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REPORT NO. RN-S-0150
TO
AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

STATUS REPORT ON ANALYSIS OF THE
COLD FLOW DEVELOPMENT TEST SYSTEM (U)

SEPTEMBER 1964

NERVA PROGRAM

CONTRACT SNP-1

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ABSTRACT

This is a status report on the analytical work performed on CFDTIS under Sub-Subtask 1.8.1. To perform the analysis, both analog and digital programs were developed to represent the CFDTIS system. Using these programs, the following areas were investigated:

1. Scheduling of TPCV
2. Tank pressure
3. Effects of back pressure
4. Effects of dry versus wet pump during start
5. Methods of improving system performance
6. Effects of chillo^udown
7. Investigation of diluent valve position on engine start-up
8. Substitution of different nozzles.

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I. INTRODUCTION

This report is a status report on the analytical work already performed in order to satisfy contractual milestone requirements under Sub-Subtask 1.8.1 for a CFDTS Analysis Report on September 1964. The purpose of the analytical investigation of the cold flow development test system (CFDTS) is to provide information on how the stored energy of the components will integrate into the bootstrapping of an engine system.

The objectives of the CFDTS¹ are:

A. Verify the control functions and start-up sequence of operations previously determined by transient analysis with a mathematical model in order to develop a reliable start-up procedure for the engine system.

B. Evaluate flow characteristics of an unfueled nuclear engine system to determine chilldown time, temperatures, flow rates, and pressure drop data throughout the system.

The start-up characteristics of a cold flow system will be demonstrated.

In order to achieve these objectives the following functions have been performed on CFDTS:

A. Mathematical models have been developed representing the transient behavior of the system. These models have been programmed on both the analog and digital computers in order to obtain performance data on the system.

1. Revised Test Plan for Cold Flow Development Test System, Report No. 2710, September 1963.

B. Investigation has been conducted in the following specific areas:

1. Scheduling of TPCV
2. Tank pressure
3. Effects of back pressure
4. Effects of dry opposed to wet pump during start
5. Methods of improving system performance
6. Effects of chill-down
7. Investigation of diluent valve position on engine start-up
8. Various nozzle configurations

II. CONCLUSIONS

The following conclusions were drawn from the analysis (since the analysis is a continuing effort, these conclusions may be modified as more details become available).

A. The energy available in the engine system is sufficient that significant start-up performance information will result from the CFDTS test.

B. TPCV settings of less than 30 degrees would probably not produce pump speeds and pressures high enough to assure a successful bootstrap operation.

C. Assuming a back pressure of 8 psia, tank pressures above 45 psia are needed to operate the TPA in the normal operating region in CFDTS. The 8-psia back pressure is representative of CFDTS operation with the ejector system simulating ETS-1 conditions. Lesser tank pressures may be possible but sufficient engine data is not available on low speed performance to determine how much less than 45-psia tank pressure is possible. Tank pressures will have an appreciable effect on chillo down times.

D. Back pressures influence the minimum tank pressures required to maintain performance in a normal TPA operating region. The effects are:

<u>Back pressure</u>	<u>Tank pressure</u>
1 psia	35 psia
8 psia	45 psia
15 psia	55 psia

E. Run durations approaching 50 seconds can be expected after opening the TPCV. Chill-down times that reach 90 seconds would probably deplete the energy in the engine system to the point where engine starts are not possible.

F. Several methods are available for increasing the performance of the system. Removing the orifice from the turbine feed line and by-passing flow around the nozzle were both investigated and found to improve peak engine response.

G. Diluent bleed is an unimportant parameter for CFDTIS.

H. For a wet or dry pump during start, small performance variations were seen in analysis with the large and small U-tube nozzles and the aluminum jacketed nozzles. However, the effects were not of major significance in CFDTIS performance.

III. MATHEMATICAL MODELS

A. ANALOG COMPUTER MODEL

The analog computer model which was used for the analysis is described in report RN-S-0091². It was developed for general controls studies on the analog computer and is a continuation of work performed on the NERVA engine over the past three years. The model is well suited to CFDTS studies. In the simulation, the hydrogen properties (see reference RN-S-0091) needed for pressure, flow, and heat transfer computations are described between temperatures of 40°R to 5000°R and pressures of 0 to 1000 psia.

Two-phase hydrogen description (see reference RN-S-0091) is limited to the nozzle and part of the reflector. Because of this limitation on the extent to which two-phase hydrogen may penetrate the system, the TPCV and PSOV are closed during the latter part of the CFDTS start-up transient.

The operating range of the model is zero-flow to full-power operation. The heat transfer is described in 16 nodes for heat storage. These are divided between the reactor assembly, nozzle, and pump. Internal flow is described in two parallel paths through the nozzle, three parallel paths through the reflector, and two parallel paths through the core. The feed system includes the description of diluent bleed and the TPCV flow and pressure drop relationships. The heat transfer during pump chill-down is also included in the feed system description. This chill-down establishes the time at which liquid enters the pump. Pressure at the pump is assumed constant and equal to tank pressure.

The feed system also includes the description of the turbopump assembly. The Mark III, Mod IV, Aerojet turbopump will be used for CFDTS. The description of

². Basic Analog Model of NERVA Engine, RN-S-0091, May 1964

the turbopump is based on preliminary Mark III, Mod IV high speed data. The pump and turbine flow characteristics for low speeds have been extrapolated linearly to zero for computations involving low speeds. Since the turbine flow rates at low turbine pressure drops are not clearly established, the description of turbine torque at low flows is still uncertain.

The CFDIS ejector system will sustain both the main nozzle and the turbine exhaust nozzle at 8-psia back pressure; although, in most cases where the ejectors are operating, the back pressure will vary during part of the transient.

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B. DIGITAL COMPUTER MODEL

The Rough Cut Engine Simulation program was used in the digital analysis. It is reported in RN-S-0114.³

The transient digital simulation program used to analyze the CFDTS system is a finite difference, explicit digital computer program that calculates material temperatures, fluid temperatures, and the pressure distribution as a function of time throughout the NERVA engine. Separate mathematical models of the turbopump, hot bleed port, reflector, shield, core, nozzle, and various tanks and lines are combined to represent the transient performance of the entire engine system.

The turbopump assembly model contains an energy balance that includes an energy storage term to account for the angular momentum of the rotating mass.

The reflector, shield, and core are represented analytically as single-fluid single-channel heat exchangers utilizing a void fraction analogy. Material and fluid nodes are 10 in the nozzle, 27 in the reflector, 14 in the shield and 27 in the core. The fluid pressure distribution throughout the system components is obtained by calculating a bulk friction factor for use with the single channel representation. Temperature and pressure results from the above mathematical model agree closely with data from non-nuclear and nuclear tests such as the NRX/A1, B4D, chemical firings in the aluminum and large throat U-tube nozzles and the 2.5" hot bleed port test.

The nozzle is treated as a single pass counter-current heat exchanger. The tubes are divided into finite distance increments for pressure drop and heat transfer considerations.

The hot-bleed port subroutine is also a counter-current, finite difference, iterative process which balances the turbine flow rate from both the diluent and hot-gas ports. Entrance and exit losses, vena contracta, and the angle of diluent injection are accounted for.

3. Transient Engine Simulation Program, SNP-1 Report No. PN-S-0114, Aerojet-General Corp., August 1964.

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A linear predictor routine is used to project the program to the succeeding time point. The predictor is accurate enough to eliminate a closure on the pump discharge pressure which greatly reduces the overall program running time.

To summarize, the transient simulation program is designed to predict the transient operation of the NERVA rocket engine system but is flexible enough to determine the thermal and hydrodynamic characteristics of a wide range of monofluid flow systems. Complete information of the program is in Transient Engine Simulation Program, SNP-1 Report No. RN-S-0114, Aerojet-General Corp., August 1964.

IV. ANALOG COMPUTER INVESTIGATION

The following studies were made using the analog computer simulation described above.

A. SCHEDULING OF TPCV

Several methods of opening the turbine power control valve (TPCV) were investigated. The control of TPCV will be influenced in each CFDTS test case by the particular purpose of that test. For example, a test is planned where the TPCV is programmed to the 90° open position in order that the extreme values of system parameters for CFDTS operation will appear. Other CFDTS tests will establish the characteristics of the heat capacity portion of engine start-up with TPCV openings of less than 45°. The TPCV control modes which were selected for the investigation are representative of the various CFDTS tests.

The investigation of TPCV control was made with the XE-Engine, U-tube nozzle configuration. The coolant tube throat area is 6.2 in². This nozzle is scheduled for use on CFDTS during the test series.

Figure 1 shows a representative method of TPCV control. When the pump chillover is completed the TPCV is opened suddenly from 0° to 30°. The valve is then programmed open to 45° at 1.5°/second. Forty-five degrees is the approximate full power setting. The tank pressure is held constant at 70 psia, the back pressure is assumed constant at 8 psia, and the diluent bleed is on. Sheet 1 of Figure 1 shows important parameters upstream of the dome plenum. The parameters of pump speed, coolant flow rate, and pump discharge pressure rise to their peak values in about 12 seconds after the TPCV is actuated. Pump speed peaks at about 8500 rpm and coolant flow rate peaks at about 26 lbs/sec. The pump discharge pressure peaks at 190 psia. When the shield inlet temperature drops below a temperature of about 100°F the TPCV and PSOV are closed (at 46 seconds). This can be seen in Sheet 2 of Figure 1 which shows the important parameters downstream of the dome plenum. Sheet 3 of Figure 1 shows the material and coolant temperatures and the coolant quality in the nozzle.

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during the transient. There is a large decrease in nozzle wall temperature prior to actuation of the TPCV because of coolant flow during pump chilldown. The wall temperatures in the reflector (which are shown in Sheet 4 of Figure 1) hold up well during the pump chill-down portion of the transient but by the time the TPCV is closed, the usable heat stored in the reflector has been depleted. The core temperatures (shown in Sheet 5 of Figure 1) indicate that a large quantity of heat remained in the core material at the time the TPCV was closed.

Figure 2 shows the transient response to a 45° step of the TPCV when the pump chilldown is complete. This method of opening the TPCV would probably be less representative of an engine start sequence than the method used in obtaining Figure 1. The values shown in Figure 2 are about the same as those shown in Figure 1. The duration of the transient is about the same. The peak values of pump speed, pressures, and coolant flow rates appear around five seconds after the opening of the TPCV as compared to 12 seconds in the case of the previous TPCV programming.

FIGURE 1

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure
 70 psia Tank Pressure TPCV Steps to 30° when Pump Chillo down is Complete
 and is Programmed to 45° at 1.5°/sec

FIGURE 1 (cont.)
CFDTs Start-up with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 30° when Pump Chillo down is Complete
and is Programmed to 45° at 1.5°/sec

FIGURE 1 (cont.)

CFDTIS Start-up with Diluent Bleed on 8 psia Back Pressure 70 psia Tank Pressure TPCV Steps to 30° when Pump Chillo down is Complete and is Programmed to 45° at 1.5°/sec

FIGURE 2

CFDTIS Start-up with Diluent Bleed on 8 psia Back Pressure 70 psia Tank Pressure TPCV Steps to 45° when Pump Chillo down is Complete

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C

FIGURE 2 (cont.)

CFDIS Start-up with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 45° when Pump Chillo down is Complete

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E

FIGURE 2 (cont.)

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 45° when Pump Chillover is Complete

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B. DETERMINATION OF THE EFFECTS OF TANK PRESSURE FOR STARTS WITH A DRY PUMP

The CFDTS will be operated in Sacramento with injectors on the chamber and turbine nozzles. During studies made to determine the tank pressure required to achieve a minimum start, an 8-psia back pressure was used. The studies for dry pump starts were made on the analog computer; the wet pump starts were investigated using the digital program. As reported in Section V of this document, a dry pump is one that has not been pre-chilled.

These runs were made without the turbine line orifice in order to show maximum variations in performance. The effect of this orifice is also discussed in Section E. The configuration used was:

1. Small throat U-tube nozzle
2. Mod III, Mark IV Turbopump
3. TPCV gate position stepped to 100%
4. Diluent valve fully opened
5. Tank temperature of 40°R
6. Back pressure of 8 psia
7. Dry pump start

Figure 3 shows the CFDTS start-up with 55-psia tank pressure. The values of parameters which are shown in these figures compare closely with those shown in Figure 4 which were run with the tank pressure at 70 psia. Lower values of tank pressures were not investigated because of the lack of definition in the off design region of the TPA.

The time to reach peak performance values is slightly shorter for high tank pressures and longer for low tank pressures. Generation I and II test results also show that the time required to chill down the pump varies inversely with tank pressure. Since the aggregate flow during chill-down effects the heat capacity available in the system for "bootstrap" operation, actual peak pressures will be related to tank pressure.

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FIGURE 3

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure
55 psia Tank Pressure TPCV Steps to 90° when Pump Chillydown is Complete

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D

FIGURE 3 (cont.)

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure
55 psia Tank Pressure TPCV Steps to 90° when Pump Chilldown is Complete

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E

FIGURE 3 (cont.)

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure 55 psia Tank Pressure TPCV Steps to 90° when Pump Chillo down is Complete

A

FIGURE 4

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure 70 psia Tank Pressure TPCV Steps to 90° when Pump Chillo down is Complete

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B

C

FIGURE 4 (cont.)

CFDTIS Start-up with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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FIGURE 4 (cont.)

CFDTS Start-up with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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C. EFFECTS OF BACK PRESSURE

The effects of back pressure was investigated on the analog computer CFDTIS simulation.

For a dry pump start, no significant changes in response were found for a change in back pressure of from 8-psia to 15-psia. This is demonstrated by comparing Figures 4 and 5.

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A

B

FIGURE 5

CFDTS Start-up with Diluent Bleed on 15 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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D. EFFECT OF DRY VERSUS WET PUMP DURING START

During a "dry" start the turbopump is chilled down by opening the PSOV and delaying the TPCV opening until liquid hydrogen is measured in the discharge of the pump. During pump chilldown, the nozzle, reflector and other parts of the engine are also being cooled.

Figure 4 shows a dry pump start.

Figure 6 represents a "wet" pump start-up of CFDTs. The chilldown portion of the transient is eliminated when the system is started in this manner. Both of these runs have the turbine line orifice removed. The pump is cooled by opening the PSOV prior to the run. The hydrogen is ducted away from the engine by a valve downstream of the pump and the engine components remain at their ambient temperature prior to the run. The TPCV and the valve downstream of the pump are actuated simultaneously at time zero. The valve downstream of the pump is a "Y" valve which ducts cryogenic hydrogen into or away from the engine. The peak values of the pump speed, pump flow rate, and pump discharge pressure are about the same as when the 90° step of the TPCV was preceded by 17 seconds of pump chilldown. However, the decay from peak values is at a lower rate. This reflects the fact that component heat content at the time of TPCV actuation has not been degraded by the pump chilldown.

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A

FIGURE 6

B

CFDTS Wet-Start with Diluent Bleed on 8 psia Back Pressure
 70 psia Tank Pressure TPCV Steps to 90° when Pump Chilldown is Complete

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C

FIGURE 6 (cont.)

D

CFDTS Wet-Start with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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E

FIGURE 6 (cont.)

CFDTS Wet-Start with Diluent Bleed on 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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E. EFFECT OF CHILLDOWN

The change in time after the PSOV until the TPCV is actuated is a function of the chilldown characteristics of the CFDTS. The description of this part of the transient is the least verified by background data. However, some idea of the effect of opening the TPCV can be obtained from a study of Generation I simulator tests. In all those tests, the TPCV was fully open at the start of the test. Consequently, the turbopump accelerated during chilldown. At the end of the chilldown, with 100 percent liquid hydrogen in the pump, the speed was relatively high. The kinetic energy in the rotor caused the pump discharge pressure to increase, thereby pumping more fluid to the turbine. This fluid gained additional energy from the heat capacity in the heat exchanger, enabling the turbine to overcome the pump load which had caused a momentary speed decrease. The turbopump speed then increased until power saturation was reached. The longer the delay in opening the TPCV after the PSOV is opened, the lower the speed at the end of chilldown. Hence, less energy will be stored in the rotor for starting the "bootstrap" operation. The sooner the TPCV is actuated the faster the pressure will rise in the pump and the higher the peak will be. If TPCV actuation is delayed until after chilldown the model indicates that "bootstrap" operation will take place.

Figures 7 and 8 show the effect of extending pump chilldown beyond the computed time of 17 seconds. In the first transient which is shown in Figure 7, the pump chilldown time is 68 seconds. At the end of chilldown, the chamber temperature is 270°R. The TPCV is opened at 68 seconds when chilldown is completed. The peak values of pump speed, pump flow rate, and pump discharge pressure reflect the decreased heat content due to the increased chilldown time. The peak value of pump discharge pressure is 338 psia whereas the peak value was 470 psia when the chill-down time was 17 seconds.

Figure 8 shows transient characteristics of system parameters when the chilldown time is extended to over 90 seconds. At 97-1/2 seconds the chamber temperature has dropped to 150°R. The turbopump description at turbine inlet temperatures this low are not accurate enough to examine a bootstrap attempt. However, it is doubtful that enough heat is left in the core material to obtain pump characteristics of

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magnitude and duration that are at all similar to those shown in the first three traces of Figure 4. In any case, extending pump chillover times to periods significantly greater than 90 seconds would not be possible at 70-psia tank pressure even with the turbine inlet line orifice removed.

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A

FIGURE 7

68 Second Chillo down on CFDTIS with Diluent Bleed Off 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillo down is Complete

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B

FIGURE 7 (cont.)

68 Second Chillydown on CFDTS with Diluent Bleed Off 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillydown is Complete

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C

FIGURE 7 (cont.)

68 Second Chillover on CFDTs with Diluent Bleed Off 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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FIGURE 7 (cont.)

68 Second Chillover on CFDTIS with Diluent Bleed Off 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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FIGURE 7 (cont.)

68 Second Chillo down on CFDTS with Diluent Bleed Off 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillo down is Complete

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FIGURE 8

100 Second Chillo down on CFDTS with Diluent Bleed Off
8 psia Back Pressure 70 psia Tank Pressure

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F. DILUENT BLEED EFFECTS

The control of diluent bleed during CFDTS will be accomplished through closure of a valve in the diluent bleed line. This will enable CFDTS startup without diluent bleed and the subsequent degradation of flow through the diluent bleed port located in the dome plenum of the CFDTS engine simulator. Several runs involving the low TPCV angles make the effect of a change in the diluent bleed flow rate more critical because of the lowered system start capabilities. The results of these runs, indicated that the system performance was not improved significantly by eliminating the diluent bleed. Figure 9 shows the important system parameters during another transient using the same activation of the TPCV as in Figure 1 but with the diluent bleed off. The effect of closing the diluent bleed valve caused no perceptible change in the values.

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A

FIGURE 9

B

CFDIS Start-up with Diluent Bleed Off 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 30° when Pump Chillo down is Complete
and is Programmed to 45° at 1.5°/sec

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G. NOZZLE BY-PASS FLOW

A by-pass system around the nozzle is being investigated in order to increase the engine system capability to bootstrap.

Figure 10 showed the response of the CFDTS to a 90° step of the TPCV when 25% of the flow is by-passed around the nozzle coolant tubes. The by-pass configuration consists of a tubing arrangement which splits flow downstream of the pump discharge and dumps into the reflector inlet plenum.

The peak values of pump speed, pump flow rate, and pump discharge pressure are quite high due to the low resistance to flow of the nozzle flow by-pass configuration. These parameters decrease from their peaks quickly because heat is extracted from the engine components at a high rate. Figure 11 shows parameters during the CFDTS start-up with a 40% flow by-pass configuration. Peak values and rates of decrease from peak values are higher in the increased flow by-pass than in the case of the 25% flow by-pass.

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A

B

FIGURE 10

CFDTS Start-up with Diluent Bleed On and 25% Nozzle Flow By-Passed
 8 psia Back Pressure 70 psia Tank Pressure
 TPCV Steps to 90° when Pump Chillover is Complete

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A

FIGURE 11

B

CFDIS Start-up with Diluent Bleed On and 40% Nozzle Flow By-Passed
8 psia Back Pressure 70 psia Tank Pressure
TPCV Steps to 90° when Pump Chilloidn is Complete

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H. SUBSTITUTION OF ALUMINUM-JACKETED NOZZLE

The aluminum-jacketed, NRX-A nozzle has been used in place of the X-E, U-tube type stainless steel nozzle. The significant changes are nozzle weight and coolant tube throat area. The NRX-A nozzle weighs 700 lbs and has a coolant tube throat area of 8.47 in^2 . The effect of a possible change from the X-E nozzle to the aluminum-jacketed NRX-A nozzle during the described test series was investigated. The results shown in Figure 12 (compared to Figure 4) indicate that the nozzle configuration does not have a large overall effect on the CFDTS startup characteristics.

The only difference in the transient response of the system appears to be in the value of coolant flow rates. The flow peaked at about 45 lbs/sec as in the case of the X-E nozzle configuration.

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A

B

FIGURE 12

CFDTS Start-up with Aluminum Jacketed Nozzle 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Childown is Complete

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TIME - SECONDS

TIME - SECONDS

C

FIGURE 12 (cont.)

D

CFDTS Start-up with Aluminum Jacketed Nozzle 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillover is Complete

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E

FIGURE 12 (cont.)

CFDTS Start-up with Aluminum Jacketed Nozzle 8 psia Back Pressure
70 psia Tank Pressure TPCV Steps to 90° when Pump Chillo down is Complete

V. DIGITAL COMPUTER INVESTIGATIONS

The following studies were performed on the digital computer simulation of the CFDTS system. (All of the runs were made with a pre-chilled pump.)

A. DETERMINATION OF THE EFFECTS OF TANK PRESSURE ON STARTS WITH A WET PUMP

The difficulty in determining the minimum tank pressure for starts resulted from the lack of good low speed turbopump data. Data on the June test of the Mod III, Mark III, turbopump indicated that the normalized turbopump maps were not adequate in representing low speed performance. Also, low speed performance runs entered design areas that were not normal to high speed operation and were therefore not well defined.

Using a pre-chilled pump, tank pressures of 100, 90, 80, 70, 50 and 40-psia were used in order to determine the effects of tank pressures on the engine performance. Figures 13 and 14 show plots for tank pressures of 50- and 70-psia. The configurations were as follows:

1. Small throat U-tube nozzle
2. Mod III Mark IV Turbopump
3. TPCV gate position set at 48%
4. Diluent valve fully opened
5. Tank temperature at 37°R
6. Ambient air pressure of 12.8 psia
7. Wet pump start

In order to achieve reasonable rates of acceleration in the area the TPA was designed for operation, a minimum of 45-psia tank pressure appears necessary. Lower tank pressures give erroneous results because of the low values of Q/N that occur.

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A

B

C

D

Figure 13

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E

Figure 13 (cont.)

A

B

Figure 14

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C

D

E

F

Figure 14 (cont.)

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B. EFFECTS OF BACK PRESSURE

The effects of back pressure to achieve an engine start were investigated within the constraints of present TPA data. The various back pressures are of interest because of the different test cells in which engine development systems will be tested. The indications are that the lower the back pressure the lower the tank pressure required. Comparative numbers are shown below:

<u>Back Pressure</u>	<u>Tank Pressure</u>
1 psia	35 psia
8 psia	45 psia
15 psia	55 psia

C. COMPARISON OF LARGE AND SMALL THROAT U-TUBE NOZZLES

A comparison was made of the acceleration rate of the large and small throat U-tube nozzles. The small-throat U-tubes were shown in Figures 13 and 14. Similar runs were made on a large U-tube nozzle. These results are shown in Figures 15 and 16. The conclusion reached from these runs is that the small-throat U-tube nozzle will accelerate faster although the difference is not significant. The apparent reason is that heat transfer in the nozzle is quicker for the small-throat U-tube nozzle engine system. The pump discharge pressure was the only parameter significantly effected by changing from the large-throat U-tube nozzle to the small-throat U-tube nozzle. Pump discharge pressure was about 15% greater in the latter at the same flow rate.

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A

B

C

D

Figure 15

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E

F

Figure 15 (cont.)

A

B

Figure 16

C

D

E

F

Figure 16 (cont.)

D. TPCV GATE POSITION WITH TURBINE INLET ORIFICE

The turbine inlet line orifice changes the operating point on the TPCV to a more desirable point and reduces the actuator requirements. However, it also restricts the performance of the engine. In order to study the effect of the orifice on engine performance, a run was made comparable with Figure 16 but the TPCV opened to 100% instead of 48%. Turbine speed with the higher TPCV opening peaked at 9700 rpm as compared to 9000 rpm with a 48% opening. Figure 17 presents the run at 100%.

A

B

C

D

E

Figure 17