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SUBJECT: Preliminary Turbopump Test Facility Requirements
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Enclosure: (1) Report N4210-R-71-049, "Preliminary Turbopump Test
Facility Requirements," dated 7 March 1971

Enclosure (1) defines the turbopump test facility requirements. This document was prepared to make available, in one place, all the requirements previously established to support turbopump testing. These requirements are to be utilized to complete the planning to satisfy the current SNSO guidelines.

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PRELIMINARY TURBOPUMP TEST FACILITY REQUIREMENTS

(To Satisfy SNSO Guidelines)

N4210-R-70-049

7 March 1971

F. X. Andrews

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I. PURPOSE OF DOCUMENT

The purpose of this document is to provide the requirements that have been established to date for the test facility operations needed to support and conduct turbopump testing at the NRDS. Most of the requirements in this document have been previously transmitted to, or discussed with, Test Operations and NRTO management.

These requirements are in agreement with the current planning of the ANSC Turbomachinery Section. The planning for the test facility (NRDS) is not complete at this time but it does not include provisions to satisfy all of these requirements. Any requirements which cannot be met at the NRDS should be established and made known at the earliest possible date so other provisions can be made to accomplish the work.

II. SUMMARY

This document contains the information required to do the planning and conceptual design work to support turbopump testing at Test Cell "C".

Maintaining the facility costs at a minimum should be kept in mind at all times due to the severe reduction in resources for the NERVA Program.

The current planning of the ANSC Turbomachinery Section assumes that the assembly, testing, and disassembly of the turbopump will be accomplished at the NRDS with NRTO personnel. It also assumes the data reduction including a performance program will be done at the NRDS by NRTO personnel. The details of these activities are presented in this document.

The first assembly effort will start in April 1972 and the first test will occur in June-July 1972.

III. SCHEDULE

The current planning requires the first turbopump test to occur during June-July 1972. The ANSC Turbomachinery Section planning currently shows the following events occurring prior to the end of September 1972:

Turbopump S/N 001

Assembly	April-May 1972
Test	June-July 1972
Disassembly	August-September 1972

Turbopump S/N 002

Assembly	June-July 1972
Test	August-September 1972

IV. FLOW SYSTEM

The required flow schematic for turbopump testing in Test Cell "C" is shown in Figure 1. Liquid hydrogen should be provided to the pump from Dewar 1 or 2. The pump inlet line must contain a fluid conditioner as well as provisions to conduct chilldown tests. Valves OBV-1 and C-1 allow the turbopump to be isolated while the facility is being chilled down through valves OBV-2 and C-2. During the chilldown of the pump, low flow rates (zero to five pounds per second) can be measured by diverting suction flow through valve ACV-1 and measuring the flow through a turbine type flowmeter, F-1.

The pump discharge line has a turbine type flowmeter, F-2, to measure pump discharge flow rate. A portion of the pump discharge flow is diverted to a catch dewar or the flare system through valve ACV-2. Another turbine

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FLOW SCHEMATIC

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type flowmeter, F-3, is utilized to measure the flow supplied to the turbine after bootstrap operation has been established. Flowmeter F-3 may also be used in conjunction with flowmeter F-2 to establish the flow being discharged through valve ACV-2.

The existing TES will be utilized to provide the required energy input to the turbine drive fluid. The temperature conditioning of the turbine drive gas will be accomplished by bypassing the TES with LH_2 through valve ACV-3. Initial turbine drive gas will be provided from the existing tank farm through valve H-53. Check valves C-3 and HC-2043 prohibit turbine drive gas from flowing into the pump discharge system during startup. Vent valves OBV-3 and H-142 are used to chilldown the facility prior to turbopump operation.

Turbine inlet pressure is controlled by valve ACV-4. The turbine flow rate during initial operation is measured using flow venturi F-4. Valve OBV-4 is required to shut off turbine flow in the event of a turbopump or system malfunction. The turbine back pressure is controlled by valve ACV-5.

V. OPERATING CONDITIONS

While test plans have not been established for the turbopumps at the present time, most of the required operating conditions are known.

The chilldown characteristics of the turbopump must be established. This includes investigation of the ability of the pump to operate (produce a head rise) with the two-phase hydrogen that occurs during the initial portion of the chilldown sequence.

Suction performance of the pump must be established as well as the effects on the turbopump resulting from its operation with two-phase hydrogen present in the inducer section of the pump.

Turbopump performance at the engine operating points must be established. The NETAP steady state data for the 1137400/Revision E Reference Engine was published in Reference (a). The turbopump conditions at the Engine Operating Points are shown in Table I.

It will also be necessary to evaluate the performance of the turbopump at its Structural Design Points. The portion of the pump map which contain these points is shown in Figure 2. The facility must be capable of operating at all conditions shown inside the turbopump structural design limit.

There will be no requirement to investigate turbopump performance during the transients which result from corrective action taken following a malfunction of a component in the Propellant Feed System.

VI. TEST ARTICLE DESCRIPTION

The test article will consist only of the turbopump. A cross section of the turbopump is shown in Figure 3.

The turbopump consists of a two-stage centrifugal pump driven by a two-stage turbine. The first stage impeller is preceded by an inducer operating at main shaft speed. The inside diameter at the pump-to-inlet duct interface is 9.5 inches, reducing to 6.9 inches at the inducer inlet. Pump impellers are arranged back-to-front with an internal continuous vaned crossover between the first and second stage impellers. The second stage impeller discharges into a vaned diffuser succeeded by a scroll with a single 4.65 inch (inside diameter) discharge duct. Pressure rise of the pump at the nominal

TABLE I

TURBOPUMP CONDITIONS AT THE ENGINE OPERATING POINTSSTART OF LIFE

	NORMAL				MALFUNCTION				NORMAL THROTTLING				MALFUNCTION THROTTLING			
	$\dot{W}$	P	T	ρ	$\dot{W}$	P	T	ρ	$\dot{W}$	P	T	ρ	$\dot{W}$	P	T	ρ
Pump Inlet	46.2	21.8	36.4	4.4220	73.9	23.6	36.4	4.4231	27.7	21.9	36.4	4.4222	55.4	23.8	35.4	4.4233
Pump Outlet	45.9	1431	55.2	4.4786	73.4	1337	54.7	4.4517	27.4	1007	52.1	4.3770	54.9	1016	49.9	4.4517
Turbine Inlet	42.3	1088	276	0.7018	44.2	1064	293	0.6471	21.7	628	315	0.3649	28.5	732	312	0.4282
Turbine Outlet	42.5	733	252	0.5286	44.8	606	259	0.4327	22.0	457	293	0.2876	28.9	462	282	0.3039
Shaft Speed	24239 rpm				26544 rpm				19595 rpm				22148 rpm			

END OF LIFE

Pump Inlet	46.2	27.8	40.6	4.2414	73.9	29.6	40.6	4.2428	27.7	27.9	40.6	4.2403	55.4	29.8	40.6	4.2430
Pump Outlet	45.9	1431	60.2	4.3169	73.4	1342	60.1	4.2764	27.5	953	55.5	4.2271	55.0	994	54.5	4.2893
Turbine Inlet	41.9	1098	287	0.6817	44.3	1079	302	0.6343	21.1	626	323	0.3538	28.2	736	322	0.4176
Turbine Outlet	42.2	739	262	0.5110	44.8	609	266	0.4224	21.3	460	301	0.2814	28.6	465	290	0.2950
Shaft Speed	24738 rpm				27275 rpm				19598 rpm				22488 rpm			

Units: $\dot{W}$ = lb/sec
P = psia
T = °R
 ρ = lb/ft³

FIGURE 2

FIGURE 3

design flow of 56 lb/sec is approximately 1600 psi with a shaft speed of 27,000 rpm. The full flow turbine is supplied GH_2 at approximately 280°R with an overall pressure ratio of about 1.5. The turbine inlet manifold configuration is of the torus type with a 7.2 inch (inside diameter) inlet duct. Discharge is through a 90° vaned elbow with an exit inside diameter of 7.25 inches.

The turbopump rotor system is supported by two sets of preloaded 65mm duplex ball bearings. One set of bearings is located between the first and second stage impellers, with the other set being located between the second stage impeller and the overhung turbine. Axial thrust of the rotor system is compensated by a self-acting balancer at speeds above, approximately, 8000 rpm. At speeds below 8000 rpm, axial thrust is absorbed by the aft bearing set. The balancer bleeds flow from the discharge of the second stage impeller and returns it to the back shroud area of the first stage impeller.

The turbopump has an overall length of approximately 39 inches and a maximum diameter of approximately 30 inches.

The preliminary computed weight of the turbopump is 770 pounds. This assumes that the rotor is fabricated from titanium, and the pump and turbine housings are of 310 stainless steel.

The size and location of the turbopump-facility interfaces are shown in Figure 4.

DUCT ID AT INTERFACES:

PUMP INLET	9.50
PUMP DISCHARGE	4.65
TURBINE INLET	7.188
TURBINE EXHAUST	7.25

TURBOPUMP INTERFACE INFORMATION

VII. TEST FACILITY DESCRIPTION

A. DUCTING

It is assumed that the testing will be done in the pump room at Test Cell "C". The location within the room is not obvious. Development of the empty location between the Rocketdyne and ANSC Pump Positions is somewhat more desirable than the destruction of one of the existing positions. However, if a reasonable cost savings can be made by converting one of the existing positions it should be utilized. There are currently no plans for any future use of the existing ANSC dual pump position.

In all cases spools to existing line sizes should be utilized whenever possible rather than installing new lines.

No provisions for growth capabilities to a feed system test are required.

The zero NPSP start capability previously considered as a requirement for the feed system tests is not required.

It will be necessary to utilize a fluid conditioner in the suction line (see Figure 1) to allow operation at and below zero NPSP after flow has been established.

The tank previously required for feed system testing will not be required.

Bypass lines to conduct chillover tests will be required (see Figure 1).

B. TURBOPUMP MOUNTING FRAME

The design of the turbopump mounting frame will be provided by the ANSC Turbomachinery Section. The fabrication of the frame and any detailed design package required for fabrication will be provided by NRTD.

C. TEST ARTICLE PURGE REQUIREMENTS

The turbopump does not have provision to be effectively purged by use of a sweep purge. It has been designed to utilize the planned purge sequence of the engine, which is to be several repeated cycles of alternately pressurizing and evacuating the system. This method will have to be used prior to operation of the turbopump during development testing as well as on the engine.

VII. CONTROL SYSTEM

The turbopump testing should be conducted using the remote control point.

The control function required on the analog valves shown in Figure 1 are presented in Table II.

A shutdown chain will be required capable of terminating the test if any one of a number of predetermined limits is exceeded.

During a test the operating point of the turbopump will be controlled utilizing the following controllers:

1. Pump Discharge Pressure (or Speed)
2. Pump Q/N
3. Turbine Drive Temperature
4. Turbine Back Pressure

TABLE II

CONTROL FUNCTIONS REQUIRED FOR ANALOG VALVES

VALVES	CONTROL FUNCTION	REMARKS
L-53	Tank Pressure	Existing
ACV-1	Position	
ACV-2	Position	
	Pump Q/N	
H-11, H-12 H-31, H-41	Differential Pressure	Existing
ACV-3	Position	
	Turbine Drive Temperature	
H-53	Position	Existing
	Turbine Drive Gas Pressure	Existing
ACV-4	Position	
	Pump Speed	
	Pump Discharge Pressure	
ACV-5	Position	
	Turbine Back Pressure	

The following sequence may be used to start the turbopump with the flow system shown in Figure 1:

1. Chill facility (Bypassing pump)
2. Chill turbopump in desired manner
3. Set Valve ACV-2 to result in desired pump Q/N (In "Position" Control)
4. Close Valve ACV-5
5. Set Valve ACV-4 for desired pump speed (or Pump Discharge Pressure)
6. Set Valve ACV-3 for desired turbine drive temperature
7. Set Valve H-53 for desired turbine drive gas pressure
8. Slowly Ramp Open Valve ACV-5 to desired position
9. Switch Valve ACV-2 to "Pump Q/N" control
10. Ramp up Valve ACV-4 demand
11. Close Valve H-53 (In "Position" Control)
12. Switch Valve ACV-5 to "Turbine Back Pressure" Control if desired

IX. INSTRUMENTATION

Detailed instrumentation requirements have not been established at the present time. The requirements shown in Table III represent a good estimate based on known requirements and past experience including the NERVA technology turbopump, the twin spool turbopump, the ANSC dual pump test program, and the LH₂ pump component development program. These requirements should be within the existing data channel capabilities.

TABLE III

INSTRUMENTATION

<u>TYPE</u>	<u>NUMBER</u>
Pressure	50
Delta Pressure	5
Hi Frequency Pressure	4
Temperature - RTT	30
Flow Rate	4
Speed	2
Accelerometer	6
Displacement	8
Valve Stem Position	8

With the exception of a limited number of "gold plated" channels required around the fluid conditioner, the accuracy of measurement obtainable by standard procedures in Test Cell "C" are adequate.

The speed probes, displacement probes, and approximately eight temperature probes will be supplied by the ANSC Turbomachinery Section. All other probes are to be supplied by the test facility.

The speed and displacement probes will be similar to those used on the LH₂ Pump Component Development Program in the CEL facility at Test Cell "C". The same signal conditioning equipment supplied by the ANSC Turbomachinery Section for those tests can be utilized.

X. DATA ACQUISITION

The data acquired by the instrumentation requested in Section IX shall be recorded either on wide-band or narrow-band tape. The system utilized on the ANSC Dual Pump Program is currently assumed to be available by the ANSC Turbomachinery Section.

The data on the narrow-band tape shall be presented in engineering units in digital form or graphic form or both and shall be capable of being used in the data reduction program, discussed in Section XI, to evaluate pump performance upon request.

A portion of the requested instrumentation will be required to be displayed during the test for operational purposes. Some channels will also have to be recorded on Sanborn recorders for quick analysis. These records should not be considered as permanent records of the data.

XI. DATA REDUCTION

The oscillograph, digital printout (N-3), Sanborn records, and any requested plots shall be available for review upon request by designated personnel after each test to determine if the test objectives were met. Performance calculations from the computer shall be done between experimental plans. All dimensional units shall be in engineering units.

Current planning by the ANSC Turbomachinery Section assumes that personnel and equipment will exist at the test facility to write and execute a performance program to perform the following operations:

1. Determine the fluid properties of hydrogen at various locations based on temperature and pressure measurements. The program shall be capable of calculating single phase properties and two phase properties based on an isentropic process.
2. Calculate pump and turbine performance parameters, for example; pump head coefficient, pump flow coefficient, pump efficiency, turbine flow parameter, turbine velocity ratio, and turbine efficiency.
3. Calculate fluid velocities and flows at various predetermined locations.

The dynamic characteristics of the turbopump will be analyzed in terms of shaft dynamics. Existing computer programs, to analyze dynamic conditions, shall be used where it is deemed necessary.

XII. SUPPORT ACTIVITIES

A. TURBOPUMP ASSEMBLY OPERATIONS

The current planning of the ANSC Turbomachinery Section assumes the turbopump will be assembled and disassembled at the NRDS by NRTO personnel.

The ANSC Turbomachinery Section will provide the assembly and disassembly procedures, special assembly tooling, all required parts including a high speed balanced rotor assembly, and an engineer to supervise the assembly and disassembly operation. The types of special assembly tooling which will be supplied are as follows:

1. Assembly stand with rotating base for end to end assembly.

The mount will also have accessory attachments for the ambient and LN_2 push-pull bearing preload test.

2. Special torque wrench adaptors.
3. Lifting and jacking plates
4. Rotor assembly and housing assembly handling and shipping cradles

It will be necessary for NRTO to provide the clean assembly area, assembly technicians (2 required), Quality Assurance Personnel (1 required), standard tools, and standard support equipment. The clean room should be maintained per MSFC Spec-164. An area with LN_2 supply for the LN_2 push-pull test will also be required outside of the clean room. The following support equipment and tools are required and are considered standard.

1. Overhead crane with good slow control for lifting parts.

2. Cleaning facilities for parts.
3. Hydraulic arbor press with approximately 50 ton capacity.
4. Method for heating parts prior to assembly of interference fits. An oven would be acceptable. The preferred method is a hot tank of TRIC.
5. Portable heaters for assembly and disassembly of interference fit part.
6. Open dewar of LN_2 for assembly of interference fits.
7. Grinding equipment for grinding flat shims to final thickness.
8. Measurement instruments, including O.D. and I.D. micrometers, vernier calipers, dial indicators, height gage, surface plate, etc.
9. Torque wrenches
10. Hand wrenches and socket sets.

The information given in Section VI can be used to estimate the amount and capacity of equipment required. The assembly techniques required will be similar to those used on the LH_2 Pump Component Development Program Test Article which is going to be assembled at E-MAD during April 1972.

B. QUALITY ASSURANCE AND SAFETY

It should be assumed that the reduction in resources for the NERVA Program has in no way reduced the Quality Assurance and Safety requirements for the turbopump development program. Personnel will be required to fulfill the standard Quality Assurance and Safety functions during the assembly and testing of the turbopumps.