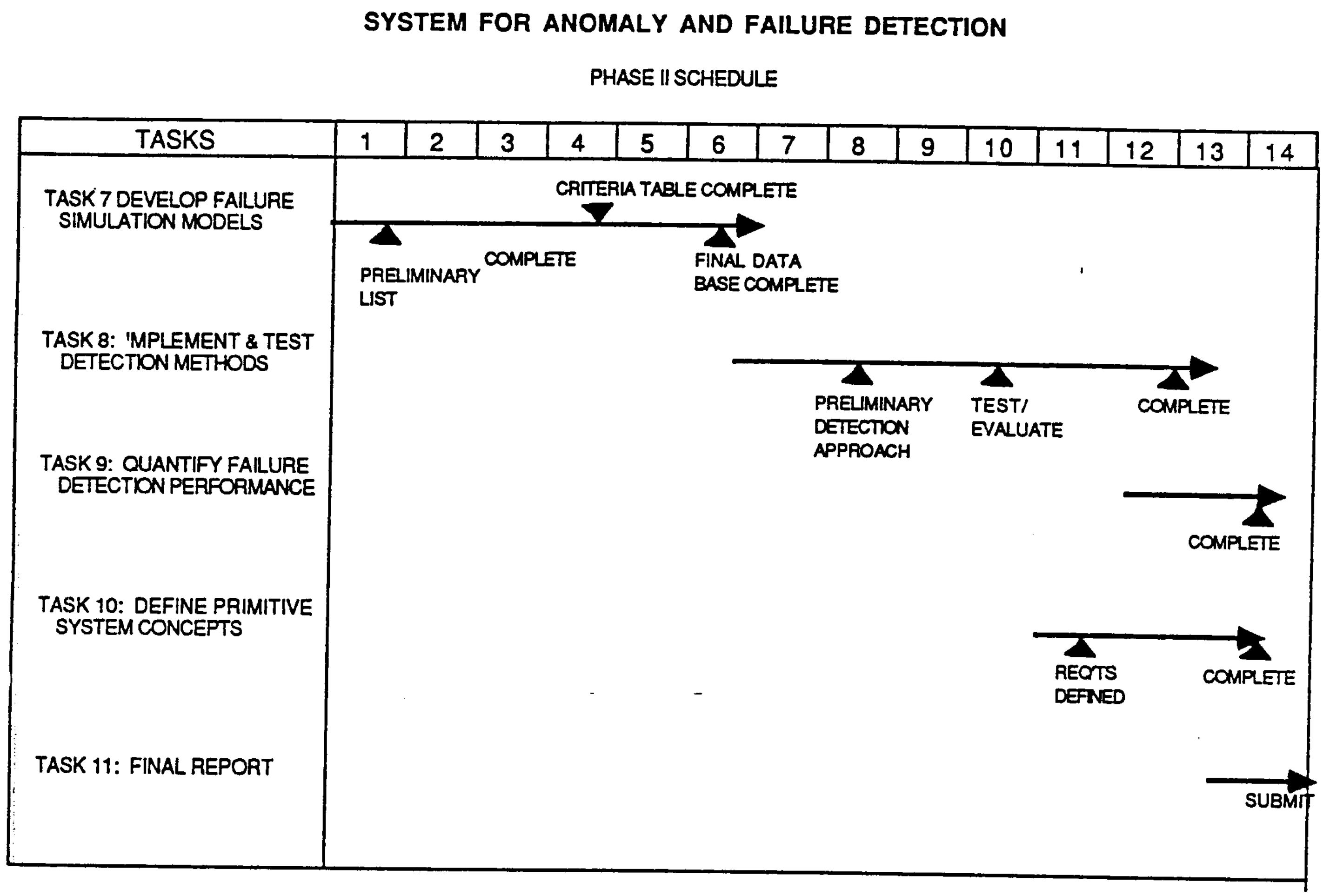


Figure 6-1: Phase II Schedule

Task 8: Implement Detection Methods

Based on the rating scheme developed in Task 2, the chosen failure detection algorithms will be implemented and tested for their ability to detect the selected failure modes, the robustness to false detection, and for their ability to detect different classes of failures. The process of choosing the methods will be iterative in nature with the goal of choosing the proper combination of algorithms that best detects the maximum number of failures. This task also corresponds to the development of algorithms specifically related to those failure modes selected in Task 7.

Task 9: Quantify Failure Detection Performance

In this task, the proposed failure detection prototype system will be quantified in terms of its performance characteristics, e.g., its ability to detect system anomalies and failure modes. This ability will be quantified in terms of the failure detection robustness, time for the failure to be detected by the software (e.g., failure detection time constant), and other performance parameters that may be derived from this study. The failure detection performance criteria will be limited to the five tests selected in Task 7.

Task 10: Define Primitive System Concepts

In this task, a primitive system functional flow diagram will be derived based on technical results from Tasks 7, 8, and 9. These top-level functional flow diagrams will yield valuable information for the hardware and software design engineers to determine the hardware/software development required for implementation of the SAFD system. This task will be limited to the five specified failure modes listed in Task 7.

Task 11: Final Report

This report will discuss the primitive system design concept, the derived requirements for the design, and component requirements. These requirements will be presented with top-level functional flow diagrams with descriptions and lists. Results of the prototype failure detection system on an analog or digital SSME model will be presented. Currently, only the SSME Digital Transient Model will be used to evaluate algorithm results.

6.3 PHASE III: DESIGN

The revised Phase III option corresponds to a request by NASA MSFC. The Phase I and II efforts will complete the initial work required to anchor the algorithm to estimated statistical parameter variations. However, it is highly recommended that the estimated statistical variations be enhanced and verified by utilization of the NTI Corporation capability to analyze raw data mathematically. This will help to alleviate uncertainty associated with the envelopes developed by Rocketdyne and add further certainty to the developed algorithms. This effort should be initiated during the Phase II effort to support Rocketdyne failure detection algorithm developments.

Figure 6-2 represents the preliminary organization structure at Rocketdyne to accomplish the Phase III efforts. The Control System Engineering Unit will coordinate the development of all the requirements specifications. This unit will develop the overall functional specification to support the hardware and software groups. The Electronics Design unit will be responsible for the development of the hardware specification and integration efforts. The Software Support Unit will develop the software requirements specifications based on the system requirements specification. Based on funding level, selected individuals will be assigned out of each functional area to support the outlined tasks.

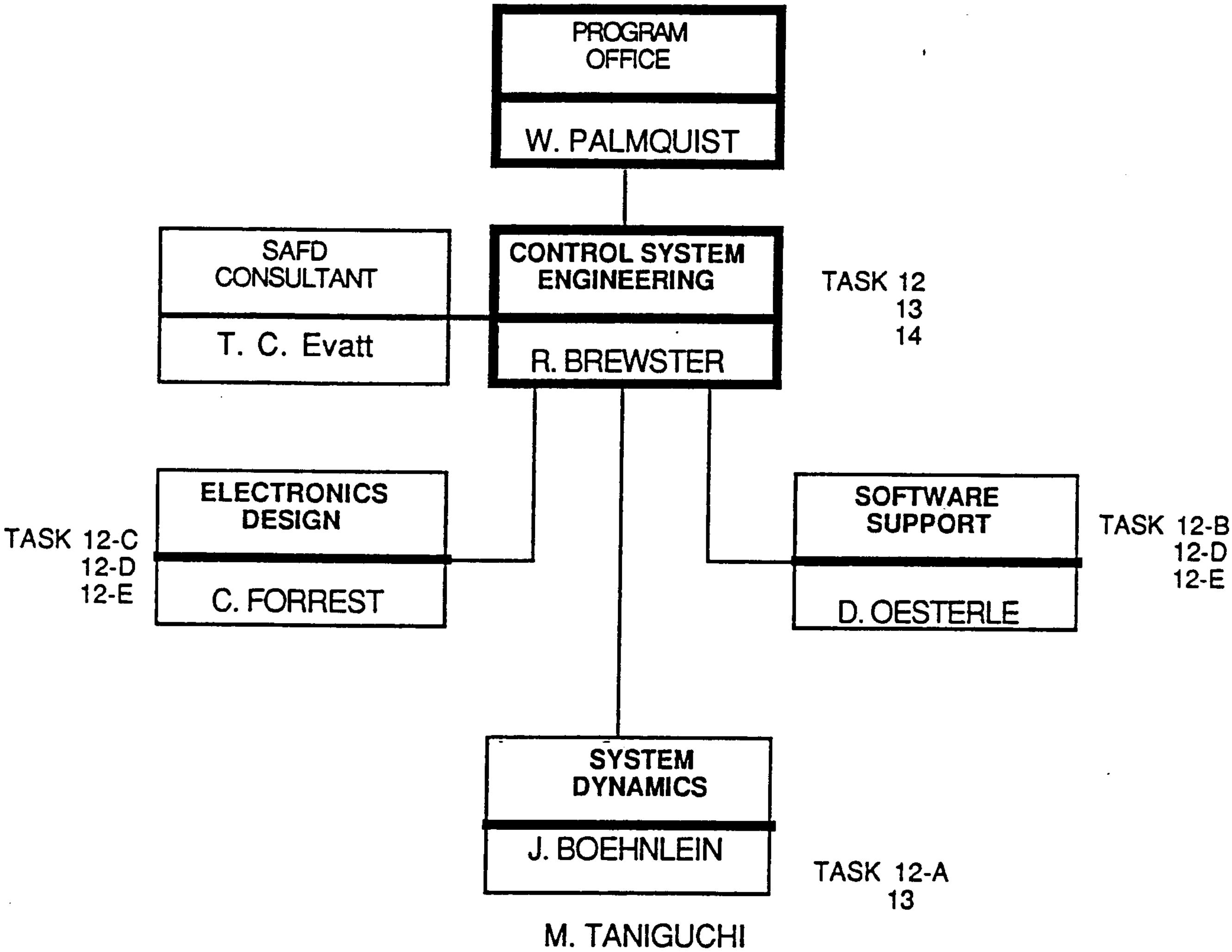


Figure 6-2: Phase II/III SAFD Organization

The SAFD detection algorithms will be tested on time histories collected from actual engine tests and also to a limited extent using the SSME Digital Transient Model for simulated criticality 1 FMEA anomalies related to the five tests selected during the Phase II effort. This effort will not complete the intensive efforts required to review all FMEA criticality 1 and 2 failure modes needed to adequately address detectable failure modes present on engine test stands. The engine-to-engine parameter variations have also been lightly addressed in the SAFD study because of funding limitations. The Phase III tasks are presented below. A preliminary schedule based on a 14-month Phase III effort is defined in Figure 6-3. Costs for the Phase III effort will remain the same as those defined in the negotiated proposal.

Task 12: Final System Design Specification/Cost Estimates

This task will encompass the definition of subtasks necessary to determine the system components (hardware/software) necessary to implement the SAFD system. This task does not include any actual software/hardware development but defines those tasks necessary for NASA MSFC planning purposes for funding to actually build and test a breadboard system on a testbed. A set of functional diagrams defining interface requirements, hardware/software functional breakdowns and scheduling and cost data will be generated. The output of this task will be the funding and supporting tasks necessary to implement a breadboard SAFD system on a selected test stand system. The list of subtasks to Task 12 are summarized below and represent the bulk of the work necessary to accomplish the efforts required during Phase III. No additional data analysis or algorithm development will be accomplished during the Phase III efforts.

SYSTEM FOR ANOMALY AND FAILURE DETECTION

PHASE III SCHEDULE

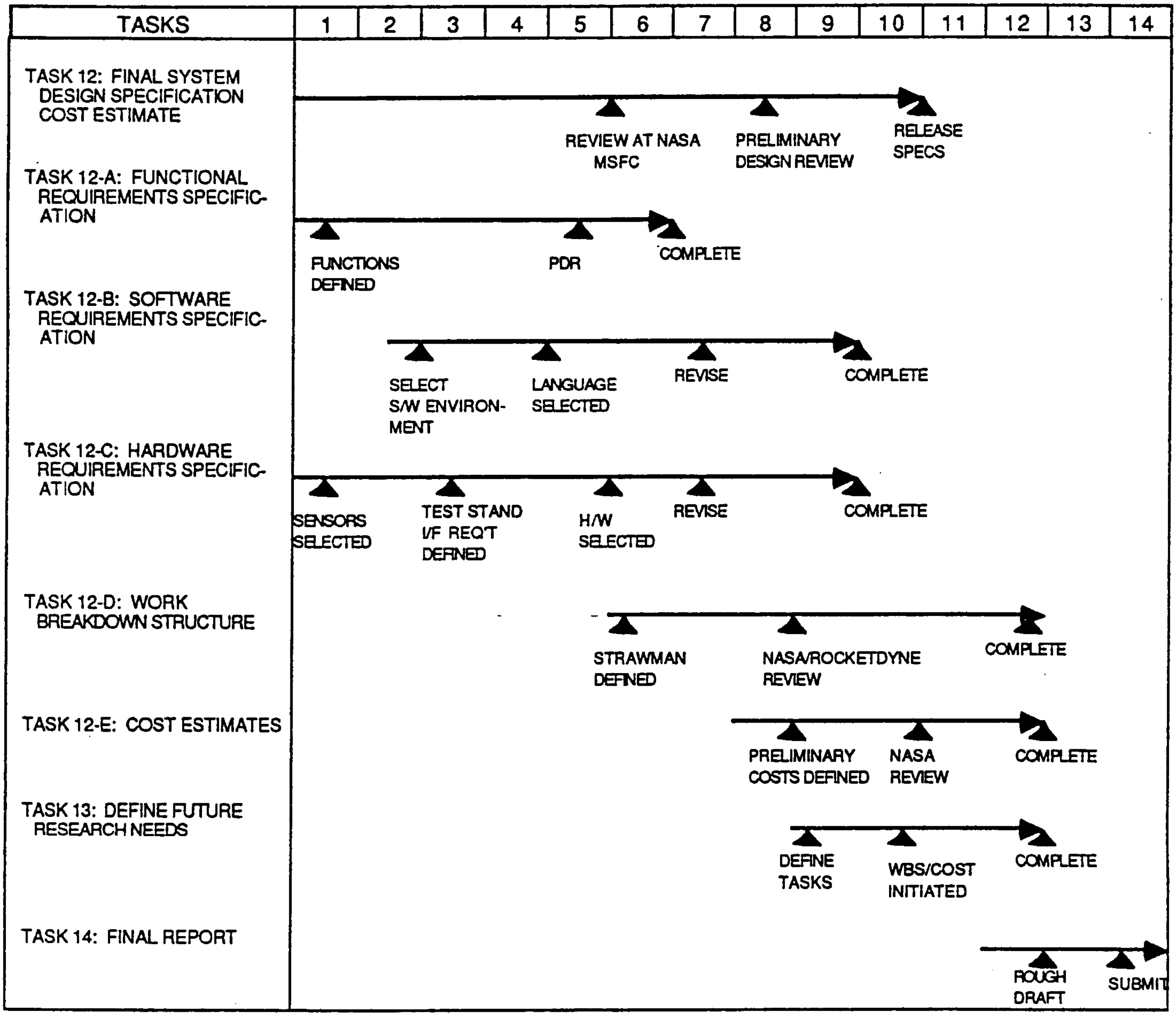


Figure 6-3: Phase III Schedule

Task 12-A: Functional Requirements

A requirements specification will be developed by Control Systems Engineering unit personnel based on Phase II efforts in algorithm definition. A system hierarchy will be defined and a detailed work breakdown structure will be correlated with the development of the system. The specification will include the preliminary interface requirements, performance requirements, and preliminary CPU and memory requirements required to accomplish the goals derived during Phase II.

Task 12-B: Software Requirements

A software requirements specification including required manpower, language selection and test support will be defined by the Rocketdyne Software Systems group. A software specification will be defined based on the Functional Requirements Specification defined in Task 12-A.

Task 12-C: Hardware Requirements

Based on the functional requirements specification, the Electronic Systems organization will define the hardware necessary to implement the SAFD system on a typical test stand including specialized electronic interfaces, computer hardware and support equipment. A computer system will be selected and recommended to NASA MSFC-off-the-shelf components will be selected whenever possible to minimize the costs of developing a breadboard system. It is recommended that a test stand be selected by NASA MSFC so detailed interface requirements can be defined for a breadboard SAFD system. Different implementations are possible for SAFD including additions to the current CADS II design for the SSME Block II controller effort to a totally new system utilizing a VAX class computing installation. Any specialized equipment that will need to be prototyped and developed as part of this program will be defined in this task.

Task 12-D: Work Breakdown Structure

A detailed work breakdown structure (WBS) will be developed to coincide with the efforts required to implement requirements defined in the above tasks. The WBS will include all tasks including those that relate to added test data analysis or simulation that relate to the definition and selection of elements of the SAFD system including manpower estimates and schedules. The WBS will also define all deliverables required to meet the SAFD functional objectives.

Task 12-E: Cost Estimation

A cost estimate will be developed that correlates to the Task 12 specifications efforts. The definition of the costs will include all required manpower, facility, hardware and special test equipment costs required to integrate a working breadboard of an SAFD system.

Task 13: Define Future Research Needs

During the Phase I/II preliminary design tasks, further research efforts will be defined that should be continued to further enhance the SAFD prototype and concept. A prioritized list will be defined with sample work breakdown structure and cost estimates for NASA MSFC to select. As a further enhancement to SAFD capabilities, new instrumentation involving condition monitoring sensors or specialized failure detection sensors will be defined. Efforts required to implement any new concepts in addition to those outlined in Task 12 will be discussed and sample work breakdown structures generated. The growth of the SAFD system into test beds for new health and condition monitoring areas will be discussed so preliminary planning for the enhanced capability can be defined by NASA MSFC.

Task 14: Final Report

This report will contain preliminary system, hardware and software design specifications. It will define plans for further study, certification, operation, and give cost and manpower estimates correlating directly to a detailed work breakdown structure for the overall goal of implementing a SAFD system on a NASA MSFC selected test facility. The design specification will follow a Rocketdyne approach to the system engineering process, which is designed to include criteria such as adaptability and optimum design concepts in its functions. The adaptability to different testing conditions and test facilities will be discussed in the specifications relating to adding new sensor information and its effect on hardware and software requirements.