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LH_2 AND LO_2 TURBOPUMP ASSEMBLIES PROGRAM TEST PLAN AND FACILITIES REVIEW MILESTONE REPORT

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NAS 8-27794

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APPENDIX

REVISED TPA TEST PLAN (1 AUGUST 1972)

The NAS 8-27794 TPA Test Plan is revised and amended in the following document.

This report includes the following:

1. Revised LO_2 TPA Development Test Matrix
2. Revised LH_2 TPA Development Test Matrix
3. LO_2 and LH_2 Acceptance Test Matrix.

LO_2 TPA TEST MATRIX (REVISED 1 AUGUST 1972)

The objective of the liquid oxygen turbopump assembly development test program is to operate the unit over the entire operating range defined by the work statement, to demonstrate mechanical integrity, map pump and turbine performance, and obtain heat soakback data. The basic program will include 50 starts for a total accumulated time of over 6000 sec (Table I).

Before the initiation of dynamic testing, a static checkout of the turbopump will be conducted. The pump will be chilled with liquid oxygen to check instrumentation at cryogenic temperatures and to activate the bypass and discharge valves and the turbopump lift-off seal. The following text, tables and figure describe in detail the planned test matrix. The test numbers and data points referred to in the text are given in table and figure form immediately following the narrative discussion.

The initial 10 tests will be conducted primarily to define pump hydrodynamic performance. To provide the greatest flexibility on these tests for speed control and power adjustments, ambient GH_2 will be used as turbine drive gas.

The first dynamic test will be conducted at 15,000 rpm to verify proper rotor balancing and assembly procedures. The instrumentation will be verified under dynamic conditions and the facility system resistance will be adjusted to nominal Q/N. The duration is planned for 30 sec with ambient GH_2 as turbine drive gas.

The objective of test No. 2 will be to pinpoint the location of rotor critical speeds. With the system resistance set at nominal Q/N, the turbopump will be ramped to 30,000 rpm and allowed to operate there for 5 sec. Critical speed locations will be established from accelerometer data.

On test No. 3, low speed H-Q characteristics of the pump will be established. The pump will be ramped to 12,000 rpm at nominal Q/N, then the flow will be varied between 30 and 70 gpm. A minimum of three stabilized data points will be obtained (ref Fig. 1).

A similar procedure will be followed on tests No. 4 and 5 to obtain H-Q characteristics at 22,500 rpm and 30,000 rpm, respectively. The duration of each test will be 200 sec.

In test No. 6 through 8, the suction performance of the LO_2 pump will be defined at the minimum inlet temperature of 168 deg specified in the work statement. Test No. 6 will be conducted at nominal speed and flow. The test will be started with the pump inlet pressure set high ($\sim$ 50 psig) to obtain a non-cavitating reference data. The inlet pressure will then be decreased slowly until cavitation ensues and a drop of 5 percent in the developed pressure is experienced, at which point the test will be terminated.

Tests No. 7 and 8 will be identical to test No. 6 except the flowrates will be 70 gpm and 150 gpm, respectively.

On test No. 9, hot gas testing of the turbine will be initiated. Test No. 9 will be limited to 5 sec duration at 30,000 rpm, with the inlet temperature to the turbine 2010 deg. Test No. 10 will be a repeat of test No. 9 except the duration will be extended to 200 sec. After the first two hot fire tests, the first stage wheel of the turbine will be removed to allow visual and dye penetrant inspection of the wheel and the turbine nozzle and manifold.

Test No. 11 will be a repeat of test No. 10 to verify proper reassembly after the inspection.

In test No. 12 through 15, a turbine power map over the specified operating range will be developed. After initial adjustments, each test will be conducted at a constant power level; the operating point will be changed only by varying the pump discharge valve resistance. For test No. 12, the system resistance will be set at point No. 3 of the H-Q map; the discharge valve setting will be varied during the test to increase pump delivered flow until Point A on the H-Q map is reached.

For test No. 13, the system will be set for operating at Point 2 on the H-Q map, then the valve setting will be adjusted to decrease the flowrate until Point B is reached and subsequently the pump flow will be increased until the developed pressure by the pump drops to 1100 psi.

For test No. 14, the system resistance will be set for Point 1 on the H-Q map and the valve will be closed subsequently until Point C on the map is reached; then the procedure will be reversed and the discharge flow increased until the developed pressure by the pump drops to 1100 psi.

For test No. 15, the system resistance and turbine power will be set to operate at Point 4 of the H-Q map, at the maximum flow point of the map.

The dead head start capability of the pump will be explored in test No. 16 through 18. On test No. 16 the start will be initiated with the discharge valve closed and bypass valve set to obtain 50 percent of nominal Q/N. When the discharge pressure reaches 1600 psi, automatic sequencing will open the discharge valve and simultaneously close the bypass valve to increase the flow to the nominal level. On test No. 17, the same procedure will be repeated except the system resistance for the bypass valve will be set at 25 percent of nominal Q/N, respectively. On test No. 18 the bypass valve will be completely closed.

Test No. 19 through 50 will be conducted in an altitude environment to determine the heat soakback characteristics of the turbopump. Before the initial dynamic test at altitude, a static chill test will be conducted to estabish altitude facility heat transfer characteristics. The pump will be filled with LOX and allowed to soak for 4 hr during which temperature data will be taken.

Test No. 19, the initial dynamic test in the altitude facility, will be conducted at nominal speed and flow using ambient GH_2 as turbine drive gas. Its duration will be 200 sec and it will be followed by a 4 hr soak during which temperature data will be recorded.

Test No. 20 will be a repeat of No. 19 except combustion products of the gas generator will be used to drive the turbine with the inlet temperature at 2010 deg.

Test No. 21 through 23 will be conducted as an integrated series in the altitude chamber to establish the thermal start characteristics of the turbopump. Each test will be at nominal speed and pump flow and of 200 sec duration. Test 21 will be followed by a 20 minute soak which will be followed immediately by test No. 22. After test No. 22, the turbopump will be allowed to soak again for 40 min after which test No. 23 will be conducted. Test No. 23 will be followed by a 60 min soak. Throughout the series, material skin temperatures and turbopump internal temperatures will be recorded.

In test No. 24 through 50, the minimum duration cycling capability of the turbopump will be demonstrated. Each test will be of 2 sec duration to be followed by 5 sec down time.

LH_2 TPA TEST MATRIX (REVISED 1 AUGUST 1972)

The test program planned for the LH_2 TPA follows the sequence described earlier for the LO_2 TPA. The LH_2 turbopump will be tested over the entire operating range defined by the work statement, to demonstrate mechanical integrity, map pump and turbine performance, and obtain heat soakback data. The basic program will include 50 starts for a total accumulated time of over 6000 sec (Table II).

Before dynamic testing, a static checkout of the turbopump will be conducted. The pump will be chilled with liquid hydrogen to check instrumentation at cryogenic temperatures and to activate the bypass and discharge valves and the turbopump lift-off seal. The following text, tables and figures describe in detail the planned test matrix. The test numbers and data points referred to in the text are given in table and figure form immediately following the narrative discussion.

The initial 10 tests will be conducted primarily to define pump hydrodynamic performance. To provide the greatest flexibility on these tests for speed control and power adjustments, ambient GH_2 will be used as turbine propellant.

The first dynamic test will be conducted at 12,000 rpm to verify proper rotor balancing and assembly procedures. The instrumentation will be verified under dynamic conditions and the facility system resistance will be adjusted to nominal Q/N. The duration is planned for 30 sec with ambient GH_2 as turbine drive gas.

The objective of test No. 2 will be to pinpoint the location of rotor critical speeds. With the system resistance set at nominal Q/N, the rotor speed will be stepped to 50,000 rpm at which point the overspeed trip will terminate the test. Critical speed locations will be established from accelerometer and Bently data.

On test No. 3, H-Q characteristics of the pump will be established at 75 percent of nominal speed. The pump will be ramped to 45,000 rpm at nominal Q/N, then the flow will be varied between 200 and 500 gpm, maintaining speed approximately constant by adjusting turbine power (ref Fig. 2).

A similar procedure will be followed on tests No. 4 and 5 to obtain H-Q characteristics at 52,500 rpm and 60,000 rpm, respectively. The duration of each test will be 200 sec.

In test No. 6 through 8, the suction performance of the LH_2 pump will be defined at the minimum inlet temperature of 37.4R specified in the work statement. Test No. 6 will be conducted at nominal speed and flow. The test will be started with the pump inlet pressure set high (~ 50 psig) to obtain non-cavitating reference data. The inlet pressure will then be decreased slowly until cavitation ensues and a drop of 5 percent in the developed pressure is experienced, at which point the test will be terminated.

Test No. 7 and 8 will be identical to test No. 6 except the flowrates will be 250 gpm and 650 gpm, respectively.

On test No. 9, hot gas testing of the turbine will be initiated. Test No. 9 will be limited to 5 sec duration at 45,000 rpm, with the inlet temperature to the turbine 2010R. Test No. 10 will be a repeat of test No. 9 except the duration will be extended to 200 sec. After the first two hot fire tests, the turbine wheels will be removed to allow visual and dye penetrant inspection of the wheel and the turbine nozzle and manifold.

On test No. 11 a full speed (60,000 rpm) hot fire test will be conducted for 300 sec at nominal Q/N.

In test No. 12 through 15, a turbine power map over the specified operating range will be developed. After initial adjustments, each test will be conducted at a constant power level; the operating point will be changed only by varying the pump discharge valve resistance. For test No. 12, the system resistance will be set at 130 percent of nominal Q/N. Then the discharge valve will be opened until a Q/N value of 140 percent of nominal will be reached.

Test No. 13 will be conducted at 60,000 rpm and at 140 percent of nominal Q/N, corresponding to a delivered flowrate of 650 gpm.

For test No. 14, the facility resistances will be set at 110 percent of nominal. The test will be initiated at 60,000 rpm and 500 gpm. Then the discharge valve will be opened until the discharge pressure drops to 1100 psig. Subsequently, the discharge valve will be closed until the discharge pressure reaches 2100 psig or the speed reaches 66,000 rpm.

On test No. 15 the system resistance will be set at 80 percent Q/N nominal and the test will be initiated at 60,000 rpm and 380 gpm. Then the discharge will be opened until the discharge pressure drops to 1100 psig. Subsequently, the discharge valve will be closed until the discharge pressure reaches 2100 psig or the speed reaches 66,000 rpm.

On test No. 15 the system resistance will be set at 80 percent Q/N nominal and the test will be initiated at 60,000 rpm and 380 gpm. Then the discharge will be opened until the discharge pressure drops to 1100 psig. Subsequently, the discharge valve will be slowly closed until the discharge pressure reaches 2100 psig or the speed reaches 66,000 rpm.

At this point, the turbine will have been operated over the entire specified power and speed range and at the required inlet temperature. The turbine wheels and stator will be removed to submit both wheels, the nozzle, and the stator to visual and penetrant inspection.

The low Q/N start capability of the LH_2 pump will be explored in Test No. 16 through 19. In test No. 16, the discharge valve will be closed on start and the bypass valve open and orificed to obtain 75 percent of nominal Q/N. When the discharge pressure reaches 1600 psig, automatic sequencing will open the discharge valve and simultaneously close the bypass valve to increase flow to the nominal level. In test No. 17 and 18, the same procedure will be repeated except the orifice for the bypass valve will be set at 50 percent and 25 percent of nominal Q/N, respectively. The bypass valve orifice setting for test No. 19 will be established based on the data obtained on the preceeding test.

Test No. 20 through 50 will be conducted in an altitude environment to determine the heat soak back characteristics of a turbopump. Before the initial dynamic test at altitude, a static chill test will be conducted to establish facility heat transfer characteristics. The pump will be filled with LH_2 and allowed to soak for 4 hr during which temperature data will be recorded.

The initial dynamic test in the altitude facility, test No. 20, will be conducted at nominal speed and pump flow using ambient gaseous GH_2 as turbine drive gas. Its duration will be 200 sec and it will be followed by a 4 hr soak during which temperature data will be taken. Test No. 21 will be a repeat of No. 20 except hot gas will be used to drive the turbine at an inlet temperature of 2010R.

Test No. 22 through 24 will be an integrated series in the altitude chamber to establish the thermal start characteristics of the turbopump. Each test will be at nominal speed and pump flow and of 200 sec duration. After test No. 22, the pump will be allowed to soak for 20 min which will be followed immediately by test No. 23. After test No. 23, the turbopump will be allowed to soak again to 40 min after which test No. 24 will be conducted. The posttest soak period after test No. 24 will be extended to 60 min. Throughout the series, materials skin temperatures and turbopump internal temperatures will be recorded.

In test No. 25 through 50, the minimum duration cycling capability of the turbopump will be demonstrated. Each test will be of 2 sec duration, separated by 5 sec down time.

LO_2 AND LH_2 ACCEPTANCE TEST MATRIX

All turbopump assemblies will be tested under hot fire conditions prior to delivery to NASA.

The Unit No. 1 LO_2 will be disassembled after development test No. 18 with 5040 sec accumulated duration. The Unit No. 1 LH_2 will be disassembled after development test No. 19 with 5632 sec accumulated duration. The turbopumps will be inspected, refurbished (if required) and reassembled. After reassembly the turbopump assemblies will be re-hot-fire tested accumulating at least 500 sec of operation on 10 operating cycles with no between run servicing. The acceptance test matrix is shown in Table III.

If the disassembly of the LO_2 and LH_2 Units No. 1 reveals no discrepancies and if the development testing on Unit No. 2 is completely satisfactory, the Unit No. 2 LO_2 and LH_2 turbopump assemblies will not be disassembled after the development test series. The Unit No. 2 LO_2 TPA will accumulate 1054 sec of time on 32 test cycles. The Unit No. 2 LH_2 TPA will accumulate 1052 sec of time on 31 test cycles. Predicated upon the successful completion of this test effort with no anominalies, no additional acceptance test effort will be conducted prior to their delivery to NASA.

Table 1. LO_2 TPA Test Matrix

Test No.	Test Day	Objective	Dur. sec	Test Conditions & Procedure
Pretest		Check system integrity, check chilldown characteristics, check bleed capability	-	Full instrumentation, normal tanking operation, bleed checkout, no gas generator operation, activate bypass and discharge valves
1	1	Set facility to nom. Q/N, instrumentation check, mechanical integrity, rotor balance and assembly check	30	Ramp to 15,000 rpm and hold, ambient GH_2 turbine drive gas
2	2	Locate critical speed	5	Ramp to full speed (30,000 rpm) (nominal Q/N), ambient GH_2 turbine drive gas
3	3	Low speed H-Q	200	Ramp to 12,000 rpm at nominal Q/N, vary Q at constant N between 30 and 70 gpm, minimum of 3 stabilized data points, ambient GH_2 turbine drive gas
4	3	H-Q at 75% N_{nom}	200	Ramp to 22,500 rpm at nominal Q/N, vary Q at constant N between 45 and 105 gpm, minimum of 5 stabilized data points, ambient GH_2 turbine drive
5	4	H-Q at nominal N	200	Ramp to 30,000 rpm at nominal Q/N, vary Q at constant N between 60 and 140 gpm, minimum of 5 stabilized data points, ambient GH_2 turbine drive gas
6	5	Cavitation performance	200	Pump inlet temperature 168R, nominal Q, nominal speed, decrease inlet pressure until discharge pressure decreases 5%, ambient GH_2 turbine drive gas

Table 1 (Continued)

Test No.	Test Day	Objective	Dur, sec	Test Conditions & Procedure
7	5	Cavitation performance	200	Same as test #6, except Q=70 gpm, N=30,000
8	5	Cavitation performance	200	Same as test #6, except Q=150 gpm, N=30,000
9	6	Hot gas checkout	5	Ramp to nominal speed (30,000 rpm), turbine inlet temperature = 2010R
10	6	Hot gas checkout	200	Nominal speed run (30,000 rpm), turbine inlet temperature = 2010R
Inspection		Inspect turbine blades, nozzles and discs	-	Remove turbine wheel for inspection
11	7	Hot gas checkout	300	Same as test #10
12	7	Map turbine power, demonstrate capability of meeting system operating requirements	300	Set system for operation at 30,000 rpm and ~125 gpm (pt 3 on chart), ramp to pt 3, follow gas generator power curve to pt A
13	8	Map turbine power, demonstrate capability of meeting system operating requirements	400	Set system for operation at 30,000 rpm and ~108 gpm (pt 2 on chart), ramp to pt 2, follow constant GG power curve to pt B and then to 1100 psig ΔP
14	9	Map turbine power, demonstrate capability of meeting system operating requirements	400	Set system for operation at 30,000 rpm and ~82 gpm (pt 1 on chart), ramp to pt 1; then follow constant GG power curve to pt C and then to 1100 psig ΔP.
15	9	Map turbine power, demonstrate capability of meeting system operating requirements	500	Set system for operation at 30,000 rpm and ~145 gpm (pt 4 on chart), ramp to pt 4
16	10	Mechanical integrity and life demo. low Q/N start capability, extended duration capability	600	Close discharge valve, set bypass valve to obtain Q/N 50%, at 1600 p_d, open discharge valve

Table 1 (Continued)

Test No.	Test Day	Objective	Dur, sec	Test Conditions & Procedure
17	10	Mechanical integrity and life demo. low Q/N start capability, extended duration capability	600	Same as Test #16, except set Q/N 25%
18	11	Mechanical integrity and life demo. low Q/N start capability, extended duration capability	600	Same as Test #16, except bypass closed
UNIT #1 REMOVED AT THIS POINT WITH 5040 SEC ACCUM DURATION				
Pretest		Establish altitude facility characteristics	-	*Altitude facility, chill T/P and let soak 4 hr, record temperature data, install Unit #2
19	12	Determine thermal resistances in turbopump	200	*Altitude facility, ramp to 30,000 rpm at nominal Q/N, ambient GH_2 turbine drive gas, soak 4 hr after test, record temperature data
20	13	Determine thermal resistances in turbopump	200	*Altitude facility, ramp to 30,000 rpm at nominal Q/N, turbine inlet temperature = 2010R, soak 4 hr after test, record temperature data
21-23	14	Determine thermal start characteristics	600	*Same as test #20, soak 20 min, restart, soak 40 min, restart, soak 60 min, record temperature data
24-50	15	Determine minimum duration cycling capability	54	*Same as test #20; 2 sec on, 5 sec off

* Altitude facility

APS OXIDIZER PUMP

ESTIMATED PERFORMANCE

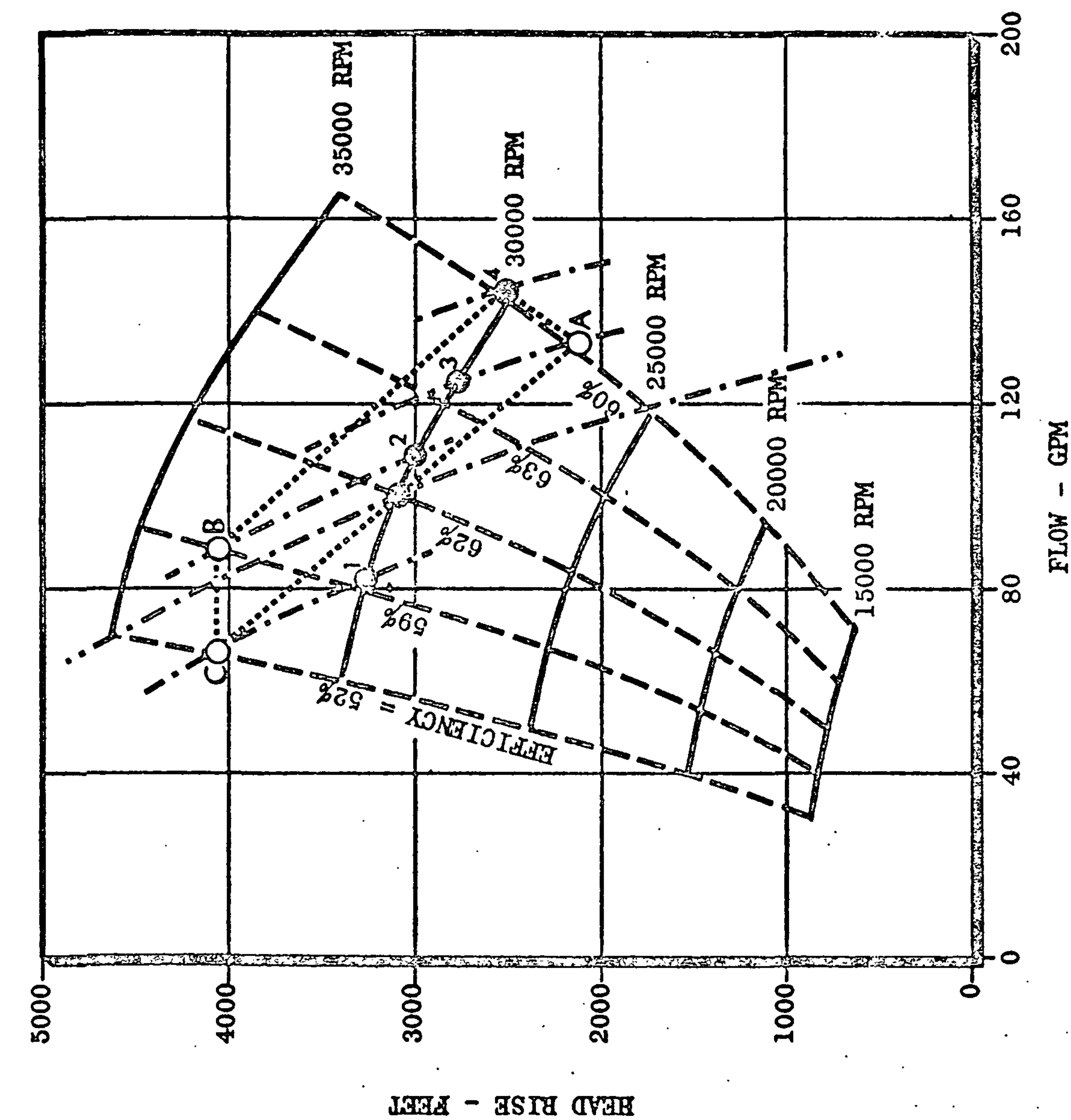

Figure 1

Table II. LH_2 TPA Test Matrix

Test No.	Test Day	Objective	Dur, sec	Test Conditions & Procedure
Pretest	1	System integrity, chill-down characteristics, bleed capability	-	Verify all instrumentation, no GG operation, normal tanking operation, bleed checkout, lift-off seal checkout, activate bypass and discharge valves
1	1	Instrumentation checkout, rotor balance check, assembly check, set facility to nominal Q/N	30	Ambient GH_2 turbine drive, set discharge to calculated position for Q/N nom. ramp to 12,000 rpm, adjust discharge valve to Q/N nominal, operate for 30 sec total
2	2	Locate rotor criticals	1.5	Prepressurize turbine GH_2 source to level required for 60,000 rpm, set O/S trip to 45,000 rpm, open gas generator GH_2 valve
3	3	H-Q test at 45,000 rpm	200	Ambient GH_2 turbine drive, set discharge at Q/N nominal, step to 45,000 rpm, vary Q from 200 to 500 gpm at constant N
4	4	H-Q test at 52,500 rpm	200	Ambient GH_2 turbine drive, set discharge at Q/N nominal, step to 52,500 rpm, vary Q from 220 to 550 gpm at constant N
5	4	H-Q test at 60,000 rpm	200	Ambient GH_2 turbine drive, step to 45,000 rpm, ramp to 60,000 rpm at Q/N nominal, vary Q from 250 to 650 gpm at constant N
6	5	Cavitation performance at minimum T_s	200	Ambient GH_2 turbine drive, pump inlet temperature = 37.4R, step to 60,000 rpm at $(Q/N)_{nom}$, maintain Q-N constant, decrease P_s until ΔH = 5% and cut
7	5	Cavitation performance at minimum T_s	200	As above, except Q=250 gpm

TABLE II (Continued)

Test No.	Test Day	Objective	Dur, sec	Test Conditions & Procedure
8	5	Cavitation performance at minimum T_s	200	As above, except Q=650 gpm
9	6	Turbine hot gas checkout	5	t_1 = 1500F, Q/N = nominal, step to 45,000 rpm
10	6	Steady-state hot gas test, planned inspection	200	Same as Test #9, remove turbine wheels and inspect, inspect nozzle
11	7	Full speed HF operation	300	t_1 = 1550F, Q/N = nominal, step to 60,000 rpm
12	7	Map turbine power	300	t_1 = 1550F, Q/N = 1.3 $(Q/N)_{nom}$, step to 60,000 rpm (580 gpm), open discharge valve to 1.4 $(Q/N)_{nom}$
13	8	Map turbine power	300	t_1 = 1550F, $(Q/N)_{start}$ = 1.4 $(Q/N)_{nom}$, step to 60,000 rpm (650 gpm)
14	9	Map turbine power	400	t_1 = 1500F $(Q/N)_{start}$ = 1.1 $(Q/N)_{nom}$, step to 60,000 rpm (500 gpm), open discharge valve until P = 1100 psig, close discharge valve until: (N = 66,000 rpm, ΔP = 2100 psi)
15	9	Map turbine power	500	t_1 = 1550F, $(Q/N)_{start}$ = 0.8 $(Q/N)_{nom}$, step to 60,000 rpm (380 gpm), open discharge valve until P = 1100 psig, close discharge valve until: (N = 66,000 rpm, ΔP = 2100 psi)
Inspection	-	Planned inspection	-	Remove turbine wheels and inspect, inspect nozzle
16	10	Demo. low Q/N start, demo. start and c/o seq, demo long duration capability	600	Hot gas turbine drive, start with bypass Q/N = 0.75 $(Q/N)_{nom}$, at P_d = 1600 psig: (open discharge $(Q/N)_{nom}$, close bypass valve)
17	10	Same as Test #47	600	Same as Test #47, except bypass Q/N = 0.5 $(Q/N)_{nom}$

Table II (Continued)

Test No.	Test Day	Objective	Dur, sec	Test Conditions & Procedure
18	11	Same as Test #47	600	Same as Test #47, except: bypass $Q/N = 0.25\ (Q/N)_{nom}$
19	11	Same as Test #47	600	Same as Test #47, except: bypass Q/N = TBD $(Q/N)_{nom}$
UNIT #1 REMOVED AT THIS POINT WITH 5631.5 SEC ACCUMULATED DURATION				
Pretest	-	Establish altitude facility characteristics	-	Altitude chamber, chill T/P and soak for 4 hr, record temperatures on strip chart, install Unit No. 2
20	12	Determine thermal resistance in turbopump	200	Altitude chamber, ambient GH_2 turbine drive, N = 60,000 rpm, Q = nominal, 4-hr soak after test
21	13	Determine thermal resistance in turbopump	200	Repeat Test #19 with hot gas
22-24	14	Determine restart characteristics	200	Altitude chamber, hot gas turbine drive, N = 60,000 rpm, Q = nominal, 20 min soak
			200	Repeat Test #21, 40 min soak
			200	Repeat Test #21, 60 min soak
25-50	15	Determine minimum	52	Altitude chamber, hot gas turbine drive, N = 60,000 rpm, Q/N = nominal, 2 sec on, 5 sec off

APS LH_2 PUMP
PREDICTED PERFORMANCE MAP

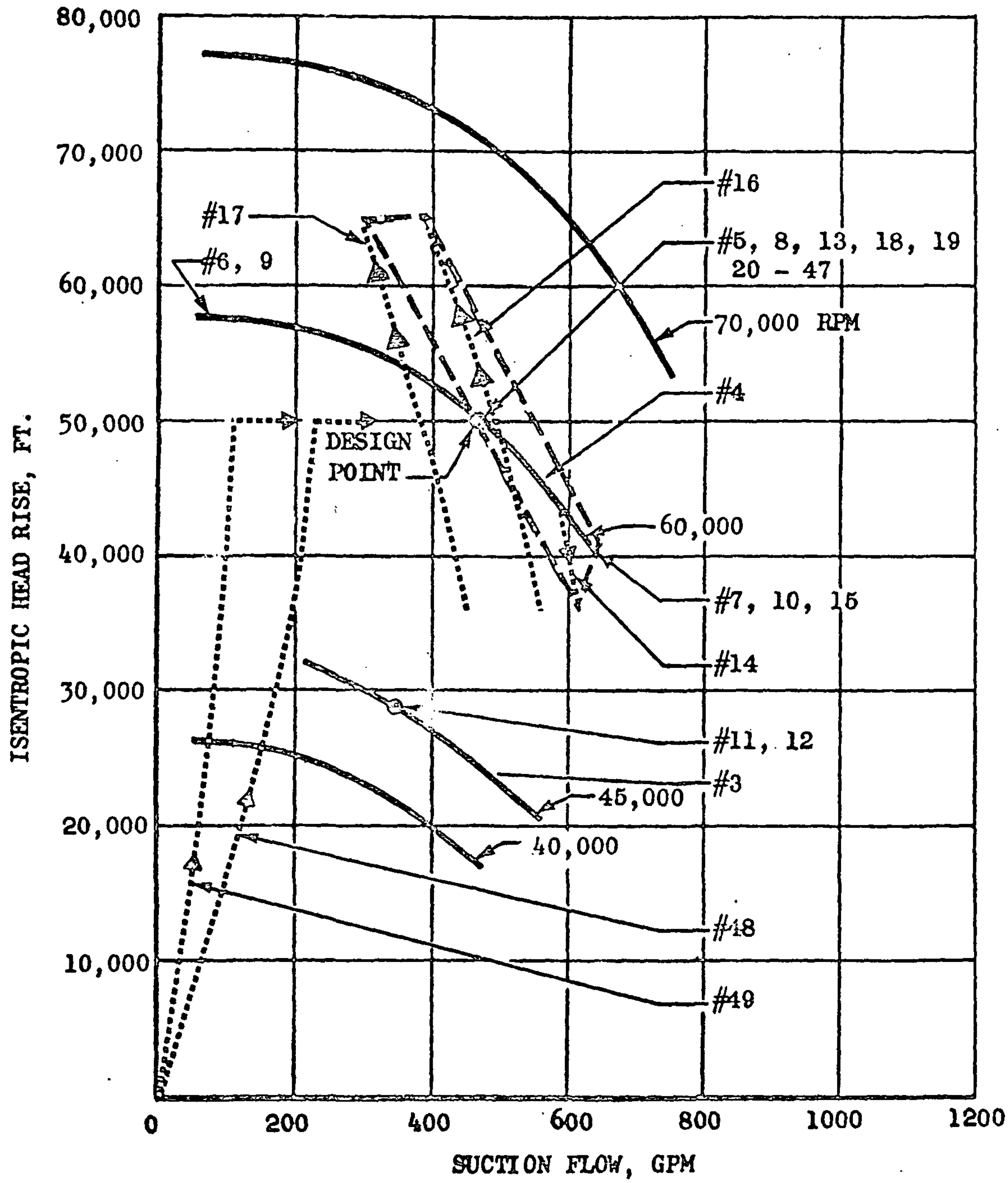

Figure 2

Table III. LO_2 & LH_2 Acceptance Test Matrix

Test No.	Test Day	Objective	Dur, sec	Test Conditions & Procedure
1	1	Verify correct assembly	5	Nominal speed, turbine inlet temperature 2010R
2	2	Verify high speed operation	100	Highest speed (high head, low flowrate corner of pump map), selected start bypass rate,
3	2	Verify high flowrate operation	100	High flowrate corner of pump map
4-10	2	Verify cyclic operation	50 ea	Nominal speed, nominal head and flow

10 TESTS TOTAL

555 SEC TOTAL