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XECF TEST PREDICTIONS

NERVA PROGRAM

CONTRACT SNP-1

NUCLEAR ROCKET OPERATIONS

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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. This facility 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 is 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 are 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, and 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 designed to accomplish these objectives as set forth in Section II.D of RN-S-0314 are currently being modified. To make this report as current as possible and yet meet the required publication date, Aerojet-General Corporation Modification No. 2 to Report RN-S-0314, as sent to Westinghouse Astronuclear Laboratory on 13 April 1967, was taken as the basis for performing the test-prediction analyses. Any subsequent changes made in Modification No. 2 or any 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 to allow the recipients of this report to incorporate changes made in the testing procedures after the report is issued.

TABLE 1-1

XECF TEST PLAN SUMMARY

<u>Test</u>	<u>Spec. Ref. Para.</u> <u>RN-S-0314</u> <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.	
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.	

<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>	

TABLE 1-1 (Cont.)

XECF TEST PLAN SUMMARY

<u>Test</u>	<u>Spec. Ref. Para.</u> <u>RN-S-0314</u> <u>Modification No. 2</u>	<u>Principal Objectives</u>	
	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.	

Description of Test

Updating Remarks

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 pre-planned value.

Similar to Run 4 of Phase I, except the pump will not be chilled, the test will be initiated by opening PSV and ambient GH_2 will be used in place of GHe after the emergency shutdown.

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.

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.

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.

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.

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 prechilled to liquid-hydrogen temperature and provides for simulation of a loss-of-propellant-flow type of 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 type of 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. Each test has a section covering all predictions applicable to monitoring and analyzing the goal of the test.

2.0 ENGINE DESCRIPTION

2.1 OVERALL ENGINE SYSTEM DESCRIPTION

The experimental Engine Cold Flow (XECF) is a full-scale NERVA experimental hot-bleed rocket engine. It is the second complete cold-flow engine system to be developed for nonnuclear testing of the NERVA experimental engine. The first complete cold-flow engine system was the Cold Flow Development Test System (CFDTS).

The XECF consists of the nonnuclear components of the XE engine and the unfueled reactor assembly that was used in CFDTS and NRX-A1 tests. A schematic diagram of the XECF engine flow system is presented in Figure 2-1.

The major subsystems of the XECF engine are:

1. Propellant Feed System
 - a. Pump Inlet Line
 - b. Turbopump
 - c. Pump Discharge Line
 - d. Turbine Inlet Line
 - e. Diluent Line
 - f. Turbine Exhaust System
2. Thrust-Chamber Assembly
 - a. Pressure Vessel
 - b. Nozzle
 - c. Hot-Bleed Port

Figure 2-1 - Piping and Instrumentation Diagram, XECF

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 Valve	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	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) Components	Venturi Meter	Venturi Meter	Same as XECF
	Overspeed Trip Valve	Turbine Power Control Valve	Same as XECF
	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 with no two inch reducer
	Flow measuring orifices	Venturi flow meter	Same as XECF
	Two-inch, ON/OFF butterfly type valve	Flow restriction orifice	Same as XECF
f. <u>Turbine Exhaust System</u>	Twin exhaust lines, manifolded 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)	Control drum ports	Adapters welded on control drum ports to match XE control drum drive shaft housing interface	Same as XECF
	Instrumentation bracket assembly installed on dome	No instrumentation bracket assembly	Same as XECF
	Lugs welded on closure flange for attachment to lower thrust structure	Closure flange diameter inserted 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

TABLE 2-1 (cont.)

<u>ITEM</u>	<u>CFDTS</u>	<u>XECF</u>	<u>XE</u>
(4) 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	A-1	Same hardware as CFDTS	A-5
	Unfueled	Unfueled	Fueled
			Core ΔP increased about 16%. Design changes to outer reflector supporting ring, support plate, inner reflector, lateral support system and several classified items.
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. Some of these systems will be used primarily during testing.

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 and compartment 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. SAFETY PURGE - $P_{sc}=100-115$ psia, $T_{sc}=1600-1700$ °R, $\dot{W}_s=115-130$ lb/sec, $\dot{M}_s=18-21$

3. SEAL LEAKAGE FLOW = 0-2 lb/sec AMBIENT N_2

4. $P_a = 12.8$ 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.

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.	Figure 3-6 Coordinates		Line No.	Figure 3-6 Coordinates
CHV-26	9-He-2	E7	GLV-412	9-GN-8	B7
CHV-47	5-He-1	E5	GLV-413	30-GN-4	C8
CHV-71	203-He-1-1/2	E4	GLV-422	5-He-1	E5
CHV-117	15-GH-6	H6	GLV-589	--	B10
CHV-148	1-GH-1	G8	GLV-794	30-GN-2	B7
CHV-149	17-He-2	G4	GLV-1201	100-GN-1	B7
CHV-306	25-GN-12	F3	GLV-1743	50-GN-1	B7
CHV-458	4-LH-6	D4	GLV-1988	227-LN-2	A10
CHV-468	32-GN-6	D8			
CHV-492	6-He-2	D6	FCV-50	30-GN-6	C7
CHV-496	30-GN-6	C6	FCV-52	2-LN-2	B8
CHV-552	17-GN-12	F8			
CHV-681	15-GH-6	D6	LF-6	3-LH-6	G4
CHV-1714	203-He-1-1/2	E4	LF-7	4-LH-6	D4
CHV-1721	15-GH-6	C4			
CHV-1722	9-GN-8	B6	NV-550	6-GN-3/4	F8
CHV-1877	--	D5			
CHV-1878	--	D5	PCV-165	4-GH-6	G4
CHV-1885	225-LN-4	B6	PCV-179	17-GH-12	G7
CHV-1908	237-GN-6	C6	PCV-180	20-GH-12	G3
			PCV-248	1-GH-1-1/2	G8
FE-12	4-LH-6	D5	PCV-250	5-GH-2	G6
FE-14	201-LH-8	E3	PCV-251	15-GH-6	D6
FE-15	15-GH-6	D7	PCV-471	106-He-6	D7
FE-50	30-GN-6	C7	PCV-517	225-LN-4	B8
FE-52	2-LN-4	A9	PCV-579	203-GH-3	E3
FE-415	106-He-6	D8			
FE-425	201-LH-8	E3	PRV-14	3-He-1	E9
			PRV-26	17-He-2	E5
GF-11	1-GH-1-1/2	G8	PRV-28	5-He-1	E5
GF-12	3-He-1	E8	PRV-107	30-GN-6	C7
GF-14	15-GH-6	D6	PRV-108	18-GN-1	F9
GF-15	9-GN-8	C7	PRV-411	9-GN-8	B6
GF-16	4-GH-6	G5	PRV-420	1-He-2	D9
GF-17	5-GH-2	G6	PRV-426	4-GH-6	G5
GF-18	5-He-1	E5	PRV-438	9-GN-8	C6
GF-29	18-GN-1	B9	PRV-439	4-He-2	E4
GF-30	30-GN-4	C8	PRV-441	9-GN-8	C6
GF-432	106-He-6	D9			
			RSV-1	103-GN-4	B10
GLV-5	8-He-1	F8	RSV-2	103-GN-4	B10
GLV-53	--	G5	RSV-6	109-GN-4	C10
GLV-196	106-He-6	D9	RSV-7	109-GN-4	C10
GLV-271	6-GN-3/4	C8	RSV-11	106-GN-4	D10
GLV-323	4-GN-1	C9	RSV-12	106-GN-4	D10
GLV-361	18-GN-1	B8	RSV-16	112-GN-4	D10
GLV-366	5-GN-1	C8	RSV-17	112-GN-4	D10
GLV-387	3-He-1	E8	RSV-21	104-He-4	E10
GLV-405	5-He-1	E5			

TABLE 3-1 (cont.)

Component Identification Number	Component Location		Component Identification Number	Component Location	
	Line No.	Figure 3-6 Coordinates		Line No.	Figure 3-6 Coordinates
RSV-22	104-He-4	E10	RSV-383	1-GH-1-1/2	G8
RSV-24	1-He-1-1/2	E9	RSV-390	20-GH-12	G3
RSV-26	115-GH-4	F10	RSV-441	201-GH-2	G5
RSV-27	115-GH-4	F10	RSV-446	204-He-1	D4
RSV-29	1-GN-8	C9	RSV-454	15-GH-6	D6
RSV-53	106-He-6	E9	RSV-455	203-He-1-1/2	E4
RSV-54	106-He-6	E9	RSV-459	4-LH-6	D4
RSV-77	1-He-1	C7	RSV-460	--	D6
RSV-78	106-He-6	D7	RSV-515	123-GH-6	F10
RSV-80	1-LH-2	F7	RSV-516	123-GH-6	F10
RSV-83	3-LH-6	E7	RSV-519	120-GH-6	G10
RSV-87	2-GH-6	G7	RSV-520	120-GH-6	G10
RSV-105	5-He-1	E5	RSV-523	117-GH-6	H10
RSV-106	5-LH-2	F6	RSV-524	117-GH-6	H10
RSV-107	4-LH-6	E5	RSV-539	32-GN-6	D7
RSV-109	19-GH-2	G5	RSV-543	--	D6
RSV-110	19-GH-4	G5	RSV-544	--	D5
RSV-128	3-LH-6	G4	RSV-545	225-LN-6	B6
RSV-129	3-LH-6	G4	RSV-548	237-GN-6	C6
RSV-132	201-LH-8	E3	RSV-621	2-GN-1-1/2	C9
RSV-134	30-GN-6	C6	RSV-701	227-LN-2	A10
RSV-142	203-He-1-1/2	E4			
RSV-185	5-GH-2	G6	RV-1914	231-GH-1	B6
RSV-186	4-GH-6	G4			
RSV-201	15-GH-6	H6			
RSV-222	9-GN-8	C6			
RSV-245	1-GN-8	C9			
RSV-246	1-GH-6	G9			
RSV-247	1-He-2	D9			
RSV-252	3-LH-6	E6			
RSV-255	9-He-2	E7			
RSV-257	17-GH-12	G7			
RSV-258	2-GH-6	G7			
RSV-271		C9			
RSV-273	1-GN-8	C9			
RSV-274	1-GH-6	H9			
RSV-275	1-He-2	D9			
RSV-276	1-GH-1-1/2	G8			
RSV-283	4-GH-3	G6			
RSV-284	17-He-2	F4			
RSV-286	5-GH-6	G7			
RSV-287	15-He-2	F4			
RSV-324	32-GN-6	D8			
RSV-325	18-GN-1	B10			
RSV-326	2-LN-4	B10			
RSV-327	--	B10			

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 engine control drums and the turbine-pump 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.

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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) Subsystem and system checkouts.
- (8) Operator training by means of simulation of engine and facility parameters.
- (9) Sufficient information and control to permit safe performance of all TSCS functions during testing. The engine safety system (ESS) that includes scram, emergency shutdown, and other emergency actions is included as part of the TSCS.

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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, including Modification No. 2, dated 12 April 1967, was considered the primary authority for establishing the test conditions and operation sequences. Test predictions are organized by phase and run number identical to Modification No. 2 of Section II.D.2 of Report RN-S-0314 (see Section 1.0).

The predicted engine characteristics were obtained by using transient engine simulation program 16179, with the printout time interval generally set for 1 sec.

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.

Program 16179 assumes 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.

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.

In addition to the above changes, the following parameters that influence the engine start characteristics were assumed as 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.

4.1.1 Run 1

The run-tank line and the pump will be chilled until LH_2 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 GH_2 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 CH_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. The pressure of the cooldown supply line will be regulated to 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 require approximately 0.25 sec to close, and its closing will stop the flow of GH_2 to the turbine. The turbopump will decelerate, and the pump discharge pressure will decay to 50 psia approximately 0.75 sec after the TPCV starts to close, at which time the emergency-cooldown-line check valve (CKV) will open and allow LH_2 to flow from the emergency cooldown system and enter the pump discharge line. LH_2 will continue flowing through the system via the CSV for 15 sec. 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 the engine components. About 41 sec after initiation of the test, GHe flow to the engine system will be established. For this analysis, it was assumed that the GHe system would operate in a flow-control mode with 10 lb/sec of GHe flow demanded. Under these conditions, the nozzle manifold pressure required is approximately 175 psia. With the introduction of GHe, the flow of LH_2 will stop and warming of the chilled engine components will occur. Predicted plots of engine parameters for this test are shown in Figures 4-7, 4-8, and 4-9. 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.

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

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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 4-10, 4-11, and 4-12. Figure 4-10 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 4-10 - XECF Test Prediction, Phase II, Run 1,
Dry Pump, $P_T = 35$ psia

Figure 4-11 - XECF Test Prediction, Phase II, Run 1,
Dry Pump, $P_T = 35$ psia

Figure 4-12 - 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. After the cooldown supply line is chilled down, line pressure will be regulated to 50 psia.

The test will be initiated by opening the PSV. When the nozzle-tube outlet temperature reaches 250°R approximately 18 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 the 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 the TPCV will be demanded closed to simulate loss of flow. The TPCV will require approximately 0.25 sec to close, and its closing will stop the flow of GH_2 to the turbine. The turbopump will decelerate, and the pump discharge pressure will decay to 50 psia approximately 0.7 sec after the TPCV starts to close, at which time the emergency-cooldown-line check valve (CKV) will open and allow LH_2 flow from the emergency cooldown system to enter the pump discharge line. LH_2 will continue flowing through the system via the CSV for 15 sec. 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, GH_2 flow to the engine system will be established. For this analysis, it was assumed that the GH_2 system would operate in a flow-control mode with 10 lb/sec of GH_2 flow demanded. Under these conditions, the nozzle manifold pressure required is approximately 275 psia. With the introduction of GH_2 , the flow of LH_2 will stop and warming of the chilled engine components will occur. Predicted plots of engine parameters for this test are shown in Figures 4-13, 4-14, and 4-15.

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 loop will be closed and a chamber pressure of 35 psia will be demanded.

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Figure 4-13 - XECF Test Prediction, Phase II, Run 2,
Dry Pump, $P_T = 35$ psia

Figure 4-14 - XECF Test Prediction, Phase II, Run 2,
Dry Pump, $P_T = 35$ psia

Figure 4-15 - XECF Test Prediction, Phase II, Run 2,
Dry Pump, $P_T = 35$ psia

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 4-16, 4-17, and 4-18. 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 CFDTTS 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 4-16 - XECF Test Prediction, Phase II, Run 3,
Dry Pump, $P_T = 60$ psia

Figure 4-17 - XECF Test Prediction, Phase II, Run 3,
Dry Pump, $P_T = 60$ psia

Figure 4-18 - 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 4-19, 4-20, and 4-21. 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 4-19 - XECF Test Prediction, Phase III, Run 2,
Dry Pump, $P_T = 35$ psia

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

Figure 4-21 - 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 Processor

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 LH₂ 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 Schematic

Figure 5-8 is a simplified schematic of the facility and shows the relative locations of transducers.

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

**PUMP DISCHARGE LINE
(PUMP TO NOZZLE TORUS)**

**PARAMETER CHANNEL
OUTLET**

PRESSURE	PT 110
	PT 112
	PT 114N
TEMPERATURE	TT 108
	TT 109
	TT 110

PUMP DIFFERENTIAL PRESSURE

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

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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

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

TABLE 5-1

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 114N	Pump Discharge (Narrow Range)	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 142	Hot-Bleed-Port Annulus	5-3
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

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REFERENCES

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
PDSV	- Pump Discharge Shutoff Valve
PSV	- Propellant Shutoff Valve
TPCV	- Turbine Power-Control Valve
TSCS	- Test-Stand Control System
XECF	- Experimental Engine Cold Flow

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