REPORT NO. RN-S-0354
XECF TEST PREDICTIONS
(REVISION A)

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<u>Divider</u>	<u>Followed By</u>
Introduction	Pages 1 through 6
Engine Description	Pages 7 through 15
Test Facilities	Pages 17 through 37
Test Predictions	Pages 39 through 83
Instrumentation	Pages 85 through 113

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REPORT NO. RN-S-0354
(REVISION A)

XECF TEST PREDICTIONS

NERVA PROGRAM

CONTRACT SNP-1

NUCLEAR ROCKET OPERATIONS

DECEMBER 1967

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CLASSIFYING OFFICER

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REPORT NO. RN-S-0354
(REVISION A)

XECF TEST PREDICTIONS

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ABSTRACT

This report describes the expected performance of the XECF test assembly. Predictions are presented and discussed for all tests outlined in RN-S-0314, XECF Test Specification, and in modifications No. 1 and 2 thereof.

The test-prediction analysis indicated that, under all test conditions considered, the test-parameter limits would at no time be exceeded; and no unsafe conditions were disclosed that could result in damage to the test article or facility.

Descriptions of the engine system, the test facility, and the instrumentation system are included so the report can be used as a comprehensive reference document during quick-look analyses of test results.

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1.0 INTRODUCTION

The XECF engine will be the first engine system to be tested in the ETS-1 facility which permits a much closer approach to testing of a flight-type nuclear-powered system than previously possible because: (1) the engine is located immediately below, and close-coupled to, the liquid-hydrogen supply tank; and (2) the engine will be fired downward in a simulated high-altitude environment.

The objectives of the XECF test series can be divided into two main categories: (1) verification that the test facilities are satisfactory and ready for proceeding to XE testing; and (2) evaluation of operating procedures that have not been demonstrated during previous tests. The first category includes checkout of the instrumentation system, control system, handling equipment, and familiarization of test personnel with the equipment. The second category includes engine startup and simulated malfunction tests.

A complete listing of the XECF program objectives is presented in Section I.B of Report RN-S-0314, XECF Test Specification, November 1966. The operational specifications to accomplish these objectives, as set forth in Section II.D. of RN-S-0314, have undergone several modifications, and additional modifications are currently being considered. The test predictions contained herein are based: (1) on the specific test requirements contained in NRO Modification No. 2, approved by the Test Specification and Procedures Review Board 5 July 1967, Meeting No. 3; and (2) on Change 5 to the XECF test specification, approved by the Test Review Board 18 October 1967. Subsequent modifications to the test specification that would affect the results of these analyses will be covered by separately published supplements to this report. The operational specifications used for this report are summarized in Table 1-1. A blank column labeled "Updating Remarks" is provided in Table 1-1 so recipients of this report may incorporate changes made in the testing procedures after the report is issued.

TABLE 1-1

XECF TEST PLAN SUMMARY

<u>Test</u>	Spec. Ref. Para. RN-S-0314 <u>Modification No. 2</u>	<u>Principal Objectives</u>
Phase I Chilled Turbopump	II.D.2.a	Provide information for chilled pump startup, demonstrate the chamber pressure control loop performance, acquire information to establish the most desirable shutdown scheme for XE-1, and observe the effects of a simulated loss of propellant flow malfunction.
	Run 1	Demonstrate bootstrap at planned conditions.
	Run 2	Attempt bootstrap at marginal conditions.
	Run 3	Attempt bootstrap at marginal conditions.
	Run 4	Simulate a loss of propellant flow shutdown with sequential introduction of LH ₂ and ambient GHe through the cooldown system.
	Run 5	Simulate an inadvertent high LH ₂ flow.

<u>Description of Test</u>	<u>Updating Remarks</u>
<p>The initial run tank pressure will be set at 35 psia. The pump will be prechilled and the reactor core will be at ambient temperature. The test will be initiated by opening PDSV and the pressure control loop will be closed when the nozzle tube outlet temperature reaches a preplanned value.</p> <p>Same as Run 1 except the tank pressure will be reduced to 25 psia.</p> <p>Same as Run 1 except the tank pressure will be set at 27 psia.</p> <p>The run tank line, pump and cooldown supply line will be prechilled, and the cooldown supply line pressure regulated to 50 psia. The test will be initiated by opening PDSV. TPCV will be stepped to 80° when the nozzle tube outlet temperature reaches a preplanned value. When pump discharge pressure reaches 50 psia the CSV will be opened. When the pump discharge pressure reaches 100 psia the TPCV will be stepped closed to simulate loss of flow.</p> <p>The run tank pressure will be set at 60 psia and V-5002 tank pressure at 100 psia. The pump and emergency cooldown line will be chilled. LH₂ flow will be initiated by opening PDSV. When the reflector inlet temperature reaches 200°R, PCV-472 will be stepped open to 30° and PDSV closed. After 3 sec, PCV-472 will be closed and PDSV reopened. V-5002 tank pressure will be increased to 400 psia. When T_c reaches 400°R PCV-472 will be stepped open to 30° and PDSV closed. After 3 sec, PCV-472 will be closed. TPCV remains closed during the test.</p>	

TABLE 1-1 (Cont.)

XECF TEST PLAN SUMMARY

<u>Test</u>	Spec. Ref. Para. RN-S-0314 <u>Modification No. 2</u>	<u>Principal Objectives</u>
	Run 6	Simulate an inadvertent high LH ₂ flow.
Phase II Warm Turbopump	II.D.2.b	Provide information for developing optimum warm pump startup procedures. Verify computer predictions and operation of the chamber pressure control loop, and observe the effects of a simulated loss of propellant flow malfunction.
	Run 1	Demonstrate bootstrap at planned conditions.
	Run 2	Simulate a loss of propellant flow shutdown with sequential introduction of LH ₂ and GH ₂ through the cooldown system.
	Run 3	Demonstrate the controlling action of the chamber pressure control loop.
Phase III Conditional Tests	II.D.2.c	To provide additional tests if further operator training is required.
	Run 1	Attempt a warm turbopump bootstrap at marginal conditions.
	Run 2	Demonstrate fixed TPCV startup with a warm pump.
Phase IV Vibration Tests	II.D.2.d	To determine the resonances, nodal deflections and amplification factors of the test stand, and what response the XE-1 will have to its vibration environment.

<u>Description of Test</u>	<u>Updating Remarks</u>
<p>Similar to Run 5 except the initial V-5002 tank pressure will be 400 psia. When the reflector inlet temperature reaches 200°R, PCV-472 will be stepped open to 30° and PDSV closed. After 10 sec the run will be terminated by closing PCV-472.</p>	
<p>Similar to Run 1 of Phase I except the pump will not be chilled; the test will be initiated by opening PSV and the pressure control loop will be closed when the nozzle tube outlet temperature reaches a preplanned value.</p> <p>Similar to Run 4 of Phase 1, except the pump will not be chilled, the test will be initiated by opening PSV and ambient GH₂ will be used in place of GHe after the emergency shutdown.</p> <p>Similar to Run 1 of Phase II, except the run tank pressure will be set at 60 psia, and a chamber pressure of 35 psia demanded.</p>	
<p>Similar to Run 1 of Phase II, except the tank pressure will be 25 psia, and pressure control loop closing will be based on results of Phase II, Runs 1 and 2.</p> <p>Similar to Run 1 of Phase II, except the pressure control loop will be open and the TPCV will be stepped to a fixed position.</p>	
<p>The engine will be excited by a sinusoidal force with the excitation points located at the nozzle-pressure vessel interface. The frequency range from 5 to 1500 cycles per second will be investigated.</p>	

The engine system will be operating under transient conditions throughout all testing. Transient analyses of the system have been made for each test phase. Phase I covers initial engine startup with the turbopump pre-chilled to liquid-hydrogen temperature and provides for simulation of a loss-of-propellant-flow malfunction. Phase II covers initial engine startup with a warm turbopump and operation of the chamber-pressure control loop and provides for simulation of a loss-of-propellant-flow malfunction. Phase III covers tests designated to be performed if additional runs are required for operator training. Phase IV provides for determination of engine and test-stand resonance frequencies.

This report is expected to be used as a working document for analysis of test results and therefore contains a description of the engine and major facility systems, predictions for each test, and detailed descriptions of pertinent engine transducer locations.

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3. Reactor Assembly

- a. Reflector
- b. Shield
- c. Core

4. Thrust-Structure Assembly

- a. Test-Stand Adapter
- b. Upper Thrust Structure
- c. External Shield
- d. Lower Thrust Structure

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2.2 COMPARISON OF CFDTS, XECF, AND XE

The CFDTS, XECF, and XE systems are similar to each other. The differences that could have a minor influence on the operational characteristics of the systems are detailed in Table 2-1.

Additional design information for XECF (including component flow and heat-transfer coefficients used in the computer model for performing pretest predictions) may be found in Report RN-S-0289, XE-Engine Systems Analysis Design Data Book.

TABLE 2-1

COMPARISON OF CFDTS, XECF AND XE SYSTEMS

<u>ITEM</u>	<u>CFDTS</u>	<u>XECF</u>	<u>XE</u>
1. PROPELLANT FEED SYSTEM			
a. <u>Pump Inlet Line</u>			
(1) Flowmeter	One 8-inch and one 4-inch turbine type flowmeter	One 8-inch turbine type	Same as XECF
(2) Cooldown Lines	Cooldown port blanked off	Five-inch cooldown lines feed to pump inlet line	Same as XECF
(3) Propellant Shutoff	Butterfly type valve, pneumatically actuated	Poppet type valve, spring actuated to close, pneumatically actuated to open	Same as XECF
b. <u>Turbopump Assembly</u>			
(1) Bearing Coolant Flow	----	The shaft to bearing retaining labyrinth annular flow area is reduced from that of CFDTS (708800-79, S/N 10)	Same as XECF
(2) Turbine Inlet Nozzle	----	The turbine inlet nozzle flow area is about 4% larger than that of CFDTS	Same as XECF
c. <u>Pump Discharge Line</u>			
(1) Length	----	Approximately 50 inches longer than CFDTS	Same as XECF
(2) Pump Discharge Shutoff Valve	Six-inch butterfly type valve	Five-inch butterfly type valve	Same as XECF
(3) Pump Discharge Vent Valve	Two-inch butterfly valve	Five-inch butterfly type valve	Same as XECF

TABLE 2-1 (cont.)

	<u>ITEM</u>	<u>CFDTS</u>	<u>XECF</u>	<u>XE</u>
	(4) Vent Line	Two-inch diameter	Five-inch diameter	Same as XECF
d.	<u>Turbine Inlet Line</u>			
	(1) Length	----	Approximately 50 inches longer than CFDTS	Same as XECF
	(2) Jacketed Section	Jacketed from hot-bleed port to pressure vessel forward flange area	Jacketed at elbow only at hot-bleed port or about one half as long as CFDTS	Same as XECF
	(3) Component Sequence	Venturi Meter, Overspeed Trip Valve, Turbine Power Control Valve	Venturi Meter, Turbine Power Control Valve, Turbine Blocking Valve	Same as XECF
e.	<u>Diluent Line</u>	Two-Inch Line, 67 inches long	Three-inch line, 107.5 inches long with 2-inch reducer at dome	Similar to XECF no two inch reducer
		Flow measuring orifices	Venturi flow meter	Same as XECF
		Two-inch, ON/OFF butterfly type valve	Flow restrictions orifice, 2.167 in., dia	Same as XECF, 1.937 in., dia
f.	<u>Turbine Exhaust System</u>	Twin exhaust lines, manifolding in upper thrust structure and exhausting to a separate ejector	Twin lines and nozzles discharging into the facility exhaust duct in the vicinity of the engine nozzle exit.	Same as XECF

TABLE 2-1 (cont.)

<u>ITEM</u>	<u>CFDTS</u>	<u>XECF</u>	<u>XE</u>
2. THRUST CHAMBER ASSEMBLY			
a. <u>Pressure Vessel</u>			
(1) Closure (Dome)	Lugs welded on closure flange for attachment to lower thrust structure	Closure flange diameter enlarged to allow for attachment to the lower thrust structure	Same as XECF
(2) Cylinder	Support brackets for turbine inlet line	Line mounting brackets removed	Same as XECF
	No instrumentation brackets	Two instrumentation brackets bolted to forward flange	Same as XECF
(3) Nozzle Flange	Instrumentation brackets	Removed CFDTS instrumentation brackets and added XECF brackets	Same as XECF
	No turbine exhaust line support bracket lugs	Added turbine exhaust line support lugs	Same as XECF
(4) Nozzle Tubes			
(a) Design	S/N 23	Same hardware as CFDTS	S/N 30
(b) Hot Side Effective Throat Area	58.30 in. ²		58.2463
(c) Minimum Coolant Flow Area	6.12 in. ²		6.4 in. ²

TABLE 2-1 (cont.)

<u>ITEM</u>	<u>CFDTS</u>	<u>XECF</u>	<u>XE</u>
(5) Hot Bleed Port	Jacketed line to hot-bleed port interface	Changed CFDTS design to allow for mating to the XECF/XE jacketed line	Same as XECF
3. REACTOR ASSEMBLY			
a. Design	Refurbished A-1 Reactor (Mostly instrumentation deletions)	Same hardware as CFDTS	A-5 Type
b. Core	Unfueled	Unfueled	Fueled, 6% increase in core ΔP
c. Reflector	Stationary Drums No Drum Actuators Inner reflector with A1 Barrel	Stationary Drums Dummy Drum Actuators Same hardware as CFDTS	Movable Drums Live Drum Actuators Thicker inner reflector and A1 barrel deleted
4. THRUST STRUCTURE ASSEMBLY			
a. <u>Test Stand Adapter</u>	None	Added test stand adapter as transition section from test stand to upper thrust structure	Same as XECF
b. <u>Upper Thrust Structure</u>			
(1) Length	----	Approximately 50 inches longer than CFDTS	Same as XECF
(2) External Shield	None	Installed between upper and lower thrust structures	Same as XECF
(3) Lower Thrust Structure			
a. Material	Aluminum	Titanium	Titanium with thinner structural sections

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3.0 TEST FACILITIES

A brief description of the ETS-1 test facility is presented herein; a more complete description is presented in Report NTO-R-0086, ETS-1 Facility Data Book.

3.1 INTRODUCTION

The Engine Test Stand No. 1 (ETS-1) complex provides facilities required for the cold-flow testing of the NERVA XE engine (XECF). An aerial photograph of the ETS-1 complex is shown in Figure 3-1. In addition to the test stand, the complex includes the engine test compartment (ETC), nuclear exhaust system (NES), the process systems, instrumentation and control systems, and an electric-power generation and distribution system. Also, ETS-1 provides the safety systems and emergency equipment and radiation shielding for the protection of personnel, facility components, and test hardware.

To support the test operations at ETS-1, a complete engine maintenance, assembly, and disassembly (E-MAD) facility has been constructed. The facility will be used for assembly and checkout of the engine prior to testing and for postoperative examination of the engine after testing.

Figure 3-1 - ETS-1 Complex

3.2 TEST STAND

The test stand (Figure 3-2) supports the test engine, the 77,000-gallon LH₂ run tank (V-5001), and the miscellaneous piping systems required for engine operation. The structure is made of aluminum and is formed by four main vertical columns that are connected by a network of cross braces and trusses. The engine load is transmitted to the main support structure through four thrust columns and the thrust support ring.

At the test stand, the test hardware is mated with the facility to provide an integrated test system. The fluid transfer systems connect to the test stand to provide engine coolant, postoperational cooldown fluids, pneumatic actuation supply fluids, inlet gas purge, water for cooling facility components and shielding, and steam for the NES.

Figure 3-2 - ETS - Configuration-Control Test-Stand Section

3.3 ENGINE TEST COMPARTMENT

The engine test compartment (ETC) has four basic functions: (1) to provide a safe, oxygen-free operating environment for the engine during the test; (2) to permit reduction in ambient atmospheric pressure around the engine in order to partially simulate space environmental conditions; (3) to reduce the damaging effects of radiation on the test-system components located outside the compartment; and (4) to allow greater personnel access to the facility areas after engine shutdown.

A sketch of the engine test compartment is shown in Figure 3-3. The walls consist of four radiation shields: two movable side shields, S-1 and S-2, (one at each side of the test stand); a top shield, S-5; and a bottom shield, S-4. A donut-shaped intermediate shield (S-6), half of which is attached to each side shield, mates with the external engine shield located at the upper end of the lower thrust structure when the two side shields are engaged in the test position. In this position, the shields reduce the external radiation levels during and immediately after the test run. Seals are used between the two side shields, between the side and bottom shield, and between the side and top shield to preclude entry of air into the compartment.

Neutron detectors, used to provide the primary nuclear input signal to the engine control and safety systems, are contained in three instrumentation packets located in the S-2 shield.

Figure 3-3 - ETC Shield Configuration

3.4 NUCLEAR EXHAUST SYSTEM

The nuclear exhaust system (NES) contains two major subsystems: the duct assembly and the steam-generator system. The duct assembly directs the hydrogen exhaust gases expelled from the engine away from the test stand so they may be burned safely and assists in reducing the pressure in the ETC during engine operation. The steam-generator system provides a continuous flow of steam to the duct during engine operation. The steam flow ejected through the duct reduces the ETC pressure during engine startup and, should sudden termination of hydrogen flow to the engine occur, prevents the back flow of air into the system.

3.4.1 Duct Assembly

3.4.1.1 Design

The duct assembly is located in a concrete vault directly below the engine test position (see Figure 3-2). The exhaust end of the duct vault is open to permit installation and removal of the duct. At the conclusion of testing, an aluminum-covered concrete door can be moved across this vault opening to shield personnel from residual radiation.

The duct consists of the primary, elbow, and secondary sections. It is fabricated from type-347 stainless steel. Two types of double-wall construction are used to provide longitudinal channels for the flow of cooling water between the inner and outer walls. The primary and secondary sections are constructed of sheet and angle sections welded together to provide rectangular channels. The elbow section is constructed of round tubes that are welded together. In addition, the elbow section is provided with an additional water jacket to prevent entrance of air into the duct if the tubular wall construction in the elbow should fail.

The duct configuration is shown in Figure 3-4. The primary section is designed as a second-throat supersonic diffuser, the first throat being that of the test-engine nozzle. To minimize the heat flux on the elbow, the supersonic exhaust stream that enters the duct is "shocked down" to a subsonic stream in the second-throat portion of the duct. The secondary section is a cylindrical duct that carries the exhaust gases away from the test stand. The steam ejector consists of a series of two-dimensional sonic nozzles attached to an uncooled torus at the inlet of the secondary section. The nozzles discharge the steam downstream along the inner surface of the duct. In Figure 3-4, an ejector nozzle is shown in the enlarged sketch.

3.4.1.2 Performance

The extent to which the duct is expected to develop and maintain the desired environmental conditions in the engine test compartment is indicated by the relationship between the engine-compartment pressure and the engine-nozzle-chamber pressure illustrated in Figure 3-5. The minimum engine-compartment pressure due to secondary ejection alone is about 7.5 psia. As the engine chamber pressure increases to approximately 140 psia, the expansion process in the primary section is sufficient to provide an engine-compartment pressure of approximately 1 psia.

3.4.2 Steam-Generator System

The steam-generator system consists of three subunits or modules connected to a common steam-collection and -discharge plenum. Each module consists of a steam generator with control, safety, and sequence equipment that renders it capable of operating independently of the other modules or as an integrated unit of the steam-generator system.

The steam-generator system has been designed to produce a normal output of superheated steam in accordance with the following specification:

NOTES:
 1. DIMENSIONS ARE IN INCHES.
 2. DIAMETER ARE INTERNAL.

Figure 3-4 - Nuclear-Exhaust-System Duct Configuration

- NOTES: 1. TURBINE EXHAUST FLOW AT DESIGN VALUE
2. EJECTOR STEAM SUPPLY; 111 psia, 1380°R,
139 LB/SEC
3. AMBIENT PRESSURE, 12.8 psia

Figure 3-5 - Engine-Compartment Pressure vs Engine Chamber Pressure

Steam Temperature	1300 $\pm$ 100°F
Steam Pressure (Minimum)	130 psia
Weight Flow (Minimum)	120 lb/sec

Each steam generator is designed to produce steam at a rate in excess of 65 lb/sec; thus, the required normal output for the system (120 lb/sec) can be met by two modules, with the third kept on standby.

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3.5 PROCESS SYSTEMS

The fluid process systems provide the storage vessels and transfer piping for the various fluids required for engine testing. The primary fluids are gaseous helium, gaseous nitrogen, gaseous hydrogen, liquid hydrogen, liquid nitrogen, and water. A simplified composite flow diagram of these process systems (less the water system) is shown in Figure 3-6. Table 3-1 provides the locations (the flow-diagram coordinates and transfer-line identification number) of the remotely operated valves, globe valves, pressure-reducing valves, check valves, pressure-control valves, filters, and flowmeters shown in Figure 3-6.

3.5.1 High-Pressure Gaseous Systems

3.5.1.1 Gaseous-Nitrogen System

The gaseous-nitrogen system provides nitrogen for: (1) the actuation of remotely operated facility valves to purge the engine, exhaust duct, and facility and (2) pressurization of liquid-nitrogen, liquid-oxygen, and propane storage vessels. The gaseous nitrogen system consists primarily of three high-pressure vessels (V-3201, V-3202, and V-3203) and associated transfer piping. In addition, a separate GN_2 system, using four 3,500 psia storage vessels, was added to the facility to supply nitrogen for inerting of the duct vault and pipe chase.

3.5.1.2 Gaseous-Helium System

The gaseous-helium system provides helium for actuation of remotely operated engine valves and for purging of the engine and facility. Also, gaseous helium is being considered as an inert propellant for an alternative cooldown system. The gaseous-helium system consists mainly of the three high-pressure vessels (V-3204, V-3205, and V-3206) and transfer piping.

Figure 3-6 - Schematic Composite Flow Diagram of Fluid Process Systems

TABLE 3-1

FACILITY VALVE, FILTER, AND FLOWMETER LOCATIONS

Component Identification Number	Component Location		Component Identification Number	Component Location	
	Line No.	*Schematic Coordinates		Line No.	*Schematic Coordinates
CHV-26	9-He-2	E7	GF-17	5-GH-2	G6
CHV-47	5-He-1	E5	GF-18	5-He-1	E5
CHV-71	203-He-1-1/2	E4	GF-29	18-GN-1	B9
CHV-117	15-GH-6	H6	GF-30	30-GN-4	C8
CHV-148	1-GH-1	G8	GF-432	106-He-6	D9
CHV-149	17-He-2	G4			
CHV-306	25-GN-12	F3	GLV-5	8-He-1	F8
CHV-468	32-GN-6	D8	GLV-53	--	G5
CHV-492	6-He-2	D6	GLV-196	106-He-6	D9
CHV-496	30-GN-6	C6	GLV-323	4-GN-1	C9
CHV-552	17-GN-12	F8	GLV-361	18-GN-1	B8
CHV-681	15-GH-6	D6	GLV-366	5-GN-1	C8
CHV-1721	15-GH-6	C4	GLV-387	3-He-1	E8
CHV-1722	9-GN-8	B6	GLV-405	5-He-1	E5
CHV-1877	--	D5	GLV-412	9-GN-8	B7
CHV-1878	--	D5	GLV-413	30-GN-4	C8
CHV-1885	225-LN-4	B6	GLV-422	5-He-1	E5
CHV-1908	237-GN-6	C6	GLV-589	--	B10
			GLV-621	--	C9
FE-12	4-LH-6	D5	GLV-794	30-GN-2	B7
FE-14	201-LH-8	E3	GLV-1201	100-GN-1	B7
FE-15	15-GH-6	D7	GLV-1743	50-GN-1	B7
FE-50	30-GN-6	C7	GLV-1988	227-LN-2	A10
FE-52	2-LN-4	A9			
FE-415	106-He-6	D8	FCV-50	30-GN-6	C7
			FCV-52	2-LN-2	B8
GF-11	1-GH-1-1/2	G8			
GF-12	3-He-1	E8	LF-6	3-LH-6	G4
GF-14	15-GH-6	D6	LF-7	4-LH-6	D4
GF-15	9-GN-8	C7			
GF-16	4-GH-9	G5	NV-550	6-GN-3/4	F8

* See Figure 3-6

TABLE 3-1 (cont.)

Component Identification Number	Component Location		Component Identification Number	Component Location	
	Line No.	*Schematic Coordinates		Line No.	*Schematic Coordinates
PCV-165	4-GH-6	G4	RSV-21	104-He-4	E10
PCV-179	17-GH-12	G7	RSV-22	104-He-4	E10
PCV-180	20-GH-12	G3	RSV-24	1-He-1-1/2	E9
PCV-248	1-GH-1-1/2	G8	RSV-26	115-GH-4	F10
PCV-250	5-GH-2	G6	RSV-27	115-GH-4	F10
PCV-251	15-GH-6	D6	RSV-29	1-GN-8	C9
PCV-456	4-LH-6	B4	RSV-53	106-He-6	E9
PCV-471	106-He-6	D7	RSV-54	106-He-6	E9
PCV-472	4-LH-6	D5	RSV-77	1-He-1	C7
PCV-517	225-LN-4	B8	RSV-78	106-He-6	D7
PCV-579	203-GH-3	E3	RSV-80	1-LH-2	F7
PCV-621	9-GN-8	B6	RSV-83	3-LH-6	E7
PCV-754	--	B8	RSV-87	2-GH-6	G7
			RSV-105	5-He-1	E5
PRV-14	3-He-1	E9	RSV-106	5-LH-2	F6
PRV-26	17-He-2	E5	RSV-107	4-LH-6	E5
PRV-108	18-GN-2	B9	RSV-109	19-GH-2	G5
PRV-411	9-GN-8	B6	RSV-110	19-GH-4	G5
PRV-420	1-He-2	D9	RSV-128	3-LH-6	G4
PRV-426	4-GH-6	G5	RSV-129	3-LH-6	G4
PRV-438	9-GN-8	C6	RSV-132	201-LH-8	E3
PRV-439	4-He-2	E4	RSV-134	30-GN-6	C6
PRV-869	30-GN-6	C7	RSV-142	203-He-1-1/2	E4
			RSV-185	5-GH-2	G6
RSV-1	103-GN-4	B10	RSV-186	4-GH-6	G4
RSV-2	103-GN-4	B10	RSV-194	--	G9
RSV-6	109-GN-4	C10	RSV-201	15-GH-6	H6
RSV-7	109-GN-4	C10	RSV-222	9-GN-8	C6
RSV-11	106-GN-4	D10	RSV-245	1-GN-8	C9
RSV-12	106-GN-4	D10	RSV-246	1-GH-6	G9
RSV-16	112-GN-4	D10	RSV-247	1-He-2	D9
RSV-17	112-GN-4	D10	RSV-252	3-LH-6	E6

* See Figure 3-6

TABLE 3-1 (cont.)

Component Identification Number	Component Location		Component Identification Number	Component Location	
	Line No.	*Schematic Coordinates		Line No.	*Schematic Coordinates
RSV-255	9-He-2	E7	RSV-460	--	D6
RSV-257	17-GH-12	G7	RSV-515	123-GH-6	F10
RSV-258	2-GH-6	G7	RSV-516	123-GH-6	F10
RSV-271	--	C9	RSV-519	120-GH-6	G10
RSV-273	1-GN-8	C9	RSV-520	120-GH-6	G10
RSV-274	1-GH-6	H9	RSV-523	117-GH-6	H10
RSV-275	1-He-2	D9	RSV-524	117-GH-6	H10
RSV-276	1-GH-1-1/2	G8	RSV-539	32-GN-6	D7
RSV-283	4-GH-3	G6	RSV-543	--	D6
RSV-284	17-He-2	F4	RSV-544	--	D5
RSV-286	5-GH-6	G7	RSV-545	225-LN-6	B6
RSV-287	15-He-2	F4	RSV-548	237-GN-6	C6
RSV-324	32-GN-6	D8	RSV-621	2-GN-1-1/2	C9
RSV-325	18-GN-2	B10	RSV-701	227-LN-2	A10
RSV-326	2-LN-4	B10			
RSV-327	--	B10	RV-1714	203-He-1-1/2	E4
RSV-383	1-GH-1-1/2	G8			
RSV-390	20-GH-12	G3			
RSV-441	201-GH-2	G5			
RSV-446	204-He-1	D4			
RSV-454	15-GH-6	D6			
RSV-455	203-He-1-1/2	E4			

* See Figure 3-6

3.5.1.3 Gaseous-Hydrogen Systems

The gaseous-hydrogen system provides hydrogen for the pressurization of three liquid-hydrogen Dewars: the main storage Dewar, V-3801 (to facilitate the transfer of liquid hydrogen to the propellant run tank, V-5001, and the high-pressure liquid-hydrogen Dewar, V-5002); the propellant run tank, V-5001 (to provide the desired engine tank pressure); and the high-pressure liquid-hydrogen Dewar, V-5002 (for emergency engine cooldown). In addition, the system supplies hydrogen for actuation of the reactor control drums and the turbine-power control valve. The primary components are three high-pressure vessels (V-3207, V-3208, and V-3209) and transfer piping.

3.5.2 Low-Pressure Liquid-Hydrogen System

The low-pressure liquid-hydrogen system provides hydrogen to the run tank, V-5001, and the high-pressure Dewar, V-5002. The system also supplies liquid hydrogen for conversion to gaseous hydrogen. The system consists primarily of the main storage Dewar, V-3801, and transfer piping.

3.5.3 High-Pressure Liquid-Hydrogen System

The high-pressure liquid-hydrogen system provides the delivery capability for engine cooldown (primarily during emergency shutdown) and consists mainly of the high-pressure storage Dewar, V-5002, and transfer piping.

3.5.4 Propellant Feed System

The propellant feed system consists primarily of the liquid-hydrogen run tank, V-5001, and transfer piping.

3.6 TEST-STAND CONTROL SYSTEM

The main function of the test-stand control system (TSCS) is to provide the overall control and monitoring requirements of ETS-1 and to integrate the engine-oriented facility and engine control and monitoring system. Specifically, the TSCS provides:

- (1) Operating control for the engine control system, including the operator consoles.
- (2) Operation of the engine-oriented facility controls system.
- (3) Test-stand nuclear instrumentation for nuclear-power monitoring.
- (4) Conditioned signals to the data-acquisition system for recording of test data.
- (5) Integration of the systems that directly control and monitor the engine and test stand into an overall control system.
- (6) Capability for integrated system verification through simulation of the engine and TSCS controlled facility parameters.
- (7) Operator training by means of simulation of engine and facility parameters.
- (8) Sufficient information and control to permit safe performance of all TSCS functions during testing.
- (9) The engine safety system (ESS) that includes scram, emergency shutdown, and other emergency actions during testing.

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3.7 FACILITY INSTRUMENTATION AND CONTROL SYSTEM

The facility instrumentation and control system consists of the facilities control system (FCS), data-acquisition system (DAS), facility safety system, power system, and communications and television.

The FCS provides equipment to control and indicate conditions and to buffer signals for the test-stand support equipment and the fluid process subsystems. This system also conditions and buffers facility signals to be recorded by the DAS. The DAS accepts conditioned signals from the facility and TSCS signal conditioners and provides analog and digital recordings.

Power to operate ETS-1 comes from three primary sources: Nevada Power and Light Company, three caterpillar diesels, and batteries. During nontesting periods, power is supplied by the Nevada Power and Light Company. During test periods, the essential-bus loads will be supplied by three 150-kw diesel units. Instrument-bus loads will be supplied by two 500-kw diesels. Utility loads will be supplied by the Nevada Power and Light Company. A switching system is provided to: (1) switch the essential loads to the Nevada Power and Light Company should the diesels fail or (2) switch the utility load to the diesel units should power be interrupted from the Nevada Power and Light Company supply. In addition to the backup provided within the normal power distribution system, 28-vdc power is provided by batteries as backup to the dc rectifiers that operate off the essential-load bus and supply power for critical pilot valves, relays, instrumentation, and control circuits.

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4.0 TEST PREDICTIONS

The predicted behavior of the XECF system during each test planned for the XECF test program is discussed in the following subsections. Report RN-S-0314, XECF Test Specification, NRO Modification No. 2, approved by the Test Specification and Procedures Review Board 5 July 1967, Meeting No. 3 and Change No. 5 to the XECF test specification approved by the Test Review Board 18 October 1967 were considered the primary authority for establishing the test conditions and operational sequence.

The test-prediction analysis indicated that, under all test conditions considered, the test-parameter limits listed in Table II.D.1 of Report RN-S-0314 would never be exceeded; and no unsafe conditions were disclosed that could result in damage to the test article or facility.

The predicted engine characteristics were obtained by using transient engine simulation program 16179, with the printout time interval generally set for 1 sec. The 16179 program is a modification of the 12013 program, the logic and equations of which are presented in Report RN-S-0114 Transient Engine Simulation Program Aug. 1964 (U)

The ability of the computer program to predict engine start-transient characteristics was tested by performing posttest computer runs for CFDTs tests conducted at XECF back-pressure conditions. In general, the computed parameters agree well with test data; however, discrepancies were noted for some parameters, particularly at reduced run-tank pressures. The probable influence of these discrepancies at XECF test conditions is more fully evaluated in discussions applicable to each particular test.

Program 16179 is made so that, at the time of test initiation (time zero), the PDSV or PSV steps open and system pressures and flow rates are instantaneously established. Therefore, as may be seen in the plots of predicted engine characteristics (Figures 4-1 through 4-21), the system

pressures and flow rates are fully developed at the start of each test. Several modifications have been made to this program to improve its ability to predict engine parameters during chilldown and initial system startup. These modifications include simulation of the turbopump suction and discharge lines, pump-bearing coolant flow, nozzle-bolt coolant flow, flow choking in the nozzle coolant tubes, and compressible flow through the core inlet orifices. The results of recent turbopump tests at the Lewis Laboratory were combined with AGC turbopump data to provide a best estimate of pump efficiency. The combined turbopump data were based on the Lewis Laboratory data at 1500 rpm, and on AGC data for pump speeds above 8000 rpm with a smooth merging of data at intermediate speeds between these values.

In addition to the above changes, the following parameters that influence the engine start characteristics were assumed at fixed values in performing test predictions (they are specified as a range of values or as approximations):

1. The initial temperature of all unchilled parts was taken as 540°R.
2. The engine-test-compartment pressure was assumed to be constant at 7.5 psia.
3. The temperature of liquid hydrogen in the run tank and of all metal parts chilled with liquid hydrogen was assumed to be 38°R.

4.1 PHASE I - CHILLED-PUMP STARTUP

Phase I tests will provide information for developing optimum chilled-pump startup procedures for XE-1. They will provide a comparison with CFDTS tests, verify the computer models for prediction of XE-1 startup, and confirm the performance of the chamber-pressure control loop. A further purpose of this phase of testing will be to acquire information on line warmup, valve sequencing, and shutdown fluid control to establish the most desirable shutdown scheme for XE-1 within the range of XECF operation. A loss-of-propellant-flow malfunction will be simulated, and the effects on performance of both facility and engine systems will be obtained. Test data to evaluate the consequence of an inadvertant high LH₂ flow malfunction from pressure, power, and reactivity standpoints will be acquired.

4.1.1 Run 1

The run-tank line and the pump will be chilled until LH₂ conditions exist at the pump discharge. Initial run-tank pressure will be set at 35 psia. Prior to initiation of flow, the reactor temperature (as indicated by reactor-core temperature measurements) will be 500 to 560°R. The engine-test-compartment pressure will be 7.5 psia. The test will be initiated by opening the PDSV with the TPCV closed and the pressure-control loop opened. The temperature of the nozzle-tube outlet fluid will decrease to 200°R approximately 12 sec after initial opening of the PDSV, at which time the pressure-control loop will be closed and a chamber pressure of 60 psia will be demanded. Closing of the pressure-control loop will initiate opening of the TPCV and allow GH₂ to flow to the turbine from the dome and hot-bleed port. The turbo-pump will accelerate from 0 rpm at 15 sec to about 750 rpm at 21 sec, after which it will accelerate more rapidly to a maximum speed of 8440 rpm at approximately 30 sec. Under XECF test conditions, the TPCV will require approximately 14 sec to open from 0 to 80° and will therefore reach the 80° open position at 26 sec. The system plenum pressures approximately follow the increase in pump speed, with the pump discharge pressure reaching a maximum pressure of 172 psia at 30 sec. Flow rates also increase with pump speed but

decrease at a slower rate after the maximum pump speed is attained because of reduction in engine flow impedance as the engine is chilled by the liquid hydrogen. Predicted plots of major engine parameters as a function of test time are presented in Figures 4-1, 4-2, and 4-3.

The conditions for this test are similar to the conditions during CFDTS Test No. 1.2-02-NNS-015, and the predicted engine behavior agrees closely with the test results. During CFDTS Test -015, a maximum pump speed of 8210 rpm was attained 29.5 sec after test initiation.

4.1.2 Run 2

Run 2 is to be a repeat of Run 1 except that the initial run-tank pressure will be set at 25 psia. These initial conditions are nearly identical to those of CFDTS Test No. 1.2-02-NNS-026, which was conducted with a run-tank pressure of 24.3 psia, a back pressure of approximately 7.5 psia, and with the turbopump chilled to LH_2 temperature. Attempts to duplicate the results of CFDTS Test No. -026 with the computer model have been of limited success because of the lack of turbopump data at very low pump speeds and low net positive suction head. Examination of the test data indicates that two-phase flow probably persists in the pump throughout most of the test. Insufficient data are available at these conditions to provide the computer model with the ability to compute pump head rise and work for two-phase flow. Several other turbopump parameters (negligible at higher system pressures) may also become significant at these low-pressure conditions. These parameters include turbine efficiency when the pressure ratio across the turbine is very low and the effects of the pump-bearing coolant flow being injected into the turbine upstream of the second-stage turbine nozzles.

Predicted plots of major engine parameters as functions of test time for Run 2 are presented in Figures 4-4, 4-5, and 4-6. The computer model indicates that the nozzle-tube outlet temperature will reach 200°R

Figure 4-1 - XECF Test Prediction, Phase I, Run 1, Chilled Pump, $P_T = 35$ psia

Figure 4-2 - XECF Test Prediction, Phase I, Run 1, Chilled Pump, $P_T = 35$ psia

Figure 4-3 - XECF Test Prediction, Phase I, Run 1, Chilled Pump, $P_T = 35$ psia

Figure 4-4 - XECF Test Prediction, Phase I, Run 2,
Chilled Pump, $P_T = 25$ psia

Figure 4-5 - XECF Test Prediction, Phase I, Run 2,
Chilled Pump, $P_T = 25$ psia

Figure 4-6 - XECF Test Prediction, Phase I, Run 2,
Chilled Pump, $P_T = 25$ psia

approximately 20 sec after initial opening of the PDSV, at which time closing of the pressure-control loop will initiate opening of the TPCV and allow GH_2 to flow to the turbine. The computer model shows an increase in pump speed to a maximum value of about 1075 rpm 54 sec after test initiation, after which speed decays very gradually. By contrast, the data from CFDTs Test No. -026 indicated that the pump speed increased slowly to 1500 rpm at 115 sec after test initiation, after which a rapid, minor bootstrap occurred to about 2800 rpm at 130 sec, with subsequent speed decay.

4.1.3 Run 3

Run 3 is to be a repeat of Run 1 except that the initial run-tank pressure will be set at 27 psia.

The discussion of problems associated with pretest predictions for Run 2 is equally applicable to this run. Previous test experience has shown that the ability of the engine system to bootstrap is very sensitive to run-tank pressures in the range of 25 to 30 psia. The purpose of this run is to provide additional information on the sensitivity to bootstrap. Since a tank pressure of 27 psia lies between that of CFDTs Test No. -026 (24.3 psia) and that of CFDTs Test No. -024 (29.5 psia), maximum pump speed is expected to be between 2850 and 7400 rpm and to occur at some time between 62 and 130 sec after opening of the PDSV. The computer-model engine-chilldown analysis indicated that the temperature of the nozzle-tube outlet fluid will reach 200°R approximately 18 sec after initial opening of the PDSV.

4.1.4 Run 4

The run-tank line, the pump, and the cooldown supply line will be chilled to LH_2 temperatures. Initial tank pressure will be set at 35 psia and the ETC pressure will be 7.5 psia at test start.

V-5002 pressure will be set at 100 psia, and the cooldown line between PCV-472 and CSV maintained below 50 psia. The test will be initiated by opening the PDSV. When the nozzle-tube outlet temperature reaches 200°R approximately 12 sec after opening of PDSV, the TPCV will be stepped to a fixed position of 80°. The pump discharge pressure will reach 50 psia approximately 22 sec after initiation of the test, at which time the CSV will be opened. Pump discharge pressure will continue to increase and will reach a value of about 100 psia 25 sec after initiation of the test, at which time the TPCV will be stepped closed to simulate loss of flow.

The TPCV will close in approximately 0.25 sec, stopping the flow of GH_2 to the turbine. The turbopump will decelerate and the pump discharge pressure will decay rapidly, reaching 50 psia approximately 0.75 sec after the TPCV starts to close. The flow-failure detection system will detect the rapid decay of pump discharge pressure and initiate an emergency shutdown, opening PCV-472 to initiate flow of facility LH_2 from V-5002 to the engine system. PCV-472 will be controlled to a demanded nozzle inlet-pressure of 50 psia.

The 50 psia supply pressure of emergency-cooldown LH_2 will sustain about 6 lb/sec of LH_2 flow through the engine during this phase of the test, which will further cool engine components. About 41 sec after initiation of the test, ambient GH_e flow to the engine system will be established at a nozzle torus inlet-pressure of 100 psia. Predicted plots of engine parameters for this test are shown in Figures 4-7, 4-8 and 4-9.

No prediction was made of the system characteristics during the ambient facility GH_e flow phase of the test. Review of the results of a facility test (to determine the cooldown line warmup characteristics during expulsion of LH_2 and warmup of the cooldown line with gaseous helium through PCV-471) showed that during the first 10 sec of gaseous helium flow, LH_2 contained between PCV-472 and the LH_2 /gas cooldown line interface downstream of CHV-1721 boiled off into the GH_e flow resulting in erratic behavior of the

Figure 4-7 - XECF Test Prediction, Phase I, Run 4, Chilled Pump, $P_T = 35$ psia

Figure 4-8 - XECF Test Prediction, Phase I, Run 4, Chilled Pump, $P_T = 35$ psia

Figure 4-9 - XECF Test Prediction, Phase I, Run 4, Chilled Pump, $P_T = 35$ psia

cooldown line fluid temperature. The analytical model at present has no capability for computing this boil-off characteristic, and there is not sufficient test data at the specified test conditions to provide a meaningful estimate of the gaseous helium temperature transient. Examination of test data indicates that the cooldown line fluid temperature will be below 250°R until boil-off of the trapped LH₂ is completed, and that this will require at least 10 sec. At completion of LH₂ boil-off, the cooldown line temperature will increase rapidly to about 450°R, with subsequent warming of the engine system components. A discussion of cooldown line warmup characteristics is presented in Section 3.3.3.4 of NTO-R-0110 ETS-1 Test Summary Report, FEP Test Series (U) 26 June 1967.

During the time of flow from the emergency cooldown system, the 16179 computer model is operated in the open-loop mode, which assumes no flow through the diluent line. In actual practice, a small amount of flow will pass through the diluent line and will rejoin the main flow in the nozzle chamber via the hot-gas bleed port.

4.1.5 Run 5

The run-tank line, the pump and the cooldown supply line will be chilled to LH₂ temperature. Initial run-tank pressure will be 60 psia and the ETC pressure will be about 7.5 psia. V-5002 tank pressure will be set at 100 psia. The TPCV will remain closed throughout the test. Propellant flow to the engine system will be started by opening PDSV. When the reflector inlet fluid temperature reaches 200°R approximately 7 sec after PDSV opens, PCV-472 will be stepped open to the mechanical limit established for the XE tests (nominal 30%) and PDSV closed. PCV-472 will be held open for 3 sec and then closed. During the time that PCV-472 is open, the 100 psia pressure in V-5002 tank will produce an increase in nozzle flow to about 10 lb/sec and a more rapid cooldown of the engine components. Immediately after closing of PCV-472, the V-5002 pressure will be increased to 400 psia, and PDSV will be reopened to further chill the engine system. The nozzle chamber fluid

temperature will decrease to 400°R at approximately 37 sec, at which time PCV-472 will again be stepped open for 3 sec. Due to the 400 psia pressure in V-5002 and the low impedance of the chilled engine system, LH₂ flow will increase rapidly during this 3 sec period. Nozzle flow will be about 35 lb/sec immediately after opening of PCV-472 and will increase to about 42 lb/sec at the time PCV-472 is again closed. At the increased flow rate, engine components will chill quickly with the nozzle chamber fluid temperature decreasing to about 125°R at the time of PCV-472 closing. Predicted plots of major engine parameters as a function of test time are presented in Figures 4-10, 4-11 and 4-12. Since TPCV is closed throughout this test, the turbine and pump parameters are not significant and have been omitted from the figures.

4.1.6 Run 6

The run-tank line, the pump, and the cooldown supply line will be chilled to LH₂ temperatures. Initial run-tank pressure will be 60 psia and ETC pressure will be about 7.5 psia. V-5002 tank pressure will be set at 400 psia. The TPCV will remain closed throughout the test. Propellant flow to the engine system will be started by opening PDSV. When the reflector inlet fluid temperature reaches 200°R approximately 7 sec after PDSV opens, PCV-472 will be stepped open to the mechanical limits established for the XE test (nominal 30%) and PDSV closed. PCV-472 will be held open for 10 sec and the test then terminated by closing PCV-472. Predicted plots of major engine parameters as a function of test time are presented in Figures 4-13, 4-14 and 4-15. Since the TPCV is closed throughout the test, the turbine and pump parameters are not significant and have been omitted from the figures. The computer model indicates that the nozzle flow rate will be about 29 lb/sec upon opening of PCV-472 and the flow will increase to about 41 lb/sec at the time PCV-472 is again closed due to reduction in engine flow impedance as the engine is chilled by the liquid hydrogen. The nozzle chamber fluid temperature will decrease to about 145°R at the time the test is terminated.

Figure 4-10 - XECF Test Prediction, Phase I, Run 5, Chilled Pump, $P_T = 60$ psia

Figure 4-11 - XECF Test Prediction, Phase I, Run 5, Chilled Pump, $P_T = 60$ psia

Figure 4-12 - XECF Test Prediction, Phase I, Run 5, Chilled Pump, $P_T = 60$ psia

Figure 4-13 - XECF Test Prediction, Phase I, Run 6, Chilled Pump, $P_T = 60$ psia

Figure 4-14 - XECF Test Prediction, Phase I, Run 6, Chilled Pump, $P_T = 60$ psia

Figure 4-15 - XECF Test Prediction, Phase I, Run 6, Chilled Pump, $P_T = 60$ psia

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4.2 PHASE II - WARM-PUMP STARTUP TESTS

Phase II tests will provide information for developing optimum warm-pump startup procedures for XE-1. They will verify the computer models for prediction of initial portions of XE-1 startup and operation of the chamber-pressure control loop. A loss-of-flow malfunction will be simulated, providing data on facility and engine systems performance.

4.2.1 Run 1

The run-tank line will be chilled until LH_2 conditions exist at the PSV. Initial tank pressure will be set at 35 psia. Before flow is initiated, the reactor temperature (as indicated by reactor-core temperature measurements) will be 500 to 560°R and the engine-test-compartment pressure will be 7.5 psia. The test will be initiated by opening the PSV and will be terminated when any test-parameter limit is reached or when the chamber temperature reaches 200°R. The temperature of the nozzle-tube outlet fluid will decrease to 200°R approximately 23 sec after initial opening of the PSV, at which time the pressure-control loop will be closed and a chamber pressure of 60 psia will be demanded. Closing of the pressure-control loop will initiate opening of the TPCV and allow GH_2 to flow to the turbine. Predicted plots of major engine parameters as functions of test time are presented in Figures 4-16, 4-17, and 4-18. Figure 4-16 shows that the maximum predicted pump speed of 7780 rpm is achieved 67 sec after initiation of the test. The peak bootstrap conditions agree well with the results obtained from CFDTS Test No. 1.2-02-NNS-019, which was conducted under similar conditions. The test data indicated that a maximum pump speed of 7850 rpm occurred 64.3 sec after test initiation. The only pronounced difference between the performance predicted for Run 1 of XECF Phase II, and CFDTS Test No. -019 is that the computer model predicts a very slow increase in pump speed between the time of TPCV opening and 62 sec, followed by an abrupt bootstrap to the peak values. Examination of data from CFDTS Test No. -019 showed a greater pump acceleration before the

Figure 4-16 - XECF Test Prediction, Phase II, Run 1, Dry Pump, $P_T = 35$ psia

Figure 4-17 - XECF Test Prediction, Phase II, Run 1, Dry Pump, $P_T = 35$ psia

Figure 4-18 - XECF Test Prediction, Phase II, Run 1, Dry Pump, $P_T = 35$ psia

start of bootstrap, with low-frequency increasing-amplitude oscillations in pump speed and system pressures between the time the TPCV opened and the time at which the pump speed exceeded 4000 rpm. The oscillation in pump speed reached a maximum peak-to-peak amplitude of 2000 rpm. These oscillations (apparently due to two-phase flow in the turbopump) are not predictable with the present computer model.

The delay in opening of the TPCV until the nozzle-tube outlet-fluid temperature reaches 200°R is intended to eliminate this type of oscillation by providing sufficient cooling of the TPA to obtain pure liquid flow; however, the extent of cooling required is not precisely known, and some oscillations may occur. If pump speed oscillates, a lower nozzle-tube outlet-fluid temperature may be used during the next test as the point for opening the TPCV. Through this procedure, this test phase will be used to establish the point at which the TPCV can be opened and a smooth-pump-speed engine start can be obtained.

4.2.2 Run 2

A warm-pump test will be performed to establish the interactions between the normal LH₂ propellant line and high-pressure LH₂ from the cooldown line during emergency shutdown and to establish the nozzle-tube outlet-fluid temperature at which the TPCV can be opened without incurring pump-speed and system-flow oscillations. For this test the run-tank propellant line and the cooldown supply line will be chilled to LH₂ temperatures. The initial tank pressure will be set at 35 psia, and the ETC pressure will be 7.5 psia at test start. The TPCV will be in position control.

V-5002 pressure will be set at 100 psia and the cooldown line between PCV-472 and CSV maintained below 50 psia.

The test will be initiated by opening the PSV. When the nozzle-tube outlet temperature reaches 100°R approximately 29 sec after opening of the PSV, the TPCV will be stepped to a fixed position of 80°. The pump

discharge pressure will reach 50 psia approximately 63 sec after initiation of the test at which time CSV will be opened. Pump discharge pressure will continue to increase until a value of about 100 psia is reached 65.1 sec after initiation of the test, at which time TPCV will be stepped closed to simulate loss of flow. The TPCV will close in approximately 0.25 sec stopping the flow of GH_2 to the turbine. The turbopump will decelerate and the pump discharge pressure will decay rapidly, reaching 50 psia approximately 0.7 sec after TPCV starts to close.

The flow failure detection system will detect the rapid decay of pump discharge pressure and initiate an emergency shutdown opening PCV-472 to initiate flow of facility LH_2 from V-5002 to the engine system. PCV-472 will be controlled to a demanded nozzle inlet pressure of 50 psia. The 50 psia supply pressure of emergency-cooldown LH_2 will sustain about 6.6 lb/sec of LH_2 flow through the engine at the start of this phase of the test, which will further cool the engine components and cause the flow to increase to about 10 lb/sec after 15 sec. About 81 sec after initiation of the test, ambient GH_2 flow to the engine system will be established at a nozzle torus inlet pressure of 100 psia. Predicted plots of engine parameters for this test are shown in Figures 4-19, 4-20 and 4-21. No prediction was made of the system characteristics during the ambient facility GH_2 flow phase of the test for reasons explained in Section 4.1.4, Run 4 of this report.

4.2.3 Run 3

This test will be performed at minimum demanded chamber pressure to observe the controlling action of the TPCV. The run-tank line will be chilled to the PSV. Initial tank pressure will be set at 60 psia. Prior to initiation of flow, the reactor temperature (as indicated by reactor core temperature measurements) will be 500 to 560°R and the engine-test-compartment pressure will be 7.5 psia. The test will be initiated by opening the PSV. The nozzle-tube outlet-fluid temperature will reach 200°R approximately 12 sec after opening of the PSV, at which time the pressure-control

Figure 4-19 - XECF Test Prediction, Phase II, Run 2, Dry Pump, $P_T = 35$ psia

Figure 4-20 - XECF Test Prediction, Phase II, Run 2, Dry Pump, $P_T = 35$ psia

Figure 4-21 - XECF Test Prediction, Phase II, Run 2, Dry Pump, $P_T = 35$ psia

loop will be closed and a chamber pressure of 35 psia will be demanded. Because of the low demand pressure, the TPCV opens slowly, and flow of GH_2 to the turbine is insignificant until 19 sec. Plots of engine parameters predicted by the computer model for this test are shown in Figures 4-22, 4-23, and 4-24. As stated previously, the computer model is not capable of accounting for two-phase flow performance of the turbopump. The model must treat the pump flow as though it were all gas or all liquid. For the test conditions specified for this test, the computer treats the pump flow as gas for the first 29 sec. Under these conditions, it is assumed that no work is done by the pump; therefore, the pump accelerates rapidly to a speed of 6275 rpm at 29 sec. After 29 sec, the computer model treats the pump flow as all liquid. This treatment results in a sudden peak in system pressures and flow at 30 sec because the inertia accumulated by the pump is now converted into pump work, with a corresponding pump deceleration. Examination of data from CFDTS Test No. 1.2-02-NNS-030, which was a warm-pump startup at 69.4-psia tank pressure, indicates that the peak in pump speed, system pressures, and flow predicted at about 30 sec probably will not occur during an actual test. Instead, a two-phase flow condition may occur in the pump during the time period from 19 to 30 sec, which can result in oscillations in pump speed, system pressures, and flows. After about 31 sec, the pump flow should become fully liquid and the remainder of the computer-model test prediction should be a reasonable representation of the system characteristics.

Figure 4-22 - XECF Test Prediction, Phase II, Run 3, Dry Pump, $P_T = 60$ psia

Figure 4-23 - XECF Test Prediction, Phase II, Run 3, Dry Pump, $P_T = 60$ psia

Figure 4-24 - XECF Test Prediction, Phase II, Run 3, Dry Pump, $P_T = 60$ psia

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4.3 PHASE III - CONDITIONAL TESTS

Tests specified in this section are those tests designated to be performed if additional runs are required for operator training.

4.3.1 Run 1

This test will be a repeat of Run 1 of Phase II except that the initial tank pressure will be set at 25 psia, a chamber pressure of 50 psia will be demanded, and the nozzle-tube outlet-fluid temperature upon opening of the TPCV will be based on the temperature at which a smooth pump-speed start transient was obtained during Phase II, Runs 1 and 2.

The problems associated with predicting engine starts at low tank pressure, which were discussed in Section 4.1.2, are equally applicable to this test. The system characteristics for this test can probably be best defined by examining the data from Phase I, Run 2, except that a longer time will be required for the nozzle-tube outlet-fluid temperature to reach a prescribed value. The computer model indicated that the nozzle-tube outlet-fluid temperature would reach 200°R approximately 42 sec after initial opening of the PSV.

4.3.2 Run 2

Initial tank pressure will be set at 35 psia. The run-tank line will be chilled until LH_2 temperatures exist at the PSV. Before flow is initiated, the reactor temperature, as indicated by reactor core temperature measurements, will be 500 to 560°R, and the engine-test-compartment pressure will be 7.5 psia. The test will be initiated by opening the PSV. The nozzle-tube outlet-fluid temperature will decrease to 200°R approximately 23 sec after initial opening of the PSV, at which time the TPCV will be stepped from a closed position to a fixed position of 39.5°. Plots of the predicted engine

characteristics as functions of test time are shown in Figures 4-25, 4-26, and 4-27. The system characteristics during the first 64 sec of this test are quite similar to those of Phase II, Run 1, and the same comments are applicable. At about 64 sec, bootstrap of the engine occurs; but, because of the high impedance of the partially opened TPCV in the turbine feed line, a maximum pump speed of 1380 rpm occurs at 66 sec, after which pump speed decays very gradually. System pressures will follow the pump speed characteristics, with the pump discharge pressure reaching a maximum value of 39 psia at the time of maximum pump speed. Flow rates will increase through the test because of a reduction in engine flow impedance as the engine is chilled by the liquid hydrogen. The nozzle-chamber fluid temperature should reach 200°R about 87 sec after opening of the PDSV, at which time the test will be terminated.

Figure 4-25 - XECF Test Prediction, Phase III, Run 2, Dry Pump, $P_T = 35$ psia

Figure 4-26 - XECF Test Prediction, Phase III, Run 2, Dry Pump, $P_T = 35$ psia

Figure 4-27 - XECF Test Prediction, Phase III, Run 2, Dry Pump, $P_T = 35$ psia

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4.4 PHASE IV - VIBRATION TESTS

The purpose of the XECF vibration tests is to conduct a resonance survey of the XECF test article and the attached ETS-1 structure as a combined system. The results of these tests will determine what resonances, modal deflections, and amplification factors will be generated in the test stand and what response the XE-1 will have to its vibration environment.

A detailed analysis of the results expected from this test is presented in AGC Report RN-TM-0437, XE Engine Dynamic Modal Analysis, May 1966.

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5.0 INSTRUMENTATION

5.1 DISCUSSION

This section contains a brief description of the DAS and detailed drawings of transducers mounted on the nonnuclear engine components.

5.1.1 Data-Acquisition System

The ETS-1 DAS has the function of conditioning and recording engine and facility test information during testing. The DAS accepts an electrical signal from various transducers within the ETS-1 complex, conditions these signals for analog or digital recording, and stores the recorded data on magnetic tape. Data signals in the ETS-1 complex come from three major sources: engine diagnostic transducers, facility control systems, and the TSCS. There are about 1500 data channels from these sources.

The DAS comprises the following subsystems:

- a. Diagnostic Signal Conditioning
- b. Digital Data System
- c. Analog Recording System
- d. Events Recording System
- e. Patching Systems
- f. Digital Data Processer

The equipment is located in three major areas: the test-cell building, the forward control room, and the control-point building. The test-cell building contains the diagnostic signal conditioners and the signal-condition output patch. The forward control room contains data patch channels, amplifiers, filters, multiplexers, and analog-to-digital conversion equipment for the digital data system. The recorder room in the control-point building

contains the data formation and control logic for the digital data system, the analog recording system, and the analog record patch. The recorder room of the control point also contains the digital data system, the master control console, and the digital-tape transports.

A variety of facilities for processing and displaying data will be available on the site for ETS-1 tests. The following is a brief description of these systems and lists the primary end use for each.

5.1.1.1 Strip Charts

On-line strip charts will be used primarily to monitor "red-lined" parameters during test operations. These strip charts will also be used for quick-look evaluation of major test parameters immediately after a test is completed and for determining the time period of events of particular interest in order to establish the requirements for special data requests. Because of the laborious process and the inaccuracy associated with reading data from the strip charts, their further use is limited when processed narrow-band data become available.

a. Digital Data System

The digital data system utilizes computer-compatible magnetic tape to store digitized data obtained from transducers embedded in the hardware. Because of its high accuracy and its capability of handling large volumes of data rapidly and semiautomatically, the system represents the most significant and the principal recording means within the DAS. It is, therefore, the principal source of data for posttest analysis of steady-state and transient engine conditions. The limitations of this data process are: (1) it is not suitable for analyzing oscillating functions of medium or high frequency and (2) because of the time required for processing, the data are not available in readable form immediately after a test.

b. Analog Magnetic Tape

The analog magnetic-tape system provides a means for recording and producing wide-band frequency data. The data obtained from this system are used mainly for vibration and transfer-function analysis.

c. Oscillographs

In addition to magnetic-tape recording, wide-band analog data may be obtained from on-line oscillographs. These oscillographs are available for study shortly after the test; however, they cannot be subjected to the computerized calibration and frequency analysis that is available with analog magnetic-tape recording. Hence, the oscillograms are useful mainly as quick-look data that are superseded by the analog magnetic-tape data when available.

5.2 ENCLOSURES

5.2.1 System Schematic

A piping and instrumentation schematic diagram, illustrating the fluid flow paths and the relative location of engine diagnostic transducers, is presented in Figure 2-1.

5.2.2 Engine Transducer Locations

The locations of all unclassified transducers are provided by the measurements requirements list (MRL). The locations of transducers within the reactor are described by the MRL. However, the locations of transducers in the engine-system lines and other components are not well described by the MRL with respect to the component in which they are inserted. Therefore, detailed drawings of the locations of transducers for nonnuclear engine parameter measurements are shown in Figures 5-1 through 5-7.

For convenience, an alpha-numerical listing of instrument transducers is provided in Table 5-1, which provides the functional description and the appropriate figure number on which the transducer location appears.

Instrumentation transducers installed on the propellant feed line between the LH_2 run tank and the turbopump are shown in Figure 5-1.

The turbopump-discharge-line transducer locations are shown in Figure 5-2.

Figure 5-3 shows the transducers installed on the nozzle tube assembly, the hot-bleed port, and the bolt-coolant lines.

Locations of the diluent- and turbine-inlet-line transducers are presented in Figure 5-4.

Pressure-vessel instrumentation is shown in Figure 5-5.

Transducers installed on the turbine exhaust lines are shown in Figure 5-7.

5.2.3 Facility Transducer Locations

A simplified schematic diagram of the facility, showing the relative locations of temperature and pressure transducers, is presented in Figure 5-8. Table 5-2 provides the locations (the schematic diagram coordinates and transfer-line identification number) of the temperature and pressure transducers shown in Figure 5-8.

More detailed drawings of the location of transducers mounted on liquid hydrogen pressure vessels V-5001, V-5502, and V-3801 are shown in Figures 5-9, 5-10 and 5-11 respectively.

The location of instrumentation transducers installed on the gaseous helium, gaseous hydrogen, liquid hydrogen fill line, and the liquid hydrogen emergency cooldown line are detailed in the isometric schematics shown in Figures 5-12 through 5-15.

EST. ITEM WEIGHTS *																	
ITEM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
LB	190	61	10	20	40	50	17	39	25	53	30	326	18	75	48	105	560

* ALL STAINLESS STEEL EXCEPT ITEM 14, 90% ALUM
 ⊙ SENSING POINT

Figure 5-1 - Propellant Feed Line

PARAMETER CHANNEL

OUTLET

PRESSURE PT 110
PT 112
PT 114

TEMPERATURE TT 108
TT 109
TT 110

PUMP DIFFERENTIAL PRESSURE

HIGH LEG PD114H
LOW LEG (FIG 5-1) PD114L

EST ITEM WEIGHTS *								
ITEM	1	2	3	4	5	6	7	8
LB	125	20	70	165	80	80	20	20

* ALL ITEMS STAINLESS STEEL
● SENSING POINT

Figure 5-2 - Pump Discharge Line

<u>PARAMETER CHANNELS</u>	
<u>NOZZLE INLET MANIFOLD</u>	
PRESSURE	PT-124 PT-128
TEMPERATURE	TT-120 TT-121 TT-123
<u>NOZZLE TUBE</u>	
PRESSURE DROP	PD-133
HIGH LEG	PT-128
LOW LEG (FIG 5-5)	PT-210
<u>THRUST CHAMBER</u>	
PRESSURE	PT-148 PT-149 PT-151
TEMPERATURE	TT-138 TT-139 TT-144
<u>HOT BLEED PORT</u>	
<u>DILUENT ANNULUS</u>	
PRESSURE	PT-160 PT-168
TEMPERATURE	TE-143
<u>BOLT COOLANT LINE</u>	
PRESSURE	PT-172
PRESSURE DROP	PD-163
HIGH LEG	PT-172

Figure 5-3 - Nozzle Assembly; Hot-Bleed Port and Bolt Coolant Line

Figure 5-4 - Turbine Inlet Line and Diluent Line

Figure 5-5 - Pressure Vessel

Figure 5-6 - Turbopump Assembly

Figure 5-7 - Turbine Exhaust Lines

Figure 5-8 - Simplified Facility Schematic

INSTRUMENTATION DATA

INSTRUMENT NUMBER	SENSOR TYPE	INSTRUMENT NUMBER	SENSOR TYPE	LOCATION (FULL TO EMPTY)	VOLUME (BASED ON 69,534 gal. = 100%)		
					%	GALLONS	LBS
TT518	RTT	LT452	Resistor	360.68"	100	69,534	40,900
		LT451	Resistor	329.12"	90	62,500	36,800
TT517	RTT	LT450	Resistor	297.82"	80	55,500	32,600
		LT445	Resistor	266.53"	70	48,600	28,600
TT516	RTT	LT444	Resistor	235.23"	60	41,700	24,500
		LT443	Resistor	203.83"	50	34,700	20,400
TT515	RTT	LT442	Resistor	172.63"	40	27,800	16,400
		LT441	Resistor	141.34"	30	20,800	12,200
TT514	RTT	LT440	Resistor	110.04"	20	13,900	9,700
TT513	RTT	LT438	Resistor	77.60"	10	7,000	4,100
TT032	"	LT437	"	69.54"	8	5,600	3,400
		LT436	"	60.08"	6	4,200	2,500
		LT435	"	48.37"	4	3,800	1,600
		LT434	"	32.28"	2	1,400	800
		LT433	"	20.46"	1	700	400
		LT432	"	0	0	0	0
		LT453	Resistor	0-360.68"	0-100	0-69,534	
		LT010	Capacitance	0-360.68"	0-100	0-69,534	

$P = 4.416 \times 10^{-3}$

LIQUID HYDROGEN RUN VESSEL DATA		
INNER VESSEL		OUTER VESSEL
.8125	Shell Thick, in	.6875
.8270	Head Thick, in	.6875
0	Corr. Allow.	0
50psig	Max Oper. Press. PSI	FULL Vacuum
50psig	Max. Allow. W.P. PSI	FULL Vacuum
Inner Vessel 65 psi @ 70°F		
Temp range -423° to 70°F		
Capacity 77,000 Gal. Max.		
Horton Pressure Vessel.		
Manufactured by		
Chicago Bridge and Iron		
Dwg. No AETRON 3350-M142		

Figure 5-9 - V5001-LH₂ Run Tank

INSTRUMENT NUMBER	SENSOR TYPE	LOCATION (FULL TO EMPTY) inches	VOLUME (BASED ON 4020 gal = 100%)		
			%	GALLONS	LBS
LT470	Resistor	102.16	100	4020	2,388
LT469	Resistor	91.25	90	3620	2,150
LT468	Resistor	82.28	80	3200	1,901
LT467	Resistor	74.16	70	2795	1,660
LT466	Resistor	66.41	60	2400	1,446
LT465	Resistor	58.81	50	2000	1,188
LT464	Resistor	51.07	40	1600	950
LT463	Resistor	42.97	30	1200	713
LT462	Resistor	34.03	20	800	475
LT460	Resistor	23.25	10	400	238
LT458	Resistor	17.68	6	245	119
TT519	RTT	0	0	0	0
LT471	Resistor	6.97-102.16	0-100	4020	
LT009	Capacitor	—	0-100	4020	

$$P = 4.37 \text{ lb/ft}^2$$

LIQUID HYDROGEN HIGH PRESS. STORAGE VESSEL		
INNER VESSEL		OUTER VESSEL
2.54L	Shell Thick, in	.5125
2272.5	Test Press., psi	Vacuum
0	Corr. Allow., in	0
591.8	MAX. Oper. Press	0 psig
Inner Vessel 1515 psi @ -423°F		
Temp. Range -423°F to 100°F		
Horton Pressure Vessel		
Manufactured by Chicago Bridge and Iron		
Dwg. No RETRON 3350-M7		

Figure 5-10 - V5002-High Pressure Storage Tank

INSTRUMENTATION DATA

INSTRUMENT NUMBER	SENSOR TYPE	LOCATION (FULL TO EMPTY)	VOLUME (BASED ON 244,959 gal = 100%)		
			%	GALLONS	LBS
LT492 TT508	Resistor RTT	440.8"	100 100	245,934	143,014
LT490	Resistor	384.4"	90.5	222,763	129,540
LT489	Resistor	358.9"	85.7	210,846	122,609
LT486	Resistor	304.7"	71	174,755	101,640
LT484	Resistor	272.4"	61.1	150,548	87,546
LT482	Resistor	241.1"	51.1	126,167	73,368
LT480	Resistor	209.6"	41.1	101,619	59,093
LT478	Resistor	176.8"	31	76,980	44,765
LT476	Resistor	141.0"	20.9	52,184	30,345
LT474	Resistor	98.1"	10.7	27,111	15,765
TT35 TT401 TT402	RTT	58.4"			
LT472	Resistor	17.5"	0	975	567
* LT493	Resistor	17.5-440.8	0-100	975-245,934	
LT002	Capacitance	16-492.1	0-100%	816-246,224	

$$\rho = 4.35 \text{ lbs./ft}^3$$

LIQUID HYDROGEN STORAGE VESSEL DATA		
INNER VESSEL		OUTER VESSEL
1.47	Shell Thick, in	.8125
143.7 (AIR)	TEST Press. psig	18.75 (AIR)
0	Corr. Allow, in	0
100 psi	Max Oper. Press	FULL VACUUM
115 psi	Max A.W. Press	0 psig
Inner Vessel 115 psig @ -423°F		
Temp Range -423°F TO 100°F		
Manufactured by Chicago Bridge and Iron		
Dwg. No RETRON 3338-M1F2		

* LT493 includes all above resistors

Figure 5-11 - V3801-LH₂ Storage Tank

NOTE:
DIMENSIONS ARE INCHES,
MEASURED IN JULY, 1967

Figure 5-12 - Gaseous Helium Cool-down Line

Figure 5-12 - Gaseous Helium Cool-down Line

NOTES:
DIMENSIONS ARE IN INCHES,
MEASURED JULY, 1967

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NOTE:
DIMENSIONS ARE IN
INCHES, MEASURED
JULY, 1967

Figure 5-14 - Liquid Hydrogen Fill Line

DIMENSIONS ARE IN INCHES,
MEASURED JULY, 1967

Figure 5-15 - Liquid Hydrogen Cool-down Line

TABLE 5-1

ENGINE INSTRUMENTATION TRANSDUCER LIST

<u>Channel</u>	<u>Description</u>	<u>Figure</u>
FE 014	Propellant-Feed-Line Flow	5-1
PD 114	Pump	5-1, 5-2
PD 133	Nozzle Tube	5-3, 5-5
PD 163	Bolt-Coolant Line	5-3
PD 208	Diluent-Line Orifice	5-4
PD 209	Diluent-Line Venturi	5-4
PD 801	Bearing Housing	5-6
PD 802	TPCV	5-4
PD 804	Turbine-Inlet-Line Venturi	5-4
PD 810	Turbine Exhaust Nozzle	5-7
PD 812	Turbine Exhaust Nozzle	5-7
PT 099	V5001 Run Tank	5-1
PT 100	Propellant-Feed-Line Flowmeter Inlet	5-1
PT 104	Pump Inlet	5-1
PT 106	Pump Inlet	5-1
PT 110	Pump Discharge	5-2
PT 112	Pump Discharge	5-2
PT 114	Pump Discharge	5-2
PT 124	Nozzle Manifold	5-3
PT 128	Nozzle Manifold	5-3
PT 148	Nozzle Chamber	5-3
PT 149	Nozzle Chamber	5-3
PT 151	Nozzle Chamber	5-3
PT 160	Hot-Bleed-Port Diluent Annulus	5-3
PT 168	Hot-Bleed-Port Diluent Annulus	5-3
PT 172	Bolt-Coolant Line	5-3
PT 210	Reflector Inlet Plenum	5-5
PT 212	Pressure-Vessel Annulus	5-5

TABLE 5-1 (cont.)

<u>Channel</u>	<u>Description</u>	<u>Figure</u>
PT 214	Pressure-Vessel Annulus	5-5
PT 226	Diluent-Line Venturi	5-4
PT 485	Pump-Shutoff-Valve Inlet	5-1
PT 810	Turbine-Inlet-Line Entrance	5-4
PT 814	Turbine-Inlet-Line Venturi	5-4
PT 815	TPCV Inlet	5-4
PT 864	Turbine Inlet (Narrow Range)	5-4
PT 866	Turbine Inlet (Total Pressure)	5-4
PT 868	Turbine Inlet (Total Pressure)	5-4
PT 870	Turbine Inlet	5-4
PT 872	TBV Inlet	5-4
PT 876	Turbine Exhaust Rotor	5-6
PT 878	Turbine Exhaust Rotor	5-6
PT 880	Turbine Exit	5-7
PT 882	Turbine Exit	5-7
PT 883	Turbine Exhaust Nozzle	5-7
PT 885	Turbine Exhaust Nozzle	5-7
PT 890	Bearing Coolant	5-6
TE 143	Hot-Bleed-Port Annulus	5-3
TE 225	Pressure-Vessel Annulus	5-5
TE 226	Pressure-Vessel Annulus	5-5
TE 832	Turbine-Inlet-Line Venturi	5-4
TE 833	Turbine-Inlet-Line Venturi	5-4
TE 834	Turbine Inlet	5-4
TE 835	Turbine Inlet	5-4
TE 844	Turbine Exit	5-7
TE 845	Turbine Exit	5-7
TE 847	Turbine Exhaust Nozzle	5-7
TE 849	Turbine Exhaust Nozzle	5-7

TABLE 5-1 (cont.)

<u>Channel</u>	<u>Description</u>	<u>Figure</u>
TE 890	Bearing Coolant	5-6
TT 031	Flowmeter Inlet	5-1
TT 032	Run Tank	5-1
TT 103	Pump Inlet	5-1
TT 105	Pump Inlet	5-1
TT 108	Pump Discharge	5-2
TT 109	Pump Discharge	5-2
TT 110	Pump Discharge	5-2
TT 120	Nozzle Manifold	5-3
TT 121	Nozzle Manifold	5-3
TT 123	Nozzle Manifold	5-3
TT 138	Nozzle Chamber	5-3
TT 139	Nozzle Chamber	5-3
TT 144	Nozzle Chamber	5-3
TT 207	Reflector Inlet Plenum	5-5
TT 210	Reflector Inlet Plenum	5-5
TT 216	Reflector Inlet Plenum	5-5
TT 227	Diluent-Line Venturi	5-4
TT 475	PSV Inlet	5-1

TABLE 5-2

FACILITY FLOW, PRESSURE AND TEMPERATURE LOCATIONS

Component Identification Number	Component Locations		Component Identification Number	Component Locations	
	Line Number	*Schematic Coordinates		Line Number	*Schematic Coordinates
FT-12	4-LH-6	D5	PT-101	4-LH-6	E5
FT-14	201-LH-8	E4	PT-103	4-LH-6	D4
FT-15	15-GH-6	D7	PT-104	201-LH-8	D4
FT-50	30-GN-6	C7	PT-181	Vessel, V-3601	B11
FT-52	2-LN-4	B9	PT-191	30-GN-6	C7
FT-415	106-He-6	D8	PT-192	30-GN-6	C6
			PT-194	2-LN-4	B9
PD-584	30-GN-6	C7	PT-441	125-GH-3/4	F10
PD-589	15-GH-6	D7	PT-442	122-GH-3/4	G10
PD-601	4-LH-6	D5	PT-443	119-GH-3/4	G10
PD-777	106-He-6	D8	PT-473	106-He-6	D7
PD-778	15-GH-6	D7	PT-475	15-GH-6	D6
PD-780	4-LH-6	D5	PT-477	5-He-1	E4
			PT-484	30-GN-6	C5
PT-001	104-GN-3/4	B10	PT-485	201-LH-8	E4
PT-002	1-GN-8	C9	PT-547	204-He-1	E4
PT-003	1-GH-6	G9	PT-580	2-LN-4	B8
PT-004	110-GH-3/4	C10	PT-586	106-He-6	D8
PT-005	1-He-6	E9	PT-587	15-GH-6	D7
PT-007	107-GN-3/4	D10	PT-598	4-GH-3	G5
PT-010	113-GN-3/4	D10	PT-814	106-He-6	D6
PT-013	105-He-3/4	E10	PT-891	4-LH-6	D4
PT-016	116-GH-3/4	F10			
PT-068	Dewar, V-3801	F7	TT-028	4-LH-6	E5
PT-075	5-GH-2	G6	TT-031	201-LH-8	E4
PT-097	Dewar, V-5002	F6	TT-032	Run Tank, V-5001	G3
PT-099	Run Tank, V-5001	G4	TT-035	Dewar, V-3801	F1
PT-100	201-LH-8	E4	TT-044	3-LH-6	G4

* See Figure 5-8

TABLE 5-2 (cont.)

Component Identification Number	Component Locations		Component Identification Number	Component Locations	
	Line Number	*Schematic Coordinates		Line Number	*Schematic Coordinates
TT-045	106-He-6	C7	TT-491	Vessel, V-3203	D10
TT-053	30-GN-6	C6	TT-492	Vessel, V-3204	D10
TT-054	30-GN-6	C8	TT-493	Vessel, V-3205	E10
TT-055	2-LN-4	B10	TT-494	Vessel, V-3206	F10
TT-103	201-LH-8	D4	TT-495	4-LH-6	D5
TT-474	4-LH-6	D4	TT-510	2-LN-4	B7
TT-475	201-LH-8	E4	TT-511	225-LN-6	B6
TT-476	--	E3	TT-520	Dewar, V-5002	F5
TT-484	Vessel, V-3207	F10	TT-527	15-GH-6	D7
TT-485	Vessel, V-3208	G10	TT-528	106-He-6	D8
TT-486	Vessel, V-3209	G10	TT-881	4-LH-6	D4
TT-489	Vessel, V-3201	C10			
TT-490	Vessel, V-3202	C10	LT-026	Vessel, V-3601	B10

* See Figure 5-8

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1. AGC Report RN-S-0314, XECF Test Specification, November 1966 (U)
2. AGC Report RN-S-0289, XE-Engine Systems Analysis Design Data Book, 1967 (CRD)
3. Report NTO-R-0086, ETS-1 Facility Data Book, August 1966 (U)
4. AGC Report RN-TM-0437, XE Engine Dynamic Modal Analysis, May 1967 (U)

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ABBREVIATIONS

CFDTS	- Cold-Flow Development Test System
CKV	- Cooldown Check Valve
CSV	- Cooldown Shutoff Valve
DAS	- Data-Acquisition System
E-MAD	- Engine Maintenance, Assembly, and Disassembly
ESS	- Engine Safety System
ETC	- Engine Test Compartment
ETS-1	- Engine Test Stand No. 1
FCS	- Facilities Control System
NES	- Nuclear Exhaust System
PCV	- Propellant Control Valve
PDSV	- Pump Discharge Shutoff Valve
PSV	- Propellant Shutoff Valve
TPCV	- Turbine Power-Control Valve
TSCS	- Test-Stand Control System
XECF	- Experimental Engine Cold Flow