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FINAL REPORT

CFDTS SERIES I, II AND III TESTS

JULY 1966

NERVA PROGRAM

CONTRACT SNP-1

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REPORT NO. RN-S-0298

FINAL REPORT
CFDTS SERIES I, II AND III TESTS

JULY 1966

ROCKET ENGINE OPERATIONS - NUCLEAR

NERVA PROGRAM

CONTRACT SNP-1

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ABSTRACT

This is the final project report for the Cold Flow Development Test System (CFDTS) program.

The primary purpose of the program was to verify that engine "bootstrapping" could be initiated by nozzle-chamber bleed to the turbine and to provide data related to the behavior of the NERVA hot bleed engine during startup. Program objectives were achieved. The system successfully "bootstrapped" and useful information was obtained for upgrading and improving the computer models simulating the system as well as for improving the engine system itself.

This report describes the engine system (which was the first test assembly containing all major engine components to form the full-size NERVA rocket engine with an unfueled reactor assembly), the test facility and the instrumentation used in the conduct of the tests, and presents a summary of the test results.

A detailed system analysis report (RN-S-0294, title CFDTS Data Analysis Final Report) of test results was prepared in conjunction with this report and is available for additional information on the system.

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for C. M. Rice
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COLD FLOW DEVELOPMENT TEST SYSTEM

Final Report

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I. SUMMARY

The Cold Flow Development Test System (CFDTS) was the first test assembly containing all the major engine components to form the full-size Nuclear Engine for Rocket Vehicle Application (NERVA) being developed as part of the AEC-NASA ROVER nuclear rocket program for upper stage rocket propulsion or space travel vehicles. The engine tests demonstrated that this type of nuclear rocket does not require an external starting system. They also demonstrated that for a flight engine a high propellant tank pressure is not required for start-up. The tank need only be pressurized to meet the net positive suction pressure (NPSP) requirement at full power.

The CFDTS consisted of an unfueled reactor, pressure vessel and nozzle, turbine and pump assembly, thrust structure, propellant feed lines, and test instrumentation. It was a prototype of the nuclear Experimental Engine (XE-1), being built for hot firing at the Nuclear Rocket Development Station (NRDS) in Nevada, except that it did not contain fissionable material in the reactor and had no external gamma shield, remote disconnects, nor radiation-hardened components.

The CFDTS engine was built to provide data related to the behavior of the engine system during chilldown and bootstrap startup prior to the generation of nuclear heat. The engine was also intended to obtain data necessary for the development of non-nuclear engine controls and to develop an optimum startup program for similar fueled reactor engines which would have the same working fluid path. Test data were needed to verify and improve the several computer codes that were developed to predict transient performance. Parameters under investigation were tank pressure, ejector back pressure, closed pressure loop control, diluent flow, and the opening program for the turbine power control valve (TPCV), for start-up with both a chilled pump (cooled to liquid hydrogen, (LH₂) temperature before admitting propellant into the engine) and a warm pump (at ambient temperature when propellant was admitted to engine).*

* The terms "chilled" and "warm" will be used throughout this report to describe the pump condition at test start. Some previous documents referring to pump condition have used the terminology "wet" instead of "chilled" and "dry" instead of "warm".

The cold flow assembly operated over the start-transient region on the heat energy stored in the various engine components which were at ambient temperature. The transfer of energy in the cold flow assembly was effected by the large temperature difference between the hydrogen propellant (-423°F) and the engine materials at ambient temperature. This energy was demonstrated to be sufficient to initiate a bootstrap, that is, to provide enough driving energy to the turbine through a hot-bleed from the nozzle chamber to start pumping propellant from the low pressure supply tank into the engine. The XE-1 will operate in essentially the same way during the early part of the start transient, after which the stored energy in the system will be supplemented by nuclear power to continue through the bootstrapping and into the power range.

A total of thirty-one CFDTs tests were conducted between April and October 1965. The tests were significant in that they proved that bootstrapping could be initiated by nozzle-chamber bleed to the turbine, with driving force derived from heat energy stored in the engine components. This concept leads to a system not dependent on auxiliary start equipment.

During engine chilldown tests (TPCV closed), it was found that with a chilled pump a more rapid system chilldown resulted than with a warm pump. Peak flow was the same in both cases, but peak was reached in 45 seconds with the chilled pump vs 59 seconds for the warm pump.

The effect of tank pressure on start-up was investigated for various system back pressures. For a back pressure of 14 psia, an increase of tank pressure from 50 to 60 psia nearly doubled the maximum pump speed and tripled the pump head rise. However, an increase of tank pressure from 70 to 90 psia increased the speed only 12% and the head rise only 23%. Peak speeds were reached in 10 and 40 seconds respectively for the 90 and 50 psia tank pressures. These data provided a measure of the time available to bring the reactor to power for nuclear startup.

Testing showed that bootstrapping occurred without turbine overspeeding even with NPSP bordering on zero. This indicated that the required propellant tank pressure in a flight engine would be governed by full-power NPSP requirements rather than by start-up conditions. The turbopump began to rotate at very low flow rates within a second of test-start when the chamber pressure had reached only 3 psia above the system back pressure. The Aerojet turbopump did not windmill during the pump chilldown operation prior to opening the TPCV.

The effect of system back pressure was investigated from 0.3 to 14.2 psia. Data showed that, for a back pressure of 12.7 psia, the pump breakaway speed (the speed at which performance markedly improved) was reached with a tank pressure of 45 psia as compared to a tank pressure of 30 psia for 7.6 psia back pressure.

Investigation of warm pump start-up was made and tests indicated that this type of operation was feasible. Warm pump operation has the advantage of eliminating the need for the pump discharge valve and its controls from the system. In warm pump start-ups there were small turbopump speed oscillations, varying between 3000 and 6000 rpm at a frequency of 0.4 cps with associated flow oscillations of 3 to 6 lbs/sec until all-liquid was established at the pump. Once all-liquid was established, the system response was similar to the response with a chilled pump start.

The tests also demonstrated that closed-loop pressure control of the TPCV to control nozzle chamber pressure during engine start-up was feasible even with a warm pump. Start-up could be accomplished with the pressure controller activated at test initiation thus allowing simplification of control circuitry and increasing system reliability.

FINAL PROJECT REPORT

COLD FLOW DEVELOPMENT TEST SYSTEM

II. INTRODUCTION

The Cold Flow Development Test System (CFDTS) was a full-scale, NERVA Experimental hot-bleed rocket engine with an unfueled reactor assembly. The major components were engine prototype models, although certain unique CFDTS components were provided where necessary to meet the CFDTS program schedule and to fulfill the functional requirements of the system. The CFDTS was the third major cold flow test system to be developed for non-nuclear testing of the NERVA engine.

The first system was the Generation I* engine simulator. This simulator included a centrifugal-type liquid hydrogen pump driven by a two-stage impulse turbine and an aluminum mockup of a reflector segment. To demonstrate the feasibility of heat-capacity startup, turbine fluid was bled from the pump discharge line and passed through the aluminum mockup of the reflector segment. A small portable computer was provided to simulate the effects of reactor heat transfer and fluid dynamics, and to simulate pump load and turbine power characteristics during startup of a nuclear engine. Much valuable information was obtained on turbopump performance and pump "bootstrapping" using the heat capacity of the pump and reflector segment. The feasibility of integrating an analog computer and engine components to simulate nuclear engine start transients was proven. The degree of nuclear engine simulation achieved by the Generation I simulator was limited by its design as well as by a lack of prototype components, but the system provided a basis for the design of more advanced simulators.

The second system was the Generation II** engine simulator which was designed to include more prototype components as well as full-size simulated components of the heated bleed engine. The turbine power control valve, the tank shut-off valve, the Aerojet-General Mark II turbopump assembly, and the pressure vessel assembly represented the engine design current at the time. The shield assembly was simulated by means of a stainless steel tube bundle which closely represented the thermal properties of the engine shield. The reflector assembly, which was made of aluminum, was designed to conform closely to the heat capacity and fluid flow characteristics of the NERVA reflector and, thus, resulted in good simulation of this component.

* Reference AGC Report No. 2223, Generation I Simulator of the Heated Bleed Engine.

** Reference AGC Report No. 2543, Generation II NERVA Engine Simulator.

A servo-controlled butterfly valve was used to simulate the pressure drop through the core. An analog computer was used to simulate reactor characteristics. Chilled and two-phase flow data were obtained and experience was gained in instrumentation and operating techniques which could be utilized in later development programs.

The CFDTTS was the third cold flow test system to be developed. It represented a logical advancement in non-nuclear engine system development since it included the major prototype components of the NERVA Experimental Engine (XE) which affect system cold-start performance. Basically, it consisted of all the non-nuclear components of the engine system and the same unfueled nuclear sub-assembly that was used in the tests of the NERVA Reactor Experiment (NRX-A1). The major components included were the pressure vessel and unfueled reactor assembly, nozzle, turbine and pump assembly, propellant feed lines and valves, upper and lower thrust structures, and engine system sequencer. Figure 1, Cold Flow Development Test System, is a pictorial representation of the system. Appendix F contains a sketch of the system showing the fluid flow path and identifies the various components of the system in schematic form. It also includes a list of abbreviations of engine components which are referred to throughout this report. It has been prepared as a foldout for reference during use of this report.

This report describes the engine system, the test set-up, test procedures, and test results for the tests performed on the system at the Sacramento Test Site of Aerojet-General Corporation.

Figure 1
Cold Flow Development System

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III. TEST OBJECTIVES

The primary and secondary objectives of the CFDTS test program are described in the following paragraphs.

A. PRIMARY OBJECTIVES

The primary objectives of the CFDTS program were:

1. Verify the control functions and start-up sequence of operations previously determined by transient analysis of a mathematical model to develop a reliable start-up procedure for the XE and NRX/EST engine systems.

Since the CFDTS was a full-scale version of the XE-Engine, but with an unfueled core, one of the primary objectives of the program was to determine proper start-up procedures for the engine system before including active fuel elements. The mathematical model that was set up to represent the various start-up conditions and parameters was to be verified and modified as required to predict engine operation accurately. The development of a computer code to simulate system performance was essential to isolating, understanding and interpreting non-nuclear start-transient phenomena. The CFDTS was intended to provide data necessary for the development and refinement of this engine system program to allow accurate predictions of the XE and NRX/EST engine system start-up.

2. Determine minimum tank pressure requirements for system start-up as a function of back pressure for both wet pump and dry pump starts.

One of the primary factors affecting engine start-up performance was the driving force across the engine system, i.e., the difference between tank pressure and engine system back pressure. For eventual flight operations it was desirable to reduce the tank pressure to a minimum consistent with reliable engine start-up. The effect of tank pressure on system start-up was to be determined and the lowest adequate pressure established. In addition, back pressure was to be varied to simulate operation at NRDS ambient pressure, ETS-1 ejector back pressure and at space-start conditions.

3. Evaluate flow characteristics of an unfueled nuclear engine system to determine chilldown times, temperatures, flow rates, and pressure drops throughout the system.

The necessity for starting the engine in a controlled manner required a thorough understanding of the flow rates, pressures and temperatures throughout the system. Development of computer codes for prediction of engine operating characteristics had to be based upon a knowledge of temperature, pressure, and flows at various points in the system.

4. Test functionally an unfueled nuclear engine assembly and its components as an integrated system to evaluate potential problems associated with the start transient.

Individual components may be exhaustively tested and proven but may perform differently than anticipated in an assembled system. Consequently, it was essential that start-up of the nuclear engine system be thoroughly investigated and understood and that the propellant supply system be perfected before operation of the engine system with an active reactor assembly.

5. Qualify the Mark III, Mod. 4 turbopump for a warm-pump start and establish minimum pump and pump inlet line chilldown times, prior to opening the TPCV, to sequence a safe warm pump start.

It was more advantageous to start the engine with a warm pump than with a chilled pump, since it would be possible to eliminate the pump discharge valve and pump discharge bleed valve, which would simplify the controls system. The disadvantage of a warm-pump start was that care must be taken not to apply power to the turbine until a certain quality of fluid was in the pump to avoid pump overspeed. The CFDTs was to be used to determine the optimum procedure for a safe warm pump start.

B. SECONDARY OBJECTIVES

Secondary objectives were to:

1. Gather performance data for various components during the bootstrap phase of an engine start-up.

It is impractical to conduct some component tests under simulated start-up conditions. It therefore was necessary to utilize the CFDTS to determine performance characteristics of various components under these conditions. The low speed turbine and pump efficiencies, valve and control circuitry response characteristics, and adequacy of instrumentation were all to be determined.

2. Determine chamber pressure level at which closed loop pressure control could be initiated.

With closed loop chamber pressure control, the TPCV position was controlled as a function of the difference between demanded nozzle chamber pressure and measured chamber pressure. With CFDTS it would be possible to establish the lowest chamber pressure at which this control loop could be closed and still obtain a satisfactory engine start-up.

3. Investigate dynamic and structural behavior of the system components during start transient.

Accelerometer measurements were to be taken on the various components to determine if they were subjected to vibrations which might be detrimental to the system. Also, strain measurements were to be taken on selected components to evaluate the severity of thermal stresses introduced during system chill-down. Furthermore, CFDTS was a useful tool in confirming dynamic and structural integrity of the thrust structure assembly and in confirming the adequacy of the method of support of the turbopump within the structure itself.

4. Assist in the development of fabrication, assembly and handling techniques for nuclear engine systems.

Since this was the first assembly of a full-scale engine system, an important side benefit was the development of fabrication, assembly and handling techniques for nuclear engine systems. It also served as a basis for developing acceptance requirements for components and for establishing and verifying reactor-pressure vessel and major component interface requirements.

C. FIRST SERIES OBJECTIVES

The primary objective of the first series of CFDTIS tests was to determine start-up characteristics of the system at ambient temperature and back pressure conditions. Of basic interest was the bootstrap capability of the system and the effect of tank pressure on bootstrapping. (Bootstrapping is the utilization of the latent heat of the rocket engine system, operating either with or without nuclear power to increase the hydrogen pressure and flow rate in the reactor core to values higher than those resulting from the propellant tank pressure alone.) A successful bootstrap provides sufficient hydrogen flow rate through the reactor to allow reactor power to be brought up to the required level in a controlled manner. In bootstrapping, liquid hydrogen flows through the pump to the reactor, acquires heat from the engine components, and changes state to a gas. From the main nozzle chamber, a portion of this gas is bled back through the turbine. In the turbine, the heat energy acquired by the hydrogen is expended to drive the hydrogen pump to increase hydrogen pressure and flow rate at the pump discharge.

Other objectives of the first series were to check out the operation of the test facility and engine system, to obtain data on system chilldown characteristics, and to evaluate flow characteristics of the system.

Table I outlines individual test objectives and test conditions for the first series of CFDTIS tests.

TABLE I

CFDTS TEST PROGRAM - SERIES I

Test No.	Test Objective & Description	Pump Start Cond.	Tank Press. PSIA	Back Press. PSIA	Dil. Valve Posit.	TPCS Program
1	Check out facility and engine system. Confirm valve sequencing. Investigate chilldown characteristics of engine system using warm pump start.	Warm	70	14.2	Closed	TPCV Closed
2	Investigate chilldown characteristics of engine system using chilled pump start and checkout system sequence for chilled pump start.	Chilled	70	14.2	Open	TPCV Closed
3	Investigate bootstrap start characteristics of engine system with chilled pump start.	Chilled	70	14.2	Open	Step & ramp open to 83° in 1 second after test start.
4	Investigate effect of increased tank pressure on bootstrap start characteristics of engine system.	Chilled	90	14.2	Open	Step & ramp open to 83° in 1 second after test start.
5	Investigate effect of low tank pressure on bootstrap start characteristics of engine system.	Chilled	50	14.2	Open	Step & ramp open to 83° in 1 second after test start.
6	Investigate effect of intermediate tank pressure on bootstrap start characteristics of engine system.	Chilled	60	14.2	Open	Step & ramp open to 83° in 1 second after test start.

D. SECOND SERIES OBJECTIVES

The major objectives of the second series of CFDTS tests were to; (1) evaluate the effect of tank pressures and back pressures on system start characteristics and determine minimum tank pressure requirements for start-up, (2) evaluate warm pump starting, (3) evaluate performance of the closed loop chamber pressure control system, (4) provide data for upgrading and refining the digital and analog models for XE and NRX/EST engine systems, (5) perform special tests and make special measurements to provide answers to particular questions and problems relating to system start up. Some of the special tests and measurements included comparison of performance with the original TPA and the improved version, the effect of a helium blanket on the TPA, the effect of diluent flow, vibration and strain measurements, infinite impedance line measurements, etc.

Table II summarizes individual test objectives and test conditions for the second series of tests.

E. THIRD SERIES OBJECTIVES

The objectives of the third series of tests were primarily to provide additional data in support of NRX/EST and further evaluation of the performance of the automatic pressure control system. Additional information was also required to fill in gaps relating to minimum tank pressure at minimum back pressure start up characteristics.

Table III summarizes individual test objectives and test conditions for the third series of tests.

TABLE II

CFDTS SERIES II TEST OBJECTIVES AND TEST CONDITIONS

TEST NO.	TEST OBJECTIVE AND DESCRIPTION	PUMP START COND.	TANK PRESS. PSIA	BACK PRESS. PSIA	DIL. VALVE POSIT.	TPCV PROGRAM
7	Evaluate difference in system performance with turbine modified to NRX/EST configuration. Chill pump until pump discharge fluid temperature stabilizes below 40°R for 30 sec., then open PDV.	Chilled	70	14.2	Open	Step and ramp to 80° at test start.
8	Evaluate difference in system performance with turbine modified to NRX/EST configuration. Chill pump until pump discharge fluid temperature stabilizes below 40°R for 30 sec., then open PDV.	Chilled	70	14.2	Open	Step and ramp to 80° at test start.
9	Evaluate performance at NRX/EST back pressure and tank pressure conditions.	Chilled	70	12.7	Open	Scheduled opening to 80° at test start.
10	Investigate effect of lower tank pressure with NRX/EST back pressure	Chilled	50	12.7	Open	Scheduled opening to 80° at test start.
11	Investigate minimum tank pressure for bootstrap start with NRX/EST back pressure.	Chilled	35	12.7	Open	Scheduled opening to 80° at test start.
12	Evaluate performance of automatic pressure control system during initial engine start-up operating using closed loop at test start in support of NRX/EST. Record vibration and strain measurements.	Chilled	70	12.7	Open	Close loop at test start. Set chamber pressure demand at value based on results of Test 9.
13	Evaluate performance of automatic pressure control system during initial engine start-up operation. Close loop subsequent to test start to verify alternate way of closing pressure loop for NRX/EST.	Chilled	70	12.7	Open	Step open to 50° at test start. Close pressure loop at chamber pressure of 35 psia. Set chamber pressure demand at 35 psia.

TABLE II

TEST NO.	TEST OBJECTIVE AND DESCRIPTION	PUMP START COND.	TANK PRESS. PSIA	BACK PRESS. PSIA	DIL. VALVE POSIT.	TPCV PROGRAM
14	Determine effect, of blanketing TPA in helium, on pump performance and system start-up characteristics in support of NRX/EST and XE.	Chilled	35	12.7	Open	Scheduled opening to 80° at test start.
15	Investigate start-up characteristics with ETS-1 back pressure. Basic information on effect of lowering back pressure. Check out ejector system under operating load at ETS-1 back pressure conditions.	Chilled	35	ETS-1	Open	Step and ramp to 80° at test start.
16	Investigate start-up characteristics with a minimum back pressure. Additional basic information on effect of lowering back pressure. Check out ejector system under operating load at minimum back pressure.	Chilled	35	Min.	Open	Step and ramp to 80° at test start.
17	Evaluate bootstrap performance at NRX/EST back pressure and intermediate tank pressure conditions to obtain additional basic information on effect of tank pressure.	Chilled	40	12.7	Open	Step and ramp to 80° at test start.
18	Obtain additional basic data on effect of lowering tank pressure to a minimum at minimum back pressure with a chilled pump start.	Chilled	30	Min.	Open	Step and ramp to 80° at test start.
19	Evaluate warm pump start under X-Engine operating conditions using conservative TPCV program.	Warm	35	ETS-1	Open	Open TPCV when pump discharge temperature reaches 43.5°R. Step to 60° and ramp to 80°.

TABLE II

TEST NO.	TEST OBJECTIVE AND DESCRIPTION	PUMP START COND.	TANK PRESS. PSIA	BACK PRESS. PSIA	DIL. VALVE POSIT.	TPCV PROGRAM
20	Determine effect of reducing pump chilldown time (time between opening PSOV and TPCV) on system start-up characteristics with warm pump start at X-Engine operating conditions.	Warm	35	ETS-1	Open	Open TPCV 9 seconds after opening PSOV. Step to 60° and ramp to 80°.
21	Determine effect on start-up characteristics of reducing pump chilldown time to minimum at X-Engine operating conditions. Record vibration and strain measurements.	Warm	35	ETS-1	Open	Open TPCV simultaneously with opening of PSOV. Step to 60° and ramp to 80°.
22	Determine effect of higher tank pressure on bootstrap start-up characteristics of system using a warm pump start.	Warm	50	ETS-1	Open	Open TPCV and PSOV simultaneously. Step and ramp to 80° at test start.
23	Obtain additional basic data on effect of lowering tank pressure to a minimum at minimum back pressure with chilled pump start.	Chilled	25	Min.	Open	Step and ramp to 80° at test start.
24	Investigate effect of lowering tank pressure at ETS-1 back pressure with warm pump start.	Warm	30	ETS-1	Open	Step and ramp to 80° at test start.
25	Investigate effect of diluent flow on system bootstrap start characteristics by removing orifice restriction in diluent line.	Chilled	70	12.7	Open	Step and ramp to 80° at test start.
26	Obtain additional basic data on effect of lowering tank pressure to a minimum at ETS-1 back pressure conditions.	Chilled	25	ETS-1	Open	Step and ramp to 80° at test start.
27	Obtain additional basic data on effect of lowering tank pressure to a minimum at ETS-1 back pressure with a warm pump start.	Warm	20	Min.	Open	Step and ramp to 80° at test start.

TABLE III

CFDTIS SERIES III TEST OBJECTIVES AND TEST CONDITIONS

TEST NO.	TEST OBJECTIVE AND DESCRIPTION	PUMP START COND.	TANK PRESS. PSIA	BACK PRESS. PSIA	DIL. VALVE POSIT.	TPCV PROGRAM
28	Evaluate performance of automatic pressure control system with closed loop at test start and NRX/EST conditions.	Chilled	70	12.7	Open	Close pressure loop at test start. Set chamber pressure demand at 50 psia.
29	Evaluate performance of automatic pressure control system with closed loop at test start using intermediate tank pressure and reduced chamber pressure demand.	Chilled	55	12.7	Open	Close pressure loop at test start. Set chamber pressure demand at 35 psia.
30	Evaluate performance of automatic pressure control system with pressure loop closed at test start under warm pump start conditions.	Warm	70	12.7	Open	Close pressure loop at test start. Set chamber pressure demand at 35 psia.
31	Obtain additional basic data on effect of lowering tank pressure to a minimum at minimum back pressure with a chilled pump start.	Chilled	20	Min.	Open	Step to 60°, ramp to 80° at test start.

IV. SYSTEM DESCRIPTION

A. APPLICABLE DOCUMENTS AND DRAWINGS

Appendix A lists documents and drawings which describe in detail the system tested and may be referred to for additional information on the CFDTS.

B. ENGINE SYSTEM

1. Overall Engine System Description

The engine used for this program is described by Aerojet Specification 10138C, Cold Flow Development Test System and by CFDTS Top Assembly Drawing, Aerojet No. 706965.

The CFDTS engine consisted of the non-nuclear components of the engine system in addition to the same unfueled reactor assembly as that used in the NRX-A1 tests. The major non-nuclear components of the engine system were the pressure vessel, nozzle, thrust structure assembly, turbine and pump assembly, propellant feed lines, pneumatically actuated control systems for the valves, and the engine sequencer system. A brief description of the system components is given below.

a. Unfueled Reactor Assembly

The unfueled reactor assembly used for the CFDTS was the same assembly that was used for the NRX-A1 test series except for minor changes in instrumentation. This complete assembly is described by WANL Drawing 937J145, Instrumented Reactor Assembly CFDTS.

b. Pressure Vessel Assembly

The pressure vessel consisted of a forward closure (P/N 298252-9) and a cylinder, (P/N 294053-19). The closure was a two-to-one elliptical dome made

from an aluminum forged pressing. The closure contained twelve instrumentation bosses, twelve control rod ports and an emergency cooldown port. There were no control rod actuators installed in this system. Unused ports were capped.

The cylinder was welded together from three aluminum, rolled-ring forgings. The forward end of the cylinder was joined to the closure with high strength steel bolts. The forward closure and cylinder were sealed together by a lead plated aluminum omega shaped seal. The aft flange of the pressure vessel contained 96 holes with steel inserts to accept the nozzle bolts. Both the forward closure and the nozzle were located by indexing pins.

c. Nozzle Assembly

The nozzle, P/N 707270 (S/N-23), was attached to the aft or lower end of the pressure vessel by bolts cooled with a flow of propellant that bypassed the nozzle tubes. The nozzle assembly had both a convergent and divergent contour. The half angle of convergence was 45° and the divergent half angle was 17.5° . The nozzle consisted of a stainless steel forging which was machined to contour and slotted to accept stainless steel tubes of "U" cross-section. The U-tubes were brazed to the machined forging.

The nozzle was regeneratively cooled by the liquid hydrogen propellant from the pump discharge line which enters the nozzle assembly through a torus inlet manifold at the exit or divergent end of the nozzle. Liquid hydrogen flowed through the U-tubes to a plenum formed by the nozzle core-support structure and the pressure vessel.

d. Thrust Structure Assembly

The thrust structure, P/N 706964, extended from the test stand CFDTs interface to the pressure vessel and consisted of an upper and a lower assembly. Both assemblies simulated the anticipated XE-1 thrust structure configuration. However, the distance from the test stand adapter interface to the pressure

vessel interface was approximately 51 inches shorter than in the X-Engine because of the absence of the shield and shortening of the upper thrust structure in the CFDTS.

The upper thrust structure was an aluminum, cylindrically shaped, semi-monocoque structure with three removable panels equally spaced to provide access to the TPA and other components. The turbopump assembly was supported within the upper thrust structure by a spider-panel structure.

The lower thrust structure, which was bolted to the pressure vessel and the upper thrust structure, was an aluminum truncated conically shaped panel structure with six equally spaced openings to provide access to controls, lines, connections, and instrumentation. These openings were closed with insertable panels during engine operation to allow inerting of the thrust structure.

e. Turbine and Pump Assembly

The turbopump assembly (TPA) for CFDTS tests was the Mark III, Mod. 4, P/N 287900-179, and consisted of a centrifugal impeller, including an inducer section, coupled to a two-stage turbine drive with a common shaft supported by hydrogen cooled bearings. Liquid hydrogen was supplied to the pump inlet through the pump suction line. In the X-Engine, turbine drive gas was bled from the thrust chamber and mixed with diluent flow tapped from the pressure vessel dome to cool the turbine drive fluid to the proper conditions. In CFDTS, the same diluent flow path was followed. The turbine was accelerated during the start-up by using hydrogen which had picked up heat from the engine components as it passed through the engine. In CFDTS, the turbine exhaust exits from two ports of the exhaust manifold to the ejector system of the test facility.

f. Propellant Feed Line Assemblies

The propellant feed lines consisted of the turbine inlet line, the pump discharge line, and the diluent line. These lines simulated those of the X-Engine. The following is a detailed description of these lines:

(1) Turbine Inlet Line and Turbine Power Control Valve

(a) The turbine inlet line carried the hydrogen heated by the reactor from the hot bleed port of the nozzle to the turbine inlet. This line was provided with a cooling jacket extending from near the forward closure and pressure vessel joint to the hot bleed port. The cooling gas for this jacket was tapped from the pressure vessel dome through the diluent line. In the X-Engine, this is necessary to keep the metal temperature of the turbine inlet line within allowable limits and to cool the hot gas from the nozzle chamber to permissible turbine inlet temperature. The diluent gas is injected from the jacket into the turbine inlet line at the hot bleed port. Cooling was not a consideration in the operation of the CFDTS, but the diluent flow was provided on the CFDTS to simulate the X-Engine.

A venturi for measuring turbine inlet flow was located above the end of the jacketed portion of the line. Above the venturi was the overspeed trip valve. This was a squib-operated valve for emergency shutdown of the system in case the turbine approached an overspeed condition.

(b) Turbine Power Control Valve

The amount of flow to the turbine was controlled by the Turbine Power Control Valve which was operated by the Engine Sequencer. This valve was located in the turbine inlet line between the turbine and the overspeed trip valve. It was a high temperature, 4-inch diameter butterfly valve which had a nominal operating pressure of 550 psig at an operating temperature of 1200°R, and a maximum flow rate of 7 lbs/sec of hydrogen. Figure 2 shows a plot of the flow factor coefficient versus shaft position.

The turbine power control valve was positioned by an electro-pneumatic servo actuator which converted an electrical position command signal to a valve position. The actuator used 215 psi hydrogen gas as the driving fluid; it had a minimum slewing velocity of 360° per second and developed a minimum of 700 in-lb. of torque.

Figure 2
Flow Factor vs Shaft Position - TPCV

(2) Pump Discharge Line

The pump discharge line delivered the liquid hydrogen from the pump to a torus around the nozzle. It was a five-inch uninsulated line with a 22-inch straight section leading from the pump, a right angle bend, a 179-inch straight section down the length of the engine, a second right angle bend, and a final 16-inch section into the nozzle manifold. The pump discharge valve, a six-inch B. H. Hadley butterfly type, was located in the 179-inch straight section of the line. Between the pump discharge valve and the inlet flange for the emergency cooldown port was a check valve to prevent any reverse flow in the line. This valve and cool-down port, although not needed for CFDTS, were in the system to simulate the X-Engine.

(3) Diluent Bleed Line

The CFDTS Diluent Bleed Line was a 2-inch diameter line approximately 67 inches long. Of this length, approximately 36 inches consisted of a flexible section and the remainder was composed of straight sections. The line emerged from the pressure vessel dome, made a 180° bend and was joined to the jacketed section of the turbine inlet line. Included in the straight portion was a 2-inch B. H. Hadley butterfly valve and a flow measuring orifice.

g. Pneumatic Control System

The pneumatic system supplied gaseous nitrogen at 200 psi as working fluid for the actuators of the propellant shutoff valve, the pump discharge valve and the diluent valve. A filtered and regulated supply of hydrogen at 200 psig and 530°R was provided to actuate the turbine power control valve. All pneumatic system gases were discharged through the turbine exhaust ejector system.

h. Cold Flow Development Test System Sequencer

(1) Purpose:

The CFDTS sequencer was designed to ensure accurate control of the propellant feed system valves during the period of start-up in which the TPCV was scheduled in an open-loop fashion prior to closing the nozzle chamber pressure control loop. This unit was designed for use both with the analog test models and with the CFDTS engine. The dual usage allowed close correlation of the actual CFDTS test results with the results obtained in analog studies, and thereby permitted upgrading of the analog engine model to a more exact representation. The required change-over from one control scheme or schedule to another was readily made by a few adjustments in the function generator chassis.

(2) Operation:

The engine sequencer for the Cold Flow Development Test System was a control unit that, upon command from the test engineer, initiated and sustained a pre-programmed sequence of command signals to operate the engine control valves. It provided signals for operation of the propellant shut-off valve (PSOV), the turbine power control valve (TPCV), the diluent valve (DV), the pump discharge valve (PDV), and the pump discharge bleed valve (PDBV). Sequencing of the PSOV, the TPCV, the PDV and PDBV was automatic and was determined by interlocks, pre-set timers and temperature inputs.

During the cold flow tests, certain operating conditions were expected to be reached which allow closure of the chamber pressure control loop. When these conditions were obtained, the sequencer was capable of switching from TPCV position function generator to pressure control. In the pressure control mode of operation, additional data could be collected to verify calculations made during preliminary design of the pressure control system. With this objective in mind, a pressure command generator was supplied with the sequencer to generate a profile which was a step and linear ramp as a function of time.

Provisions also were made in the sequencer to effect a shutdown in the event of turbopump assembly (TPA) overspeed. The sequencer would signal the TPCV to begin closing in the event of a minor overspeed condition until the speed was within the pre-set upper limit, at which point the overspeed cutback circuitry would be switched out and the normal pressure or valve position command signal would regain control of the TPCV.

The sequencer was also designed to prevent opening of the TPCV unless the PSOV was open; and, in addition, the sequencer assured that the TPCV was closed prior to closing of the PSOV.

The pictorial description of the operation of the sequencer is shown in Figure 3, "Block Diagram - CFDTS Sequencer".

2. Comparison Between CFDTS and X-Engine

The non-nuclear components of the CFDTS were similar to those of the nuclear engines (X-Engine) except for variations of a minor nature which did not compromise the usefulness of the CFDTS tests in simulating nuclear engine start conditions.

Because of H-5 test stand space limitations and the lack of a requirement for an external radiation shield, the overall CFDTS thrust structure was approximately 50 inches shorter than the overall X-Engine thrust structure. The CFDTS pump discharge and turbine inlet lines were shorter than the X-Engine lines by this amount. This difference in line lengths was acceptable for simulation because relatively small changes in line pressure losses and flow characteristics resulted.

Certain X-Engine components contributed nothing to the dynamics of engine operation. Consequently, it was unnecessary to provide such components in the CFDTS. These included the instrumentation, wiring, controls, connectors and tubing required for the detection of radiation, the control drum actuators, and their actuation system.

BLOCK DIAGRAM-CFDTS SEQUENCER

Figure 3

Block Diagram - CHTS Sequencer

The CFDTS turbine exhaust system was connected to a test facility exhaust ejector and therefore was not provided with X-Engine turbine exhaust nozzles. The CFDTS did not require an emergency cooldown line. However, since there was a check valve in the X-Engine pump discharge line which prevented backflow to the pump from the emergency cooldown system, the CFDTS had the same type check valve to provide flow similarity. The CFDTS turbine inlet line included a squib valve to be actuated in the event of turbine overspeed. This valve was not included in the X-Engine.

The CFDTS was equipped with an engine sequencer which controlled the system start-up. This sequencer provided a method of using either pre-programmed input for start-up, or a closed chamber pressure or temperature loop. The X-Engine controls provide not only the pre-programmed or pressure loop start-up, but in addition, provide nuclear power controls, steady-state operation controls, scram, emergency cooldown and normal shut-down controls.

3. Hardware Changes Between First and Second Series Tests

After the conclusion of the first series of tests, changes were made in engine hardware to approximate more closely the latest X-Engine and NRX/EST designs.

The turbopump assembly and turbine exhaust manifold were upgraded to the latest NRX/EST configuration. The major changes included increasing the inlet area of the turbine inlet manifold, reducing bearing labyrinth clearances and smoothing out flow passages. In addition, a larger exhaust collector and exhaust manifold were installed to reduce turbine back pressure and equalize resistance to flow.

The hot bleed port was also modified to increase diluent flow to simulate more closely the latest NRX/EST design. By-pass holes were added to by-pass the primary cooling path circuit and reduce the total impedance of the bleed port. The changes considerably increased diluent flow over that in the configuration used in the first series of CFDTS tests.

C. TEST FACILITIES

The CFDTs tests were conducted at the Aerojet-General Corporation Liquid Rocket Plant Test Facility, H-5. This test facility consisted primarily of a propellant supply system, an engine test stand, and an ejector system. An integral part of the system was the controls and data acquisition equipment. An isometric view of the test facility is shown in Figure 4 and a flow diagram of that portion of the H-area test system which was used by the CFDTs is shown in Figure 5. A brief description of the major facility components is given below.

1. Propellant Supply System

a. Main Run Tank

The main run tank for these tests was tank V-H11. This tank had a capacity of 105,000 gallons of liquid hydrogen at a pressure of 100 psi and a temperature of -423°F . To minimize heat gain to the tank, the tank was insulated with a vacuum jacket. The inner tank was supported by a load cell so that the weight flow rate of the hydrogen from the tank could be calculated.

A 36-inch diameter vortex breaker was installed just above the supply line exit at the bottom center of the inner tank. The line was 10 inches in diameter where it emerged from the outer tank and was then reduced to an eight-inch diameter. Immediately below the tank was a "T" section which dropped straight into the CFDTs test stand (H-5) while the branch directed the flow to test facilities H-4 and H-6.

b. Run Tank Propellant Line Assembly

The run tank propellant line was an 8-in. diameter vertical line 11.8 feet long connecting the tank safety valve to the propellant shutoff valve. Included as a part of this line were two turbine type flow meters, one 8-in. and

Figure 4

H-5 Test Facility

one 4-in. in diameter*. These were followed by a wire mesh screen which protected the pump in the event of failure of any upstream component. This line was insulated along its entire length by three to four inches of polyethylene foam-in-place insulation.

2. Ejector System

Consistent with the CFDTS test objectives to analyze start transient operating characteristics at various back pressures, a multistage GN_2 driven ejector system was provided for the H-5 test stand. This system consisted of two, two-stage ejectors, one for the main nozzle exhaust and the other for the turbine exhaust. The ejector system was capable of simulating the back pressure conditions expected during a start transient in ETS-1, or constant back pressure environments from 1 psia to 15 psia (see Figure 6).

The ejector system could maintain an initial back pressure of 1 psia on the nozzle and 0.5 psia on the turbine exhaust. Since the back pressure capability was dependent on the flow through the ejectors, it was possible to maintain the back pressure at any level desired by the addition of gaseous hydrogen through a "spoiler" gas system. As the engine flow increased during the test, the spoiler gas flow was decreased to maintain the required back pressure. By controlling the spoiler gas flow rate as a function of the nozzle chamber pressure, it was possible to maintain constant back pressure equal to that of Test Cell "A" at NRDS (12.7 psia at the elevation of Test Cell "A") or to simulate the ETS-1 characteristics (see Figure 6). It was necessary to control the back pressure only until such time as sonic flow conditions were established at the nozzle throat. After this, as long as sonic conditions existed, the back pressure could vary without affecting engine operation.

* The 4-in. flowmeter was located at the throat of a venturi section in the pipe, while the 8-in. meter was in a straight section of pipe.

3. Control System

The control system for the H-5 facility was independent of the instrumentation system except for the electrical ground which was common to both systems.

The power supply system for the controls function consisted of two, solid-state, Perkins power supply systems which converted standard ac power to 28 vdc. Each of these units could supply 200 amp current for a total capacity of 400 amps. A system of batteries, capable of supplying the necessary voltage and current for the duration of the test, was maintained as an emergency auxiliary power supply.

The power from the control room was supplied to a vector board and to a patch network, both located in the H-area terminal room. The vector board was used to control the facilities and the propellant feed line system whereas the patch network was used to control the engine sequencer and the test equipment.

To determine the proper operation of the facility and engine control valves remotely from the control room, the position of these valves was measured by microprecision switches and the resulting information was indicated on the control panel by panel lights.

The timing of events for this facility was controlled by transistorized, solid-state timing relays. However, engine start-up was controlled by the engine controls sequencer as described in Paragraph IV.B.1.h, above.

4. Data Acquisition System

The data acquisition system for H-area consisted primarily of transducers, a balance and calibration system, amplification and readout equipment, and a computer system. For a flow diagram of the instrumentation systems, see Figures 7 and 8. A brief description of the equipment for these tests is given below:

Figure 7

a. Instrumentation Channels

The following data acquisition channels were available in the H-5 facility for CFDTs:

<u>Channel Description</u>	<u>Available for Tests</u>	<u>Available for Facilities</u>
Strain gage	108	36
FTT	84	18
TC/CC	84	12
TC/CA	78	26
TC/CUCop	18	0
Valve trace	24	0
Flow and speed	12	0
High frequency	12	0

b. Data Recording Channels

The following data recording channels were available for the CFDTs tests:

<u>Data Conversion and Recording Channels</u>	<u>Available Channels</u>
Beckman and CSC Systems	
Low level signal input (unamplified)	96
High level signal input (amplified)	92
Digital "Time interval measurement"	4
Low level digital system	192 (120 I/C) (60 RTT) (12 other)
<u>Other Readout and Recording Systems</u>	
Analog magnetic tape system	58
Oscillograph	48
Strip chart	52
Electronical visual gage	24

c. Data Readout Equipment

(1) Digital System

The digital system was an accurate, high speed, data processing system capable of accepting inputs in the form of analog voltages, pulse width information, or pulse train information. The output of this system was recorded on digital magnetic tape for use in a variety of applications, such as direct entry into the computer system, or it could be used in the tape-card converter to generate punched cards. The main advantages of the digital system were its high sampling rate speed, accuracy and quick access to data.

The equipment was divided into two primary systems, a 96 channel, low level unit, and a 92 channel, high level unit plus four digital channels. The input signal to the high level channels was amplified before being submitted to the analog-to-digital converter and each signal was sampled at the rate of either 40, 20, or 10 samples per second. The low level system received the output signal directly from the transducer without amplification. This signal was sampled at the rate of 10 samples per second. A late addition to the H-5 area was an additional 192 channel low level Consolidated Systems Corporation temperature measuring system.

(2) Magnetic Tape

Fifty-eight channels of magnetic tape data were available. This equipment basically consisted of FM and AM recording amplifiers, playback amplifiers, voltage regulators, tape transport, and power supply. The main advantage of the equipment was that it could record and reproduce data over a large frequency range. The data could then be stored for an indefinite time or could be played back at a slower speed, i.e., over an expanded time scale, and recorded by other systems.

(3) Oscillograph

One 48 channel oscillograph was available for CFDTS testing. This oscillograph could continuously record parameters up to approximately 2000 cps. The system was not as accurate as the Beckman or the magnetic tape systems and was used primarily for transient information as a back-up for other data systems.

(4) Strip Chart Equipment

The available strip chart equipment was of the slow response type and recorded continuously. This equipment was used primarily for visually indicating events as they occurred during the test.

D. INSTRUMENTATION

1. Instrumentation Plan

The planned instrumentation for the CFDTS included equipment for sensing and recording all measurements necessary to fulfill the test objectives. Measurements included pressures, temperatures, flow rates, valve positions, vibrations and strains. The Piping and Instrumentation Diagram - CFDTS (Figure 9), identifies and gives the approximate location of the instrumentation utilized on the CFDTS.

To ensure that the desired test data were obtained from these tests, redundant measurements were taken at critical locations throughout the system.

The pressure and temperature transducers were ranged in accordance with pretest analysis predictions. For the chilldown tests, when the turbopump was not rotating, the pressure transducers at primary locations were low range to obtain the best data possible. Upstream of the reflector inlet, propellant temperatures ranged from ambient to liquid hydrogen temperatures during startup. These temperatures were measured with a narrow range RTT (35°R to 60°R) for accurate pump

INSTRUMENTATION SYMBOLS	
	PRESSURE TRANSDUCER, EXTERNALLY MOUNTED
	TEMP TRANSDUCER, EXTERNALLY MOUNTED
	GAS TEMP TRANSDUCER
	PRESSURE TRANSDUCER, INTERNALLY MOUNTED
	TEMP TRANSDUCER, INTERNALLY MOUNTED
	MATERIAL TEMP TRANSDUCER
	VIBRATION TRANSDUCER
	DIFFERENTIAL PRESSURE
ENGINE VALVES	
	PROPELLANT SHUTOFF VALVE
	DILUENT VALVE
	TURBINE OVERSPEED SHUTOFF VALVE (SQUIB ACTUATED)
	TURBINE POWER CONTROL VALVE
	PUMP DISCHARGE BLEED VALVE
	PUMP DISCHARGE VALVE
	PNEUMATIC SUPPLY SHUTOFF VALVE (PNEUMATIC)
RUN TANK PRESSURIZATION AND VENT VALVES	
	PRESSURE REDUCING REGULATOR SHUTOFF VALVE (N.I.)
	PRESSURE CONTROL VALVE ORIFICE (N.I.)
	PRESSURIZATION FLOW CONTROL VALVE (N.I.)
	TANK PRESSURIZATION SHUTOFF VALVE (N.I.)
	PRESSURE VENT FLOW CONTROL VALVE (N.I.)
RUN TANK PROPELLANT LINE VALVES	
	TANK SAFETY VALVE
	TANK SAFETY VALVE BY PASS VALVE
	RUN TANK PROPELLANT LINE BLEED VALVE
EJECTOR SYSTEM VALVES	
	EJECTOR SUPPLY FLOW CONTROL VALVE
	EJECTOR SUPPLY SHUTOFF VALVE
	FIRST STAGE NOZZLE EJECTOR SHUTOFF VALVE
	SECOND STAGE NOZZLE EJECTOR SHUTOFF VALVE
	FIRST STAGE TURBINE EXHAUST EJECTOR SHUTOFF VALVE
	SECOND STAGE TURBINE EXHAUST EJECTOR SHUTOFF VALVE
	NOZZLE EXHAUST MAKEUP GAS CONTROL VALVE
	TURBINE EXHAUST MAKEUP GAS CONTROL VALVE
PURGE SYSTEM VALVES	
	TURBOPUMP BEARINGS PURGE VALVE
	TURBINE EXHAUST EJECTOR PURGE VALVE
	NOZZLE EXHAUST EJECTOR PURGE VALVE
	TURBINE INLET LINE PURGE VALVE
	PUMP INLET, ENGINE PURGE VALVE
	RUN TANK PROPELLANT LINE PURGE VALVE
	TURBINE INLET LINE BLEED VALVE
VALVE SYMBOLS	
	GLOBE VALVE
	GATE VALVE
	BALL VALVE
	BUTTERFLY VALVE
	CHECK VALVE
	FLOW CONTROL VALVE
	REMOTE SHUTOFF VALVE
	BURST DIAPHRAGM
	RELIEF VALVE
MISCELLANEOUS SYMBOLS	
	GAS FILTER
	LIQUID FILTER
	PRESS. REDUCING REGULATOR
	CFDTS-TEST STAND, MECHANICAL INTERFACE
	TURBINE TYPE FLOW METER WITH FLOW STRAIGHTENER
	PRESSURE SWITCH
	RESTRICTION ORIFICE
	ELECTRICAL INTERLOCK
	ELECTRICAL
	SFC SIGNAL FAILURE CLOSES VALVE
	SFO SIGNAL FAILURE OPENS VALVE

Figure 9
Piping and Instrumentation Diagram - CFDTS
40

bootstrap data, a wide range RTT (35°R to 535°R) for continuous measurement during chilldown and a thermocouple with a faster response to temperature changes during chilldown to correct any temperature measurement lag of the wide range RTT. All reactor material and fluid temperature measurements taken between the reflector inlet and the reactor core outlet were made with thermocouples supplied with the nuclear sub-assembly. All fluid temperature measurements upstream of the reflector inlet and downstream of the core outlet were made with wide range RTT's and thermocouple probes. All surface temperatures were measured with contact thermocouples.

The system instrumentation could also be used to determine flow rates at the turbine inlet and exhaust, through the diluent line and from the main nozzle. The run tank propellant line flow rate could be compared with the sum of the turbine and main nozzle flows plus the corrections for storage of propellant in the engine system and for flow of hydrogen from the pump, through the labyrinth seals into the turbine. The turbine flow was measured in the turbine inlet line. The main nozzle flow was calculated from chamber conditions after sonic conditions were reached at the nozzle throat.

2. Instrumentation for First Series of Tests (Tests 001 through 006)

In the first series of tests, approximately 215 pressure, temperature, flow rate and valve position measurements were taken on each test. These included both diagnostic and facility measurements. From these measurements, approximately 295 recording channels were used which included digital information through Beckman and CSC systems, and analog information on strip charts, oscillographs, and FM tapes.

The Measurements Requirements List showing instrumentation channels measured and recorded for the first series of CFDTS tests (Tests 001 through 006) is given in Appendix C.

3. Instrumentation for Second Series of Tests (Tests 007 through 027)

After completion of the first series of tests, the data were analyzed and modifications in the instrumentation plan for the second series were made based on this analysis.

For the second series of tests, fifty measurements were eliminated. Twenty-one material temperature measurements were deleted because sufficient data were obtained in the first series. In addition, 29 channels were eliminated as unnecessary dual ranging, unneeded redundancy, or no longer required because sufficient information was already obtained about the system.

One hundred and twelve measurements were added for specific diagnostic information. Eight measurements were added more accurately to determine pressure drops across various components. Sixteen measurements were added to investigate further two-phase flow phenomena, and thirty-nine measurements were added to obtain more detailed information on flow distribution in and around plenums. Also, forty-five measurements were added on selected tests to investigate vibration and strain phenomena, and four measurements were added to determine turbine pressures and temperatures and bearing coolant flow more precisely.

In the second series approximately 285 sensing measurements were taken and 345 recording channels were used.

The Measurement Requirements List, showing instrumentation channels measured and recorded for the second series of CFDTIS tests (Tests 007 through 027), is given in Appendix C.

4. Instrumentation for Third Series of Tests (Tests 028 through 031)

Because most system diagnostic information was obtained in the first and second series of tests, the number of measurements used in the third series was reduced to an absolute minimum consistent with basic program requirements. These consisted of primary pressure, temperature, flow, valve position, and facility measurements.

In the third series approximately 50 sensing measurements were taken and 85 recording channels were used.

The Measurement Requirements List, showing instrumentation channels measured and recorded for the third series of CFDTs tests (Tests 028 through 031), is given in Appendix C

5. Description of Transducers

a. Pressure Transducers

Strain gage type pressure transducers were used throughout the system. These transducers required a 10 volt excitation to a 350 ohm bridge network and had a 30 millivolt output at full scale. The data channels used for pressure measurements were ranged by shunt calibration.

b. Temperature Transducers

The temperature measuring devices for these tests were resistance temperature transducers (RTT), thermocouple probes, and surface mounted thermocouples. Narrow range RTT's were used for temperature measurement in the lower temperature region to obtain accurate LH_2 and two-phase measurements. Some wide range RTT's were used to measure the entire anticipated temperature range (ambient temperature to the LH_2 temperature region). To determine the rapid changes in fluid temperatures, open element, immersion type thermocouple probes were used. The temperatures of the equipment surfaces were measured several places throughout the system by copper-constantan and chromel-alumel thermocouples.

For additional information concerning the pressure or temperature transducer requirements and specifications, refer to the Instrumentation-Data Book, REON Report No. 2320 (CFDTs section of Volume IV).

c. Flow Measuring Devices

The flow into the pump was measured by two turbine-type flow-meters in series in the run tank propellant line. These meters were volumetric flow measuring transducers. The frequency (cps) of the output signal was directly proportional to flow rate. Each pulse represented a discrete volume of flow. The volumetric measurement was converted to weight-flow-rate, using the measured density upstream of the meters. One of the meters had a venturi section to accommodate a four-inch impeller to measure low flow rates (from 2.5 lbs/sec to 25 lbs/sec) while the other meter had a straight-through pipe section housing an eight-inch impeller to measure flow rates from 7.5 lbs/sec to 75 lbs/sec.

The flow from the main nozzle hot bleed port into the turbine was measured by a venturi in the turbine inlet line instrumented for pressure, temperature and differential pressure.

The flow through the diluent line was measured by an orifice in the diluent line instrumented for pressure, differential pressure across the orifice and temperature.

The equations used for measuring flow were based on ASME Fluid Meters Report equations using discharge coefficients and expansion factors from empirically derived data. The equations used were as follows:

(1) Main Nozzle Flow

$$\dot{W}_{MN} = \frac{8.14 P}{\sqrt{T}}, \text{ lb/sec } H_2 \text{ where } P = \text{Nozzle Chamber Pressure} \\ \text{and } T = \text{Nozzle Chamber Temperature}$$

(2) Diluent Line Flow (Orifice Meter)

$$\dot{W}_D = 0.6835 Y_1 \sqrt{\gamma \Delta P} \text{ lb/sec. } H_2 \text{ where}$$

γ = Density of LH_2 based on diluent line fluid pressure and temperature

ΔP = Differential pressure of fluid across the orifice

Y_1 = Adiabatic expansion factor

$$Y_1 = 1 - \left[0.333 + 1.145 (\beta^2 + 0.7\beta^5 + 12\beta^{13}) \right]^{x_k}$$

where $k = 1.4$

$$x = \frac{P_1 - P_2}{P_1}$$

$$\beta = 0.746$$

(3) Turbine Inlet Flow (Venturi Meter)

$$\dot{W}_{TI} = 3.223 Y_a \sqrt{\gamma \Delta P} \text{ lb/sec. } H_2$$

where γ = Density of LH_2 based on turbine inlet line fluid pressure and temperature

ΔP = Venturi differential pressure of fluid

Y_a = Adiabatic expansion factor

$$Y_a = \left[r^{\frac{2}{k}} \left(\frac{k}{k-1} \right) \left(\frac{1-r^{\frac{k-1}{k}}}{1-r} \right) \left(\frac{1-\beta^4}{1-\beta^4 r^{\frac{2}{k}}} \right) \right]^{\frac{1}{2}}$$

where $k = 1.4$

$$r = \frac{P_2}{P_1}$$

$$\beta = 0.62$$

(4) Bearing Housing Flow

$$\dot{W}_{BH} = 0.0172 \sqrt{\gamma x \Delta P} \text{ lb/sec } LH_2 \text{ where}$$

γ = Density of LH_2 based on bearing housing fluid pressure and temperature

ΔP = Differential pressure of fluid across bearing housing

d. Position Indicating Devices

The position of the valves throughout the system were determined by electrical potentiometers and limit switches which were integral parts of the valves.

e. Transducer Requirements

The transducer requirements for the program were specified in the Instrumentation Data Book, REON Report No. 2320 (CFDTS section of Volume IV).

f. Transducer Mounting

The pressure transducers were mounted as closely as practical to the engine, utilizing brackets and mountings furnished with the CFDTS. The exact location is given in Drawing No. 1013500, Transducer Mounting, CFDTS.

g. Transducer Calibration

The transducers used in these tests were calibrated in accordance with Aerojet Standard Practices. The calibration references for the Flow Measuring, Strain Gage and Temperature Measuring Systems are given in the CFDTS Test Plan, Report No. RN-S-0148.

3. Data Channel Measurement Tolerances

The accuracy of the measurements was basically as stated in AGC TM-125, Revision D, Instrumentation Accuracy for Performance Calculations, dated 30 October 1962 and AGC Memo 8740:0139, Instrumentation Accuracy for M-1, dated 20 May 1964. Data channel measurement tolerances based on the data available are shown in Figures 10 and 11.

MEASURING SYSTEM	CHANNEL TOLERANCE
<u>PRESSURE</u>	
CLASS A TRANSDUCER (2 CHANNEL AVERAGE)	± 0.297 %
CLASS A TRANSDUCER (SINGLE CHANNEL)	± 0.420 %
CLASS B TRANSDUCER (SINGLE CHANNEL)	± 0.471 %
CLASS C TRANSDUCER (SINGLE CHANNEL)	± 0.754 %
CLASS D TRANSDUCER (SINGLE CHANNEL)	± 0.901 %
<u>DIFFERENTIAL PRESSURE</u>	
CLASS E TRANSDUCER (STATHAM P80)	± 0.808 %
CLASS E TRANSDUCER (STATHAM PM280)	± 0.596 %
<u>THERMOCOUPLE</u>	
COPPER/CONSTANTAN (32°F R.J.) (-425°F TO +100°F RANGE)	± 9.9°F
CHROMEL/ALUMEL (32°F R.J.) (-425°F TO +100°F RANGE)	± 7.3°F
CHROMEL/CONSTANTAN (32°F R.J.)	UNDER STUDY
<u>ASSUMPTIONS:</u>	
1. ALL TOLERANCES ARE 3 SIGMA DEVIATION AT THE OPERATING LEVEL.	
2. TOLERANCES BASED ON 5 TO 10 SECOND STEADY STATE TESTING.	
3. PRESSURE TRANSDUCERS ARE NOT AT CRYOGENIC TEMPERATURES.	
4. NO LH ₂ FLOWMETER CALIBRATIONS HAVE BEEN PERFORMED.	

Figure 10
Data Channel Measurement Tolerances - Pressure and Thermocouples

MEASURING SYSTEM	CHANNEL TOLERANCE
<u>RESISTANCE TEMPERATURE TRANSDUCERS (134 CT)</u>	
POTENTIOMETRIC CODE K (-425°F TO -400°F) (LH ₂)	± 0.054°F*
	± 0.11 °F (1)
	± 0.15 °F (2)
	± 0.24 °F (3)
POTENTIOMETRIC CODE L (-425°F TO +75°F) (LH ₂ & GH ₂)	± 1.77 °F (3)
POTENTIOMETRIC CODE N (-425°F TO -300°F) (LH ₂ & GH ₂ ;	± 0.50 °F (3)
BRIDGE COMPLETION SYSTEM CODE 1 (-300°F TO -200°F) (LOX)	± 0.44 °F
POTENTIOMETRIC (-425°F TO -260°F) (LOX)	± 0.45 °F
<u>VOLUMETRIC FLOW (TURBINE TYPE FLOWMETER)</u>	
LOX USE - D-6 LOX CALIBRATION	± 0.78%
D-6 LOX CALIBRATION MASS FLOW INC. TEMP-DENSITY ERROR	± 0.81%
D-6 WATER CALIBRATION FOR LOX USE	± 2.0%
LH ₂ USE - H-5 LH ₂ CALIBRATION	± 1.0% (EST)
D-6 WATER CALIBRATION FOR LH ₂ USE	± 2.2% (EST)
GH ₂ USE - UNIV. OF COLORADO CALIBRATION (DENSITY SIMULATION)	UNDER STUDY
AGC VOLUMETRIC CALIBRATION	UNDER STUDY
NOTES:	
	* ESTIMATED ACHIEVEMENT LEVEL AFTER FIXED POINT MULTI-RTT CRYOSTAT IS OPERATIONAL
	(1) USING SPECIAL DATA REDUCTION OF ANY 134 CT RTT
	(2) USING STANDARD DATA REDUCTION OF SELECTED 134 CT RTT
	(3) USING STANDARD DATA REDUCTION OF ANY 134 CT RTT

Figure 11
Data Channel Measurement Tolerances - RTT and Flow

The pressure transducers were divided into classes A through D in accordance with their accuracy. The resistance temperature transducers were classified in accordance with the temperature range for which they were intended, i.e., K for temperatures from -425°F to -400°F , L for temperatures from -425°F to $+75^{\circ}\text{F}$, N for temperatures from -425°F to -300°F and W for temperatures from -200°F to -425°F . The type of transducer used was dictated by the accuracy requirements in the Measurement Requirements List, Appendix C.

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V. CFDTS ASSEMBLY AND PRE-TEST OPERATION

A. CFDTS ASSEMBLY

The Cold Flow Development Test System was assembled and prepared for testing during the months of December 1964 through February 1965.

1. Receiving and Inspection of Reactor Assembly

The unfueled reactor for CFDTS was delivered to Aerojet Sacramento from WANL, Large, Pennsylvania, by rail on 9 December 1964. For a complete description of the shipping procedures and the reactor shipping instrumentation see "CFDTS Shipping Procedures Between WANL - Large, Pennsylvania, and Aerojet-General Corporation, Sacramento, California; Astronuclear Laboratory Westinghouse Electric Corporation."

The reactor was transferred from the Sacramento rail siding to the Final Assembly Area in Building 2002 by means of a WANL-provided tractor-trailer. With the outer container still loaded on the trailer, the inner container was removed, placed on the inner container stand, and the cover was removed. The reactor was then lifted from the inner container and inspected in preparation for insertion into the pressure vessel.

The pressure vessel, upper and lower thrust structures, propellant feed lines and valves, nozzle, the turbopump assembly, and other engine hardware were received in the shop and inspected in accordance with established Aerojet inspection procedures.

2. Assembly Operations

The basic plan for assembly of the CFDTS was to completely assemble the engine system in the shop, then partially disassemble the engine into the major components, i.e., the upper and lower thrust structures, the pressure

vessel and reactor assembly, and the propellant feed line assemblies, for shipment to the H Test Area in the Sacramento Plant via flat-bed trucks. The engine was assembled per the detailed assembly procedures listed in Appendix B, Section A. A CFDTIS Engine Assembly Log Book was maintained to record assembly activities, problems and corrective action. A general breakdown of the assembly of the system is given below. Figure 12 shows the assembly of the CFDTIS in the assembly stand.

The first assembly step was to install the pressure vessel in the Pneumagrip (an engine-holding device utilizing pneumatic members that grip the pressure vessel). This was accomplished by opening the jaws of the Pneumagrip, lifting the pressure vessel in the vertical position and installing it in the Pneumagrip. The pressure vessel was aligned so that it was exactly in the vertical position, the jaws were closed, and the tires of the Pneumagrip were inflated. The reactor was then installed in the pressure vessel and dimensionally checked to assure proper seating. The internal shield was lifted into position above the pressure vessel and the reactor instrumentation was threaded through the shield which was lowered onto the reactor assembly. A retainer ring was slipped over each instrumentation bundle and the closure was lifted into a position above the pressure vessel. The instrumentation wiring was threaded through the instrumentation ports and the closure was lowered onto the pressure vessel. All closure bolts were installed and torqued. The control drum shafts were installed through the closure ports and the port caps were installed. The seals and caps were installed in the instrumentation ports. The instrumentation support ring was bolted to the closure and the reactor instrumentation leads were attached to the ring. The instrumentation plate was then attached to the support ring and the reactor pressure transducers were mounted. The pressure vessel and reactor were rotated to the nozzle-up position, the pressure vessel leak test plate was installed on the nozzle end of the pressure vessel, and a leak check of the forward closure was performed.

The next step was to attach the nozzle, which was installed with the pressure vessel in the nozzle-up position. This was accomplished by picking up the nozzle with the bridge crane and lowering it into place. Special tooling was used to seat the nozzle on the reactor vessel before installing the nozzle bolts.

Figure 12
CFDTIS in the Assembly Stand

The pressure vessel and reactor assembly were rotated to the nozzle-down position for installation of the thrust structure assembly. The lower thrust structure was lifted with the thrust structure lifting adapter and installed on the pressure vessel and reactor assembly.

The TPA was positioned on its test installation stand in the CFDTIS assembly area. The Upper Thrust Structure was lifted by means of the thrust structure lifting adapter and a Hydra-Set with the overhead crane. It was then lowered to a position just above the turbopump assembly. The TPA was raised into position with a hydraulic jack on the installation stand. The mating clamp between the pump inlet line and the TPA was installed and torqued to the design requirement. The TPA was disengaged from its installation stand, the turbine exhaust manifold assembly was added and the assembly was then moved into position on the lower thrust structure. The bolts between the lower and upper thrust structures were then installed.

Upon completion of the mounting of the Upper and Lower Thrust Structure Assemblies on the engine, the pump discharge line, including and pump discharge valve, and the turbine inlet line were installed. To align the TPA flanges with the mating turbine inlet line and pump discharge line (and their respective supporting brackets), it was necessary to loosen the clamp holding the TPA to the Upper Thrust Structure, lower the TPA slightly, and rotate it a degree or so until optimum alignment was obtained. The diluent line was connected from the Pressure Vessel Dome to the turbine inlet line. Miscellaneous instrumentation brackets were installed and the entire engine system was leak checked. This completed the assembly of the engine.

3. Partial Disassembly and Transfer of Engine to the Test Area

The fully assembled engine was partially disassembled into its major components for shipment from the assembly shop to the test area. The pump discharge and turbine inlet lines were removed. The upper thrust structure assembly was removed from the lower thrust structure and the lower thrust

structure was removed from the pressure vessel and reactor assembly. These components were shipped separately to the test area.

After mounting the transportation shock measuring instrumentation on the pressure vessel and reactor assembly, it was removed from the engine assembly stand and installed on the CFDTS transport trailer. On 18 February 1965, the pressure vessel and reactor assembly was transported to the Test Stand H-5 in the Sacramento Plant Test Area. The shocks experienced in handling and transporting the reactor assembly were carefully monitored in the X, Y, and Z axes and continuously recorded. The recorded speed for the run (a distance of about five miles) was from two to five miles per hour. The maximum shock load experienced by the assembly was 0.3 g in the horizontal axis parallel to the direction of travel. The maximum shock load experienced in the vertical axis was 0.2 g. These loads were well within the maximum allowable shock load limit of 0.5 g. Figure 13 is a photograph of the vibration monitoring equipment used in transporting the pressure vessel and reactor assembly to the test area.

B. ASSEMBLY OF CFDTS INTO TEST STAND

Upon arrival at the H-5 test site, the engine components were inspected for damage during shipment. No damage was found.

The pressure vessel and reactor assembly (PVARA) was lifted from the transport trailer with a mobile crane. To avoid the possibility of sudden movements and possible damage to the reactor, a Hydra-Set was used between the crane hook and the PVARA to lift the PVARA free of the trailer in 0.005-in. incremental movements. The PVARA was then swung in a horizontal position into the test area assembly cart, the trunnions on the Pneumagrip were engaged in the trunnion supports of the assembly cart, and the assembly was rotated to the nozzle-down position. The lower and upper thrust structures were installed and the assembly cart was then rolled on rails into the test stand. The assembly was raised into position and bolted to the test stand thrust beams. At this point, the Pneumagrip was removed from the engine by swinging it open and removing the assembly cart

Figure 13
Vibration Monitoring Equipment

which supported it. After removing the Pneumagrip, the cart was rolled back into the test stand for use as a work platform. Propellant feed lines and associated valving were installed.

An engine purge system was installed to permit purging the system with either gaseous nitrogen or helium. The pneumatic system for operating the valves was installed, using gaseous hydrogen to actuate the TPCV and gaseous nitrogen to operate the other engine valves.

The test set-up was completed with the installation of the instrumentation transducers and the connections of these and the controls wiring to the control room. Figure 14 shows the CFDTS installed in the test stand, just prior to installation of the adapter that joined the nozzle to the ejector duct.

C. PRE AND POST TEST SEQUENCE

The detailed test procedures used for the conduct of the test are listed in Appendix B, Section C, of this report. A general description of the procedure used prior to and after each test is given below:

1. Pre-Test Purge

Prior to the initiation of the test, the tank safety valve, propellant shutoff valve and turbine power control valve were closed and pump discharge valve and turbine overspeed shutoff valve (squib actuated) were opened. (Refer to Figure 15, Schematic Diagram CFDTS Engine Valves and Purge Flow Pattern, for valve identification and location.) This placed the valves in the "PSOV" start condition of the CFDTS engine sequencer with the exception that the TSV was closed. All other valves shown in Figure 15 were closed.

The Run Tank Propellant Line Bleed Valve (valve No. 5) was opened at the bottom of the RTPLA to allow venting to the stack.

Figure 14
CFDTS in Test Stand

Figure 15
Schematic Diagram - CFDTs Engine Valves and Purge Flow Pattern

The Run Tank Propellant Line Purge Valve (valve No. 1) was opened at the top of the RTPL to admit GN_2 into the RTPL at 20 SCFM for one minute.

Turbine Inlet Line Purge Valve (valve No. 12) was opened to admit GN_2 into the turbine inlet line at approximately 10 SCFM for a minimum of one minute.

Pump Inlet Engine Purge Valve (valve No. 4) was opened to admit nitrogen through the pump inlet line into the engine system at approximately 20 SCFM for a minimum of five minutes.

Diluent Valve (valve No. 11) was opened to allow a flow of nitrogen from the pressure vessel through the diluent jacket for a minimum of three minutes.

Turbine Exhaust Ejector Purge Valve (valve No. 14) was opened to admit nitrogen into the turbine exhaust ejector at approximately 15 SCFM for a minimum of two minutes.

The main nozzle Exhaust Ejector Purge Valve (valve No. 16) was opened to admit nitrogen into the nozzle ejector at approximately 15 SCFM for a minimum of five minutes. This purge was maintained until the ejectors were turned on.

The Thrust Structure Purge Valve (valve No. 15) was opened to admit nitrogen into the Thrust Structure. The flow of nitrogen continued throughout the test with the Thrust Structure Vent monitored for the presence of hydrogen.

This completed the pre-fire purge sequence.

2. Chiltdown of Run Tank Propellant Line

Immediately prior to a test run, the purge gas to the Run Tank Propellant Line (valve No. 1) and the Pump Inlet Line (valve No. 4) was changed

from nitrogen to hydrogen to prevent possible freezing of nitrogen in the line upon the introduction of the LH_2 .

When the hydrogen purge was completed, the Run Tank Propellant Line Purge Valve (valve No. 1) and the Pump Inlet Engine Purge Valve (valve No. 4) were closed. The Turbine Exhaust Ejector Purge Valve (valve No. 14) and the Nozzle Exhaust Ejector Purge Valve (valve No. 16) remained open to provide a continuous purge on the turbine and nozzle ejector systems to keep air out of the engine.

The main run tank was maintained at a pressure of 20 psia and equilibrium temperature of approximately 38.5°R or less.

Run Tank propellant line pressure and temperature measurements were recorded to determine the liquid hydrogen conditions.

The tank safety valve was opened to allow liquid hydrogen to flow into the run tank propellant line. The run tank propellant line bleed valve was cycled to bleed liquid hydrogen intermittently until it was assured that the flow meters would not overspeed and then the run tank propellant line bleed valve was allowed to remain open. The bleed continued until the fluid temperature in the line stabilized at minimum temperatures.

3. Post-Test Purge

Testing was terminated by closing the turbine power control valve. The propellant shutoff valve was closed and the run tank propellant line bleed valve opened. The ejector duct nitrogen purges were turned on and the ejector drive-fluid supply was closed. The run tank propellant line was purged with GH_2 followed by GN_2 . The rate of purge gas flow was low enough so that the flowmeters either did not turn or turned at a very low rpm.

The pump inlet was purged with GH_2 for three minutes to boil off any liquid hydrogen in the system. This was followed by a purge of GN_2 to inert the engine system until initiation of the GN_2 warming cycle or the engine trickle purge.

The GN_2 and GH_2 system supply manifolds were vented, the run tank pressure vented and the ejector purges closed.

This completed the post-fire purge operations. Between test runs, a trickle purge of nitrogen was maintained through the pump inlet engine purge valve to keep the engine inerted.

D. TEST PARAMETER LIMITS

During the test certain parameters were continuously monitored to signal an emergency shutdown in the event of a malfunction. The critical parameters monitored and their shut-down values were as follows:

1. Pressure of main hydrogen gas supply - 900 psig (minimum)
2. Pressure of main nitrogen gas supply - 900 psig (minimum)
3. Main run vessel liquid level (H-11) - 10% minimum
4. Ejector skin temperature - 440°R minimum
5. Temperature of hydrogen in the nozzle chamber - test stop at 160°R
6. Pump speed (NTPA) - 26,000 rpm maximum
7. Turbopump assembly vibration - test stop at 4.5 mils movement

E. PHOTOGRAPHIC COVERAGE

1. Still Photos

Still photos were taken at various stages of the assembly and testing of the engine system. Photos were taken of the various components showing how they were installed in the assembly shop. Photos were also taken showing the

installation of the engine in the test stand, the installation of the instrumentation on the engine, and connections of the lines and purge systems. A list of still photos taken during assembly and testing of the system is given in Appendix D. Copies of these photos are available on request.

2. Documentary Film

In addition to still photos, color documentary film was taken showing the transportation of the reactor on the railroad car, the unloading and installation of the reactor in the assembly shop, the assembly of the engine in the shop, its transportation to the test area, and its installation in the test stand. Appendix D contains a list of documentary film taken.

3. Test Film

Motion pictures were also taken of each test run from test start minus 5 seconds to test stop plus 5 seconds. Black and white and infra-red footage was taken at 64 frames per second on the first six tests. Color film at 64 frames per second was taken on tests 007 thru 031. A list of this film is given in Appendix D.

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VI. DESCRIPTION OF RUNS AND TEST HIGHLIGHTS

A. SERIES I, TESTS 001 THROUGH 006

1. CFDTS Test No. 001

The first CFDTS test was conducted on 15 April 1965 in accordance with the procedures and requirements established in the CFDTS Test Specification Report No. RN-S-0191, Rev. 1, March 1965.

The objectives of the test were to obtain warm pump chilldown data for the engine system and to check out the test facility, instrumentation, and controls.

After a complete checkout of controls and instrumentation, the run tank propellant line (RTPL) was chilled to the propellant shut-off valve (PSOV) by bleeding off LH_2 just above the PSOV until the fluid temperature in the RTPL stabilized at a minimum which was 40.5°R . During this chilldown, the run tank pressure was maintained at 21 psia.

An engine system purge with GN_2 was maintained during the chilldown of the RTPL until immediately prior to opening of the PSOV, at which time the purge gas was changed to helium for approximately 15 seconds to drive GN_2 out of the system. The run tank propellant line was chilled following the procedure described in Section IV,C,2, above. The purpose of chilling the line and pump was to assure liquid through the pump at test start and during the test.

Approximately 30 seconds after the fluid temperature in the RTPL line was stabilized at minimum (40.5°R), the tank pressure was raised to 68 psia. The propellant line bleed was continued at the higher tank pressure until the fluid temperature again stabilized.'

The ejector system was turned on at this point with the GN_2 drive pressure set at 100 psig. The basic function of the ejectors in this test was to assure sufficient flow of GN_2 in the exhaust ducts to avoid any possibility of oxygen backing up in the ducts and creating a hazard. This flow reduced system back pressure to 14.2 psia.

The test was then initiated by opening the PSOV. The valve opening time was approximately 3.5 seconds. During the test the turbine power control valve (TPCV) remained closed and the turbine rotor lock was in place.

After 22 seconds the fluid flow out of the pump was essentially liquid and after 28 seconds the fluid temperature stabilized at 47.4°R . After 55 seconds, the nozzle chamber temperature reached 160°R and the test was terminated by closing the PSOV.

The maximum propellant line flow was 16.9 lbs/sec and the maximum chamber pressure was 21.1 psia.

Following the test, the system was first purged by introducing GH_2 into the pump inlet line. GH_2 was flowed to boil residual LH_2 out of the system and the purge gas was then switched to GN_2 . To raise the temperature of the engine system to ambient more quickly in preparation for the next run, GN_2 purge gas heated to 110°F was used.

Post-test inspection revealed no damage to test hardware or the test facility.

2. CFDTS Test No. 002

Because of the successful demonstration of system integrity and accumulation of valid data in the first test, the decision was made by the Test Review Board to proceed immediately to a chilled pump chilldown test. This test was conducted on 16 April 1965.

The objective of the test was to determine the effect on the engine system of chilling the pump prior to initiating fluid flow through the engine.

Approximately 12 hours were required for the engine system to warm up uniformly to ambient after the first chilldown test. To determine whether or not LN_2 was collecting at the bottom of the thrust structure during chilldown, two temperature measurements were added in the thrust structure and it was resealed and inserted with GN_2 prior to test.

After a complete functional checkout of the facility and test hardware, the RTPL was chilled in the same manner as in the first test to 38.6°R with the run tank pressure at 19 psia. The tank pressure was raised to 68.7 psia and after the fluid temperature again stabilized at a minimum, the PDV was closed and the PDBV was opened prior to opening the PSOV. The pump was chilled with a bleed flow rate of 8 to 10 lbs/sec of LH_2 until the pump discharge fluid temperature stabilized at a minimum of 39.4°R . The pump was chilled in 156 seconds under these conditions.

As in the first test, the ejectors were set at 100 psig GN_2 drive pressure, the TPCV remained closed, and the turbine rotor lock remained in place.

The test was initiated by the CFDTTS sequencer which closed the PDBV and opened the PDV. The PDV opened in approximately two seconds. After 47 seconds, the nozzle chamber temperature reached 160°R and the test was terminated by closing the PSOV.

In this test, maximum propellant line flow was 17.2 lbs/sec and the maximum chamber pressure was 22.2 psia. Because the pump was pre-chilled, the flow rate was higher than in the first test and the chamber temperature decreased more rapidly.

At the conclusion of the test, the system was purged with GH_2 and GN_2 according to post-test purge procedures and heated GN_2 was then purged through the engine system to raise the temperature to ambient for the next test.

Post-test inspection revealed no damage to test hardware.

3. CFDTS Test No. 003

After analysis of results of the first and second tests, the decision was made by the Test Review Board to proceed to a bootstrap* test. This test was conducted on 17 April 1965. The prime objective of the test was to determine the bootstrap capability of the system using a 70 psia tank pressure.

Prior to the test, the upper thrust structure was opened and the turbine rotor lock removed. The thrust structure was then resealed and inerted with GN_2 for the test to prevent any possibility of fire in case of a GH_2 leak in the structure. The turbine power control valve was programmed to ramp open at test start.

After a complete functional checkout of the test hardware and facility, the run tank propellant line was chilled to a minimum of 39.2°R following the same procedure used in the previous test to assure liquid hydrogen conditions out of the RTPL. The pump was then chilled until the pump discharge fluid temperature stabilized at 40°R with a tank pressure of 69.7 psia. The purpose of chilling the propellant line and pump was to assure liquid through the pump at test start and during the test. The pump was chilled for 167 seconds. The ejectors were turned on, with the GN_2 drive pressure set at 100 psig, shortly prior to test start.

*For a definition of bootstrap refer to Section IIIC, Page 12.

The test was initiated by opening the PDV. Simultaneously, the TPCV was opened to allow fluid flow from the nozzle chamber to the turbine. The valve opening times were approximately 2.0 seconds for the PDV and 1.0 second for the TPCV. After 29.7 seconds the nozzle chamber temperature reached 160°R and the test was terminated by closing the PSOV after the TPCV was first closed to protect the pump from possible overspeed because of cavitation. The closing times were approximately 0.4 seconds for the TPCV and 6.2 seconds for the PSOV.

The engine system successfully bootstrapped with a steady build-up of turbine speed and system pressure. A maximum pump speed of 5260 rpm was attained. Maximum pump head rise was 54 psi, maximum fluid flow rate was 21.4 lbs/sec and maximum chamber pressure was 44.5 psia. Breakaway torque of the turbine was very low, and first indication of pump rotation appeared with the first indication of pressure to the turbine.

At the conclusion of the test, the system was inerted and warmed to ambient temperature following post-test procedures as in the previous tests.

Post test inspection revealed no damage to test hardware.

4. CFDTS Tests Nos. 004, 005, and 006

Tests Nos. 004, 005, and 006 were chilled pump tests run at 14.2 back pressure to evaluate the effect of different tank pressures on bootstrap start. The tank pressures for these tests were 90 psia, 50 psia, and 60 psia respectively. The TPCV was programmed to step to 55° and ramp open to 83° within one second after test start.

Prior to Test 004 the tap for the heated nitrogen purge was relocated from a tap on the diluent line to the cap on the emergency cooldown port immediately below the pump discharge valve to heat the reactor core and other system components more quickly and uniformly. Introducing heated nitrogen at this point reduced the time required to reach ambient temperature significantly in this and subsequent tests and resulted in more uniform warmup of the system. It required about six to eight hours to warm the engine system after this change.

The procedures followed in these tests were basically the same as those followed in Test 003. The RTPL was first chilled to assure liquid hydrogen conditions out of the RTPL. The pump was then chilled until pump discharge fluid temperatures stabilized at minimum. The ejector systems were turned on and the tests were initiated by opening the PDV and TPCV simultaneously. In Test 004 the pump reached a maximum rpm of 5932 in 9.7 seconds, in Test 005 a maximum rpm of 2190 was reached in 38.5 seconds, and in Test 006 a maximum rpm of 4220 was reached in 28.1 seconds.

At the conclusion of Test 006, the engine system was purged of hydrogen and then secured for a long-term shutdown. Test 006 completed the first series of CFDTS tests.

B. SERIES II, TESTS 007 THROUGH 027

1. Test No. 007

The first test of the second series of CFDTS Tests was conducted at 1:00 AM, 6 October 1965. The purpose of the test was to checkout the test facility, instrumentation, and controls and to evaluate the difference in system performance with the TPA modified to the latest NRX/EST configuration. Accordingly, the same test conditions and procedures were followed as those for Test 003 in the first series conducted in April 1965. The pump start condition was chilled, the run tank pressure was 70 psia, and the back pressure was 14.2 psia. During pump chilldown a drop was noted in chamber temperature and during the test the turbine speed attained was much less than predicted (3380 rpm). Immediately after the test the quick look data was examined and it became apparent that the turbine power control valve had not been in the programmed position during the test. A check of the TPCV revealed that the pin fixing the valve gate to the valve shaft had dropped out. The pin was replaced and staked so that it could not drop out again. Preparations were then initiated for the next test.

2. Test No. 008

Test No. 008 was conducted at 10:30 PM on 9 October 1965. The purpose of the test was to again compare the performance of the improved TPA with the old TPA. Test conditions and procedures were the same as for Test 007. The pump discharge valve and turbine power control valves were opened simultaneously. The PDV opened in 1.7 seconds and the TPCV in 1.0 second which was typical for the tests.

A peak pump speed of 7445 rpm was reached in 12.6 seconds. (This compares with a peak pump speed of 5260 rpm at 16.0 seconds attained in Test 003 with the old TPA and represents approximately 40% improvement in pump speed.) After 27.2 seconds the nozzle chamber temperature reached 160°R and the test was terminated by closing the propellant shutoff valve and the TPCV. The closing times were 0.6 seconds for the TPCV and 6.0 seconds for PSOV. To protect the pump from possible overspeed because of unloading while power was still applied through the turbine, the TPCV was fully closed before the PSOV closing was initiated.

The engine system successfully bootstrapped as expected. Turbine speed and system pressures and flows built up smoothly to peak after initial fluctuations during the first 5 or 6 seconds. Breakaway torque of the turbine was very low, and first indication of pump rotation appeared with the first indication of pressure to the turbine.

At the conclusion of the test, the system was purged of hydrogen and heated GN₂ was introduced to warm the system in preparation for the next test.

3. Tests Nos. 009, 010, 011, and 017

Tests No. 009, 010, 011 and 017 were chilled pump tests run at NRX/EST (12.7 psia) back pressure to evaluate the effect on bootstrap start of varying the tank pressure. The nominal tank pressures were 70 psia, 50 psia, 35 psia, and 40 psia respectively. For these tests the TPCV was programmed to step open to 60° and fast ramp to 80°.

Prior to test start the run tank propellant line and pump were chilled to below 40°R except in Test 011 where the pump discharge temperature was 41.2°R at test start. As in previous chilled pump starts, the purpose of chilling the propellant line and pump was to assure liquid through the pump at test start and during the test. Examination of test data showed that NPSP was maintained at all times during these tests and the criterion of liquid through the pump was achieved.

Peak pump speeds attained were 7700 rpm with the 70 psia tank pressure, 6900 rpm with 50 psia tank pressure, 1995 rpm with 40 psia tank pressure, and 1650 rpm with 35 psia.

In Test 017 oscillations of ± 1 psi at 1 cps occurred in the run tank from 17 seconds to 42 seconds after test start. These oscillations were reflected throughout the entire engine system. Oscillations of ± 75 rpm were noted in turbine speed and oscillations of ± 3 lb/sec in flow. Oscillations in pressures up to the core inlet were greatly attenuated through the reactor and nozzle chamber pressure fluctuations were relatively of much smaller magnitude. A malfunction had apparently developed in the run tank pressurization control system during the test. This was corrected prior to the next test.

4. Tests No. 012 and 013

The objectives of Tests 012 and 013 were to evaluate the performance of the automatic pressure control system. Two modes of operation of the control system were considered. In Test 012 the pressure loop was closed at test start and the chamber pressure demand was set at 45 psia. In Test 013 the turbine power control valve was set to step open to 50° at test start and the chamber pressure demand was set at 35 psia. In both Tests 012 and 013 the tank pressure was 70 psia and the back pressure 12.7 psia.

In Test 012 the automatic pressure control system responded as predicted. However, because of the rapid transients and the small error signals at the very low chamber pressures of CFDTs relative to design pressures, the

control loop did not hold the chamber pressure to 45 psia as demanded. The turbine power control valve required approximately 7 seconds to open to 80°. When the chamber pressure exceeded the chamber pressure demand of 45 psia, the TPCV began to close and when the chamber pressure fell below 45 psia because of loss of thermal energy in the system, it again opened, demonstrating the response of the control system.

In Test 013 the TPCV opened as programmed to 50° and when the chamber pressure exceeded the demand of 35 psia, the TPCV closed 6°. As chamber pressure decayed at the end of the run, the valve opened again and continued opening until closed at test stop, again demonstrating the response of the control system.

5. Test No. 014

The objective of Test 014 was to determine if a difference in startup performance resulted from blanketing the TPA in helium instead of nitrogen because of the differences in heat transfer characteristics of the two fluids. The tank pressure and back pressure selected for the comparison were 35 psia and 12.7 psia for comparison with Test 011.

No significant differences were noted in system performance. There were some fluctuations in pressures induced by the run tank pressurization control system evident for about 20 seconds during the middle part of the test. These should be considered when analyzing the test data. A peak pump speed of 1610 rpm was reached in 61.7 seconds. However, the speed curve was very flat (between 1450 and 1600 rpm) for about 40 seconds.

6. Tests No. 015 and 016

The objectives of Tests 015 and 016 were to investigate the effects of back pressure on bootstrap startup for comparison along with Test 011 (12.7 back pressure). Test conditions for Test 015 were tank pressure 35 psia,

back pressure 7.5 psia (ETS-1), pump condition at test start chilled. Test conditions for Test 016 were tank pressure 35 psia, back pressure 0.25 psia, and pump condition at test start chilled. The maximum pump speed attained in Test 015 was 8210 rpm at 29.5 seconds and in Test 016 was 8700 rpm at 14.6 seconds.

For the first 7 seconds of Run 016, NPSP was very low. Between 7 - 8 seconds into the run NPSP increased rapidly to 12 psi indicating an increase in fluid density. This sudden increase caused a momentary drop in pump speed from 4900 rpm to 4000 rpm after which pump speed again increased in typical bootstrap fashion to peak.

7. Tests No. 018 and 023

The objectives of Tests 018 and 023 were to determine minimum tank pressure for bootstrap start at minimum back pressure conditions with a chilled pump. The back pressure for both tests was 0.25 psia and the tank pressure was 30 psia for Test 018 and 25 psia for Test 023.

In both tests the system bootstrapped smoothly even with the low tank pressures. Peak pump speeds were 8700 rpm at 14.6 seconds for Test 018 and 4600 rpm at 36.7 seconds for Test 023.

Difficulty was experienced in Test 023 when the pump discharge bleed valve froze open and did not close upon signal from the sequencer at test start or in response to the manual override signal from the control console during the run. The purpose of the test was achieved in that the system would bootstrap at the low tank pressure (25 psia) and minimum back pressure.

After the test the valve appeared to close normally when it was recycled. The decision was made by the Test Review Board to proceed to the next test, but manually cycle the valve periodically during chilldown and manually close the valve prior to test start.

8. Tests No. 019, 020, and 021

Tests 019, 020, and 021 were designed to evaluate warm pump starts and to determine optimum opening times for the TPCV. These tests were run at a 35 psia tank pressure and a 7.5 psia back pressure. In Test 019 the TPCV was opened when the fluid temperature at pump discharge reached 43.5°R to ensure liquid out of the pump. In Test 020 the TPCV was opened in approximately half the time after test start as in Test 019. In Test 021 the TPCV was opened simultaneously with the PSOV. The pattern of flows, pressures, and pump speeds obtained was basically the same in all three tests. Pump speed increased smoothly to about 2000 rpm and then began to oscillate with increasing amplitude to a maximum of about ± 1000 rpm with decreasing frequency (from 0.5 to 0.25 cps) until the system finally bootstrapped to a speed of 7700 to 7800 rpm. Similar oscillations were observed in all pressure and flow parameters. Opening the TPCV sooner tended to delay the time to reach peak values. For example, in Test 021 where the valves were opened simultaneously, a peak speed of 7700 rpm was reached in 71 seconds. In Test 019 where the TPCV was opened 19 seconds after the PSOV was opened, a peak speed of 7850 rpm was reached in 64.3 seconds.

In Test 019 the turbine ejector back pressure oscillated in the beginning phase of the test, smoothed out during the middle of the test, and then oscillated again after peak was reached. Toward the end of the test the oscillations reached amplitudes of about ± 1 psi at frequencies of 2 cps. The ejector control system was rechecked after Test 019 and the oscillations were greatly reduced in Tests 020 and 021.

9. Tests No. 022 and 024

Tests 022 and 024 were for the purpose of evaluating the effects of tank pressure on bootstrap startup characteristics using a warm pump start. Test 022 was run at 50 psia tank pressure, and Test 024 was run at 30 psia tank pressure. The back pressure for both tests was 7.5 psia and the TPCV was opened at test start. In Test 022 a maximum pump speed of 8700 rpm was attained in

30.1 seconds, and in Test 024 a maximum pump speed of 7400 rpm was attained in 61.4 seconds. In both tests oscillations in pump speed, pressures, and flows followed the pattern of previous warm pump tests.

Difficulty was experienced in Test 024 with the pump discharge bleed valve when it froze in the closed position and would not open during pre-test chilldown for the originally planned test. The original test conditions were for a chilled pump start at 25 psia tank pressure and ETS-1 back pressure. When the bleed valve would not operate, the test conditions were changed to a dry pump start which did not require the bleed valve to open. Prior to running the warm start test, a warm helium purge was introduced to warm the partially chilled pump. Subsequent check of data indicated the TPA was partially chilled to about 325°R at test start instead of being at ambient temperature (520°R). This should be taken into account when analyzing data for this test.

Following the test, the pump discharge bleed valve was replaced with a spare 2 in. Hadley valve. The new valve appeared to operate normally.

10. Test No. 025

The purpose of Test 025 was to evaluate the effect of increased diluent flow on system startup characteristics. The diluent line orifice was removed from the line to decrease the pressure loss in the line. Removing the orifice reduced the loss coefficient from 38.3 to 17.1. The test conditions were tank pressure 70 psia, back pressure 12.7 psia and the pump was chilled at test start. These conditions were similar to the test conditions of Test 009 for comparison.

Test results indicated a slight improvement in bootstrap with the diluent flow increased. A maximum pump speed of 8000 rpm was reached in 12.3 seconds in Test 025 compared with a maximum pump speed of 7700 rpm in 11.6 seconds in Test 009.

11. Tests No. 026 and 027

The purpose of Tests 026 and 027 were to evaluate minimum tank pressures for bootstrap start at EIS-1 back pressure and minimum back pressure. The test conditions for Test 026 were tank pressure 25 psia, back pressure 7.5 psia, and the pump was chilled at test start. The test conditions for Test 027 were tank pressure 20 psia, back pressure minimum (0.3 psia), and the pump was warm at test start. The IPCV program for both tests was step to 60° and fast ramp to 80° at test start. In Test 026 pump speed built up slowly to about 1500 rpm in 80 seconds and held at this speed for about 35 seconds. At this point the GN₂ supply pressure for operating the ejectors began to decrease and nozzle back pressure began to increase. About 10 seconds later turbine back pressure also began to increase. Meanwhile, pump speed increased and reached a maximum of 2850 rpm at 130 seconds. At this time nozzle back pressure was about 9.1 psia and turbine back pressure about 8.2 psia. The run duration was 152 seconds.

In Test 027 pump speed built up smoothly to about 8000 rpm over a period of about 40 seconds. After 42 seconds the main nozzle ejector was shut down because of a lack of ejector GN₂ supply pressure and the pump began oscillating between 9000 and 16,000 rpm. At about 110 seconds into the run the pump stopped oscillating, system flows and pressures increased and pump speed built up in normal bootstrap fashion to 6550 rpm. The run duration was 115 seconds.

C. SERIES III, TESTS 028 THROUGH 031

1. Tests No. 028, 029, and 030

Tests No. 028, 029, and 030 were primarily control tests to evaluate the performance of the automatic pressure control system simulating NRX/ESI test conditions. The back pressure for all three tests was 12.7 psia, the tank pressure for Tests 028 and 030 was 70 psia and for Test 029, 55 psia. Tests 028 and 029 were chilled pump starts and Test 030 was a warm pump start. In all three tests the pressure loop was closed at test start. In Test 028 the

chamber pressure demand was set at 50 psia, and in Tests 029 and 030 the chamber pressure demand was 35 psia.

In each test the TPCV began to close when the measured chamber pressure exceeded the chamber pressure demand. In Test 028 the TPCV closed 11°, in Test 029 13°, and in Test 030 30° before decay in chamber pressure, primarily caused by the decay in system energy, reversed the error signal and caused the TPCV to open. Because of the rapid startup transients, the change in TPCV position because of the control system did not significantly affect the startup. The test, however, satisfactorily demonstrated the response of the control system under the test conditions.

2. Test No. 031

The purpose of Test 031 was to obtain additional basic data on the effect of lowering tank pressure to a minimum at minimum back pressure with a chilled pump start. Tank pressure was 20 psia and back pressure was minimum.

The startup characteristics were very similar to those of Test 027 except that the frequency of the oscillations in pump speed, pressure and flows was less in the chilled start than the dry start. A maximum pump speed of 5900 rpm was reached at 96.6 seconds when the pump was loaded. When the pump was unloaded, a maximum pump speed of 14,520 rpm was reached.

Test No. 031 concluded the third series of tests and the system was secured for a long-term shutdown.

VII. TEST RESULTS

A first series of six tests was completed in April 1965. A second series of twenty-one tests was completed in October 1965 and a third series of four tests was completed in November 1965. Detail measurements of engine system pressures, temperatures, flows, vibrations, strains, and valve positions were taken during each test and printed out in digital printouts.* Selected parameters from each test were plotted on Cal Comp plots. The Measurements Requirements Lists for each series of tests, Appendix C, list the measurements taken. Those parameters which were plotted on Cal Comp plots and the Cal Comp plot number are listed in Appendix E.

This large quantity of data could not be reproduced and contained in this report. Accordingly, for purposes of presenting a summary of test results and illustrating comparative differences between tests, certain parameters have been selected for discussion and are included in the following section. Further information and more detailed data including detailed analyses of specific phases of component and system performance may be found in systems analysis reports currently under preparation. See AGC REON reports RN-S-0250, RN-S-0256, and RN-S-0294.

The results of the first series of six tests performed in April 1965 provided system chilldown data for both chilled pump and warm pump chilldowns (Tests 001 and 002) and demonstrated the feasibility of chilled pump bootstrap start-up (Tests 003, 004, 005, and 006).

The results of the second series of 21 tests performed in October 1965 and the third series of four tests performed in November 1965 demonstrated the effect of tank pressure on bootstrap start-up at NRX/EST back pressure (12.7 psia) conditions (Tests 009, 010, 011, and 017); the effect of tank pressure on bootstrap start-up at ETS-1 back pressure (7.5 psia) conditions (Tests 015, 021, 022, 024, and 026) for both chilled and warm pump starts; the effect of tank pressure at minimum back pressure (0.25 psia) conditions (Tests 016, 018, 023, 027 and 031); and the effect of TPCV opening time on warm pump start characteristics (Tests 019, 020 and 021). The operation and response of the automatic pressure control system was

*Approximately 215 measurements were taken on each test in the first series, 285 measurements on each test in the second series, and 50 measurements on each test in the third series. Figure 9, Piping and Instrumentation Diagram schematically shows their locations.

evaluated in Tests 012, 013, 028, 029 and 030. The results of Tests 008, 014, and 025 provided answers to specific questions. Test 008 evaluated the performance of the upgraded TPA, Test 014 showed the effect of blanketing the TPA in helium, and Test 025 demonstrated the effect of increasing the diluent line flow by removing the diluent line orifice.

Test conditions and peak values of major system performance parameters for each of the above tests are summarized in Table IV.

A. RESULTS OF FIRST SERIES TESTS - APRIL 1965, TESTS 001 THRU 006

1. Chilled and Warm Pump Chillydown Tests

a. Comparison Between Chilled Pump and Warm Pump Chillydown

The first two tests were chillydown runs at 70 psia tank pressure. Run 001 was a warm pump chillydown (i.e., the pump was at ambient temperature) and Run 002 was a chilled pump chillydown (i.e., the pump was chilled to LH_2 temp prior to opening the PDV). A comparison of flow rates, chamber pressures, and chamber temperatures for the runs is shown in Figure 16. From an examination of these curves, it appears that a sufficient amount of liquid hydrogen vaporized in the pump to increase flow resistance and reduce the flow through the system in the initial phases of the warm pump run. As a result, during the warm pump run, heat energy was extracted from the system at a slower rate, i.e., chamber temperature was reduced more slowly (55 seconds vs 47 seconds to reach 160°R) and chamber pressure peaked lower (21.1 psia vs 22.2 psia) and later (32 seconds vs 30 seconds) than in the chilled pump run.

b. Flow Streaming

A comparison of temperature measurements throughout the system indicated little flow streaming in the chillydown runs, i.e., a small stream of unusually low or high temperature fluid that could be followed from one component

TABLE IV
CFDTS TEST CONDITIONS AND TEST RESULTS SUMMARY

TEST CONDITIONS									TEST RESULTS										REMARKS
TEST NO	TEST DATE	TANK PRESSURE PSIA	BACK PRESSURE		DILUENT VALVE POSITION	PUMP CONDITION AT START	TPCV PROGRAM	RUN DURATION SEC	MAXIMUM PUMP SPEED		MAXIMUM PROPELLANT LINE FLOW LB/SEC	MAXIMUM PUMP DISCHARGE PRESSURE PSIA	MAXIMUM PRESSURE RISE ACROSS PUMP PSIA	MAXIMUM CHAMBER PRESSURE		MAXIMUM TURBINE INLET PRESSURE PSIA	MAXIMUM TURBINE FLOW LB/SEC		
			NOZZLE PSIA	TURBINE PSIA					RPM	AT SEC				PSIA	AT SEC				
SERIES I	001	4/15/65	68 0	13 8	14 2	CLOSED	WARM	TPCV CLOSED	55	NONE	N/A	16 9	N/A	-15 5	21 1	32	N/A	NONE	CHILLDOWN TEST CHILLDOWN TEST
	002	4/16/65	68 7	13 8	14 2	OPEN	CHILLED	TPCV CLOSED	47 2	NONE	N/A	17 2	N/A	-16 0	22 2	30	N/A	NONE	
	003	4/17/65	69 7	13 8	14 2	OPEN	CHILLED	STEP OPEN AT TEST START	29 7	5260	16 0	21 4	124 0	55 0	44 1	17	17	1 0	
	004	4/19/65	89 8	13 9	14 3	OPEN	CHILLED	STEP OPEN AT TEST START	22 8	5932	9 7	26 1	156 0	68 0	54 0	11	11	1 2	
	005	4/20/65	48 2	13 9	14 3	OPEN	CHILLED	STEP OPEN AT TEST START	62 0	2190	38 5	12 5	58 0	9 0	19 6	40	39	0 3	
	006	4/20/65	57 7	13 8	14 3	OPEN	CHILLED	STEP OPEN AT TEST START	44 9	4219	28 1	16 0	92 0	35 0	32 4	29	29	0 7	
SERIES II	007	10/ 6/65	69 5	14 0	14 2	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	37 5	3460	18 8	19 0	92 3	23 0	32 3	20 8	22 8	0 5	TPCV POSITION LOST COMPARISON WITH OLD TPA
	008	10/ 9/65	69 3	13 9	14 1	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	27 2	7445	12 6	29 2	175 1	109 2	63 3	13 9	55 5	1 4	
	009	10/11/65	68 4	12 8	12 6	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	24 0	7700	11 6	30 4	181 6	115 8	64 4	12 4	56 5	1 4	CONTROLS TEST
	010	10/12/65	49 0	12 7	12 5	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	40 9	6900	25 8	25 7	136 5	92 5	52 5	25 8	45 9	1 1	
	011	10/12/65	33 3	12 7	12 5	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	99 5	1665	54 4	9 5	39 5	5 0	14 9	80 4	14 3	0 2	CONTROLS TEST
	012	10/13/65	69 4	12 7	12 5	OPEN	CHILLED	CLOSE PRESSURE LOOP AT START SET P _c DEMAND AT 45 PSIA	25 4	7740	12 5	30 4	184 1	118 0	65 2	12 6	57 1	1 4	
	013	10/13/65	68 9	12 7	12 5	OPEN	CHILLED	STEP TO 50° AT START SET P _c DEMAND AT 35 PSIA	33 1	4650	14 3	22 3	111 0	42 8	38 2	14 3	26 4	0 7	H ₂ BLANKET ON TPA
	014	10/14/65	34 1	12 7	12 5	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	93 2	1610	61 7	8 0	39 0	5 0	14 7	26 8	14 4	0 2	
	015	10/15/65	34 4	7 5	7 5	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	43 8	8210	29 5	27 6	162 4	130 7	60 4	29 5	52 9	1 3	SLUG OF WARM FLUID IN RTPL DURING TEST 1 CPS OSCILLATIONS DEVELOPED IN RUN TANK DURING TEST
	016	10/15/65	34 7	0 25	0 3	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	30 8	8700	14 9	26 0	177 7	145 3	59 5	15 5	52 2	1 25	
	017	10/16/65	39 5	12 7	12 7	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	76 3	1995	52 8	10 2	47 0	7 0	16 6	78 0	15 9	0 25	TPCV OPENED 17 8 SECONDS AFTER PSOV OPENED
	018	10/16/65	29 7	0 25	0 3	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	29 3	8700	14 6	27 0	170 0	144 0	61 0	16 1	53 5	1 3	
	019	10/18/65	35 4	7 4	7 0	OPEN	WARM	OPEN TPCV WHEN THPD REACHES 43 5°R STEP AND RAMP TO 80°	73 2	7850	64 3	29 8	149 0	119 0	59 2	64 3	52 0	1 25	TPCV OPENED 13 2 SECONDS AFTER PSOV OPENED
	020	10/18/65	34 5	7 3	7 3	OPEN	WARM	OPEN TPCV 9 SEC AFTER PSOV OPENS STEP AND RAMP TO 80°	77 9	7820	65 4	29 2	149 0	119 5	59 2	65 4	52 0	1 3	
	021	10/19/65	34 4	7 3	7 3	OPEN	WARM	OPEN TPCV SIMULTANEOUSLY WITH PSOV STEP AND RAMP TO 80°	80 7	7700	71 0	29 3	143 6	114 6	57 5	71 0	50 7	1 3	PDBV FROZE OPEN DURING RUN PARTIAL PUMP CHILLDOWN PRIOR TO TEST DILUENT LINE ORIFICE REMOVED FOR THIS AND SUBSEQUENT TESTS
	022	10/19/65	49 5	7 4	7 4	OPEN	WARM	STEP AND RAMP TO 80° AT START	36 2	8700	30 1	32 5	190 8	147 8	70 2	30 1	61 7	1 5	
	023	10/20/65	25 1	0 3	0 3	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	64 0	4600	36 7	19 8	64 0	40 6	22 0	38 0	19 2	0 5	EJECTORS UNBALANCED AT 42 SECONDS
	024	10/20/65	29 5	7 4	7 3	OPEN	WARM	STEP AND RAMP TO 80° AT START	71 8	7400	61 4	27 0	132 0	106 5	54 2	61 4	47 2	1 2	
	025	10/21/65	69 3	12 7	12 7	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	27 7	8000	12 3	31 0	191 0	127 0	68 2	12 8	60 0	1 5	EJECTORS UNBALANCED AT 43 SECONDS
	026	10/22/65	24 3	7 6	7 5	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	152 3	2850	129 9	7 4	38 7	13 7	13 8	129 9	12 2	0 3	
	027	10/22/65	19 7	0 3	0 3	OPEN	WARM	STEP AND RAMP TO 80° AT START	115 3	6550 (15930	108 8 53 - PUMP UNLOADED)	18 5	85 0	67 0	33 5	109 3	30 0	0 75	
SERIES III	028	11/9/65	69 2	12 7	12 7	OPEN	CHILLED	CLOSED PRESSURE LOOP AT START SET P _c DEMAND AT 50 PSIA	25 5	7550	12 0	28 7	178 0	113 8	63 0	12 4	55 7	1 3	CONTROLS TEST
	029	11/9/65	54 4	12 7	12 7	OPEN	CHILLED	CLOSED PRESSURE LOOP AT START SET P _c DEMAND AT 35 PSIA	36 1	6840	20 5	25 0	144 0	93 0	53 0	20 3	48 0	1 2	CONTROLS TEST
	030	11/11/65	69 4	12 7	12 7	OPEN	WARM	CLOSED PRESSURE LOOP AT START SET P _c DEMAND AT 35 PSIA	32 5	7430	23 0	28 6	172 0	108 0	64 0	23 2	54 0	1 3	CONTROLS TEST
	031	11/12/65	19 5	0 2	0 2	OPEN	CHILLED	STEP TO 60° FAST RAMP TO 80°	103 9	5900 (14520	96 6 57 - PUMP UNLOADED)	16 0	70 0	52 0	27 0	96 6	25 0	0 6	EJECTORS UNBALANCED AT 43 SECONDS

Figure 16
CFDTS Chilledown Runs
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to another through the engine system. (Refer to Appendix E for listing of Cal-Comp temperature plots for Runs 001 and 002). For example, the two temperatures measured at the nozzle tube outlet agreed with each other, although, the three valid measurements downstream at the reflector outlet showed wide variation during the steepest part of the transient (up to 150°R variation in Run 001, and 70°R in Run 002). The two temperatures measured at the shield outlet agreed well, but one of the three nozzle chamber temperatures was much colder than the other two (up to a maximum of about 60°R). Examination of the physical relationships between points of unusually high or low temperatures did not show temperature streaming. Rather, these points appeared to be only local changes. A short distance downstream from a point of low temperature might be a point of normal or high temperature. It appeared that as a result of mixing in the various plenums, the temperature variations were almost completely smoothed out by the time the flow reached the core inlet and caused no problem during start-up.

2. System Bootstrap Tests

Tests 003 through 006 were bootstrap runs and were planned to obtain system operating parameters during startup with various tank pressures. Run 003 was at a nominal tank pressure of 70 psia, Run 004 at 90 psia, Run 005 at 50 psia and Run 006 at 60 psia. The TPCV was fully opened within 1 second of the test start on all four runs. All of these runs were made with a chilled pump.

a. Bootstrapping

The most significant result of these tests was that they proved bootstrapping could be initiated by nozzle chamber bleed to the turbine, with the driving force derived from energy stored in the engine components. It was also significant that the engine bootstrapped in the smooth, controlled manner. The pump accelerated smoothly, flow fluctuations were small after the initial 5 or 6 seconds, and chamber pressure fluctuations were not significant. This makes it feasible to close the pressure control loop at very low chamber pressures and thereby gain system control early in the start-up.

Response of the engine to bootstrap in these tests was predominantly influenced by tank pressure. Higher tank pressure resulted in faster extraction of heat energy from the system, higher propellant flows, and higher pump speeds. The change of tank pressure from 50 psia to 90 psia resulted in approximately three times the pump speed (2190 rpm to 5930 rpm), three times the propellant flow (8.6 lbs/sec to 24 lbs/sec), and one fourth the time to reach maximum flow (35.5 seconds to 9.7 seconds). See figures 17, 18 and 19 for effects of tank pressure on maximum pump speed, maximum head rise, maximum flow rate and run duration.

b. Turbine Performance

Figure 20 shows a plot of turbine speed versus time for each of the four bootstrap tests. The test data indicate that the turbine began to rotate at the first sign of pressure rise in the system. For example, in Run 004, the turbine began to turn within a second after start of the test and reached a maximum value of 5932 rpm with the 89.9 tank pressure*. Differences in turbine speed at different tank pressures became more pronounced at the lower pressures. An increase in tank pressure of from 50 psia to 60 psia nearly doubled the maximum turbine rpm. However, raising the pressure from 70 to 90 psia resulted in only a 12% increase in turbine rpm. Figure 17 shows a plot of tank pressure versus pump speed. This again shows the rapid fall of pump speed with a small decrease in tank pressure at the lower tank pressures. If the trend, in fact, were to continue, an extension of the curve would indicate zero pump speed at 40 to 45 psia tank pressure for the components and configuration of TPA used in this system.

The initial acceleration rates of the engine were reasonable for fueled reactor engine operation. Speed peaked in about 10 seconds for a 90 psia tank pressure and 40 seconds for a 50 psia tank pressure. This provided a measure of the time available to bring the reactor to power for engine startup. The maximum acceleration for TPA was 900 rpm/sec in the 90 psia tank pressure run.

*Refer to Cal-Comp Plots, Run 004. See Appendix C for listing of plots.

Figure 17
Tank Pressure vs Maximum Pump Speed and Time to Maximum Speed

Figure 18
Tank Pressure vs Maximum Flow Rate and Run Duration

Figure 19
Tank Pressure vs Maximum Head Rise

Figure 20
Turbine Speed vs Time for Various Tank Pressures

These tests also showed no indication of turbopump windmilling during chilldown of the pump prior to test start. Fluid flows through the pump during chilldown as high as 17.5 lbs/sec were experienced in Run 004 with no pump rotation recorded. However, with a chamber pressure rise of less than 3 psia the turbine began to rotate. This indicated very low turbine flow rates were needed to accelerate the pump and that the breakaway torque was small.

c. Flow Streaming

An examination of the fluid temperatures measured throughout the system indicated, as it had on the chilldown runs, that no definite flow streaming or paths of continuous low or high temperatures existed. Measurements of temperature in the same part of the system during the several runs varied widely in some cases, but often the relative positions of areas of unusually high or low temperatures would change at the next set of measurements.

There were two temperatures measured at the nozzle tube outlet. One of these was as much as 80°R lower than the other during the time when the cool-down rate at this point was a maximum. The reflector outlet temperatures differed by as much as 120°R and the shield outlet by as much as 35°R. Of the three temperatures measured in the nozzle, two agreed well with each other while the third (which was the one nearest the hot bleed port) was as much as 60°R cooler at times.

d. Flow Oscillations

Wide variations in flow (see figure 21) as measured by the flow meters in the run tank propellant line were noted during the initial 5 or 6 seconds after test start in all of the runs. These measured variations were not reflected in pressure fluctuations or temperature fluctuations in the line during this period of time except to a minor degree. It was conjectured that the measured flow oscillations might be the result of film and bulk boiling in a downward flow of a cold fluid through a hot pipe, with coalesced bubbles of GH_2 passing back

Figure 21
Pump Inlet Flow Rate vs Time for Various Tank Pressures

upstream. The flow oscillations smoothed out after the initial 5 or 6 seconds of the run. The pump accelerated from zero rpm in a smooth fashion and chamber pressure rose smoothly. Adverse effects on the system from the initial fluctuations appeared negligible.

3. COMPONENT PERFORMANCE

a. Heat Gain by the LH₂ in the Run Tank Propellant Line

Test data from the CFDTS indicated some heat gain by the LH₂ as it passed through the run tank propellant line. (For a description of the line see Section III.) The heat gain appeared to be an inverse function of flow rate. Table V shows the temperature rise of the fluid down the RTPL for Tests 002 through 006. The accuracy of the RTT measurements at LH₂ temperatures was approximately $\pm 0.3^{\circ}\text{R}$. In determining the heat gain in the line where the difference between the two measurements was only 1.5°R and the accuracy of the RTT measurements at LH₂ temperatures was $\pm 0.3^{\circ}\text{R}$, high accuracy heat gain calculations were not obtainable. However, under marginal NPSP operating conditions an increase in LH₂ temperature in the line of the magnitude measured ($+0.7$ to $+1.6^{\circ}\text{R}$) could significantly affect NPSP at the pump inlet and increase the possibility of pump cavitation. The measured heat gain in the line points up the desirability of insulating the facility line into the pump inlet.

b. Heat Transfer Characteristics in the Pump Inlet Line

Examination of the data of the material temperatures of the pump inlet line, i.e., that section of line from the PSOV outlet to the pump inlet, indicated that the line did not cool as fast as the other components of the engine system. The data appeared to be consistent when locations of the thermocouples were taken into account, i.e., the thinner sections of the line cooled to near LH₂ temperature, while the thicker sections remained around 300°R .

TABLE V

CFDTS TEST SERIES I DATALH₂ TEMPERATURES IN THE RUN TANK PROPELLANT LINE

TEST No.	TIME OF MEASUREMENT	FLOW RATE LBS/SEC	LH ₂ TEMPERATURE AT TANK OUTLET, °R	LH ₂ TEMPERATURE AT PUMP INLET, °R	TEMPERATURE INCREASE, °R
001		Warm Pump Chillover - Not Applicable			
002	Test Start	6.0	37.1	38.6	+1.5
	Max. $\dot{W}$	17.2	37.1	38.4	+1.3
003	Test Start	6.0	37.7	39.3	+1.6
	Max. $\dot{W}$	21.3	37.7	39.1	+1.4
004	Test Start	6.0	38.7	39.7	+1.0
	Max. $\dot{W}$	26.3	38.7	39.4	+0.7
005	Test Start	5.8	38.3	39.3	+1.0
	Max. $\dot{W}$	16.0	38.8	39.6	+1.0
006	Test Start	5	38.8	40.1	+1.3
	Max. $\dot{W}$	16.0	38.8	39.6	+0.8

Calculations of average heat transfer coefficient were made. Table VI summarizes selected material temperatures from which the heat transfer coefficient calculations were made. These include measurements of the TPA inlet line, turbopump housing, and the outlet line at the beginning of pump chillover, at opening of the PDV (test start) and at closing of the PSOV (test stop).

An estimate was made of the magnitude of the average heat transfer coefficient between the opening of the PSOV and test start (h_1), and between test start and test stop (h_2) by using a heat balance across the system, i.e., heat gained by the fluid = heat transferred through the line material. In addition, average heat transfer coefficients based on CFDTIS data between test start and test stop (comparable to h_2) were calculated using various theoretical methods, (1) Colburn's equation for all liquid flow, (2) McCarthy-Wolf's equation for all vapor flow, (3) Core's method for subcooled nucleate boiling, (4) Hendrix's correlation for two-phase flow and (5) Bromley's film boiling correlation. These are summarized in Table VII and compared with values of h_1 and h_2 calculated from test data. It can be seen that the computed values of h_1 and h_2 are consistent, i.e., larger heat transfer coefficients were obtained on tests at higher tank pressures, and for any one run h_1 is greater than h_2 . Also, the computed values of h_1 and h_2 agree most closely with the heat transfer coefficients derived from Bromley for film boiling.

The relatively low observed heat transfer coefficients indicate less intimate contact between the cold fluid and the warm pump inlet line walls and the existence of annular flow (liquid core) even though the liquid was sub-cooled by about 5°R. It should be noted that tests both in cryogenic and non-cryogenic systems have shown that fluids can exist in a metastable equilibrium, i.e., simultaneous presence of saturated liquid and superheated vapor, and the assumption of all-liquid flow when the indicated fluid temperature is below or at the saturation temperature may not be valid.

TABLE VI

PUMP INLET LINE AND TPA

MATERIAL TEMPERATURE DATA* - CFDTS

	Turbopump Inlet Line Temperature, °R				Turbopump Housing Temperature, °R		Turbopump Discharge Line Temperature, °R			
Time	TPIL-1	TPIL-2	TPIL-3	TPIL-4	TTPH-1	TTPH-2	TPDL-1	TPDL-2	TPDL-3	TPDL-4
	(Run No. 1, FS-1 = 42 sec, FS-2 = 97 sec)									
0	513	377	-	513	-	514	95	125	-	218
Start	513	349	-	-	-	514	-	-	-	-
Stop	466	316	-	-	-	59	-	-	-	-
	(Run No. 2, FS-1 = 155.8 sec, FS-2 = 203 sec)									
0	515	-	-	517	522	522	518	516	-	513
Start	364	-	-	370	81	54	49	516	-	514
Stop	312	-	-	305	75	54	47	59	-	69
	(Run No. 4, FS-1 = 163.6 sec, FS-2 = 186.4 sec)									
0	525	500	525	530	530	531	526	528	528	528
Start	328	365	56	343	61	45	52	530	530	529
Stop	297	345	43	314	60	46	42	88	121	77
	(Run No. 5, FS-1 = 260.3 sec, FS-2 = 322.3 Sec)									
0	521	-	520	-	519	520	523	527	527	526
Start	286	-	51	-	72	52	50	515	517	518
Stop	241	-	56	-	69	50	52	54	72	64
	(Run No. 6, FS-1 = 195.7 sec, FS-2 = 240.6 Sec)									
0	508	-	506	-	507	506	498	518	518	521
Start	316	-	49	-	77	55	48	522	518	521
Stop	276	-	54	-	72	54	51	58	91	55

* Accuracy of TC's below 300°R is $\pm 10^{\circ}\text{R}$

TABLE VII
CFDTS PUMP INLET LINE
OBSERVED AND CALCULATED HEAT TRANSFER COEFFICIENTS

Test No.	Tank Pressure psia	OBSERVED*		CALCULATED*					
		$\bar{h}_1 \times 10^4$	$\bar{h}_2 \times 10^4$	(1) Liquid	(2) Vapor	(3) Subcooled Nucleate Boiling	(4) Two-Phase		(5)
				$h \times 10^4$	$h \times 10^4$	$h \times 10^4$	$h \times 10^4$		Film Boiling $h \times 10^4$
							X = .1	X = .9	
2	70	0.21	0.35	6.1	2.4	13.2	5.18	1.28	0.31
3	70	0.21	0.37	8.8	2.5	13.3	7.50	1.85	0.31
4	90	0.25	0.33	11.8	4.5	13.1	8.85	2.18	0.45
5	50	0.22	0.28	5.5	2.5	14.0	4.67	1.15	1.13
6	60	0.23	0.30	6.8	2.9	13.7	5.83	1.55	0.61

* Refer to text for source of theoretical heat transfer coefficients (1), (2), (3), (4), and (5).

B. RESULTS OF SECOND AND THIRD SERIES TESTS - OCTOBER AND NOVEMBER 1965,
TESTS 007 THRU 031

1. Typical Parameter Profiles (Chilled Pump)

a. Typical Major Parameter Profile

Figure 22 shows the relationship between four of the major parameters for a typical chilled pump test i.e., run 009 with a tank pressure of 70 psia, and a back pressure of 12.7 psia. Peak speed, pressures and flows occurred at approximately the same time. For this run, peak pump speed and pump discharge pressure occurred at 11.6 seconds, chamber pressure peaked at 12.4 seconds, and flow rate at 13.7 seconds. Turbine speed rose smoothly from test start whereas pump discharge pressure and pump inlet flow oscillated during the first 5 or 6 seconds before smoothing out. Chamber pressure rose smoothly after an initial delay of two to three seconds. When the energy available in the system was exhausted, pump speed, pressures, and flows fell rapidly. At 22.4 seconds the TPCV was closed cutting power to the turbine. The TPCV closed in 0.7 seconds, after which the PSOV closing was initiated. The PSOV required approximately six seconds to close and did not greatly reduce flow until the last two seconds of closing because it was a butterfly-type valve. It is interesting to note that after an initial sharp short drop, the flow remained nearly constant until the PSOV was closed.

b. Typical Temperature Profile

A typical profile of temperatures versus time (Run 009) is shown in Figure 23. Since Run 009 was a chilled pump start, pump discharge temperature was at liquid hydrogen temperature at test start. The fluid in the nozzle manifold quickly dropped to liquid hydrogen temperature in about 2 seconds and the nozzle was cooled to this temperature in about 12 seconds. The temperature of the fluid in the turbine exhaust was initially at liquid hydrogen temperature because of leakage from the pump through the bearing coolant passages during the long pump chilldown period. This temperature rose as soon as flow through the turbine was introduced from the chamber nozzle and then fell as the reactor core cooled.

Figure 22
 Pump Speed, Propellant Flow, Core Inlet Pressure, and Chamber
 Pressure vs Time

Figure 23
Typical Temperatures vs Time

At test-stop the turbine exhaust temperature fell rapidly since flow from the chamber was cut off, but LH_2 continued to flow through the bearing coolant passages. Initial temperature in the nozzle chamber was maintained longer than in other components because the bulk of the system mass was in the reactor core. At the flow rates experienced in this run, the temperature in the nozzle chamber remained fairly level for about 10 seconds and then began to drop at a uniform rate. When the chamber temperature reached 160°R the test was terminated.

c. Typical Pressure Profile

Figure 24 shows relative pressure drops through the system for a typical run (Test 009). After the first 4 or 5 seconds of the run, pressure oscillations were damped and pressures rose and decayed smoothly. A drop in pump inlet line pressure of approximately 6 psi (at a flow rate of 30.4 lb/sec) was the result of pressure drop in the run tank propellant line. During the run the largest pressure drop of any single component was across the reactor core. This was 76 psi at the maximum flow rate of 30.4 lb/sec. Pressure drops across other components at this flow rate were 14 psi from the pump discharge to nozzle tube outlet, 23 psi from nozzle tube outlet to core inlet, 7.7 psi from the nozzle chamber to turbine inlet, and 43.9 psi across the turbine. Analysis of pressure data indicated that the time for a pressure pulse to travel through the system was approximately 50 milliseconds.

2. Effect of Tank Pressure on Bootstrap Start-Up Characteristics (Chilled Pump)

The effect of tank pressure on bootstrap start-up at NRX/EST back pressure (12.7 psia) is shown in Figure 25. From these curves it can be seen that at a tank pressure of approximately 40 psia and below, the bootstrapping action was weak. The speed gradually increased to a maximum (1995 rpm at 40 psia tank pressure and 1650 rpm at 35 psia tank pressure) and gradually decayed until the heat content of the system was exhausted. When the tank pressure was changed from 40 psia to 50 psia, the relatively small increase in tank pressure resulted in a more than three-fold increase in pump speed (from 1995 rpm to 6900 rpm). At tank pressures of 50 psia and above, a change in tank pressure resulted in a relatively small increase in pump speed.

CHILLED PUMP, TANK PRESSURE 70 PSIA,
BACK PRESSURE 12.7 PSIA

Figure 24
Typical Pressures vs Time

Figure 25
Effect of Tank Pressure on Bootstrap Startup

The same characteristic effect was also apparent when the back pressure was changed from 12.7 psia to 7.5 psia and 0.25 psia except that higher speeds were attained with lower tank pressures. This was expected because the driving force across the system necessary to initiate bootstrap, i.e., the difference between tank pressure and back pressure, was a function of back pressure as well as tank pressure.

3. Effect of Back Pressure on Bootstrap Start-Up Characteristics

The effect of reducing back pressure while holding a constant tank pressure of 35 psia is shown in Figure 26. The bootstrapping effect was not strong when the back pressure was 12.7 psia (1650 rpm). When back pressure was reduced to 7.5 psia, a marked increase in maximum speed attained resulted. In fact, reducing the back pressure from 12.7 psia to 7.5 psia (approximately 5 psi) resulted in greater peak speed (8130 rpm) than that attained with a 70 psia tank pressure at 12.7 back pressure. Reducing the back pressure from 7.5 psia to 0.25 psia (approximately 7 psi), however, did not produce as marked a change. Only a relatively small increase in speed resulted (from 8130 rpm at 7.5 psia to 8520 rpm at 0.25 psia).

Figure 27 is a plot of tank pressure versus peak speed for the different test back pressures used. It illustrates the effects of both back pressure and tank pressure on bootstrap start-up.

Figure 28 is a plot of the time to reach peak pump speed vs tank pressure. It shows the relationship between tank pressure and the time to reach peak pump speed for back pressures of 0.25 psia, 7.5 psia, and 12.7 psia and gives an indication of the time available to bring the reactor to power for engine startup.

4. Effect of Tank Pressure on Warm Pump Bootstrap Start-Up

Figure 29 shows the effect of tank pressure on warm pump bootstrapping. As with the chilled pump start, the time to reach peak speed decreased with an increase in tank pressure. This was because the greater initial driving force across the system resulted in a higher propellant flow rate which chilled the pump, pump discharge line, and nozzle manifold faster so that pumping of all-liquid fluid (not a mixture) could begin earlier. Also, the higher the tank

Figure 26
Effect of Back Pressure on Bootstrap Startup

Figure 27
Peak Pump Speed vs Tank Pressure at Constant Back Pressure

Figure 28
 Tank Pressure vs Time to Peak Pump Speed at Constant
 Back Pressure

Figure 29
Effect on Tank Pressure on Warm Pump Bootstrap Startup

pressure the higher the peak speed since more energy was available in the system at the time the pumping of the all-liquid fluid could begin. Another difference noted was that the number of speed oscillations before peak bootstrap speed was reached tended to decrease as the tank pressure increased. At 35 psia tank pressure, 10 major oscillations occurred, whereas at 50 psia tank pressure 7 major oscillations occurred.

5. Effect of TPCV Opening Time on Bootstrap Start-Up Characteristics (Warm Pump)

Tests 019, 020, and 021 were warm pump tests to investigate the effect of opening the turbine power control valve at different times after opening the propellant shut off valve. In test 019 the TPCV was opened 18 seconds after the PSOV opened, in Test 020 13 seconds after, and in Test 021 the TPCV was opened simultaneously with the PSOV. Figure 30 shows the effect of varying the TPCV opening times on pump speed (test 019 and 021). Contrary to what had been initially expected, the peak speed was reached earlier and was slightly higher when the TPCV opening was delayed. This effect may have been caused by slightly higher fluid flows before the TPCV was opened while the pump was not rotating. The result was a slightly quicker chilldown of the pump and nozzle tubes which enabled peak speed to be reached sooner. The same effect, but to a lesser degree, was noted in Test 020 where the TPCV was opened 13 seconds after the PSOV opened. Here again, pump speed peaked sooner than when the TPCV was opened simultaneously with the PSOV, and the peak speed reached was almost exactly the same as in Run 019 (7850 rpm in Run 019 and 7820 rpm in Run 020).

6. "Bootstrapping" in CFDTS Low Tank Pressure Tests

Two low tank-pressure CFDTS tests were conducted to obtain data on minimum tank pressure starts. Run 027 was a warm pump start at 19.7 psia tank pressure and 0.3 psia back pressure. In both tests, after 42 seconds, the main nozzle ejector was shut down because of a lack of ejector GN_2 supply pressure and the main nozzle back pressure rose to between 13 and 14 psia within 3 seconds. Because one of the test objectives was to determine if it were possible to overspeed

Figure 30
Effect of TPCV Opening Time on Bootstrap Startup

the pump under initial low tank pressure start conditions, the turbine back pressure was maintained as low as possible during the decay of ejector GN_2 supply pressure. Between 42 and 45 seconds turbine back pressure rose to 1.0 to 1.5 psia and remained at approximately this level. The difference in nozzle back pressure and turbine back pressure resulted in a pressure differential across the turbine which caused pump speed to build up in a manner not related to normal system characteristics. Figure 31 is a plot of pump speed vs time for the dry pump low tank pressure test (Run 027). The pattern of the plot was almost identical in the chilled pump start (Run 031) except the test was shorter (104 seconds vs 115 seconds).

Prior to 42 seconds into each run, normal test conditions prevailed for tank pressure, back pressure, and type of start. During this period, pump speed reached 8000 rpm. However, a check of the test data during this part of each run indicated that the condition of the fluid in the pump was primarily gas. Flows measured in the run tank propellant line were extremely erratic. Pump discharge pressures fluctuated between 18 and 28 psia in the warm pump test and 20 to 30 psia in the chilled pump test. Calculated NPSP was close to zero, occasionally reaching 1.0 or 1.5 psia. Chamber pressures fluctuated between 2 and 4 psia in the warm pump test and 4 to 8 psia in the chilled pump test.

These flows and pressures were in contrast to a normal bootstrap run such as Test 018 (29.7 psia tank pressure, 0.25 back pressure, chilled pump start). In Test 018, at approximately 8000 rpm pump speed, flows measured were smoothly increasing and were about 20 lbs/sec. Pump discharge pressure was about 150 psia and NPSP about 12 psia. Chamber pressure was about 48 psia.

From a comparison of the above runs it can be seen that although pump speeds as high as 8000 rpm were being experienced in the low tank pressure tests, the system was not bootstrapping in the same manner as in the higher tank pressure runs. There was essentially no pressure rise across the pump, and fluid flow through the pump was very erratic. If bootstrapping is defined as obtaining a head rise across the pump, then it might be construed that a weak form of bootstrapping was obtained (the pump discharge pressure fluctuated between 20 and 30 psia

WARM PUMP,
TANK PRESSURE 20 PSIA,
BACK PRESSURE 0.3 PSIA *

*MAIN NOZZLE EJECTOR WAS TURNED OFF AT 43 SECONDS AND NOZZLE
BACK PRESSURE ROSE IN 5 SECONDS TO 13.5 PSIA

Figure 31
Effect of Minimum Tank and Back Pressure

in the chilled pump run and 18 to 28 psia in the warm pump run). From the data it is not possible to tell whether a stronger form of bootstrap might have developed, given sufficient time, because the pump discharge pressure appeared to be fluctuating within a constant range during the last 10 to 12 seconds before the nozzle back pressure began to rise. The indication of bootstrapping in the warm pump run was similar to the chilled pump run except the pump discharge pressure appeared to be fluctuating in a slightly lower range and the range appeared to be still slowly rising at the time the nozzle back pressure began to rise.

Subsequent to the 42 seconds point, when the main nozzle back pressure rose to approximately 13.5 psia while the turbine exhaust ejector remained at approximately 1.0 to 1.5 psia, the TPA accelerated to 16,000 rpm in the warm pump run and 14,500 in the chilled pump run. Little or no NPSP was available with the low tank pressure and large oscillations in pump speed resulted (refer to Figure 30). At 102 seconds into the warm pump run and 90 seconds into the chilled pump run, the pump inlet temperature finally dropped low enough to hold a positive NPSP. Pump discharge pressure, fluid flow, and chamber pressure rose to approximately 15 lb/sec, 75 psia and 27 psia respectively, at a pump speed of 6000 rpm, so that a definite bootstrap was experienced. System pressures, and pump speed then decayed with depletion of system heat energy and the test was terminated.

Whether the system would have firmly bootstrapped with the low tank pressures and balanced back pressures could not be determined because of facility limitations (lack of ejector drive gas capacity). At the time the main nozzle ejector was shut down, the major system components (downstream of the nozzle tubes in the flow path) were still essentially at ambient temperatures. Eventually a definite bootstrap was obtained with the unbalanced back pressures. This was about 45 seconds after the nozzle ejector was shut down in the chilled pump test and 55 seconds after in the warm pump test. It would have been interesting to see what might have happened had there been a sufficient supply of GN_2 ejector drive gas to conduct a complete run at minimum back pressures. However, this was not possible without extensive modification of the GN_2 supply system. The main nozzle ejector alone consumed up to 300 pounds per second of GN_2 to develop the low back pressure (0.2 psia).

7. Comparison of Warm Pump and Chilled Pump Start Up

A comparison of warm and chilled pump start-up is shown in Figure 32. The chilled pump start up was free of the speed oscillations seen in the warm pump start up. Since the chilled pump was already cooled, the time to reach peak speed was much less than for a warm pump. As the chilled pump start up occurred faster, the peak speed reached was higher because the system was warmer than in the case of the warm pump start up. In chilling the pump the cold fluid by-passed the rest of the system in the chilled pump tests and passed through it in the warm pump tests. Difference in peak speed was relatively small (only 6-1/2% in this case), whereas the difference in time to reach peak speed was quite significant (30 seconds for a chilled pump versus 70 seconds for a warm pump). It must be realized that it required about 2 minutes of LH_2 flow through the pump discharge 2-in. bleed valve to cool the pump to the chilled condition.

A comparison of the propellant flow for a chilled and warm pump test is given in Figure 33. The warm pump flow oscillations were much more severe than the chilled pump flow oscillations, although the maximum flow rates were approximately the same. The amplitude of the flow oscillations indicated by the curves does not really represent the true variation in rate of flow since the propellant passing through the turbine-type flow meters was alternately gas, liquid, or a mixture at various instants during the pump chillover. Analysis of the pressure drop measurements across the run tank propellant line components indicated a reversal of flow at times during this period. The propellant line flow measurements were valid only when liquid hydrogen was flowing through the turbine meters.

8. Fluid Conditions in the Pump During Warm Pump Start Up

An analysis was made of fluid conditions in the pump during warm pump start up. Figures 34 and 35 show the relationship between pump speed, pump inlet temperature, pump inlet pressure, NPSP, and fluid condition (liquid or gas) during Test 019. Zero NPSP, peak pump inlet and outlet temperatures and minimum

Figure 32
Comparison of Chilled and Warm Pump Startup, Pump Speed vs Time

Figure 33
Comparison of Chilled and Warm Pump Startup, Fluid Flow vs Time

Figure 34
Relation Between Pump Speed, Pump Inlet Temperature and Pressure,
and NPSP During Warm Pump Startup Up

Figure 35
Hydrogen Condition in Pump During Warm Pump Start Up

pump inlet and outlet pressures were approximately in phase with the speed peaks. The temperature peaks on the pressure-enthalpy plots (Figure 3.5) were in the vapor region and the low temperature points were in the liquid region, close to the saturated liquid line.

The liquid hydrogen picked up heat from the ambient pump inlet line and subsequently boiled. The pump alternately speeded up and slowed down as the condition of the fluid in the pump was vapor or liquid, unloading and loading it.

When the condition of the fluid in the pump was vapor, its speed began to increase. Pump discharge pressure immediately began to fall, resulting in lower turbine inlet pressure and less power to the turbine driving the pump. The results of these interactions in the system were that, at the time of peak pump speeds for those cycles while the pump was being chilled, system pressures (pump discharge, chamber, turbine inlet) were near minimum. Conversely, when pump speeds were at minimum, system pressures were nearly at maximums. These cycles repeated until the pump was chilled and the boiling stopped. The pump then speeded up to a final peak in phase with system pressures. Because of the feedback nature of the cycles, the system was self-regulating and the pump did not overspeed. This type of feedback cycle was also experienced in Test 027 where minimum tank pressures with a warm pump start were the test conditions.

9. Controls Tests

Tests 012, 013, 028, 029, and 030 were tests to evaluate the performance of the automatic pressure control system. In Test 013 the turbine power control valve was stepped open to 50 degrees at test start. The pressure loop was closed at a chamber pressure of 35 psia and the chamber pressure demand was set at 35 psia. Figure 36 shows the effect on the system of this mode of operating the pressure control system. The TPCV was opened to 50° and remained at this position

CHILLED PUMP,
TANK PRESSURE 70 PSIA,
BACK PRESSURE 12.7 PSIA

TPCV PROGRAM
OPENED TPCV TO 50° AT TEST START
CLOSED LOOP AT 35 PSIA
CHAMBER PRESSURE WITH
DEMAND SET AT 35 PSIA

NOTE:
90° INDICATES TPCV OPEN
0° INDICATES TPCV CLOSED

Figure 36
Effect of Closing Pressure Control Loop

until the chamber pressure reached 35 psia. At this point the pressure loop was closed. As the chamber pressure exceeded 35 psia, the TPCV began to close and closed approximately 6° (from 50° to 44°) before the chamber pressure fell below 35 psia. As chamber pressure decayed at the end of the run the TPCV began to open and opened approximately 18° (from 44° to 62°) before the valve was closed by terminating the test. The response of the system was slow at the very low pressures and error signals experienced in the test and did not flatten the chamber pressure curve significantly. However, this was expected because the system was designed for response at rated chamber pressures of about 550 psia with error signals proportional to rated chamber pressure.

In Test 029 an alternate mode of operating the automatic pressure control system during initial engine start-up was programmed. In this test the pressure loop was closed at the test start and the chamber pressure demand was set at 35 psia. (See Figure 37). At the start of the test the chamber pressure demand exceeded the measured chamber pressure and caused the TPCV to ramp to full open in about 8.5 seconds. The TPCV remained full open until the measured chamber pressure exceeded the demanded chamber pressure. At this point the TPCV began to close. When the measured chamber pressure fell below the demanded pressure the TPCV again began to open. In this test the TPCV closed from 82° to 65° and opened again to 82°. The system performed about as expected and the response was relatively slow at the very low pressures and error signals of the test. Again the chamber pressure and pump speed curves were not flattened because of the slow response of the TPCV and the fact that at the low flows of the CFDTs tests, little effect on turbine inlet line flow was noticeable until the TPCV was closed to more than the 50° position. (Refer to Figure 2, Flow Factor vs Shaft Position, TPCV).

Figure 37
Effect of Closing Pressure Control Loop

10. Special Tests and Measurements

a. Turbopump

(1) Comparison of Performance With Unmodified and Improved TPA

After the completion of the first series of CFDTs tests in April 1965, the TPA and turbine exhaust manifold were removed and upgraded to the latest NRX/EST configuration. Test No. 008 was then run under the same conditions as Test No. 003 in the first series to determine the effect of the improved TPA on system start up characteristics. Figure 38 shows a comparison of pump speeds and nozzle chamber pressures for the two runs. Pump speed increased 41% from 5260 rpm at 16 seconds to 7445 rpm at 12.6 seconds. Chamber pressure increased similarly from 44.5 psia at 17 seconds to 63.3 psia at 13.9 seconds. The improved performance was attributed primarily to increasing the inlet area of the turbine inlet manifold, reducing bearing labyrinth clearances and smoothing out turbine flow passages.

(2) Turbopump Data

Turbopump speed and engine flow rates obtained in CFDTs tests were higher than pretest predictions. These predictions were extrapolated from TPA operational data for higher TPA power ranges than experienced in the CFDTs. The higher efficiencies developed by the TPA resulted in better TPA performance than had been expected. Detailed analyses of TPA performance characteristics at cold flow conditions are being made and will be available in the near future.

b. Effect of Blanketing TPA in Helium

Another special test performed was blanketing the TPA in helium instead of nitrogen and determining the effect on TPA performance of the difference in heat transfer characteristics of the two fluids. To obtain the

CHILLED PUMP,
TANK PRESSURE 70 PSIA,
BACK PRESSURE 14.2 PSIA

Figure 38
Comparison of Series I Test with Series II Test

greatest effect, two tests at marginal bootstrap conditions were compared. Tests 011 and 014 were run at a tank pressure of 35 psia and a back pressure of 12.7 psia. The TPCV was programmed to open to 80° at test start. In Test 011 the TPA was blanketed in nitrogen and in Test 014 the TPA was blanketed in helium. Very little difference in performance was observed between the tests. In Test 011 a maximum pump speed of 1665 rpm was reached at 54.4 seconds and in Test 014 the maximum speed attained was 1610 rpm at 61.7 seconds. These differences may have been due to normal differences in ambient start conditions rather than the effect of the helium blanket.

c. Effect of Diluent Flow

In Test 025 the diluent line orifice was removed from the diluent line to decrease the pressure loss in the line and increase diluent line flow. Removing the orifice reduced the line loss coefficient from 38.3 to 17.1. The same test conditions as in Test 009 were used; tank pressure 70 psia and back pressure 12.7 psia. Figure 39 shows a comparison of pump speed versus time before and after removal of the orifice. The effect of increasing diluent flow was a slight increase in maximum pump speed (from 7700 rpm to 8000 rpm) and a slight delay in bootstrapping (run duration was 24 seconds versus 27.7 seconds). This delay effect was reflected in system flows, pressure, and temperatures and may have been due to colder fluid from the dome reaching the turbine via the diluent line instead of through the core. The effect was offset as the run progressed and the chamber pressure built up so that the slightly higher maximum pump speed was reached at a slightly later point in time.

d. Vibration and Strain Measurements During Start-Up

Accelerometer and strain measurements were taken to obtain vibration and strain information during the start transient. In Tests 007 through 011 vibration information was obtained from accelerometers mounted on the TPA, pump discharge line, nozzle manifold, and pressure vessel flange. On Tests 012 through 027 vibration measurements were taken on the TPA, the nozzle flange and

PUMP SPEED VS TIME,
CHILLED PUMP, TANK PRESSURE 70 PSIA,
BACK PRESSURE (12.7 PSIA)

Figure 39
Effect of Change in Diluent Line

turbine inlet line. In addition, on Tests 012 through 027, strain measurements were taken on the pump inlet line and the thrust structure. A list of these measurements may be found in the Measurements Requirements List (Appendix C) as Special Group I, Special Group II, and Special Group III measurements.

Of special interest were TPA vibrations during chilled and warm pump starts. The data indicated that although certain vibrations may exist during steady-state pump operation, the "g" loadings were apparently related to pump acceleration and as the pump acceleration increased the "g" loads increased. Figure 40 is a plot of pump speed and acceleration versus time. An examination of the peak "g" measurement ($\pm 73g$) from Test 021 showed the maximum vibration occurred at frequencies in excess of 10,000 cps. This corresponded to displacements (assuming sinusoidal vibration) of approximately 7 micro inches. It should be noted that displacements of this small magnitude do not produce significant stress in the TPA or lines.

e. "Infinite Line" Experiment

The proper function of the control system for the NRX/EST experiments at NRDS, (i.e., the chamber pressure control loop) required accurate measurement of chamber pressure. Pressure transducers available at the time of NRX/EST testing were susceptible to radiation damage. Thus it was necessary to locate the transducers behind radiation shields and couple them to the engine nozzle chamber with pneumatic tubing. The frequency response of the remotely located transducers was poor relative to that of close-coupled transducers. To optimize response and to reduce acoustic resonance effects in the remotely located transducer pressure measurement system, an "infinite-line" technique was proposed for NRX/EST. The "infinite-line" consisted of a long coiled tube open at the pressure source (nozzle chamber) and closed at the other end with a pressure transducer mounted in the line approximately 25 ft away from the nozzle chamber.

The CFDTS test setup simulated the equipment and measurement conditions to be encountered during the startup phase of NRX/EST. A coiled tube 325-ft in length (0.187 in OD x 0.028 in wall thickness) was tapped into the

Figure 40
Pump Speed and Acceleration vs Time

nozzle chamber. Twenty-five feet from the nozzle chamber a pressure transducer was mounted on the "infinite line". To measure the true nozzle pressure environment a second transducer was coupled as closely as possible to the nozzle and also mounted in the "infinite-line". The line was purged with nitrogen prior to the test run to simulate NRX/EST conditions.

The output of both transducers was recorded on wide-band analog tape recorders to minimize system-induced magnitude and phase distortions. To confirm the theoretical model, the recorded data were spectrally analyzed to determine the "infinite-line" transfer function, i.e., the amplitude and phase relationship between pressures existing within the nozzle and pressures existing within the "infinite-line" at the remote transducer station.

By knowing the gas type, temperature, and pressure; the theoretical amplitude ratio and phase lag were calculated and compared with experimental results. As seen in Figure 41, agreement between experimental and theoretical values at the fundamental pulse frequency is good considering the approximate nature of the numerical integration techniques* used and the amount of noise present.

It was encouraging that the experimental values agreed as well as they did since the pulse analysis was a transient phenomenon while the theoretical model assumed that steady-state conditions prevailed. The good agreement implied that transient effects produced by a pressure pulse of the type encountered during CFDTIS startup were suppressed by the infinite line.

C. QUALITY OF TEST DATA

In general, quality of the test data was good. With few exceptions, as noted below, the data were considered valid and within the accuracy of the measurement system.

*Fourier analysis by numerical integration was used to calculate the amplitude ratio and phase lag.

Figure 41
 Amplitude Ratio and Phase vs Frequency

In the first series of tests (Tests 001 through 006) only one critical measurement, pump discharge pressure on Test No. 004, was lost. In this instance, it was possible to extrapolate the value of the parameter from a downstream measurement and a comparison with previous tests. Also several temperature measurements were deleted after Test 001 because the thermocouples were inoperative. These were primarily temperature measurements on the Control Drum and the Inner Nozzle Wall and the Reactor Core Module. In Test 001, CSC (Consolidated Systems Corporation) data system was not turned on until approximately 15 seconds into the run. As a result, there was some uncertainty in the material and fluid temperatures during the initial part of the run. To aid in interpretation and analysis of data, a sheet listing parameters about which there may have been a question was included with each digital data printout. In the second and third series of tests a Discrepant Data Review Report was prepared for each test. A copy of this report was included with each digital data printout. Any adjustments or corrections to preliminary data were made prior to the issuance of final data so that final Cal Comp plots and final digital printouts showed valid data. If a parameter appeared questionable, it was included but qualified as questionable on the plot. The overall quality of the data was very good in this series of tests. Out of the total number of measurements taken, 98.3% were considered valid and within the accuracy of the measurement system.

Subsequent to the release of the final data, detailed analysis revealed a discrepancy in turbine flow calculations because of the use of a different flow coefficient than originally specified. Consequently, for accurate analysis of turbine characteristics, turbine flow should be corrected by a factor of 1.063. Further analysis also revealed anomalies in the pressure drops across the 8 in. Potter Flowmeter and the filter screen in the run tank propellant line assembly. Investigation revealed that because of the locations of the pressure taps for the differential pressure measurements of these components, a venturi effect in the line was measured which obscured the true pressure drops across the components.

D. POST TEST INSPECTIONS

At the conclusion of each test the CFDTIS was visually examined and a controls and facility system check was made.

An apparent hardware malfunction appeared in the last test of the first series (Test 006). During this run a slight amount of GH_2 was detected in the inerting gas of the upper thrust structure. The amount of GH_2 detected did not approach the mandatory shutdown ("Kill") level, and the test was successfully concluded. The source of the leak was not determined, since, immediately after the last run, the TPA and associated manifold and feed lines were removed from the upper thrust structure. The TPA was returned to the shop for disassembly, inspection, and modifications to incorporate latest design changes. Inspection of the TPA revealed no apparent degradation to any component because of CFDTIS testing. Inspection was also made of the pump discharge line, turbine inlet line, diluent line, associated valves, and the aft end of the reactor. There was no apparent damage to any of these components.

Following Test 007, inspection revealed that the pin securing the valve gate to the valve shaft of the turbine power control valve was missing. The pin was found in the turbine housing on top of the first stage nozzles. The pin was removed from the housing, replaced in the valve shaft, and staked so that it could not drop out again.

During Test 024 the pump discharge bleed valve froze open. After the test, the access panels in the thrust structure were removed. The lines and components inside the thrust structure were inspected and the bleed valve appeared to be malfunctioning. It was replaced with a spare 2-in. Hadley valve and the thrust structure was resealed. The pump discharge bleed valve functioned satisfactorily on Test 025, but again froze during chilldown prior to Test 026. The thrust structure was again opened up and the lines and components examined. It was discovered that the pump discharge valve seals were leaking which allowed LH_2 to leak into the thrust structure and freeze the pump discharge bleed valve actuator. When the seals were replaced, no further difficulty was experienced with the system.

At the conclusion of the third series of tests (after Test 031) the run tank propellant line assembly was disassembled and the 4-in. and 8-in. Potter flow-meters were removed for post-test calibration. At this time the filter screen in the line was examined for signs of contamination or foreign particles. There was no indication of any foreign material on the filter screen and it appeared to be as clean as when installed.

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VIII. CONCLUSIONS

A. ACHIEVEMENT OF TEST OBJECTIVES

The test objectives for the CFDTS tests were achieved. These objectives were basically to obtain chilldown data, to evaluate flow characteristics of the system, to determine bootstrap capability of the system with different tank pressures, back pressure, and pump-start conditions, and to evaluate performance of the automatic pressure control system during start-up. Inasmuch as this was the first test assembly of the full size NERVA engine in which all major engine components were brought together for operation as a unit, basic questions with respect to the start-up and performance of the system in the start-up transient were answered. Because CFDTS operated in an area where detailed component performance data were lacking, pre-test predictions did not agree closely with system performance, and the tests provided much useful information for upgrading and improving the analog and digital models simulating the engine.

B. BOOTSTRAPPING

The major objective of the CFDTS was achieved, i.e., the system was successfully "bootstrapped." Sufficient latent heat energy was delivered from the other engine components to the turbine to drive the pump and maintain operation of the pump until the reactor is able to supply adequate nuclear power to ramp to rated power of the engine. Thus auxiliary equipment is not required to start the engine.

It was also significant that the engine could be started using a warm pump without major problems. Thus, pre-chilling of the pump is not required. This makes feasible the elimination of the pump discharge valve and its controls and further simplifies the engine system.

An additional significant conclusion from these tests was that they proved it feasible to initiate bootstrap start-up with the pressure control loop

of TPVC activated at test start. This allowed simplification of control circuitry and increased system reliability.

C. STABILITY OF THE ENGINE SYSTEM DURING START-UP

An important conclusion derived from these tests was that pressure, temperature, and flow oscillations do not constitute a problem during start-up for the test conditions under which the system was examined and for the engine configuration tested. Even with the minimum tank pressure tested and the least stable pump start condition (20 psia tank pressure, warm pump) it was not possible to overspeed the pump or create damaging pressure oscillations in the system. The maximum pump speed attained under these conditions was 15,930 rpm. This was considerably under the pump "kill" parameter limit of 26,000 rpm. The reason that it was not possible to overspeed the pump may have been due primarily to the characteristic of the pump in that it did not pump gaseous fluid. Consequently, as soon as the pump became unloaded because of the low NPSP of the fluid in the pump resulting in gas in the pump, pressure in the engine system dropped almost immediately so that power to the turbine fell off. This allowed the pump speed to reduce before reaching an overspeed condition. From these tests, it appears that the dynamics of the engine system are such that without addition of reactor energy (when system temperatures are no greater than ambient, or about 540°R) it is not possible to create pressure and pump speed conditions harmful to the system. Flow instabilities encountered, even at NPSP's approaching zero, were insufficient to overspeed or damage the pump. This, of course, greatly simplifies any possible problems associated with start-up.

It was also observed that temperature variations with respect to flow streaming, i.e., paths of continuous low or high temperatures through the system, did not pose a problem. By the time the fluid reached the core inlet, temperature variations were small and the fluid was well mixed.

D. EFFECTS OF VARYING TANK PRESSURE AND BACK PRESSURE

It was found that when other conditions were the same, i.e., the back pressure was constant and the pump start condition was the same (either chilled or warm), a higher tank pressure resulted in a higher peak pump speed being attained in a shorter period of time. This was expected because a greater driving force across the system should have resulted in greater fluid flow and quicker transfer of heat energy from engine components to the fluid building up higher pressures and making available more energy to the turbine.

It was also noted that below a minimum tank pressure, which depended primarily on back pressure, the characteristic bootstrap curve of pump speed (and system fluid pressures) did not develop. Instead there was a relatively flat curve without any pronounced peak that gradually decayed when system energy was depleted. The tank pressure below which the characteristic bootstrap would not take place appeared to be approximately 40 psia when the back pressure was 12.7 psia, 25 psia when the back pressure was 7.5 psia, and 20 psia when the back pressure was 0.25 psia (refer to Figure 27). The pump speeds developed under these conditions were approximately 2000 rpm, 3000 rpm, and 3500 rpm respectively. It apparently required tank pressures greater than 45 psia, 30 psia, and 25 psia to obtain the characteristic bootstrap curves at back pressures of 12.7 psia, 30 psia, and 0.25 psia. The minimum tank pressures required to obtain the characteristic bootstrap are undoubtedly related to pressure ratios available across the turbine and corresponding turbine efficiencies. Detailed analyses of turbine performance characteristics at cold flow conditions are being made using data from CFDTS tests and will be available shortly.

It was also observed that oscillations in pressures and pump speeds, even though not pronounced enough to be damaging at any time, were less severe at higher tank pressures than they were at lower tank pressures.

E. CHILLED PUMP AND WARM PUMP STARTS

Under the same tank pressure and back pressure conditions, the engine system bootstrapped more quickly and pump speed peaked higher with a chilled pump than with a warm pump start. Since in the chilled pump start the pump was already cooled, fluid flow was not impeded by vaporizing of fluid in the pump. This permitted faster cooling of the nozzle manifold, nozzle tubes, reflector, etc., enabling greater fluid flow through the rest of the system more quickly and a quicker bootstrap.

Conversely, in the warm pump start, fluid flow was impeded until the pump was chilled. While the pump was chilling, cold fluid was flowing through the rest of the system, cooling it so that by the time the pump was chilled and the system was able to bootstrap, less latent heat energy was available and a slightly lower peak speed was attained.

Prior to CFDTIS tests some question had developed relative to the optimum program for opening the TPCV for a warm pump start. As a result of these tests, it can be concluded that it is feasible to open the TPCV to full open at test start without detrimental effects on the engine start transients. It was noted, however, that opening the TPCV at test start delayed the time to reach peak speed. This was contrary to what was initially expected. Also it was noted that the peak speed reached was slightly lower when the TPCV and PSOV were opened simultaneously and the time to reach it was delayed. These differences, however, were not significant.

F. PERFORMANCE OF AUTOMATIC PRESSURE CONTROL SYSTEM

As a result of these tests it can be concluded that it is feasible to activate the automatic control system at test start and close the chamber pressure control loop for controlling the position of the TPCV at test initiation. However, the response of the TPCV at the low chamber pressures and transient conditions, experienced in bootstrap start under cold flow engine conditions, was so slow that closing the pressure loop did not appreciably affect the chamber pressure. This was

expected because the system was designed for response at rated chamber pressures of 550 psia instead of the chamber pressures of about 60 psia experienced in these tests.

The feasibility of activating the automatic pressure control system at test start allows simplification of control circuitry and increased system reliability.

G. SPECIAL TESTS AND MEASUREMENTS

1. Comparison of Performance with Original and Improved TPA's

Improvements in the TPA (by increasing the inlet area of the turbine inlet manifold, reducing bearing labyrinth clearances and smoothing out turbine flow passages) resulted in approximately a 40% increase in maximum turbine speed with corresponding increase in pump discharge and chamber pressures.

2. Effect of Blanketing TPA in Helium

In tests comparing blanketing the TPA in helium to blanketing the TPA in nitrogen, no significant differences in performance were observed. Consequently it can be concluded that for cold flow conditions, a helium blanket for the TPA does not measurably improve pump performance characteristics.

3. Effect of Diluent Flow

Increasing diluent flow caused a small increase in pump speed (about 3.5%) pressures, and flows and a slight delay in reaching maximum speed, pressures, and flows. From the test results it can be concluded that changing diluent flow within fairly broad limits produces only a minor effect on bootstrap start-up characteristics.

4. Vibration

Analysis of vibration data indicated vibration "g" loadings were apparently related to pump acceleration. As the pump acceleration increased, "g" loads increased. The maximum "g" loads ($\pm 73g$) occurred at frequencies in excess of 10,000 cps and were of such magnitude as not to be damaging to the system at these frequencies. Maximum displacements (assuming sinusoidal vibration) were in the order of 7 micro inches.

5. Infinite Line for Chamber Pressure Measurement

Agreement between experimental and theoretical values using the infinite line for measurement of chamber pressure was good. It can be concluded, as a result of these tests, that it is feasible to use the infinite line technique as an interim method of measuring chamber pressure for NRX/EST until radiation hardened pressure transducers can be made available.

6. Turbopump Windmilling and Breakaway Torque

The tests showed no evidence of turbopump windmilling during chilldown of the pump prior to test start with fluid flows through the pump as high as 17 lbs/sec. However, with a chamber pressure rise of less than 3 psia the turbine began to rotate. Consequently, it can be concluded that provisions need not be made to restrict the pump from windmilling and that only very low flow rates need be established to begin acceleration of the pump because breakaway torque is small.

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APPENDIX A

REFERENCE DOCUMENTS AND DRAWINGS

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APPENDIX A

Reference Documents and Drawings

1. Documents

The following is a list of pertinent CFDTS reference documents:

<u>Document No.</u>	<u>Title</u>
AGC Report No. RN-S-0294 June 1966	CFDTS Data Analysis Final Report
AGC Report No. RN-S-0256 January 1965	CFDTS Performance Analysis Year-End Report
AGC Report No. RN-TM-0299 December 1965	CFDTS Test Series II and III Data Summary
AGC Report No. RN-S-0250 November 1965	Year-End Compilation of CFDTS Data Analysis
AGC Report No. RN-TM-0196 May 1965	CFDTS Test Series I - Data Summary
AGC Report No. RN-S-0213 April 1965	CFDTS Pre-Test Predictions
AGC Report No. RN-S-0204 March 1965	Performance Test Report and Operation Manual on CFDTS Sequencer
AGC Report No. RN-S-0191 Revision 1 March 1965	Test Specification for Cold Flow Development Test System
AGC Report No. RN-TM-0173 March 1965	CFDTS Malfunction Analysis
February 1965	CFDTS Engine Assembly Procedures
February 1965	CFDTS Engine System Data Log Book
AGC Report No. RN-S-0159 Volumes I and II October 1964	Operational Support Plan - CFDTS
AGC Report No. RN-S-0150 September 1964	Status Report on Analysis of the Cold Flow Development Test System
AGC Report RN-S-0148 Second Revision September 1964	Test Plan for Cold Flow Development Test System

<u>Document No.</u>	<u>Title</u>
AGC Report No. RN-S-0114 August 1964	Transient Engine Simulation Program
AGC Report No. RN-S-0091 May 1964	Basic Analog Model of NERVA Engine
AGC Report No. RN-TM-125 Revision D 30 October 1962	Instrumentation Accuracy for Performance Calculations
AGC Spec. 10138C	Test System, Development, Cold Flow, for NERVA Hot-Bleed Rocket Engine XE-1 (0)
AGC Report No. 2320	Instrumentation Data Book

2. Drawings

The following is a list of pertinent CFDTS reference drawings:

<u>Drawing No.</u>	<u>Title and Description</u>
1. 706965	Top Assembly - CFDTS (Includes a basic parts list and the complete assembly)
2. 094939	Nuclear Sub-Assembly Interface Control - CFDTS (Includes reactor to pressure vessel and closure interface)
3. 708809	Pressure Vessel and Reactor Assembly (Includes nozzle and reactor instrumentation support)
4. 706964	Upper Thrust Structure Top Assembly (This includes pump inlet line and TPA)
5. 1010090	Piping and Instrumentation Diagram - CFDTS (All measurements) (Shows relative location of instrumentation with coded callouts)
6. 1010091	Piping and Instrumentation - CFDTS (Basic Measurements) (Measurements to be recorded on every test)
7. 1013500	Transducer Mounting - CFDTS (Shows relative location of engine transducers and run tank propellant line transducers)
8. 707500	H-Area Flow Schematic for CFDTS
9. 709399	Instrumentation Location (CFDTS (Shows dimensional location of engine and propellant feed line instrumentation)
10. 706919	Criteria for Run Tank Propellant Line Assembly (RTPLA)
11. 101357	Pneumatic Installation for CFDTS (Shows pneumatic supply piping, valve and purge locations)
12. 094429	Interconnecting Diagram, Sequencer - CFDTS (Shows electrical schematic of the sequencer)

<u>Drawing Number</u>	<u>Title and Description</u>
13. 095554	Block Diagram - CFDTs Sequencer (Indicates flow of events from engine system to manual controls, indicators display)
14. 937J145	Reactor Assembly
3. <u>Quality Assurance Documentation</u>	
<u>Document No.</u>	<u>Title</u>
1. NASA NPC-200-2	Quality Program Provisions for Space System Contractors
2. AGC Report 2469, Vol. II, Rev. A	Quality Assurance Program Plan for NERVA Propulsion System
4. <u>Safety Documentation</u>	
<u>Document No.</u>	<u>Title</u>
1. AGC LRO Test Division	Safety Manual
5. <u>Security Documentation</u>	
<u>Document No.</u>	<u>Title</u>
1. AGC LRO Project Directive 25D	NERVA Security Classification

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APPENDIX B

ASSEMBLY, DISASSEMBLY, AND TEST PROCEDURES

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APPENDIX B

ASSEMBLY, DISASSEMBLY, AND TEST PROCEDURES

A. Inspection and Assembly Documentation

<u>Procedure Number</u>	<u>Description</u>
P-0	Standard Operating Procedures for the CFDTS Assembly Area
P-1	Operational Procedure for Installation of Pressure Vessel into Assembly Stand
P-2	Receiving and Inspection of Reactor and Assembly into Pressure Vessel
P-3	Receiving and Inspection of Simulated Shield and Assembly into Pressure Vessel
P-4	Receiving and Inspection of Reactor Miscellaneous Components
P-5	Installation of Reactor Miscellaneous Components and Forward Closure
P-7	Assembly of Nozzle to Pressure Vessel, Nozzle-Down Position
P-8	Assembly of Nozzle to Pressure Vessel, Nozzle-up Position
P-9	Assembly of Turbopump Assembly, Upper Thrust Structure Assembly, Lower Thrust Structure, Pressure Vessel and Reactor Assembly
P-11	Operational Procedure for Installation of Propellant Feed Lines to Pressure Vessel and Final Assembly of the CFDTS
P-13	Operational Procedure for Disassembly of the CFDTS and Shipment to Test Division

B. Test Facilities Checkout Prior to Installation of the CFDTS

<u>Procedure No.</u>	<u>Description</u>
P-22	Propellant Feed System (Run Tank propellant line assembly and tank pressure regulation system checkout)

- P-23 Ejector Performance (Pre-CFDTS installation checkout and operation of the injector control system)
- P-24 Overspeed Circuitry (Checkout procedure for the turbopump assembly overspeed trip device)
- P-25 Facility Emergency Power (Checkout procedure for the standby power supply for critical CFDTS components and test equipment components)

C. Test Stand Installation and Run Procedures

<u>Procedure No.</u>	<u>Description</u>
P-28	Handling and Installation of CFDTS into Test Stand
P-29	Sequencer Operation and Checkout
P-30	Electrical and Mechanical Systems Checkout
P-31	Electrical Controls Pre-Test Checkout
P-32	Test Engineer's Pre-Test and Post-Test Checkout Procedures
P-33	Test Conductor's Checkout Procedures
P-36	Post-Test Inspection and Removal from Test Stand
P-37	Shipment to Assembly Area

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APPENDIX C

CFDTS MEASUREMENTS REQUIREMENTS LIST

CFDTS MEASUREMENT REQUIREMENTS LIST

TEST SERIES I

TEST RUN - TEST SERIES I

CFDTS MEASUREMENT REQUIREMENTS LIST
DATE- 04/07/65

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MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SYS F R	RECORDING INSTRUMENT	P R	EMERS DEPTH	PROBE LTH
1	RUN TANK PROPEL LINE	PRTPL-1	1	-235.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.5 PSI (C)	12	B40-T	P	N/A	N/A
2	RUN TANK PROPEL LINE	PRTPL-2	1	-235.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.5 PSI	8	B40	S	N/A	N/A
3	RUN TANK PROPEL LINE	PRTPL-3	1	-141.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.4 PSI (C)	12	B40-T-S	P	N/A	N/A
4	RUN TANK PROPEL LINE	PRTPL-4	1	-141.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.4 PSI	8	B40	S	N/A	N/A
5	PUMP INLET LINE	PPIL-1	1	-119.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.5 PSI	12	B40-T	P	N/A	N/A
7	PUMP INLET LINE	PPIL-3	1	-91.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.4 PSI (C)	12	B40-T	P	N/A	N/A
8	PUMP INLET LINE	PPIL-4	1	-91.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+- 0.4 PSI	8	B40	S	N/A	N/A
10	PUMP DISCHARGE	PPD-1	1	-55.0	19.0	100	PRESS	500PSIG	15PSIA	400PSIA	+- 2.5 PSI (C)	8	B40-S	P	N/A	N/A
11	PUMP DISCHARGE	PPD-2	1	-55.0	19.0	100	PRESS	100PSIA	1 PSIA	100PSIA	+- 0.5 PSI (C)	12	B40-T	P	N/A	N/A
12	PUMP DISCHARGE	PPD-3	1	-55.0	19.0	100	PRESS	500PSIG	15PSIA	400PSIA	+- 2.5 PSI	8	B40	P	N/A	N/A
15	PUMP DIFF DROP	DPDP-1	1	-55.0	19.0	100	PRESS	50PSID	0 PSID	15 PSID	+- 0.25PSI (C)	8	B40	P	N/A	N/A
16	NOZZLE MANI. INLET	PNMI-1	1	124.0	22.5	120	PRESS	100PSIA	1PSIA	100PSIA	+- 0.5PSI	12	B40-T	P	N/A	N/A
18	NOZZLE MANIFOLD	PNM-1	1	124.0	16.0	160	PRESS	500PSIG	15PSIA	400PSIA	+- 3.0PSI	8	B40	S	N/A	N/A
20	NOZZLE MANIFOLD	PNM-3	1	124.0	16.0	65	PRESS	500PSIG	15PSIA	400PSIA	+- 3.0PSI	8	B40	P	N/A	N/A
21	NOZZLE MANIFOLD	PNM-4	1	124.0	16.0	30	PRESS	100PSIA	1PSIA	100PSIA	+- 0.5PSI	12	B40-T	P	N/A	N/A
25	NOZZLE TUBE OUTLET	PNT0-1	1	71.0	26.0	40	PRESS	100PSIA	1PSIA	100PSIA	+- 0.5PSI	12	B40-T	P	N/A	N/A
26	NOZZLE TUBE OUTLET	PNT0-2	1	71.0	26.0	165	PRESS	500PSIG	15PSIA	290PSIA	+- 2.0PSI	8	B40	S	N/A	N/A
28	NOZZLE TUBE OUTLET	PNT0-4	1	71.0	26.0	75	PRESS	500PSIG	15PSIA	290PSIA	+- 2.0PSI	8	B40	P	N/A	N/A
29	NOZZLE TUBE OUTLET	PNT0-5	1	71.0	26.0	50	LASL	50PSID	-25PSI	+25PSI	+- 0.5PSI	100	T	S	N/A	N/A
32	NOZZLE TUBE DIFF	DPNT-2	1	71.0	26.0	300	PRESS	100PSID	0PSID	100PSID	+- 1.0PSI	8	B40	P	N/A	N/A
40	REFLECTOR OUTLET	PRO-1	1	13.0	26.0	70	PRESS	50PSIA	1PSIA	50PSIA	+- 0.5PSI	12	B40-T	P	N/A	N/A
41	REFLECTOR OUTLET	PRO-2	1	13.0	26.0	70	PRESS	500PSIG	15PSIA	250PSIA	+- 2.0PSI	8	B40	P	N/A	N/A
42	REFLECTOR OUTLET	PRO-3	1	13.0	26.0	190	PRESS	500PSIG	15PSIAA	250PSIA	+- 2.0PSI	8	B40	S	N/A	N/A
44	REFLECTOR OUTLET	PRO-5	1	13.0	26.0	190	LASL	50PSID	-25PSIA	+25PSI	+- 0.5PSI	100	T	S	N/A	N/A
53	SHIELD INL SECONDPASS	PSISP-1	1	-3.6	12.8	296	PRESS	500PSIG	15PSIA	250PSIA	+- 2.0 PSI	4	B20	P	N/A	N/A
55	SHIELD INL SECONDPASS	PSISP-2	1	-3.6	13.5	158	PRESS	50PSIA	1PSIA	50PSIA	+- 0.5PSI	4	B20	P	N/A	N/A
58	CORE INLET	PCI-1	1	15.4	13.0	118	PRESS	500PSIG	15PSIA	240PSIA	+- 2.0PSI	4	B20	P	N/A	N/A
59	CORE INLET	PCI-2	1	15.4	13.0	205	PRESS	50PSIA	1PSIA	50PSIA	+- 0.5PSI	4	B20	P	N/A	N/A
60	CORE INLET	PCI-3	1	15.4	3.0	228	PRESS	500PSIG	15PSIA	240PSIA	+- 2.0PSI	4	B20	S	N/A	N/A
65	NOZZLE CHAMBER	PNC-4	1	86.1	15.4	78	PRESS	50PSIA	1PSIA	50PSIA	+- 0.25PSI (C)	12	B20-T	P	N/A	N/A
66	NOZZLE CHAMBER	PNC-1	1	86.1	15.4	342	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI	4	B20	S	N/A	N/A
67	NOZZLE CHAMBER	PNC-2	1	86.1	15.4	78	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI (C)	4	B20-S	P	N/A	N/A
68	NOZZLE CHAMBER	PNC-3	1	86.1	15.4	198	RECUN	750PSIA	1PSIA	135PSIA	+- 3.0PSI (C)	4	B20	P	N/A	N/A
72	DILUENT LINE	PDL-1	1	-14.0	39.3	179	PRESS	500PSIG	15PSIA	250PSIA	+- 2.0PSI	12	B40-T-S	P	N/A	N/A
74	DILUENT JACKET	PDJ-1	1	85.0	19.0	190	PRESS	500PSIG	15PSIA	250PSIA	+- 2.0PSI	8	B40	P	N/A	N/A
76	DIL LINE ORIFICE DIFF	DPDLO-1	1	-14.0	39.3	179	PRESS	50PSID	0PSID	30PSID	+- 0.25PSI	8	B40-S	P	N/A	N/A
78	TURBINE INLET LINE	PTIL-1	1	89.0	19.0	169	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI	4	B20	P	N/A	N/A
80	TURBINE INLET LINE	PTIL-3	1	9.0	41.0	169	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI	4	B20-S	P	N/A	N/A
81	TURBINE INLET LINE	PTIL-4	1	9.0	41.0	169	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI	4	B20	S	N/A	N/A
82	TURBINE INLET LINE	PTIL-5	1	-49.6	32.0	175	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI	4	B20-S	P	N/A	N/A
84	TIL VENTURI DIFF	OPTILV-1	1	9.0	39.0	169	PRESS	20PSID	0PSID	20PSID	+- 0.1PSI (C)	4	B20-S	P	N/A	N/A
85	TIL VENTURI DIFF	OPTILV-2	1	9.0	43.5	169	PRESS	20PSID	0PSID	20PSID	+- 0.1PSI	4	B20	S	N/A	N/A
87	TPCV DIFF	OPTPCV-1	1	-49.6	32.0	175	PRESS	50PSID	0PSID	30PSID	+- 0.5PSI	4	B20	P	N/A	N/A
88	TPCV DIFF	OPTPCV-2	1	-49.6	32.0	175	PRESS	50PSID	0PSID	30PSID	+- 0.5PSI	4	B20	S	N/A	N/A
89	TURBINE INLET	PTI-1	1	-47.6	9.0	210	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI (C)	4	B20-S	P	N/A	N/A
90	TURBINE INLET	PTI-2	1	-47.6	13.0	181	PRESS	200PSIG	15PSIA	135PSIA	+- 1.0PSI	4	B20	S	N/A	N/A
91	TURBINE EXHAUST NOZ	PTEN-1	1	-38.4	16.0	94	PRESS	30PSIA	0.5PSIA	20PSIA	+- 0.3PSI (C)	4	B20	P	N/A	N/A
92	TURBINE EXHAUST NOZ	PTEN-2	1	-38.4	16.0	274	PRESS	30PSIA	0.5PSIA	20PSIA	+- 0.3PSI	4	B20	S	N/A	N/A
93	TURBINE INLET	PTI-3	1	-47.6	13.0	181	PRESS	50PSIA	0.5PSIA	50PSIA	+- 0.5PSI (C)	12	B20-T	P	N/A	N/A
105	TPA BEAR. HOUS. DIFF.	DPBH	1	-51.0	N/A	N/A	PRESS	50 PSID	0 PSID	50 PSID	+- 1.0 PSI	2	B10	P	N/A	N/A

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MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED MIN.	RANGE MAX.	SYSTEM ACCURACY	SYS F R	RECORDING INSTRUMENT	P R	EMERS DEPTH	PROBE LTH
109	RUN TANK PROPEL LINE	THRTPL-1	1	-235.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R (C)	12	B40-T	P	2.68	4.00
110	RUN TANK PROPEL LINE	THRTPL-2	1	-235.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8	B40	S	2.68	4.00
111	RUN TANK PROPEL LINE	THRTPL-3	1	-141.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R (C)	12	B40-T-S	P	2.68	4.00
112	RUN TANK PROPEL LINE	THRTPL-4	1	-141.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8	B40	S	2.68	4.00
114	PUMP INLET LINE	THPIL-1	1	-119.	N/A	N/A	RTT	CODE L	35 R	535 R	+ 2.0 R	12	B40-T	P	3.36	4.00
116	PUMP INLET LINE	THPIL-3	1	-68.	N/A	N/A	RTT	CODE L	35 R	535 R	+ 2.0 R	12	B40-T	P	3.36	4.00
117	PUMP INLET LINE	THPIL-4	1	-91.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R (C)	8	B40	P	3.36	4.00
118	PUMP INLET LINE	THPIL-5	1	-91.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8	B40	S	3.36	4.00
119	PUMP INLET LINE	THPIL-6	1	-65.	N/A	N/A	TC/CA	N/A	35 R	535 R	+ 10.0 R	12	T	S	2.70	5.00
124	PUMP DISCHARGE	THPD-1	1	-55.0	19.0	100	RTT	CODE L	35 R	535 R	+ 2.0 R	12	B20-T	P	1.88	2.50
125	PUMP DISCHARGE	THPD-2	1	-55.0	19.0	100	RTT	CODE K	35 R	60 R	+ 0.3 R (C)	4	B20-S	P	1.88	2.50
126	PUMP DISCHARGE	THPD-3	1	-55.0	19.0	100	TC/CA	N/A	35 R	535 R	+ 10.0 R	12	T	S	2.12	3.00
127	PUMP DISCHARGE	THPD-4	1	-55.0	19.0	100	RTT	CODE K	35 R	60 R	+ 0.3 R (C)	4	B20	P	1.88	2.50
133	NOZZLE MANIFOLD	THNM-2	1	124.0	16.0	80	RTT	CODE L	35 R	535 R	+ 2.0 R	12	B20-T	P	1.85	2.5
134	NOZZLE MANIFOLD	THNM-3	1	124.0	16.0	170	RTT	CODE L	35 R	535 R	+ 2.0 R	4	B20	S	1.85	2.5
136	NOZZLE MANIFOLD	THNM-5	1	124.0	16.0	55	TC/CA	N/A	35 R	535 R	+ 10.0 R	12	T	S	1.15	2.5
140	NOZZLE TUBE OUTLET	THNT0-2	1	71.0	26.0	180	PTT	CODE L	35 R	535 R	+ 2.0 R	4	B20	S	1.74	2.5
141	NOZZLE TUBE OUTLET	THNT0-3	1	71.0	26.0	60	RTT	CODE L	35 R	535 R	+ 2.0 R	12	B20-T	P	1.74	2.5
144	NOZZLE TUBE OUTLET	THNT0-6	1	69.0	22.4	165	TC/CC	N/A	35 R	535 R	+ 10.0 R	12	T	S	N/A	N/A
151	REFLECTOR OUTLET	THRO-2	1	15.5	18.4	161	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	2	B10	S	N/A	N/A
153	REFLECTOR OUTLET	THRO-4	1	15.5	22.4	35	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	2	B10	S	N/A	N/A
156	REFLECTOR OUTLET	THRO-7	1	12.6	24.4	293	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	2	B10	S	N/A	N/A
158	REFLECTOR OUTLET	THRO-9	1	9.8	22.4	52	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	2	B10	S	N/A	N/A
159	REFLECTOR OUTLET	THRO-10	1	9.8	22.4	295	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	2	B10	P	N/A	N/A
175	CORE INLET	THCI-5	1		6.3	106	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	3	CSC	S	N/A	N/A
176	CORE INLET	THCI-1	1		11.2	121	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	3	CSC	B	N/A	N/A
177	CORE INLET	THCI-7	1		15.2	121	TC/CC	N/A	100 R	535 R	+ 3.0 RAT300 R	3	CSC	S	N/A	N/A
183	CORE MODULES	TCM-1	3	N/A	N/A	0	TC/CA	N/A	150 R	535 R	+ 10.0 R	1	CSC	S	N/A	N/A

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MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SYS F R	RECORDING INSTRUMENT	P EMERS R	DEPTH	PROBE LTH
184	CORE MODULES	TCM-2	1	N/A	N/A	0	TC/CA	N/A	150 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
186	CORE MODULES	TCM-4	3	N/A	N/A	180	TC/CA	N/A	150 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
187	CORE MODULES	TCM-5	3	N/A	N/A	180	TC/CA	N/A	150 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
188	CORE MODULES	TCM-6	1	N/A	N/A	180	TC/CA	N/A	150 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
189	CORE MODULES	TCM-7	3	N/A	N/A	180	TC/CA	N/A	150 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
192	INNER REFLECTOR	TIR-1	1	23.0		70	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
193	INNER REFLECTOR	TIR-2	3	34.2		70	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
194	INNER REFLECTOR	TIR-3	3	45.5		70	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
195	INNER REFLECTOR	TIR-4	1	62.3		70	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
201	CONTROL DRUM	TCD-1	1	48.4	21.6	36	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
202	CONTROL DRUM	TCD-2	1	48.4	23.5	26	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
203	CONTROL DRUM	TCD-3	3	24.4	21.6	156	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
204	CONTROL DRUM	TCD-4	3	24.4	23.5	146	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
205	CONTROL DRUM	TCD-5	3	61.4	21.6	275	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
206	CONTROL DRUM	TCD-6	3	61.4	23.5	266	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
213	OUTER REFLECTOR	TOR-1	3	18.4	21.6	45	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
214	OUTER REFLECTOR	TOR-2	3	50.4	23.0	45	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
215	OUTER REFLECTOR	TOR-3	3	34.4	21.6	165	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
216	OUTER REFLECTOR	TOR-4	3	66.4	23.0	165	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
217	OUTER REFLECTOR	TOR-5	1	48.4	21.6	255	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
218	OUTER REFLECTOR	TOR-6	3	32.4	22.4	255	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
219	OUTER REFLECTOR	TOR-7	3	50.4	22.7	255	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
220	OUTER REFLECTOR	TOR-8	1	64.4	23.0	255	TC/CC	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
221	NOZZLE CHAMBER	THNC-1	1	86.1	15.4	250	RTT	CODE L	200 R	535 R	+2.0 R	4	B20	S	1.75	4.0
222	NOZZLE CHAMBER	THNC-2	1	86.1	15.4	133	RTT	CODE L	200 R	535 R	+2.0 R	4	B20	S	1.75	4.0
223	NOZZLE CHAMBER	THNC-3	1	86.1	15.4	13	RTT	CGDE L	200 R	535 R	+2.0 R	4	B0 -S	P	1.75	4.0
232	SHIELD INL SECONDPASS	THSISP-8	1	-8.4	15.9	110	TC/CC	N/A	100 R	535 R	+3.0 R	3	CSC	P	N/A	N/A
234	SHIELD INL SECONDPASS	THSISP10	1	-11.0	3.9	144	TC/CC	N/A	100 R	535 R	+3.0 R	3	CSC	P	N/A	N/A
238	TURBINE INLET LINE	THIIL-1	1	89.0	19.0	169	TC/CA	N/A	200 R	535 R	+3.0 R	4	B20	P	1.75	3.5
243	TURBINE INLET LINE	THIIL-3	1	-49.6	32.0	175	RTT	CODE L	200 R	535 R	+2.0 R	4	B20	P	1.94	2.5
244	TURBINE INLET LINE	THIIL-4	1	-49.6	32.0	175	RTT	CODE L	200 R	535 R	+2.0 R	4	B20	P	1.94	2.5
246	TURBINE INLET	THII-1	1	-47.6	13.0	181	RTT	CODE L	250 R	535 R	+2.0 R	4	B20	P	1.94	2.5
247	TURBINE INLET	THII-2	1	-47.6	9.0	210	TC/CA	N/A	250 R	535 R	+3.0 R	4	B20	S	.40	2.0
249	TURBINE EXHAUST NOZ.	THTEN-1	1	-38.4	16.0	94	TC/CA	N/A	250 R	535 R	+3.0 R	2	B10	P	1.75	3.0
251	TURBINE EXHAUST NOZ.	THTEN-2	1	-38.4	16.0	274	TC/CA	N/A	250 R	535 R	+3.0 R	2	B10	P	1.95	3.0
253	DILUENT LINE	THDL-1	1	-5.8	40.0	179	TC/CA	N/A	100 R	535 R	+3.0 R	8	B40-S	P	0.63	1.5
255	DILUENT JACKET	THDJ-1	1	89.0	19.0	159	TC/CA	N/A	150 R	535 R	+3.0 R	4	B20	P	0.33	1.25
257	TPA BEARING	TB-1A	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	P	N/A	N/A
258	TPA BEARING	TB-1B	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	S	N/A	N/A
259	TPA BEARING	TB-2A	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	P	N/A	N/A
260	TPA BEARING	TB-2B	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	S	N/A	N/A
261	TPA BEARING	TB-3A	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	P	N/A	N/A
262	TPA BEARING	TB-3B	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	S	N/A	N/A
263	TPA BEARING	TB-4A	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	P	N/A	N/A
264	TPA BEARING	TB-4B	1	N/A	N/A	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	2	B10	S	N/A	N/A
265	NOZZLE WALL INNER	TNWI-1	3	125.0	13.0	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
266	NOZZLE WALL INNER	TNWI-2	3	114.0	9.5	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
267	NOZZLE WALL INNER	TNWI-3	3	102.0	6.0	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
268	NOZZLE WALL INNER	TNWI-4	1	94.0	5.0	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
269	NOZZLE WALL OUTER	TNWO-1	3	117.0	11.5	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A

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MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED MIN.	PREDICTED MAX.	SYSTEM ACCURACY	SYS F R	RECORDING INSTRUMENT	P R	EMERS DEPTH	PROBE LTH
270	NOZZLE WALL OUTER	TNWO-2	3	103.0	7.0	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
271	NOZZLE WALL OUTER	TNWO-3	3	97.0	5.3	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
272	NOZZLE WALL OUTER	TNWO-4	1	91.0	10.0	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
273	NOZZLE WALL OUTER	TNWO-5	3	85.0	16.0	60	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
274	PRESSURE VESSEL	TPV-1	3	13.0	26.5	0	TC/CA	N/A	100 R	535 R	+10.0 R	1	CSC	S		
275	PRESSURE VESSEL	TPV-2	3	13.0	26.5	180	TC/CA	N/A	100 R	535 R	+10.0 R	1	CSC	S		
276	PRESSURE VESSEL	TPV-3	1	42.0	26.0	0	TC/CA	N/A	100 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
277	PRESSURE VESSEL	TPV-4	1	42.0	26.0	180	TC/CA	N/A	100 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
278	PRESSURE VESSEL	TPV-5	3	70.0	26.5	0	TC/CA	N/A	100 R	535 R	+10.0 R	1	CSC	S		
279	PRESSURE VESSEL	TPV-6	3	70.0	26.5	185	TC/CA	N/A	100 R	535 R	+10.0 R	1	CSC	S		
281	NOZZLE WALL INNER	TNWI-5	3	86.0	13.5	0	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
282	NOZZLE WALL INNER	TNWI-6	3	76.0	18.0	60	TC/CA	N/A	300 R	535 R	+10.0 R	1	CSC	S		
286	PRESSURE VESSEL CLOS	TPVC-1	3	-9.0	20.0	60	TC/CA	N/A	300 R	535 R	+10.0 R	1	CSC	S		
287	PRESSURE VESSEL CLOS	TPVC-2	3	-9.0	20.0	180	TC/CA	N/A	300 R	535 R	+10.0 R	1	CSC	S		
288	PRESSURE VESSEL CLOS	TPVC-3	3	-9.0	20.0	300	TC/CA	N/A	300 R	535 R	+10.0 R	1	CSC	S		
289	PRESSURE VESSEL CLOS	TPVC-4	3	-13.0	6.0	60	TC/CA	N/A	300 R	535 R	+10.0 R	1	CSC	S		
297	PUMP DISCHARGE LINE	TPDL-1	1	-55.0	39.0	120	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
298	PUMP DISCHARGE LINE	TPDL-2	3	16.0	38.6	120	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
299	PUMP DISCHARGE LINE	TPDL-3	3	70.0	38.6	120	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
300	PUMP DISCHARGE LINE	TPDL-4	1	126.0	39.0	120	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
301	TURBINE INLET LINE	TTIL-1	3	-49.0	34.0	169	TC/CA	N/A	200 R	535 R	+10.0 R	1	CSC	S		
302	TURB IN LINE JACKET	TTILJ-1	3	33.0	43.5	159	TC/CA	N/A	200 R	535 R	+10.0 R	1	CSC	S		
303	TURB IN LINE JACKET	TTILJ-2	3	103.0	35.0	169	TC/CA	N/A	200 R	535 R	+10.0 R	1	CSC	S		
304	TURB IN LINE JACKET	TTILJ-3	3	107.0	35.0	169	TC/CA	N/A	200 R	535 R	+10.0 R	1	CSC	S		
305	PUMP INLET LINE	TPIL-1	1	-90.	4.4	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	1	B10	S	N/A	N/A
306	PUMP INLET LINE	TPIL-2	1	-79.	4.2	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	1	B10	S	N/A	N/A
307	PUMP INLET LINE	TPIL-3	3	-73.	4.2	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
308	TPA HOUSING	TTPH-1	1	-59.0	4.0	0	TC/CA	N/A	35 R	535 R	+10.0 R	1	B10	S	N/A	N/A
309	TPA HOUSING	TTPH-2	1	-57.0	8.0	0	TC/CA	N/A	35 R	535 R	+10.0 R	1	B10	S	N/A	N/A
310	TPA HOUSING	TTPH-3	3	-55.	13.0	0	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
311	PUMP INLET LINE	TPIL-4	3	-67.	4.4	N/A	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
312	NOZZLE MANIFOLD	TNM-1	3	126.0	31.5	310	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
313	NOZZLE MANIFOLD	TNM-2	3	126.0	31.5	130	TC/CA	N/A	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A
319	PUMP DISCHARGE VALVE	LPDV-1	1	PDV	ACT	N/A	POT	90	0	90	N/A	N/A	0-SB	P	N/A	N/A
320	PSIV	LPSDV-1	1	PSIV	ACT	N/A	POT	90	0	90	N/A	N/A	0-SB	P	N/A	N/A
321	PSIV	LPSDV-2	1	PSIV	ACT	N/A	LT SW	N/A	0	90	N/A	N/A	0	S	N/A	N/A
322	TPCV	LTPCV-1	1	TPCV	ACT	N/A	PJT	90	0	90	+ 0.7 MEAS VAL	N/A	B20-0-SB	P	N/A	N/A
323	TPCV	LTPCV-2	1	TPCV	ACT	N/A	PJT	90	0	90	+ 0.7 MEAS VAL	N/A	B20-0-SB	S	N/A	N/A
324	DILUENT VALVE	LDV-1	1	DV	ACT	N/A	POT	90	0	90	N/A	N/A	0-SB	P	N/A	N/A
327	TPA	YTPA	1				DISP		0 INCH	0.010IN	N/A	N/A	2K T-V	P	N/A	N/A
328	TPA	ZTPA	1				DISP		0 INCH	0.010IN	N/A	N/A	2K T-V	P	N/A	N/A
330	RUN TANK PROPEL LINE	QRTPL-1	1	-200.	N/A	N/A	TURB	7630GPM	760GPM	4680GPM	+ 1.5 MEAS VAL	N/A	B40-0-S	P	N/A	N/A
331	RUN TANK PROPEL LINE	QRTPL-2	1	-160.	N/A	N/A	TURB	2540GPM	2540GPM	2540GPM	+ 1.5 MEAS VAL	N/A	B40-0-S	P	N/A	N/A
332	PUMP DIS BLEED VALVE	LPBIV-1	1	PBIV	ACT	N/A	POT	90	0	90	N/A	N/A	0-SB	P	N/A	N/A
334	PUMP SPEED	NTPA-1	1	-51.0	N/A	N/A	PRURE	30000	0 RPM	15K RPM	+ 0.3 MEAS VAL	N/A	B20-T-S	P	N/A	N/A
402	PROPELLANT FUEL TANK	PFT-H11	F	N/A	N/A	N/A	PRESS	100PSIG	0PSIG	70PSIG	N/A	N/A	2 B10-S	P	N/A	N/A
407	RUN TANK OUTLET	PFTO-1	1	-324.	N/A	N/A	PRESS	100PSIG	15 PSIA	70 PSIA	+ 0.5 PSI (C)	N/A	4 B20-S	P	N/A	N/A
411	PNEUMATIC SYSTEM	PPS-1	F	N/A	N/A	N/A	PRESS	200PSIG	0PSIG	120PSIG	N/A	N/A	2 B10-S	P	N/A	N/A
412	PNEUMATIC SUPPLY TPCV	PPSTPCV1	1	198.0	22.0	270	PRESS	500PSIG	N/A	215PSIG	+ 3.0PSI	N/A	4 B20-S	P	N/A	N/A
414	NOZZLE EXHAUST DUCT	PNED-1	1	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	17PSIA	+ 0.25PSI (C)	12	B20-T-S	P	N/A	N/A

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TEST RUN - TEST SERIES I

CFDTS MEASUREMENT REQUIREMENTS LIST
DATE- 04/07/65

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MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SYS F R	RECORDING INSTRUMENT	P EMERS R	DEPTH	PROBE LTH
415	NOZZLE EXHAUST DUCT	PNED-2	1	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	17PSIA	+ 0.25PSI	4	B20	S	N/A	N/A
416	NOZZLE EJECTOR	PNE-1	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2	B10-S	P	N/A	N/A
417	NOZZLE EJECTOR	PNE-2	F	N/A	N/A	N/A	PRESS	30PSIA	0PSIA	18PSIA	N/A	2	B10	S	N/A	N/A
418	NOZZLE EJECTOR	PNE-3	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2	B10-S	P	N/A	N/A
419	NOZZLE EJECTOR	PNE-4	F	N/A	N/A	N/A	PRESS	15PSIA	0PSIA	18PSIA	N/A	2	B10	S	N/A	N/A
421	TURBINE EXHAUST LINE	PTL-1	1	N/A	N/A	N/A	PRESS	30PSIA	0.5PSIA	17PSIA	+ 0.3 PSI (C)	12	B20-T-S	P	N/A	N/A
422	TURBINE EXHAUST LINE	PTL-2	1	N/A	N/A	N/A	PRESS	50PSIA	0.5PSIA	17PSIA	+ 0.3 PSI	4	B20	P	N/A	N/A
423	TURBINE EXHAUST EJECT	PTEE-1	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2	B10-S	P	N/A	N/A
424	TURBINE EXHAUST EJECT	PTEE-2	F	N/A	N/A	N/A	PRESS	30PSIA	0PSIA	18PSIA	N/A	2	B10	S	N/A	N/A
425	TURBINE EXHAUST EJECT	PTEE-3	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2	B10-S	P	N/A	N/A
426	TURBINE EXHAUST EJECT	PTEE-4	F	N/A	N/A	N/A	PRESS	15PSIA	0PSIA	18PSIA	N/A	2	B10	S	N/A	N/A
429	GN2 SUPPLY MANIFOLD	PGGN2M	F	N/A	N/A	N/A	PRESS	6K PSIG	0PSIG	5K PSIG	N/A	2	B10-S	P	N/A	N/A
430	EJECTOR SUPPLY CV OUT	PESCV-0	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	500PSIG	N/A	2	B10-S	P	N/A	N/A
436	NOZZLE EXHAUST DUCT	THNED-1	1	N/A	N/A	N/A	TC/CC	N/A	250 R	535 R	+ 3.0 R	2	B10-S	P	N/A	N/A
437	NOZZLE EXHAUST DUCT	THNED-2	F	N/A	N/A	N/A	TC/CC	N/A	200 R	535 R	N/A	2	B10	S	N/A	N/A
438	NOZZLE EJECTOR	TGNE-1	F	N/A	N/A	N/A	TC/CC	10MV	300 R	535 R	N/A	2	B10	S	0.75	3.75
439	NOZZLE EJECTOR	TGNE-2	F	N/A	N/A	N/A	TC/CC	10MV	300 R	535 R	N/A	2	B10	S	0.0	3.75
442	TURBINE EXHAUST LINE	THTEL-1	F	N/A	N/A	N/A	TC/CC	10MV	200 R	535 R	N/A	2	B10-S	S	0.5	3.75
443	TURBINE EXHAUST EJECT	TGTEE-1	F	N/A	N/A	N/A	TC/	10MV	300 R	535 R	N/A	2	B10	S	0.0	3.75
444	TURBINE EXHAUST EJECT	TGTEE-2	F	N/A	N/A	N/A	TC/	10MV	300 R	535 R	N/A	2	B10	S	0.0	3.75
447	PRESS FLOW CONT. VAL.	LPFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	12	O-S	P	N/A	N/A
448	PRESS VENT FLOW CON.V	LPVFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	12	O-S	P	N/A	N/A
450	NOZ EXH SPOIL GAS CV	LNESGCV	F	N/A	N/A	N/A	POT	N/A	N/A	N/A	N/A	12	O	P	N/A	N/A
451	TRB EXH SPOIL GAS CV	LTESGCV	F	N/A	N/A	N/A	POT	N/A	N/A	N/A	N/A	12	O	P	N/A	N/A
452	SPOILER GAS MANIFOLD	PSGM	F	N/A	N/A	N/A	PRESS	5K PSIG	0PSIG	5K PSIG	N/A	2	B10-S	P	N/A	N/A
453	GH2 SUPPLY MANIFOLD	PGGH2M	F	N/A	N/A	N/A	PRESS	6K PSIG	0PSIG	5K PSIG	N/A	2	B10-S	P	N/A	N/A
454	PRES CV URIFICE INLET	PGPCVU-I	F	N/A	N/A	N/A	PRESS	5K PSIG	0PSIG	2K PSIG	N/A	2	B10-S	P	N/A	N/A
455	PRES CV PRES REG DOME	PGPCVPR	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	2K PSIG	N/A	2	B10-S	P	N/A	N/A
456	PRES CV PRES REG OUT	PGPCVPRO	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	2K PSIG	N/A	2	B10-S	P	N/A	N/A
457	HYDRALIC CV DISCHARGE	PHDCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	4K PSIG	N/A	2	B10-S	P	N/A	N/A
458	HYDRALIC CV RETURN	PHRCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	4K PSIG	N/A	2	B10-S	P	N/A	N/A
459	ACCUMULATOR CV	PACCCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	3K PSIG	N/A	2	B10-S	P	N/A	N/A
460	BURNOFF DUCT NOZ EJECT	T300-2A	F	N/A	N/A	N/A	PYRO	10MV	PYROMET	R	N/A	2	S	P	N/A	N/A
461	BURNOFF DUCT TURB EJECT	T800-2B	F	N/A	N/A	N/A	PYRO	10MV	PYROMET	R	N/A	2	S	P	N/A	N/A
462	TEMP FUEL TANK OUTLET	TFTO-A	F	N/A	N/A	N/A	RTT	C0DE-K	35 R	60 R	N/A	2	B10	S	2.68	0.00
463	NOZ EJE WALL 1ST STAG	TSNE-1	F	N/A	N/A	N/A	TC/CC	10MV	350 R	560 R	N/A	2	B10-S	P	N/A	N/A
464	NOZ EJE WALL 2ND STAG	TSNE-2	F	N/A	N/A	N/A	TC/CC	10MV	350 R	560 R	N/A	2	B10-S	P	N/A	N/A
465	EXH BURN OFF DUCT	T800-3A	F	N/A	N/A	N/A	PYRO	10MV	PYROMET	R	N/A	2	S	P	N/A	N/A
466	EXH BURN OFF DUCT	T800-3B	F	N/A	N/A	N/A	PYRO	10MV	PYROMET	R	N/A	2	S	P	N/A	N/A

CFDTS MEASUREMENT REQUIREMENTS LIST

TEST SERIES II

TEST RUN

CFDTS MEASUREMENT REQUIREMENTS LIST SERIES II
DATE- 31 AUG 1965 PAGE- 1

MES NO.	COMPONENT	SYMBOL	G	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH NO	PLOT NO
1	RUN TANK PROPEL.LINE	PRTPL-1	1	-235.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.5 PSI (C)	8 B40	P N/A	N/A	3
3	RUN TANK PROPEL.LINE	PRTPL-3	1	-141.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.5 PSI (C)	8 B40-S	P N/A	N/A	3
7	PUMP INLET LINE	PPIL-3	1	-91.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.4 PSI (C)	8 B40	P N/A	N/A	3.4
8	PUMP INLET LINE	PPIL-4	1	-91.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.4 PSI	8 B40	S N/A	N/A	
10	PUMP DISCHARGE	PPD-1	1	-55.0	19.0	100	PRESS	500PSIG	15PSIA	280PSIA	+ 1.5 PSI (C)	8 B40-S-0	P N/A	N/A	3.4
12	PUMP DISCHARGE	PPD-2	1	-55.0	19.0	100	PRESS	500PSIG	15PSIA	280PSIA	+ 1.5 PSI	8 B40-S	S N/A	N/A	
12	PUMP DISCHARGE	PPD-3A	1	-55.0	19.0	100	PRESS	500PSIG	15PSIA	280PSIA	+ 2.5PSIA	NA CONTROL	S N/A	N/A	
13	FLOW METER DIFF.	DPFM-8	1	-200	N/A	N/A	PRESS	5PSID	0PSID	3PSID	+ 0.1PSI	4 B10	S N/A	N/A	24
14	FLOW METER DIFF.	DPFM-4	1	-160	N/A	N/A	PRESS	5PSID	0PSID	3PSID	+ 0.1PSI	4 B10	S N/A	N/A	24
15	PRES RISE ACROSS PUMP	DPTP-1	1	-55.0	19.0	100	PRESS	200PSID	0PSID	200PSID	+ 1.0 PSI (C)	8 B40-S	P N/A	N/A	3
16	NOZZLE MANI. INLET	PNMI-1	1	124.0	22.5	120	PRESS	100PSIA	1PSIA	100PSIA	+ 0.5PSI	8 B40	P N/A	N/A	
18	NOZZLE MANIFOLD	PNM-1	1	124.0	16.0	180	PRESS	500PSIG	15PSIA	280PSIA	+ 1.5PSI	8 B40	P N/A	N/A	4
20	NOZZLE MANIFOLD	PNM-3	1	124.0	16.0	65	PRESS	500PSIG	15PSIA	280PSIA	+ 1.5PSI	8 B40	S N/A	N/A	
26	NOZZLE TUBE OUTLET	PNTG-2	1	71.0	20.0	165	PRESS	500PSIG	15PSIA	260PSIA	+ 1.5PSI	8 B40	P N/A	N/A	4
28	NOZZLE TUBE OUTLET	PNTG-4	1	71.0	20.0	60	PRESS	500PSIG	15PSIA	260PSIA	+ 1.5PSI	8 B40	S N/A	N/A	
31	NOZZLE TUBE DIFF.	DPNT-1	2	N/A	N/A	180	PRESS	100PSID	0PSID	75PSID	+ 0.5PSI	8 B40	S N/A	N/A	
32	NOZZLE TUBE DIFF.	DPNT-2	1	N/A	N/A	300	PRESS	100PSID	0PSID	75PSID	+ 0.5PSI	8 B40	P N/A	N/A	7
33	NOZZLE TUBE DIFF.	DPNT-3	2	N/A	N/A	75	PRESS	100PSID	0PSID	75PSID	+ 0.5PSI	8 B40	S N/A	N/A	
34	RTPLA FILTER DIFF.	DPRTLF-1	1	N/A	N/A	N/A	PRESS	5PSID	0PSID	3PSID	+ 0.1PSI	4 B10	S N/A	N/A	24
36	PUMP DISC CK VAL DIFF	DPPDCV	4	N/A	N/A	120	PRESS	5PSID	0PSID	1PSID	+ 0.1PSID	I B10	S N/A	N/A	24
42	REFLECTOR OUTLET	PRO-3	1	13.0	26.0	190	PRESS	300PSIG	15PSIA	230PSIA	+ 1.5PSI	8 B40	P N/A	N/A	4
43	REFLECTOR OUTLET	PRO-4	2	13.0	26.0	310	PRESS	300PSIG	15PSIA	230PSIA	+ 1.5PSI	8 B40	S N/A	N/A	
50	OUTER REFLECTOR DIFF.	OPUR-1	4	N/A	20.0	310	PRESS	50PSID	0PSID	20PSID	+ 0.25PSI	8 B40	P N/A	N/A	7
51	PV/REFLECTOR ANNULUS	PPVRA-1	4	13.0	20.0	105	PRESS	300PSIG	15PSIA	230PSIA	+ 1.0PSI	8 B40	S N/A	N/A	5
52	PV/REFLECTOR ANNULUS	PPVRA-2	4	13.0	20.0	293	PRESS	300PSIG	15PSIA	230PSIA	+ 1.0PSI	8 B40	S N/A	N/A	
53	SHIELD INLET SEC.PASS	PSISP-1	1	-3.6	12.8	296	PRESS	300PSIG	15PSIA	220PSIA	+ 1.0PSI	4 B20	P N/A	N/A	5
55	SHIELD INLET SEC.PASS	PSISP-3	2	-3.6	13.5	158	PRESS	300PSIG	15PSIA	220PSIA	+ 1.0PSI	4 B20	P N/A	N/A	
58	CORE INLET	PCI-1	1	15.4	13.0	118	PRESS	300PSIG	15PSIA	210PSIA	+ 1.0PSI	4 B20	P N/A	N/A	4
60	CORE INLET	PCI-3	1	15.4	3.0	228	PRESS	300PSIG	15PSIA	210PSIA	+ 1.0PSI	4 B20	S N/A	N/A	
61	REF.CUTTU CORE IN DIF	DPRG-CI1	1	N/A	N/A	N/A	PRESS	20PSID	0PSID	20PSID	+ 0.4PSI	4 B20	P N/A	N/A	7
64	NOZZLE CHAMBER	PNC-3A	F	86.1	15.4	198	PRESS	100PSIA	1PSIA	95PSIA	N/A	NA CONTROL	P N/A	N/A	
66	NOZZLE CHAMBER	PNC-1	1	86.1	15.4	78	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI	8 B40	P N/A	N/A	4
67	NOZZLE CHAMBER	PNC-2	1	86.1	15.4	78	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI (C)	8 B40-S	P N/A	N/A	5
68	NOZZLE CHAMBER	PNC-3	1	86.1	15.4	198	PRESS	750PSIA	1PSIA	95PSIA	+ 3.0PSI (C)	20 B40-CONT.	P N/A	N/A	5
72	DILUENT LINE	PDL-1	1	-14.0	39.3	179	PRESS	300PSIG	15PSIA	220PSIA	+ 1.0PSI	8 B20-S	P N/A	N/A	
73	DILUENT LINE	PDL-2	4	-14.0	39.3	179	PRESS	300PSIG	15PSIA	220PSIA	+ 1.0PSI	8 B20	S N/A	N/A	
74	DILUENT JACKET	PDJ-1	1	89.0	19.0	190	PRESS	200PSIG	15PSIA	180PSIA	+ 1.0PSI	8 B20	P N/A	N/A	5
75	DILUENT JACKET	PDJ-2	4	89.0	19.0	190	PRESS	200PSIG	15PSIA	180PSIA	+ 1.0PSI	8 B20	S N/A	N/A	
76	DIL LINE ORIFICE DIFF	DPDLO-1	1	14.0	39.3	179	PRESS	50PSID	0PSID	30PSID	+ 0.25PSI	4 B20-S	P N/A	N/A	
77	DIL LINE ORIFICE DIFF	DPDLO-2	4	14.0	39.3	179	PRESS	50PSID	0PSID	30PSID	+ 0.25PSI	4 B20	S N/A	N/A	
78	TURBINE INLET LINE	PTIL-1	1	89.0	19.0	169	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI	4 B20	P N/A	N/A	5
80	TURBINE INLET LINE	PTIL-3	1	9.0	41.0	169	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI (C)	4 B20-S	P N/A	N/A	5
82	TURBINE INLET LINE	PTIL-5	1	-49.6	32.0	175	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI	4 B20-0	P N/A	N/A	5
84	TIL VENTURI DIFF.	DPTILV-1	1	9.0	39.0	169	PRESS	20PSID	0PSID	10PSID	+ 0.2PSI (C)	4 B20-S	P N/A	N/A	
85	TIL VENTURI DIFF.	DPTILV-2	1	9.0	43.5	169	PRESS	10PSID	0PSID	10PSID	+ 0.1PSI	4 B20	S N/A	N/A	
87	TPCV DIFF.	DPTPCV-1	1	-49.6	32.0	175	PRESS	10PSID	0PSID	10PSID	+ 0.1PSI	4 B20	P N/A	N/A	5
90	TURBINE INLET	PTI-2	1	-47.6	13.0	131	PRESS	100PSIA	0.5PSIA	95PSIA	+ 0.5PSI	4 B20	P N/A	N/A	4
93	TURBINE EXHAUST	PTE-1	1	-38.4	13.0	359	PRESS	30 PSIA	0.5PSIA	25PSIA	+ 0.2PSI	4 B20	S N/A	N/A	6
94	TURBINE EXHAUST	PTE-2	1	-38.4	13.0	179	PRESS	30 PSIA	0.5PSIA	25PSIA	+ 0.2PSI	4 B20	S N/A	N/A	6
95	TURBINE INLET	PTI-3	1	-47.6	13.0	131	PRESS	100PSIA	0.5PSIA	95PSIA	+ 0.5PSI (C)	4 B20-S	P N/A	N/A	6

TEST RUN

CFDTS MEASUREMENT REQUIREMENTS LIST SERIES II
DATE- 31 AUG 1965 PAGE- 2

MES NO.	COMPONENT	SYMBOL	G	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH	PLOT NO
96	2ND STG TURB RTR EXT	P2TRE-1	1				PRESS	50PSIA	0.5PSIA	20PSIA	+ 0.25PSI (C)	8 B20-S	P N/A	N/A	6
97	2ND STG TURB RTR EXT	P2TRE-2	1				PRESS	50PSIA	0.5PSIA	20PSIA	+ 0.25PSI	8 B20	P N/A	N/A	6
101	BOLT COOLANT LINE DIF	DPBCL-1	4	105.0	12.0	139	PRESS	20PSID	0PSID	15PSID	+ 0.2PSI	1 B10	P N/A	N/A	7
102	BOLT COOLANT LINE DIF	DPBCL-2	4	105.0	12.0	229	PRESS	20PSID	0PSID	15PSID	+ 0.2PSI	1 B10	S N/A	N/A	7
103	BOLT COOLANT LINE DIF	DPBCL-3	4	105.0	12.0	349	PRESS	20PSID	0PSID	15PSID	+ 0.2PSI	1 B20	S N/A	N/A	7
106	TANK SAFETY VALVE DIF	DPTSV-1	1	N/A	N/A	N/A	PRESS	10PSID	0PSID	5PSID	+0.1PSI	2 B10	P N/A	N/A	24
109	RUN TANK PROPEL.LINE	THRTPL-1	1	-235.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40	P 2.68	4.00	9
111	RUN TANK PROPEL.LINE	THRTPL-3	1	-141.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40-S	P 2.68	4.00	9
117	PUMP INLET LINE	THPIL-4	1	-91.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40	P 3.36	4.00	9.23
118	PUMP INLET LINE	THPIL-5	1	-91.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40	S 3.36	4.00	
124	PUMP DISCHARGE	THPD-1A	1	-55.0	19.0	100	RTT	CODE K	35 R	60 R	+0.3 R	NA CONTROL	P 1.88	2.50	
125	PUMP DISCHARGE	THPD-2	1	-55.0	19.0	100	RTT	CODE K	35 R	60 R	+ 0.3 R	4 B20-S	P 1.88	2.50	9.23
127	PUMP DISCHARGE	THPD-4	1	-55.0	19.0	100	RTT	CODE K	35 R	60 R	+ 0.3 R	4 B20	P 1.88	2.50	
132	NOZZLE MANIFOLD	THNM-1		124.0	16.0	295	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.85	2.50	10
133	NOZZLE MANIFOLD	THNM-2	1	124.0	16.0	80	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.85	2.50	10.23
134	NOZZLE MANIFOLD	THNM-3	1	124.0	16.0	170	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.85	2.50	10
139	NOZZLE TUBE OUTLET	THNT0-1	2	71.0	26.0	290	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.74	2.50	10.23
140	NOZZLE TUBE OUTLET	THNT0-2	1	71.0	26.0	180	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	S 1.74	2.50	10
141	NOZZLE TUBE OUTLET	THNT0-3	1	71.0	26.0	75	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	S 1.74	2.50	10
142	NOZZLE TUBE OUTLET	THNT0-4	2	69.3	22.4	45	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
143	NOZZLE TUBE OUTLET	THNT0-5	2	69.3	23.0	105	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
144	NOZZLE TUBE OUTLET	THNT0-6	1	69.3	22.4	165	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
145	NOZZLE TUBE OUTLET	THNT0-7	2	69.3	22.4	225	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
146	NOZZLE TUBE OUTLET	THNT0-8	2	69.3	21.6	285	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
147	NOZZLE TUBE OUTLET	THNT0-9	2	69.3	22.4	285	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
148	NOZZLE TUBE OUTLET	THNT0-10	2	69.3	23.0	285	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
149	NOZZLE TUBE OUTLET	THNT0-11	2	69.3	21.6	345	TC/CC	10MV	35 R	535 R	+10.0 R	1 CSC	S		11
150	REFLECTOR OUTLET	THRO-1	2	15.3	18.4	161	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
151	REFLECTOR OUTLET	THRO-2	1	15.5	18.4	161	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
152	REFLECTOR OUTLET	THRO-3	2	15.3	22.8	165	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
153	REFLECTOR OUTLET	THRO-4	1	15.5	22.4	35	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
154	REFLECTOR OUTLET	THRO-5	2	15.3	22.4	25	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
155	REFLECTOR OUTLET	THRO-6	1	12.6	24.4	113	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
156	REFLECTOR OUTLET	THRO-7	1	12.6	24.4	293	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
157	REFLECTOR OUTLET	THRO-8	2	9.8	22.4	353	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
158	REFLECTOR OUTLET	THRO-9	1	9.8	22.4	52	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
159	REFLECTOR OUTLET	THRO-10	1	9.8	22.4	295	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
160	REFLECTOR OUTLET	THRO-11	2	9.8	22.4	214	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
161	REFLECTOR OUTLET	THRO-12	1	9.8	22.4	115	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
162	REFLECTOR OUTLET	THRO-13	2	9.8	22.4	171	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	1 CSC	S N/A	N/A	12
169	PV/REFLECTOR ANNULUS	THPVRA-1	4	13.0	26.0	113	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	1 B10	S 0.05	1.62	10
170	PV/REFLECTOR ANNULUS	THPVRA-2	4	13.0	26.0	285	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	1 B10	S 0.05	1.62	10
171	CORE INLET	THCI-1	2	15.4	15.2	1	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14
172	CORE INLET	THCI-2	2	15.4	11.2	1	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14
173	CORE INLET	THCI-3	2	15.4	6.3	358	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14
174	CORE INLET	THCI-4	2	15.4	5.4	54	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14
175	CORE INLET	THCI-5	1	15.4	6.3	106	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	P N/A	N/A	14.23
176	CORE INLET	THCI-6	1	15.4	11.2	121	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14
177	CORE INLET	THCI-7	1	15.4	15.1	121	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14
178	CORE INLET	THCI-8	2	15.4	11.4	177	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14

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MES NO.	COMPONENT	SYMBOL	G	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH	PLOT NO	
179	CORE INLET	THCI-9	2	15.4	5.1	242	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14	
180	CORE INLET	THCI-10	2	15.4	10.2	355	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14	
181	CORE INLET	THCI-11	2	15.4	15.2	241	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14	
182	CORE INLET	THCI-12	2	15.4	15.4	298	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	14	
183	CORE MODULES	TCM-1	3	N/A	N/A	0	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22	
184	CORE MODULES	TCM-2	1	N/A	N/A	0	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22	
186	CORE MODULES	TCM-4	3	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22	
187	CORE MODULES	TCM-5	3	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22	
188	CORE MODULES	TCM-6	1	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22	
189	CORE MODULES	TCM-7	3	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22	
192	INNER REFLECTOR	TIR-1	1	23.0		70	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	21	
193	INNER REFLECTOR	TIR-2	3	34.2		70	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	21	
194	INNER REFLECTOR	TIR-3	3	45.5		70	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	21	
195	INNER REFLECTOR	TIR-4	1	62.3		70	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	21	
217	OUTER REFLECTOR	TOR-5	1	48.4	21.6	255	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	20	
218	OUTER REFLECTOR	TOR-6	3	32.4	22.4	255	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	20	
219	OUTER REFLECTOR	TOR-7	3	50.4	22.7	255	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	20	
220	OUTER REFLECTOR	TOR-8	1	64.4	23.0	255	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	20	
221	NOZZLE CHAMBER	THNC-1	1	86.1	15.4	250	RTT CODE L	100 R	535 R	+ 2.0 R	4 B40CSC SC	P 1.75 4.0	15			
222	NOZZLE CHAMBER	THNC-2	1	86.1	15.4	138	RTT CODE L	100 R	535 R	+ 2.0 R	4 B40CSC SC	P 1.75 4.0	15			
223	NOZZLE CHAMBER	THNC-3	1	86.1	15.4	18	RTT CODE L	100 R	535 R	+ 2.0 R (C)	4 B40-SCSCSC	P 1.75 4.0	15,23			
224	NOZZLE CHAMBER	THNC-4	1	86.1	15.4	342	TC/CA	10MV	100 R	535 R	+3.0 RAT 300 R	2 B40	P 15.0 18.0	15		
225	SHIELD INLET SEC.PASS	THSISP-1	2	-8.4	15.0	349	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
226	SHIELD INLET SEC.PASS	THSISP-2	2	-9.8	11.1	46	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
227	SHIELD INLET SEC.PASS	THSISP-3	2	-8.4	15.0	49	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
228	SHIELD INLET SEC.PASS	THSISP-4	2	-10.7	5.0	22	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
229	SHIELD INLET SEC.PASS	THSISP-5	2	-10.7	4.4	260	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
230	SHIELD INLET SEC.PASS	THSISP-6	2	-9.8	11.5	284	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
231	SHIELD INLET SEC.PASS	THSISP-7	2	-8.4	15.3	287	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
232	SHIELD INLET SEC.PASS	THSISP-8	1	-8.4	15.9	110	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
233	SHIELD INLET SEC.PASS	THSISP-9	2	-8.4	15.0	230	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
234	SHIELD INLET SEC.PASS	THSISP10	1	-11.0	3.9	144	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
235	SHIELD INLET SEC.PASS	THSISP11	2	-9.8	11.1	167	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
236	SHIELD INLET SEC.PASS	THSISP12	2	-8.4	15.0	170	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
237	SHIELD INLET SEC.PASS	THSISP13	2	-8.4	15.0	0	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 CSC	S N/A	N/A	13	
238	TURBINE INLET LINE	THIIL-1	1	89.0	19.0	169	TC/CA	10MV	200 R	535 R	+ 3.0 RAT300 R	4 B20	P 1.75 3.5	16		
239	TURBINE INLET LINE	THIIL-2	4	89.0	19.0	169	TC/CA	10MV	200 R	535 R	+ 3.0 RAT300 R	4 B20	P 1.75 3.5	16		
243	TURBINE INLET LINE	THIIL-3	1	-49.6	32.0	175	RTT CODE L	200 R	535 R	+ 3.0 RAT300 R	4 B20-Q-SC	P 1.94 2.5	16			
246	TURBINE INLET	THI-1	1	-47.6	13.0	181	RTT CODE L	250 R	535 R	+ 2.0 R	4 B20-SCSCSC	P 1.94 2.50	16,23			
248	TURBINE INLET	THI-3		-47.6	13.0	181	RTT CODE L	250 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.94 2.50	16			
249	TURBINE EXHAUST	THTE-1	1	-38.4	16.0	94	RTT CODE L	200 R	535 R	+ 2.0 R	R 2 B20	P 3.44 4.00	16,23			
251	TURBINE EXHAUST	THTE-2	1	-38.4	16.0	274	RTT C DE L	200 R	535 R	+ 2.0 R	R 2 B20	P 3.44 4.00	16			
253	DILUENT LINE	THDL-1	1	-5.8	40.0	179	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	4 B20-S	P 0.63 1.5	16		
254	DILUENT LINE	THDL-2	4	-5.8	40.0	179	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	4 B20	P 0.63 1.5			
255	DILUENT JACKET	THDJ-1	1	89.0	19.0	169	TC/CA	10MV	150 R	535 R	+ 3.0 RAT300 R	4 B20	P 0.33 1.25	16		
265	NOZZLE WALL INNER	TNWI-1	3	125.0	13.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	18	
266	NOZZLE WALL INNER	TNWI-2	3	114.0	9.5	60	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	18	
267	NOZZLE WALL INNER	TNWI-3	3	102.0	6.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	18	
268	NOZZLE WALL INNER	TNWI-1A	1	125.0	13.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	18	
269	NOZZLE WALL OUTER	TNWO-1	3	117.0	11.5	60	TC/CA	10MV	35 R	535 R	+10.0 R	1 CSC	S N/A	N/A	19	

TEST RUN

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MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY FR	RECORDING INSTRUMENT	P R	EMER DEPT	PROB LTH	PLOT NO
270	NOZZLE WALL OUTER	TNWO-2	3	103.0	7.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	19
271	NOZZLE WALL OUTER	TNWO-3	3	97.0	5.3	60	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	19
272	NOZZLE WALL OUTER	TNWO-4	1	91.0	10.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	19
273	NOZZLE WALL OUTER	TNWO-5	3	85.0	16.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	19
281	NOZZLE WALL INNER	TNWI-2A	3	114.0	9.5	60	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	18
282	NOZZLE WALL INNER	TNWI-3A	3	102.0	6.0	60	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	18
297	PUMP DISCHARGE LINE	TPDL-1	1	-55.0	32.0	110	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
298	PUMP DISCHARGE LINE	TPDL-2	3	-30.6	39.0	120	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
299	PUMP DISCHARGE LINE	TPDL-3	3	-26.4	39.0	120	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
300	PUMP DISCHARGE LINE	TPDL-4	1	11.2	39.0	120	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
301	PUMP DISCHARGE LINE	TPDL-5	3	48.8	39.0	120	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
302	PUMP DISCHARGE LINE	TPDL-6	3	90.4	39.0	120	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
303	PUMP DISCHARGE LINE	TPDL-7	3	124.0	23.5	120	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	25
304	PUMP INLET LINE	TPIL-5	3	-90.0	4.4	131	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
305	PUMP INLET LINE	TPIL-1	1	-90.	4.4	311	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
306	PUMP INLET LINE	TPIL-2	1	-84.	4.2	311	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
307	PUMP INLET LINE	TPIL-3	3	-73.	4.2	311	TC/CA	10MV	35 R	535 R	+10.0 R	1	B10	S	N/A	N/A	17
308	TPA HOUSING	TPH-1	1	-59.	4.0	0	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
309	TPA HOUSING	TPH-2	1	-57.	8.0	0	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
310	TPA HOUSING	TPH-3	3	-55.	13.0	0	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
311	PUMP INLET LINE	TPIL-4	3	-67.	4.4	311	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
312	PUMP INLET LINE	TPIL-6	3	-84.0	4.4	131	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
313	PUMP INLET LINE	TPIL-7	3	-73.0	4.2	131	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
314	PUMP INLET LINE	TPIL-8	3	-67.0	4.4	131	TC/CA	10MV	35 R	535 R	+10.0 R	1	CSC	S	N/A	N/A	17
319	PUMP DISCHARGE VALVE	LPDV-1	1	PDV	ACT.	N/A	POT	90	0	90	N/A	NA	B20-SB	P	N/A	N/A	1
320	PSOV	LPSOV-1	1	PSOV	ACT.	N/A	POT.	90	0	90	N/A	NA	B20-SB	P	N/A	N/A	1
321	PSOV	LPSOV-1A	1	PSOV	ACT.	N/A	POT.	90	0	90	N/A	NA	CONTROL	P	N/A	N/A	
322	TPCV	LTPCV-1	1	TPCV	ACT	N/A	POT	90	0	90	+ 0.7 (MEAS. VAL	NA	B20-SB	P	N/A	N/A	1
324	DILUENT VALVE	LDV-1	1	DV	ACT	N/A	POT	90	0	90	N/A	NA	SB	P	N/A	N/A	
325	DILUENT VALVE	DV-S	1	DV	ACT.	N/A	LT-SW	N/A	N/A	N/A	N/A	NA	CONTROL	P	N/A	N/A	
326	PUMP DISCH VALVE	PDV-S	1	PDV	ACT.	N/A	LT-SW	N/A	N/A	N/A	N/A	NA	CONTROL	P	N/A	N/A	
327	TPA	YTPA	1				DISP.		0 INCH	0.010IN	N/A	2K V	P	N/A	N/A		
328	TPA	ZTPA	1				DISP.		0 INCH	0.010IN	N/A	2K V	P	N/A	N/A		
330	RUN TANK PROPEL.LINE	QRTPL-1	1	-200.	N/A	N/A	TURB.	7630GPM	760GPM	4680GPM	+ 1.5 (MEAS VAL	NA	B40-S	P	N/A	N/A	
331	RUN TANK PROPEL.LINE	QRTPL-2	1	-160.	N/A	N/A	TURB.	2540GPM	254GPM	2540GPM	+ 1.5 (MEAS VAL	NA	B40-S	P	N/A	N/A	
332	PUMP DISC.BLEED VALVE	LPDBV-1	1	PDBV	ACT.	N/A	POT	90	0	90	N/A	-SB	P	N/A	N/A		
333	PUMP DISCH BLEED VAL	PDBV-S	1	PDBV	ACT.	N/A	LT-SW	N/A	N/A	N/A	N/A	NA	CONTROL	P	N/A	N/A	
334	PUMP SPEED	NTPA-1	1	-51.0	N/A	N/A	PROBE	30K	0 RPM	15K RPM	+ 0.3 (MEAS VAL	NA	B20-S	P	N/A	N/A	1
335	PUMP SPEED	NTPA-2	1	-51.0	N/A	N/A	PROBE	30K	0 RPM	15K RPM	+ 0.3 (MEAS VAL	NA	B20-S-CONT	P	N/A	N/A	
402	PROPELLANT FUEL TANK	PFT-H11	F	N/A	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+0.5PSI (C)	8	B40-S	P	N/A	N/A	3
403	PROPELLANT FUEL TANK	PFTH11A2	F	N/A	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	N/A	NA	CONTROL	P	N/A	N/A	
407	RUN TANK OUTLET	PFTO-1	1	-324.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.5 PSI (C)	8	B40-S	P	N/A	N/A	3
411	PNEUMATIC SYSTEM	PPS-1	F	N/A	N/A	N/A	PRESS	200PSIG	0PSIG	120PSIG	N/A	2	B10-S	P	N/A	N/A	
412	PNEUMATIC SUPPLY TPCV	PPSTPCV1	1	198.0	22.0	270	PRESS	500PSIG	N/A	215PSIG	+ 3.0PSI	4	B20-S	P	N/A	N/A	
413	NOZZLE EXHAUST DUCT	PNED-1A	F	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	18PSIA	N/A	NA	CONTROL	P	N/A	N/A	
414	NOZZLE EXHAUST DUCT	PNED-1	1	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	18PSIA	+ 0.25PSI (C)	8	B40-S	P	N/A	N/A	4.8
415	NOZZLE EXHAUST DUCT	PNED-2	1	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	18PSIA	+ 0.25PSI	8	B40	S	N/A	N/A	
416	NOZZLE EJECTOR	PNE-1	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2	B10-S	P	N/A	N/A	8
417	NOZZLE EJECTOR	PNE-2	F	N/A	N/A	N/A	PRESS	30PSIA	0PSIA	18PSIA	N/A	2	B10	S	N/A	N/A	8
418	NOZZLE EJECTOR	PNE-3	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2	B10-S	P	N/A	N/A	8

TEST RUN

CFDTS MEASUREMENT REQUIREMENTS LIST SERIES II
DATE- 31 AUG 1965 PAGE- 5

MES NO.	COMPONENT	SYMBOL	G	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH	PLOT NO
419	NOZZLE EJECTOR	PNE-4	F	N/A	N/A	N/A	PRESS	30PSIA	0PSIA	18PSIA	N/A	2 B10	S N/A	N/A	8
420	EJECTOR BALANCE DIFF	DPEB	F	N/A	N/A	N/A	PRESS	5PSID	0PSID	1PSID	+0.1PSID	2 B10-S	P N/A	N/A	24
421	TURBINE EXHAUST LINE	PTL-1	1	N/A	N/A	N/A	PRESS	30PSIA	0.5PSIA	15PSIA	+ 0.3PSI (C)	4 B20-S	P N/A	N/A	4.8
422	TURBINE EXHAUST LINE	PTL-1A	1	N/A	N/A	N/A	PRESS	30PSIA	0.5PSIA	15PSIA	+A0.3PS	NA CONTROL	P N/A	N/A	6
423	TURBINE EXHAUST EJECT	PTEE-1	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2 B10-S	P N/A	N/A	8
424	TURBINE EXHAUST EJECT	PTEE-2	F	N/A	N/A	N/A	PRESS	30PSIA	0PSIA	18PSIA	N/A	2 B10	S N/A	N/A	8
425	TURBINE EXHAUST EJECT	PTEE-3	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	300PSIG	N/A	2 B10-S	P N/A	N/A	8
426	TURBINE EXHAUST EJECT	PTEE-4	F	N/A	N/A	N/A	PRESS	30PSIA	0PSIA	18PSIA	N/A	2 B10	S N/A	N/A	8
429	GN2 SUPPLY MANIFOLD	PG N2M	F	N/A	N/A	N/A	PRESS	6K PSIG	0PSIG	5K PSIG	N/A	2 B10-S	P N/A	N/A	
430	EJECTOR SUPPLY CV OUT	PESCV-0	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	500PSIG	N/A	2 B10-S	P N/A	N/A	
431	EJECTOR SUPPLY CV OUT	PESCV-0A	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	500PSIG	N/A	NA CONTROL	P N/A	N/A	
436	NOZZLE EXHAUST DUCT	THNED-1	1	N/A	N/A	N/A	TC/CC	10MV	250 R	535 R	+ 3.0 R	2 B10-S	P N/A	N/A	15
437	NOZZLE EXHAUST DUCT	THNED-2	F	N/A	N/A	N/A	TC/CC	10MV	200 R	535 R	N/A	2 B10	S N/A	N/A	
438	NOZZLE EJECTOR	TGNE-1	F	N/A	N/A	N/A	TC/CC	10MV	300 R	535 R	N/A	2 B10	S 0.75	3.75	
439	NOZZLE EJECTOR	TGNE-2	F	N/A	N/A	N/A	TC/CC	10MV	300 R	535 R	N/A	2 B10	S 0.0	3.75	
442	TURBINE EXHAUST LINE	TMTL-1	F	N/A	N/A	N/A	TC/CC	10MV	200 R	535 R	N/A	2 B10-S	S		
443	TURBINE EXHAUST EJECT	TGTEE-1	F	N/A	N/A	N/A	TC/CC	10MV	300 R	535 R	N/A	2 B10	S 0.5	3.75	
444	TURBINE EXHAUST EJECT	TGTEE-2	F	N/A	N/A	N/A	TC/CC	10MV	300 R	535 R	N/A	2 B10	S 0.0	3.75	
445	INSIDE THRUST STRUCT	TITS	F	-5.0	26.0	70	TC/CC	10MV	140 R	535 R	N/A	NA S	P N/A	N/A	
446	EJECTOR FLOW CV	LEFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	NA SB	P N/A	N/A	
447	PRESS FLOW CONT. VAL.	LPFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
448	PRESS VENT FLOW CON.V	LPVFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
450	NOZ EXH SPOIL GAS CV	LN S6CV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
451	TRB EXH SPOIL GAS CV	LT S6CV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
452	SPOILER GAS MANIFOLD	PSGM	F	N/A	N/A	N/A	PRESS	5K PSIG	0PSIG	5K PSIG	N/A	2 B10-S	P N/A	N/A	
453	GH2 SUPPLY MANIFOLD	PG H2M	F	N/A	N/A	N/A	PRESS	6K PSIG	0PSIG	5K PSIG	N/A	2 B10-S	P N/A	N/A	
454	PRES CV ORIFICE INLET	PGPCVO-1	F	N/A	N/A	N/A	PRESS	5K PSIG	0PSIG	2K PSIG	N/A	2 B10-S	P N/A	N/A	
455	PRES CV PRES REG DOME	PGPCVPR	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	2K PSIG	N/A	2 B10-S	P N/A	N/A	
456	PRES CV PRES REG OUT	PGPCVPRO	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	2K PSIG	N/A	2 B10-S	P N/A	N/A	
457	HYDRAVIC CV DISCHARGE	PHDCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	4K PSIG	N/A	2 B10-S	P N/A	N/A	
458	HYDRAVIC CV RETURN	PHRCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	4K PSIG	N/A	2 B10-S	P N/A	N/A	
459	ACCUMULATOR CV	PACCCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	3K PSIG	N/A	2 B10-S	P N/A	N/A	
460	BURNOFF DUCT NOZ EJECT	TBOD-2A	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R		N/A	2 S	P N/A	N/A	
461	BURNOFF DUCT TURB EJECT	TBOD-2B	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R		N/A	2 S	P N/A	N/A	
462	TEMP FUEL TANK OUTLET	TFTO-A	F	N/A	N/A	N/A	RTT	CUDE-K	35 R	60 R	N/A	2 B10	P 2.68	4.00	
463	NOZ EJECT WALL 1ST STAG	TSNE-1	F	N/A	N/A	N/A	TC/CC	10MV	350 R	560 R	N/A	2 B10-S	P N/A	N/A	
464	NOZ EJECT WALL 2ND STAG	TSNE-2	F	N/A	N/A	N/A	TC/CC	10MV	350 R	560 R	N/A	2 B10-S	P N/A	N/A	
465	EXH BURN OFF DUCT	TBOD-3A	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R		N/A	2 S	P N/A	N/A	
466	EXH BURN OFF DUCT	TBOD-3B	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R		N/A	2 S	P N/A	N/A	
467	NOZZLE DUCT SPOIL GAS	PGNDSG	F	N/A	N/A	N/A	PRESS	2K PSIG		1.5KPSI	N/A	2 B10	S N/A	N/A	
468	TURB. DUCT SPOIL GAS	PGTDSG	F	N/A	N/A	N/A	PRESS	2K PSIG		500PSIG	N/A	2 B10	S N/A	N/A	
469	NOZZLE DUCT SPOIL GAS	TGNDSG	F	N/A	N/A	N/A	TC/CC	10MV	360 R	560 R	N/A	2 B10	S		
470	TURB. DUCT SPOIL GAS	TGTDG	F	N/A	N/A	N/A	TC/CC	10MV	360 R	560 R	N/A	2 B10	S		
471	PRESS SWITCH NOZ CHAM	PSNC	F	86.1	15.4	342	PRESS	SWITCH	N/A	20PSIG	N/A	NA CONTROL	P N/A	N/A	
472	PRESS SWIT NOZ EXH DU	PSNED	F	N/A	N/A	N/A	PRESS	SWITCH	N/A	5PSIG	N/A	NA CONTROL	P N/A	N/A	
500	NET POSITIVE SUCTION	NPSP		CALCU	ATED	PARA	ETER								3
501	DILUENT FLOW	WD		CALCU	ATED	PARA	ETER								2
502	PROPELLANT FLOW	WRTPL-1		CALCU	ATED	PARA	ETER								2
503	PROPELLANT FLOW	WRTPL-2		CALCU	ATED	PARA	ETER								2
504	MAIN NOZZLE FLOW	WMN		CALCU	ATED	PARA	ETER								2

TEST RUN

CFDTS MEASUREMENT REQUIREMENTS LIST SERIES II
DATE- 31 AUG 1965 PAGE- 6

MES NO.	COMPONENT	SYMBOL	G P	STA	RAD THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN. MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH	PLOT NO
505	TURBINE FLOW	WTI				CALCU ATED PARA ETER							2
506	LH2 DENSITY IN RTPLA	RHO-RTPL				CALCU ATED PARA ETER							9

TEST RUN - TEST SERIES II

CFDTS MEASUREMENT REQUIREMENTS LIST (SPECIAL-GROUP 1)

DATE- 14 SEPT 1965

PAGE- 1

MES NO.	COMPONENT	SYMBOL	G P	STA	HAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN. MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P R	EMER DEPT	PROB LTH	PLOT NO
337	PRESSURE VESSEL FLANG	GPVF-1X	5	0.5	54.0	108	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	M+R
338	TPA	GTPA-1Y	5	-53.0	3.8	199	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	L+M
339	TPA	GTPA-2Y	5	-53.0	3.8	100	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	N
340	TPA	GTPA-1Z	5	-53.0	3.8	199	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	P+T
341	PUMP DISCHARGE LINE	GPDL-1X	5	-56.0	39.0	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	L
342	PUMP DISCHARGE LINE	GPDL-1Y	5	-56.0	39.0	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	N
343	PUMP DISCHARGE LINE	GPDL-1Z	5	-56.0	39.0	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	P
344	PUMP DISCHARGE LINE	GPDL-2Y	5	-3.1	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	O
345	PUMP DISCHARGE LINE	GPDL-2Z	5	-3.1	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	Q
346	PUMP DISCHARGE LINE	GPDL-3Y	5	-18.6	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	O
348	PUMP DISCHARGE LINE	GPDL-4Y	5	-49.6	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	M
349	PUMP DISCHARGE LINE	GPDL-4Z	5	-41.6	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	Q
350	PUMP DISCHARGE LINE	GPDL-5Y	5	75.5	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	O
352	PUMP DISCHARGE LINE	GPDL-6X	5	100.6	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	M
353	PUMP DISCHARGE LINE	GPDL-6Y	5	100.6	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	O
354	PUMP DISCHARGE LINE	GPDL-6Z	5	100.6	38.7	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	Q
355	PUMP DISCHARGE LINE	GPDL-7X	5	126.0	38.2	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	L
356	PUMP DISCHARGE LINE	GPDL-7Y	5	126.0	38.2	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	N
357	PUMP DISCHARGE LINE	GPDL-7Z	5	126.0	38.2	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	P
358	NOZZLE MANIFOLD	GNM-1X	5	127.0	22.5	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	L
359	NOZZLE MANIFOLD	GNM-1Y	5	127.0	22.5	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	N+M
360	NOZZLE MANIFOLD	GNM-1Z	5	127.0	22.5	120	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	P
364	PRESSURE VESSEL FLANG	GPVF-1Y	5	0.5	54.8	168	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	M+R
365	PRESSURE VESSEL FLANG	GPVF-1Z	5	0.5	54.8	168	ACCEL	+10K	-25G +25G		2K T	S	N/A	N/A	Q+T

TEST RUN - TEST SERIES II

CFDTS MEASUREMENT REQUIREMENTS LIST (SPECIAL-GROUP 2)
DATE- 14 SEPT 1965 PAGE- 1

MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH	PLOT NO
338	TPA	GTPA-1Y	5	-53.0	3.8	199	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	W
340	TPA	GTPA-1Z	5	-53.0	3.3	199	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	T
361	NOZZLE FLANGE	GNF-1X	5	80.6	44.0	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	R
362	NOZZLE FLANGE	GNF-1Y	5	80.6	44.0	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	W
363	NOZZLE FLANGE	GNF-1Z	5	80.6	44.0	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	T
365	PRESSURE VESSEL FLANG	GPVF-1Z	5	0.5	54.8	30	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	T
366	TURBINE INLET LINE	GTIL-1X	5	103.9	36.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	R
367	TURBINE INLET LINE	GTIL-1Y	5	103.9	36.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	W
368	TURBINE INLET LINE	GTIL-1Z	5	103.9	36.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	T
369	TURBINE INLET LINE	GTIL-2Y	5	60.3	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	S
370	TURBINE INLET LINE	GTIL-2Z	5	60.3	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	U
371	TURBINE INLET LINE	GTIL-3Y	5	35.3	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	S
372	TURBINE INLET LINE	GTIL-3Z	5	35.3	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	U
373	TURBINE INLET LINE	GTIL-4Y	5	13.4	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	S
374	TURBINE INLET LINE	GTIL-4Z	5	13.4	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	U
375	TURBINE INLET LINE	GTIL-5Y	5	-23.6	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	S+W
376	TURBINE INLET LINE	GTIL-5Z	5	-23.6	44.2	168	ACCEL	+10K	-25G	+25G		2K T	S N/A	N/A	U

TEST RUN - TEST SERIES II

CFDTS MEASUREMENT REQUIREMENTS LIST (SPECIAL-GROUP 3)
DATE- 14 SEPT 1965 PAGE- 1

MES NO.	COMPONENT	SYMBOL	G P	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN. MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH	PLOT NO
292	THRUST STRUCTURE	TPIL-9	5	-78.5	4.2	120	TC/CA	+10MV	100 R 535 R	+3.0 R AT300 R	1 B10	S N/A	N/A	
293	THRUST STRUCTURE	TPIL-10	5	-78.5	4.2	300	TC/CA	+10MV	100 R 535 R	+3.0 R AT300 R	1 B10	S N/A	N/A	
294	THRUST STRUCTURE	TTS-1	5	-78.5	5.0	102	TC/CA	+10MV	100 R 535 R	+3.0 R AT300 R	1 B10	S N/A	N/A	
295	THRUST STRUCTURE	TTS-2	5	-78.5	5.0	282	TC/CA	+10MV	100 R 535 R	+3.0 R AT300 R	1 B10	S N/A	N/A	
296	THRUST STRUCTURE	TTS-3	5	-90.0	5.0	102	TC/CA	+10MV	100 R 535 R	+3.0 R AT300 R	1 B10	S N/A	N/A	
315	PUMP INLET LINE	SPIL-1	5	-78.5	4.2	120	SG		-4KMIN		2 BID	S N/A	N/A	26
316	PUMP INLET LINE	SPIL-2	5	-78.5	4.2	300	SG		-4KMIN		2 BID	S N/A	N/A	26
317	THRUST STRUCTURE	STS-1	5	-78.5	5.0	102	SG		-4KMIN		2 BID	S N/A	N/A	26
318	THRUST STRUCTURE	STD-2	5	-78.5	5.0	282	SG		-4KMIN		2 BID	S N/A	N/A	26

CFDTS MEASUREMENT REQUIREMENTS LIST

TEST SERIES III

TEST RUN - TEST SERIES III

CFDTS MEASUREMENT REQUIREMENTS LIST

DATE- 05 NOV 1965

PAGE- 1

MES NO.	COMPONENT	SYMBOL	G	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH NO	PLOT
1	RUN TANK PROPEL.LINE	PRTP-1	1	-235.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.5 PSI (C)	8 B40	P N/A	N/A	3
7	PUMP INLET LINE	PPIL-3	1	-91.	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.4 PSI (C)	8 B40	P N/A	N/A	3.4
12	PUMP DISCHARGE	PPD-2	1	-55.0	19.0	100	PRESS	500PSIG	15PSIA	280PSIA	+ 1.5 PSI	8 B40-S	S N/A	N/A	
15	PRES RISE ACROSS PUMP	DP-1	1	-55.0	19.0	100	PRESS	200PSID	0PSID	200PSID	+ 1.0 PSI (C)	8 B40-S	P N/A	N/A	3
18	NOZZLE MANIFOLD	PNM-1	1	124.0	16.0	180	PRESS	500PSIG	15PSIA	280PSIA	+ 1.5PSI	8 B40	P N/A	N/A	4
26	NOZZLE TUBE OUTLET	PNTU-2	1	71.0	26.0	180	PRESS	500PSIG	15PSIA	260PSIA	+ 1.5PSI	8 B40	P N/A	N/A	4
42	REFLECTOR OUTLET	PRO-3	1	13.0	26.0	190	PRESS	300PSIG	15PSIA	230PSIA	+ 1.5PSI	8 B40	P N/A	N/A	4
55	SHIELD INLET SEC.PASS	FSISP-3	2	-3.0	13.5	158	PRESS	300PSIG	15PSIA	220PSIA	+ 1.0PSI	4 B20	P N/A	N/A	
58	CORE INLET	PCI-1	1	15.4	13.0	118	PRESS	300PSIG	15PSIA	210PSIA	+ 1.0PSI	4 B20	P N/A	N/A	4
64	NOZZLE CHAMBER	PNC-3A	F	86.1	15.4	198	PRESS	100PSIA	1PSIA	95PSIA	N/A	NA CONTROL	P N/A	N/A	
67	NOZZLE CHAMBER	PNC-2	1	86.1	15.4	78	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI (C)	8 B40-S	P N/A	N/A	5
68	NOZZLE CHAMBER	PNC-3	1	86.1	15.4	198	PRESS	750PSIA	1PSIA	95PSIA	+ 3.0PSI (C)	20 B40-CDNT.	P N/A	N/A	5
72	DILUENT LINE	PDL-1	1	-14.0	39.3	179	PRESS	300PSIG	15PSIA	220PSIA	+ 1.0PSI	9 B20-S	P N/A	N/A	
74	DILUENT JACKLT	PDJ-1	1	89.0	19.0	190	PRESS	200PSIG	15PSIA	180PSIA	+ 1.0PSI	8 B20	P N/A	N/A	5
80	TURBINE INLET LINE	FTIL-3	1	9.0	41.0	169	PRESS	100PSIA	1PSIA	95PSIA	+ 0.5PSI (C)	4 B20-S	P N/A	N/A	5
84	TIL VENTURI DIFF.	OPTILV-1	1	9.0	39.0	169	PRESS	20PSID	0PSID	10PSID	+ 0.2PSI (C)	4 B20-S	P N/A	N/A	
95	TURBINE INLET	PTI-3	1	-47.6	13.0	181	PRESS	100PSIA	0.5PSIA	95PSIA	+ 0.5PSI (C)	4 B20-S	P N/A	N/A	6
96	2ND STG TURB RTR EXT	P2TRE-1	1				PRESS	50PSIA	0.5PSIA	20PSIA	+ 0.25PSI (C)	8 B20-S	P N/A	N/A	6
109	RUN TANK PROPEL.LINE	THRTPL-1	1	-235.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40	P 2.68	4.00	9
111	RUN TANK PROPEL.LINE	THRTPL-3	1	-141.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40-S	P 2.68	4.00	9
117	PUMP INLET LINE	THPIL-4	1	-91.	N/A	N/A	RTT	CODE K	35 R	60 R	+ 0.3 R	8 B40	P 3.36	4.00	9.23
125	PUMP DISCHARGE	THPD-2	1	-55.0	19.0	100	RTT	CODE K	35 R	60 R	+ 0.3 R	4 B20-S	P 1.88	2.50	9.23
133	NOZZLE MANIFOLD	THNM-2	1	124.0	16.0	80	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.85	2.50	10.23
139	NOZZLE TUBE OUTLET	THNTD-1	2	71.0	26.0	290	RTT	CODE L	35 R	535 R	+ 2.0 R	4 B20CSC SC	P 1.74	2.50	10.23
175	CORE INLET	THCI-5	1	19.4	6.3	106	TC/CC	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	P N/A	N/A	14.23
183	CORE MODULES	TCM-1	3	N/A	N/A	0	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22
184	CORE MODULES	TCM-2	1	N/A	N/A	0	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22
186	CORE MODULES	TCM-4	3	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22
187	CORE MODULES	TCM-5	3	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22
188	CORE MODULES	TCM-6	1	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22
189	CORE MODULES	TCM-7	3	N/A	N/A	180	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	2 B10CSC SC	S N/A	N/A	22
223	NOZZLE CHAMBER	THNC-3	1	86.1	15.4	18	RTT	CODE L	100 R	535 R	+ 2.0 R (C)	4 B40-SCSCSC	P 1.75	4.0	15.23
224	NOZZLE CHAMBER	THNC-4	1	86.1	15.4	342	TC/CA	10MV	100 R	535 R	+ 3.0 RAT 300 R	2 B40	P 15.0	18.0	15
246	TURBINE INLET	THTI-1	1	-47.6	13.0	181	RTT	CODE L	250 R	535 R	+ 2.0 R	4 B20-SCSCSC	P 1.94	2.50	16.23
249	TURBINE EXHAUST	THTE-1	1	-38.4	16.0	94	RTT	CODE L	200 R	535 R	+ 2.0 R	R 2 B20	P 3.44	4.00	16.23
253	DILUENT LINE	THDL-1	1	-5.8	40.0	179	TC/CA	10MV	100 R	535 R	+ 3.0 RAT300 R	4 B20-S	P 0.63	1.5	16
307	PUMP INLET LINE	TPIL-3	3	-73.	4.2	11	TC/CA	10MV	35 R	535 R	+ 10.0 R	1 B10	S N/A	N/A	17
319	PUMP DISCHARGE VALVE	LPDV-1	1	PDV	ACT.	N/A	POT	90	0	90	N/A	NA B20-SB	P N/A	N/A	1
320	PSOV	LPSOV-1	1	PSOV	ACT.	N/A	POT.	90	0	90	N/A	NA B20-SB	P N/A	N/A	1
321	PSOV	LPSGV-1A	1	PSOV	ACT.	N/A	POT.	90	0	90	N/A	NA CONTROL	P N/A	N/A	
322	TPCV	LTPCV-1	1	TPCV	ACT.	N/A	POT	90	0	90	+ 0.7(MEAS.VAL	NA B20-SB	P N/A	N/A	1
324	DILUENT VALVE	LDV-1	1	DV	ACT.	N/A	POT	90	0	90	N/A	NA SB	P N/A	N/A	
325	DILUENT VALVE	DV-S	1	DV	ACT.	N/A	LT-SW	N/A	N/A	N/A	N/A	NA CONTROL	P N/A	N/A	
326	PUMP DISCH VALVE	PDV-S	1	PDV	ACT.	N/A	LT-SW	N/A	N/A	N/A	N/A	NA CONTROL	P N/A	N/A	
327	TPA	YTPA	1				DISP.		0 INCH	0.010IN	N/A	2K V	P N/A	N/A	
328	TPA	ZTPA	1				DISP.		0 INCH	0.010IN	N/A	2K V	P N/A	N/A	
330	RUN TANK PROPEL.LINE	QRTPL-1	1	-200.	N/A	N/A	TURB.	7630GPM	760GPM	4680GPM	+ 1.5(MEAS VAL	NA B40-S	P N/A	N/A	
331	RUN TANK PROPEL.LINE	QRTPL-2	1	-160.	N/A	N/A	TURB.	2540GPM	254GPM	2540GPM	+ 1.5(MEAS VAL	NA B40-S	P N/A	N/A	
333	PUMP DISCH BLEED VAL	PDBV-S	1	PDV	ACT.	N/A	LT-SW	N/A	N/A	N/A	N/A	NA CONTROL	P N/A	N/A	
334	PUMP SPEED	NTPA-1	1	-51.0	N/A	N/A	PROBE	30K	0 RPM	15K RPM	+ 0.3(MEAS VAL	NA B20-S	P N/A	N/A	1

TEST RUN - TEST SERIES III

CFDTS MEASUREMENT REQUIREMENTS LIST

DATE- 05 NOV 1965

PAGE- 2

MES NO.	COMPONENT	SYMBOL	G	STA	RAD	THETA	TRANS TYPE	TRANS RANGE	PREDICTED RANGE MIN.	PREDICTED RANGE MAX.	SYSTEM ACCURACY	SY RECORDING FR INSTRUMENT	P EMER R DEPT	PROB LTH NO	PLOT
335	PUMP SPEED	NTPA-2	1	-51.0	N/A	N/A	PROBE	30K	0 RPM	15K RPM	+ 0.3(MEAS VAL	NA 820-S-CONT	P N/A	N/A	
402	PROPELLANT FUEL TANK	PFT-H11	F	N/A	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+0.5PSI(C)	8 840-S	P N/A	N/A	3
403	PROPELLANT FUEL TANK	PFTH11A2	F	N/A	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	N/A	NA CONTROL	P N/A	N/A	
407	RUN TANK OUTLET	PFTO-1	1	-324	N/A	N/A	PRESS	100PSIG	15PSIA	70PSIA	+ 0.5 PSI (C)	8 840-S	P N/A	N/A	3
411	PNEUMATIC SYSTEM	DPS-1	F	N/A	N/A	N/A	PRESS	200PSIG	0PSIG	120PSIG	N/A	2 810-S	P N/A	N/A	
412	PNEUMATIC SUPPLY TPCV	PPSTPCV1	1	198.0	22.0	270	PRESS	500PSIG	N/A	215PSIG	+ 3.0PSI	4 820-S	P N/A	N/A	
413	NOZZLE EXHAUST DUCT	PNED-1A	F	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	18PSIA	N/A	NA CONTROL	P N/A	N/A	
414	NOZZLE EXHAUST DUCT	PNED-1	1	N/A	N/A	N/A	PRESS	30PSIA	1PSIA	18PSIA	+ 0.25PSI (C)	8 840-S	P N/A	N/A	4.8
421	TURBINE EXHAUST LINE	PTEL-1	1	N/A	N/A	N/A	PRESS	30PSIA	0.5PSIA	15PSIA	+ 0.3PSI (C)	4 820-S	P N/A	N/A	4.8
422	TURBINE EXHAUST LINE	PTEL-1A	1	N/A	N/A	N/A	PRESS	30PSIA	0.5PSIA	15PSIA	+A0.3PS	NA CONTROL	P N/A	N/A	6
430	EJECTOR SUPPLY CV OUT	PESCV-0	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	500PSIG	N/A	2 810-S	P N/A	N/A	
431	EJECTOR SUPPLY CV OUT	PESCV-0A	F	N/A	N/A	N/A	PRESS	500PSIG	0PSIG	500PSIG	N/A	NA CONTROL	P N/A	N/A	
446	EJECTOR FLOW CV	LEFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	NA SB	P N/A	N/A	
447	PRESS FLOW CONT. VAL.	LPFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
448	PRESS VENT FLOW CON.V	LPVFCV	F	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
450	NOZ EXH SPOIL GAS CV LN SGCV	F N/A	N/A	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
451	TRB EXH SPOIL GAS CV LY SGCV	F N/A	N/A	N/A	N/A	N/A	POT.	N/A	N/A	N/A	N/A	SB	P N/A	N/A	
452	SPOILER GAS MANIFOLD	PSGM	F	N/A	N/A	N/A	PRESS	5K PSIG	0PSIG	5K PSIG	N/A	2 810-S	P N/A	N/A	
453	GH2 SUPPLY MANIFOLD	PG H2M	F	N/A	N/A	N/A	PRESS	6K PSIG	0PSIG	5K PSIG	N/A	2 810-S	P N/A	N/A	
454	PRES CV ORIFICE INLET	PGPCVO-I	F	N/A	N/A	N/A	PRESS	5K PSIG	0PSIG	2K PSIG	N/A	2 810-S	P N/A	N/A	
455	PRES CV PRES REG DOME	PGPCVPR	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	2K PSIG	N/A	2 810-S	P N/A	N/A	
456	PRES CV PRES REG OUT	PGPCVPRO	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	2K PSIG	N/A	2 810-S	P N/A	N/A	
457	HYDRALIC CV DISCHARGE	PHOCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	4K PSIG	N/A	2 810-S	P N/A	N/A	
458	HYDRALIC CV RETURN	PHRCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	4K PSIG	N/A	2 810-S	P N/A	N/A	
459	ACCUMULATOR CV	PACCCV	F	N/A	N/A	N/A	PRESS	4K PSIG	0PSIG	3K PSIG	N/A	2 810-S	P N/A	N/A	
460	BURNOFF DUCT NOZ EJEC	T80D-2A	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R	N/A	N/A	2 S	P N/A	N/A	
461	BURNOFF DUCT TURB EJE	T80D-2B	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R	N/A	N/A	2 S	P N/A	N/A	
462	TEMP FUEL TANK OUTLET	TFTO-A	F	N/A	N/A	N/A	RTT	CODE-K	35 R	60 R	N/A	2 810	P 2.68	4.00	
463	EXH BURN OFF DUCT	T80D-3A	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R	N/A	N/A	2 S	P N/A	N/A	
466	EXH BURN OFF DUCT	T80D-3B	F	N/A	N/A	N/A	PYRO	10MV	PYROMET R	N/A	N/A	2 S	P N/A	N/A	
467	NOZZLE DUCT SPOIL GAS	PGNDSG	F	N/A	N/A	N/A	PRESS	2K PSIG		1.5KPSI	N/A	2 810	S N/A	N/A	
468	TURB. DUCT SPOIL GAS	PGTDSG	F	N/A	N/A	N/A	PRESS	2K PSIG		500PSIG	N/A	2 810	S N/A	N/A	
471	PRESS SWITCH NOZ CHAM	PSNC	F	80.1	15.4	342	PRESS SWITCH	N/A		20PSIG	N/A	NA CONTROL	P N/A	N/A	
472	PRESS SWITCH NOZ EXH DU	PSNEO	F	N/A	N/A	N/A	PRESS SWITCH	N/A		5PSIG	N/A	NA CONTROL	P N/A	N/A	
500	NET POSITIVE SUCTION	NPSP					CALCU	ATED	PARA	ETER					3
502	PROPELLANT FLOW	WRTPL-1					CALCU	ATED	PARA	ETER					2
503	PROPELLANT FLOW	WRTPL-2					CALCU	ATED	PARA	ETER					2
504	MAIN NOZZLE FLOW	WMN					CALCU	ATED	PARA	ETER					2
505	TURBINE FLOW	WTI					CALCU	ATED	PARA	ETER					2
506	GH2 DENSITY IN RTPLA	RHQ-RTPL					CALCU	ATED	PARA	ETER					9

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APPENDIX D

PHOTOGRAPHIC COVERAGE

1. CFDTS STILL PHOTOS

<u>Photo No.</u>	<u>Subject</u>
1264SP 528 through 540	Checkout of CFDTS weight and C.G. dummy in assembly fixtures and on transportation tests
1264SP 1591 through 1612	Reactor components
1264SP 1613, 1614 & 1615	Removal of Inner from Outer Container
1264SP 1766 through 1770	Reactor Reflector and Screen
1264SP 1866 through 1978	Removal of Reactor from Inner Container
1264SP 2402 and 2420	Reactor, CFDTS
1 65SP 435 through 446	Assembly of CFDTS Major Components
1 65SP 1471, 1472	Assembly of CFDTS UTS
2 65SP 513 through 521	CFDTS Assembly in Assembly Stand
2 65SP 875 through 882	CFDTS Components in Upper Thrust Structure
2 65SP 1490 through 1493	Shipment of CFDTS to Test Area
3 65SP 434	CFDTS in Test Stand
4 65SP 849 through 865	CFDTS Installed in Test Stand, Instrumentation and Controls Leads
4 65SP 1665, 1666 & 1667	CFDTS Instrumentation Leads
11 65SP 662, 663 & 664	Infinite Impedance Line

2. CFDTIS DOCUMENTARY FILM

<u>Date</u>	<u>Roll Number</u>	<u>Subject</u>	<u>Footage</u>	<u>Classifi- cation</u>	<u>Type Film</u>
12-10-64	D-1449	Reactor Arriving at Gate #1	400	Uncl	Color
12-10-64	D-1450	Transporting Reactor, Roseville to Nimbus	100	Uncl	Color
12-10-64	D-1451	Transporting Reactor, Roseville to Nimbus	200	Uncl	Color
12-11-64	D-1458	Unloading of Reactor at Gate #1	100	Uncl	Color
12-11-64	D-1459	Removal of Reactor Container, Bldg. 2002	400	Uncl	Color
12-11-64	D-1464	Reactor Installation, Bldg. 2002	220	Uncl	Color
12-15-64	D-1466	Reactor Installation, Bldg. 2002	400	Uncl	Color
12-15-64	D-1467	Reactor Installation, Bldg. 2002	400	Conf	Color
12-15-64	D-1468	Reactor Installation, Bldg. 2002	400	Uncl	Color
12-15-64	D-1469	Reactor Installation, Bldg. 2002	400	Uncl	Color
12-15-64	D-1470	Reactor Installation, Bldg. 2002	400	Conf	Color
12-15-64	D-1471	Reactor Installation, Bldg. 2002	400	Uncl	Color
1- 6-65	D-1505	Nozzle Assembly	120	Uncl	Color
1- 8-65	D-1514	TPA Installation	100	Uncl	Color
1- 8-65	D-1515	Nozzle Installation	160	Uncl	Color
1- 8-65	D-1518	Installation	65	Uncl	Color
2- 4-65	D-1586	Installation of Pump on Engine	300	Uncl	Color
2-15-65	D-1616	Assembly of Lower and Upper Thrust Structure	180	Uncl	Color
2-18-65	D-1624	CFDTIS Transported to Test Area	100	Uncl	Color
2-22-65	D-1635	Assemble of Upper and Lower Thrust Structure	200	Uncl	Color
2-25-65	D-1641	CFDTIS in Test Stand H-5	100	Uncl	Color
3-16-65	D-1697	CFDTIS in Test Stand H-5	50	Uncl	Color

3. CFDTs TEST FILM

<u>Run No.</u>	<u>Roll No.</u>	<u>Type of Film</u>	<u>FPS</u>	<u>Camera Location</u>	<u>Classification</u>
001	L-68653	Black & White	64	West Apron	Unclassified
	68654	Black & White	64	East Apron	Unclassified
	68655	Black & White	64	Apron	Unclassified
	68656	Black & White	64	House	Unclassified
	68657	Infra Red	64	House	Unclassified
003	L-68663	Black & White	64	House	Unclassified
	68664	Black & White	64	House	Unclassified
	68665	Black & White	64	Apron Front	Unclassified
	68666	Black & White	64	East Apron	Unclassified
	68667	Infra Red	64	West Apron	Unclassified
004	L-68677	Black & White	64	Overall House	Unclassified
	68678	Black & White	64	Pipe-House	Unclassified
	68679	Black & White	64	Girder	Unclassified
	68680	Black & White	64	West Apron	Unclassified
	68681	Infra Red	64	East Apron	Unclassified
005	L-68688	Black & White	64	Front Apron	Unclassified
	68689	Black & White	64	East Apron	Unclassified
	68690	Black & White	64	West Apron	Unclassified
006	L-68705	Infra-Red	64	House	Unclassified
	68706	Black & White	64	House	Unclassified
	68707	Black & White	64	Front Apron	Unclassified
	68708	Black & White	64	East Apron	Unclassified
	68709	Black & White	64	West Apron	Unclassified

<u>Run No.</u>	<u>Roll No.</u>	<u>Type of Film</u>	<u>FPS</u>	<u>Camera Location</u>	<u>Classification</u>
007	L-69914	Color	64	Cart Front	Unclassified
	69915	Color	64	Stand	Unclassified
008	L-69946	Color	64	Stand	Unclassified
	69947	Color	64	Cart	Unclassified
009	L-69948	Color	64	Stand	Unclassified
	69949	Color	64	Cart	Unclassified
010	L-69961	Color	64	Stand	Unclassified
	69962	Color	64	Cart	Unclassified
011	L-69963	Color	64	Cart	Unclassified
	69964	Color	64	Stand	Unclassified
012	L-69975	Color	64	Cart	Unclassified
013	L-69976	Color	64	Stand	Unclassified
014					
015	L-69992	Color	64	Cart	Unclassified
016	L-69993	Color	64	Stand	Unclassified
017					
018	L-70006	Color	64	Stand	Unclassified
019	L-70007	Color	64	Cart	Unclassified
020	L-70008	Color	64	Stand	Unclassified
021	L-70009	Color	64	Cart	Unclassified
022	L-70014	Color	64	Cart	Unclassified
023	L-70015	Color	64	Cart	Unclassified
024	L-70030	Color	64	Cart	Unclassified
025	L-70031	Color	64	Stand	Unclassified
026	L-70032	Color	64	Cart	Unclassified
	70033	Color	64	Stand	Unclassified

<u>Run No.</u>	<u>Roll No.</u>	<u>Type of Film</u>	<u>FPS</u>	<u>Camera Location</u>	<u>Classification</u>
027	L-70034	Color	64	Stand	Unclassified
	70035	Color	64	Cart	Unclassified
028	LS-00069	Color	64	Stand	Unclassified
029	LS-00070	Color	64	Cart	Unclassified
030	LS-00102	Color	64	Apron	Unclassified
031	LS-00103	Color	64	Cart	Unclassified

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APPENDIX E

LIST OF CAL-COMP PLOTS FOR TEST SERIES I, II, & III

1. LIST OF CAL-COMP PLOTS FOR TEST SERIES I

The following is a list of Cal-Comp plots made for the measurements taken in Test Runs 001, 002, 003, 004, 005, and 006. These plots are available from the CFDTs Project:

<u>Plot 1:</u>	<u>Plot 5:</u>	<u>Plot 9:</u>	<u>Plot 13:</u>
#402 PFT-H-11	#330 QRTPL-1	#298 TPD-2	#26 PNT-2
#407 PFTO	#331 QRTPL-2	#299 TPD-3	#28 PNT-4
#5 PPIL-1	#334 NTPA-1	#297 TPD-1	#32 DPNT-2
#7 PPIL-3		#300 TPD-4	#40 PRO-1
#8 PPIL-4	<u>Plot 6:</u>	#312 TNM-1	#41 PRO-2
#15 DPTP-1	#305 TPIL-1	#313 TNM-2	#42 PRO-3
	#306 TPIL-2		#25 PNT-1
<u>Plot 2:</u>	#308 TTPH-1	<u>Plot 10:</u>	<u>Plot 14:</u>
#1 PRTPL-1	#309 TTPH-2	#133 THNM-2	#201 TCD-1
#2 PRTPL-2	#307 TPIL-3	#134 THNM-3	#202 TCD-2
#3 PRTPL-3	#311 TPIL-4		#203 TCD-3
#4 PRTPL-4	#310 TTPH-3	<u>Plot 11:</u>	#204 TCD-4
NPD		#265 TNWI-1	#205 TCD-5
		#266 TNWI-2	#206 TCD-6
<u>Plot 3:</u>	<u>Plot 7:</u>	#267 TNWI-3	
461 TFTO-A	#10 PPD-1	#268 TNWI-4	<u>Plot 15:</u>
#109 THRTPL-1	#11 PPD-2	#281 TNWI-5	#213 TOR-1
#110 THRTPL-2	#12 PPD-3	#282 TNWI-6	#214 TPR-2
#111 THRTPL-3	#18 PNM-1		#215 TOR-3
#112 THRTPL-4	#20 PNM-3	<u>Plot 12:</u>	#216 TOR-4
	#21 PNM-4	#269 TNWO-1	#217 TOR-5
<u>Plot 4:</u>	#16 PNMI-1	#270 TNWO-2	#218 TOR-6
#114 THPIL-1		#271 TNWO-3	#219 TOR-7
#116 THPIL-3	<u>Plot 8:</u>	#272 TNWO-4	#220 TOR-8
#117 THPIL-4	#124 THPD-1	#273 TNWO-5	
#118 THPIL-5	#125 THPD-2		
	#127 THPD-4		

Plot 16:

#274 TPV-1
#275 TPV-2
#276 TPV-3
#277 TPV-4
#278 TPV-5
#279 TPV-6

Plot 17:

#151 THRO-2
#156 THRO-7
#158 THRO-9
#153 THRO-4
#159 THRO-10

Plot 18:

#53 PSISP-1
#55 PSISP-3
#58 PCI-1
#59 PCI-2
#60 PCI-3
#72 PDL-1
#74 PDJ-1

Plot 19:

#232 THSISP-8
#234 THSISP-10

Plot 20:

#192 TIR-1
#193 TIR-2
#194 TIR-3
#195 TIR-4

Plot 21:

#175 THCI-5
#176 THCI-6
#177 THCI-7

Plot 22:

#66 PNC-1
#67 PNC-2
#65 PNC-4
#78 PTIL-1
#82 PTIL-5

Plot 23:

#414 PNED-1
#415 PNED-2
#91 PTEN-1
#92 PTEN-2
#421 PTEL-1
#422 PTEL-2

Plot 24:

#255 THDJ-1
#238 THTIL-1
#243 THTIL-3
#244 THTIL-4
#221 THNC-1
#222 THNC-2
#233 THNC-3
#436 THNED-1

Plot 25:

•
W_D
•
W_{RTPL}-1
•
W_{RTPL}-2
•
W_{MN}
•
W_{TI}

Plot 26:

#7 PPIL-3
#10 PPD-1
#20 PNM-3
#28 PNT0-4
#41 PRO-2
#58 PCI-1
#67 PNC-2
#89 PTI-1
#414 PNED-1

Plot 27:

#140 THNT0-2
#141 THNT0-3

Plot 28:

#89 PTI-1
#90 PTI-2
#95 PTI-3
#87 DPTPCV-1
#88 DPTPCV-2

Plot 29:

#302 TTILJ-1
#303 TTILJ-2
#304 TTILJ-3
#301 TTIL-1

Plot 30:

#183 TCM-1
#184 TCM-2
#186 TCM-4
#187 TCM-5
#188 TCM-6
#189 TCM-7

Plot 31:

#246 THTI-1
#247 THTI-2
#249 THTE-1
#250 THTE-2

Plot 32:

#286 TPVC-1
#287 TPVC-2
#288 TPVC-3
#289 TPVC-4

2. LIST OF CAL-COMP PLOTS FOR TEST SERIES II

The following is a list of Cal-Comp plots made for the measurements taken in Test Runs 007 through 027. These plots are available from the CFDTS Project:

<u>Plot 1:</u>	<u>Plot 4: (cont.)</u>	<u>Plot 7:</u>	<u>Plot 10:</u>
#319 LPDV-1	#66 PNC-1	#32 DPNT-2	#132 THNM-1
#320 LPSOV-1	#90 PTI-2	#50 DPDR-1	#133 THNM-2
#322 LTPCV-1	#414 PNED-1	#61 DPRO-C11	#134 THNM-3
#334 NTPA-1	#421 PTEL-1	#101 DPBCL-1	#139 THNT0-1
		#102 DPBCL-2	#140 THNT0-2
		#103 DPBCL-3	#141 THNT0-3
<u>Plot 2:</u>	<u>Plot 5:</u>	<u>Plot 8:</u>	#169 THPVRA-1
#501 WD	#51 PPVRA-1		#170 THPVRA-2
#502 WRTPL-1	#53 PSISP-1	#414 PNED-1	
#503 WRTPL-2	#67 PNC-2	#416 PNE-1	<u>Plot 11:</u>
#504 WMN	#68 PNC-3	#417 PNE-2	#142 THNT0-4
#505 WTI	#74 PPJ-1	#418 PNE-3	#143 THNT0-5
	#78 PTIL-3	#419 PNE-4	#144 THNT0-6
<u>Plot 3:</u>	#80 PTIL-3	#421 PTEL-1	#145 THNT0-7
#1 PRTPL-1	#82 PTIL-5	#423 PTEE-1	#146 THNT0-8
#3 PRTPL-3	#87 DPTPCV-1	#424 PTEE-2	#147 THNT0-9
#7 PPIL-3		#425 PTEE-3	#148 THNT0-10
#10 PPD-1		#426 PTEE-4	#149 THNT0-11
#15 DPTP-1	<u>Plot 6:</u>		
#402 PFT-H11	#93 PTE-1	<u>Plot 9:</u>	<u>Plot 12:</u>
#407 PFTO-1	#94 PTE-2	#109 THRTPL-1	#150 THRO-1
#500 NPSP	#95 PTI-3	#111 THRTPL-3	#151 THRO-2
	#96 P2TRE-1	#117 THPIL-4	#152 THRO-3
<u>Plot 4:</u>	#97 P2TRE-2	#125 THPD-2	#153 THRO-4
#7 PPIL-3	#422 PTEL-1A		#154 THRO-5
#10 PPD-1			#155 THRO-6
#18 PNM-1			#156 THRO-7
#26 PNT0-2			#157 THRO-8
#42 PRO-3			#158 THRO-9
#58 PCI-1			#159 THRO-10

Plot 12: (cont.)

#160 THRO-11
#161 THRO-12
#162 THRO-13

Plot 14: (cont.)

#180 THCI-10
#181 THCI-11
#182 THCI-12

Plot 17: (cont.)

#307 TPIL-3
#308 TPH-1
#309 TPH-2
#310 TPH-3
#311 TPIL-4

Plot 21:

#192 TIR-1
#193 TIR-2
#194 TIR-3
#195 TIR-4

Plot 13:

#225 THSISP-1
#226 THSISP-2
#227 THSISP-3
#228 THSISP-4
#229 THSISP-5
#230 THSISP-6
#231 THSISP-7
#232 THSISP-8
#233 THSISP-9
#234 THSISP-10
#235 THSISP-11
#236 THSISP-12
#237 THSISP-13

Plot 15:

#221 THNC-1
#222 THNC-2
#223 THNC-3
#436 THNED-1

#298 TPD-1
#299 TPD-2
#300 TPD-3

Plot 18:

#265 TNWI-1
#266 TNWI-2
#267 TNWI-3
#268 TNWI-1A
#281 TNWI-2A
#282 TNWI-3A

Plot 22:

#183 TCM-1
#184 TCM-2
#186 TCM-4
#187 TCM-5
#188 TCM-6
#189 TCM-7

Plot 14:

#171 THCI-1
#172 THCI-2
#173 THCI-3
#174 THCI-4
#175 THCI-5
#176 THCI-6
#177 THCI-7
#178 THCI-8
#179 THCI-9

Plot 16:

#238 THTIL-1
#239 THTIL-2
#243 THTIL-3
#246 THTI-1
#248 THTI-3
#249 THTI-4
#251 THTI-5
#253 THTI-6
#255 THTI-7

Plot 19:

#269 TNWO-1
#270 TNWO-2
#271 TNWO-3
#272 TNWO-4
#273 TNWO-5

Plot 23:

#117 THPIL-4
#125 THPB-2
#133 THNM-2
#139 THNT-1
#175 THCI-5
#223 THNC-3
#246 THTI-1
#249 THTI-2

Plot 20:

#217 TOR-5
#218 TOR-6
#219 TOR-7
#220 TOR-8

Plot 24:

#13 DPFM-8
#14 DPFM-4
#34 DPRTLF-1
#36 DPFDCV
#106 DPTSV-1

Plot 17:

#297 TPD-1
#305 TPIL-1
#306 TPIL-2

Plot 25:

#299 TPD-3
#300 TPD-4
#301 TPD-5
#302 TPD-6
#303 TPD-7

Plot 26:

#315 SPIL-1
#316 SPIL-2
#317 STS-1
#318 STS-2

Plot 27:

#292 TPIL-9
#293 TPIL-10
#294 TTS-1
#295 TTS-2
#296 TTS-3

Plot 28:

#68 PNC-3
#63 PNC-5

3. LIST OF CAL-COMP PLOTS FOR TEST SERIES III

The following is a list of Cal-Comp plots made for the measurements taken in Test Runs 028 through 031. These Plots are available from the CFDTS Project:

<u>Plot 1:</u>	<u>Plot 2:</u>	<u>Plot 3:</u>	<u>Plot 4:</u>
#319 LPDV-1	#502 WRTPL-1	#402 PFI-HII	#7 PPIL-3
#320 LPSOV-1	#503 WRTPL-2	#407 PFTO-1	#12 PPD-2
#322 LTPCV-1	#504 WMN	#3 PRTPL-3	#18 PNM-1
#334 NTPA-1	#505 WTI	#7 PPIL-3	#26 PNT0-2
	#500 NPSP	#15 DPTP-1	#42 PRO-3
	#506 RHO-RTPL	#12 PPD-2	#55 PSISP-3
			#67 PNC-2
			#95 PTI-3
			#414 PNED-1
			#421 PTEL-1
			#5 PCI-1

<u>Plot 5:</u>	<u>Plot 6:</u>	<u>Plot 7:</u>	<u>Plot 8:</u>
#67 PNC-2	#109 THRTPL-1	#117 THPIL-4	#183 TCM-1
#68 PNC-3	#111 THRTPL-3	#125 THPD-2	#184 TCM-2
#72 PDL-1	#117 THPIL-4	#133 THNM-2	#186 TCM-4
#74 PDJ-1	#125 THPD-2	#139 THNTO-1	#187 TCM-5
#80 PTIL-3	#307 TPIL-3	#253 THDL-1	#188 TCM-6
#95 PTI-3		#175 THCI-5	#189 TCM-7
#96 P2TRE-1		#223 THNC-3	
#421 PTEL-1		#224 THNC-4	
#414 PNED-1		#246 THTI-1	
		#249 THTE-1	
		#243 THTIL-3	

LIST OF ABBREVIATIONS

AGC	-	Aerojet-General Corporation
ASME	-	American Society of Mechanical Engineers
CFDTS	-	Cold Flow Development Test System
CSC	-	Consolidated Systems Corporation
DV	-	Diluent Valve
EST	-	Engine System Test
ETS	-	Engine Test Stand
FS-1	-	Fire Switch - 1, i.e., Test Start
FS-2	-	Fire Switch - 2, i.e., Test Termination
LTS	-	Lower Thrust Structure
MRL	-	Measurements Requirements List
NERVA	-	Nuclear Engine for Rocket Vehicle Application
NES	-	Nuclear Exhaust System
NPSP	-	Net Positive Suction Pressure
NRDS	-	Nuclear Rocket Development Station
NRX	-	NERVA Reactor Experimental
NTS	-	Nevada Test Site
PDV	-	Pump Discharge Valve
PDBV	-	Pump Discharge Bleed Valve
PSOV	-	Propellant Shut-Off Valve
PVARA	-	Pressure Vessel and Reactor Assembly
REON	-	Rocket Engine Operations Nuclear
RTPL	-	Run Tank Propellant Line
RTT	-	Resistance Temperature Transmitter
SCFM	-	Standard Cubic Feet per Minute
TC	-	Thermocouple
TM	-	Technical Memorandum
TPA	-	Turbopump Assembly
TPCV	-	Turbine Power Control Valve
TSV	-	Tank Safety Valve
UTS	-	Upper Thrust Structure
WANL	-	Westinghouse Astro Nuclear Laboratory
XE	-	Experimental Engine

SKETCH OF COLD FLOW ENGINE SYSTEM

CFDTS FINAL REPORT

APPENDIX F

SKETCH OF COLD FLOW ENGINE SYSTEM AND LIST OF ABBREVIATIONS