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AIAA 2001-0608

Large Liquid Engine Test Facility

G. Mendez, ~~R. Drake and J. Carlile~~
Air Force Research Laboratory
Edwards AFB, CA

39th AIAA Aerospace Sciences Meeting & Exhibit
8-11 January 2001 / Reno, NV

AIAA 2001-0608

LARGE LIQUID ENGINE TEST FACILITY

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Margin between columns should only be 1/4 inch.

Per AIAA style sheet, abstract should only be one paragraph, not more than 200 words.

ABSTRACT

The Air Force Research Laboratory (AFRL), in order to support the Evolved Expendable Launch Vehicle (EELV) Program, recently activated a large liquid rocket engine test stand after a 25 year dormancy. Test Stand 1A, located at Edwards AFB CA, was left in a semi-abandoned condition since the early 1970's. With no definitive plans for re-activation, the facility was left to weather in the dry desert air.

The objective was to provide the Air Force with the capability to test large liquid rocket engines up to 1.6 million pounds of thrust which utilize liquid oxygen for the oxidizer and either liquid hydrogen or kerosene for fuel. A high pressure hydrogen turbopump spin capability was also added to enable turbopump component development testing.

This paper will review the lessons learned and observations from designing, modifying, and activating the test stand and performing the initial development activity on the new RS-68 rocket engine being developed for the Boeing Delta IV launch vehicle.

INTRODUCTION

In order to provide the capability to test large liquid rocket engines, it would require the refurbishment of an existing Test Stand, gas storage vessels, components, control room, and new wiring installation. Test Area 1-120, which has three Test Stands, Test Stand 1A, 2A, and 1B, was most suited to perform this objective. Test Stand 1A was originally built for Atlas vehicle testing in the late 1950's. It was then modified to support F1 engine testing for the Saturn vehicle in the 1960's. Test Stand 2A is a component Test Stand built up in support of engine component testing, Test Stand 1B is a two position vertical Test Stand built up for testing F1 engines.

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Test Stand 2A had been modified for Advanced Launch System (ALS) testing in the early 1990's. During this modification, gas storage vessels were installed. It was decided that these vessels could be utilized for both 1A and 2A test capability. The "sharing" of common systems would benefit ~~to~~ both Test Stands 1A and 2A. Therefore, Test Stand 1A, was chosen to be refurbished to support testing of large liquid rocket engines.

The decision was made early on to refurbish the Test Stand for use of liquid hydrogen as a fuel. Since liquid hydrogen requires vacuum jacketing and a flarestack for venting hydrogen, the Test Stand would provide the maximum flexibility for either kerosene or liquid hydrogen fueled rocket engines.

Refurbishment of the Test Stand began with a number of large procurements. The Thrust Measurement System (TMS), the hydrogen offload station, the hydrogen flarestack, the removal of the 60,000 gallon RP-1 tank, the installation of the 90,000 gallon double walled cryogenic vessel, and the installation of the Allen-Bradley control computers.

add:

During the procurement phase, the designs for the upper run feed lines, the facility pneumatic control panel, facility purge, and engine purge panels were completed. Components for the various panels and piping systems were procured or refurbished from existing available hardware.

Each new system went through an activation phase after being constructed. Activation of a system included cleaning, leak checks, calibration, and checkout. The following systems were activated for Test Stand 1A: facility hydraulics, flarestack lighting, vacuum systems, fire suppression system, gaseous nitrogen and helium purge panels, thrust measurement system, fire detection system, facility instrumentation and controls.

Upon completion of the activation of the individual systems, orifices were installed to simulate hardware on discharge lines, and a "all system blowdown" (ASBD) was performed using liquid nitrogen as a simulated propellant. After successful completion of the ASBD, the run tanks were filled with liquid oxygen and liquid hydrogen, and ~~a~~ an Oxidizer and Fuel system blowdown was performed, using the actual propellant.

should be "an"

lc

Facility data reviews were performed, and the Test Stand was now active and ready to begin testing engine hardware.

lc

In Jan 98 the first of 12 Turbopump Test Assembly (TPTA) tests were performed. This was followed by 6 Powerpack tests. The first liquid oxygen/liquid hydrogen engine hot-fire test on Test Stand 1A was performed on 8 Aug 98.

It had been nearly 29 years since the last engine test on Test Stand 1A, and for the third time in its history, Test Stand 1A would be instrumental in developing a new rocket engine for the Air Force.

HISTORICAL

lc

Test stand 1A was originally built for Atlas Intercontinental Ballistic Missile (ICBM) testing in the late 1950's. Construction began in 1955, with the first Atlas ICBM tests in 1957. In 1959 during a test, the Atlas missile exploded, damaging the test stand. With only two Atlas tests remaining, it was impractical to repair the test stand. Several months later work began on the test stand to modify and reconfigure for F1 engine testing. Modifications to the test stand consisted of the following:

1. Removal of the Atlas tower.
2. Installation of a new Thrust Measurement System.
3. New Run tank support structure.
4. Fabrication of storage and run tanks.
5. Enlargement of Flame deflector system ~~was enlarged.~~
6. Expansion of Fire suppression system ~~expanded~~ on test stand.
7. Addition of New instrumentation and control systems ~~added.~~

lc USE SAME STYLE ON ALL

These modifications were completed in 1960. On May 25, 1961 the first F-1 engine was tested. Tests continued throughout the 1960's, with the last test completed in 1969.

EELV PROGRAM

The Air Force Evolved Expendable Launch Vehicle (EELV) program was created to partner with industry to develop a national launch capability that satisfies both Government and Commercial payload requirements and reduces the cost of space launch by at least 25%.

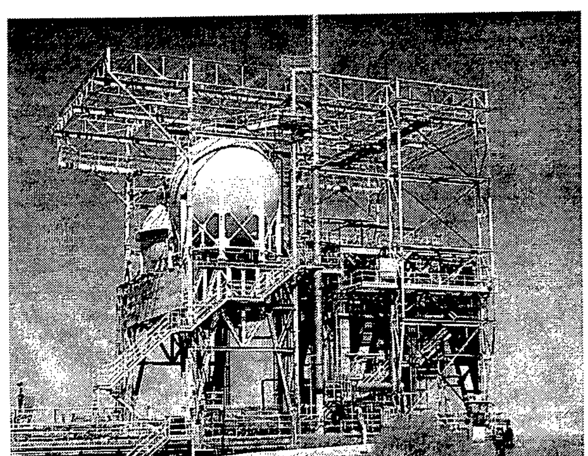

FIGURE LEGEND?

DESIGN

The test stand structure required modification to support the weight of the new 90,000 gallon liquid hydrogen run tank. This support truss was added to the vessel bridge support structure. Other structural modifications included access platforms, piping supports, component mounting supports, grating, handrail, and staircase repair.

NEEDS REVISION

New component panels were designed and constructed. These panels are used for valve control pressure, facility nitrogen and helium purge supplies, engine nitrogen and helium purge supplies. Each panel was then cleaned and proof pressure checked before being mounted on the test stand.

New instrumentation and controls were required for the test stand. The Allen-Bradley system uses touch screens to control components on the test stand. The Cyber Data Acquisition System was used for recording hardware test data. The wiring for these data and control computers was run from terminal boxes in the control room through the access tunnel to the terminal point in the basement of the test stand. Electrical conduit runs were then required to provide wires to the components on the test stand. Programming of the Allen-Bradley programmable logic controller and touch screens was performed on-site.

The liquid hydrogen run tank required the installation of a new capacitance tank level indicator.

The liquid oxygen offload station was designed with two hook-up stations to support the transfer of fluid from two liquid oxygen tractor-trailers to the liquid oxygen run tank.

The liquid hydrogen offload station was designed with two trailer hook-up stations to support the offloading of two liquid hydrogen tractor-trailers to the liquid hydrogen run tank. This offload station has additional requirements of having permanent vacuum jacketing, and vent lines that are connected to the main hydrogen flarestack.

REFURBISHMENT

In order to provide a reduction in cost and schedule, existing piping, components, and conduit were utilized.

Components such as the 18" tank isolation, 18" pre-valve, 14" run tank pressure safety valves, and numerous smaller components were refurbished for use on the test stand.

Spell out in. rather than symbo

The Liquid Oxygen run tank required refurbishment of the float level indicator. This indicator travels up and down with fluid level along a fixed rod. The rod contains instrumentation to detect the magnetic slide on the level indicator.

The fire suppression system located on all levels of the test stand required flushing and minor redesign to become operational. The firex system boost pump required minor modification to allow remote operation from the control room.

Due to new environmental laws, the Flame deflector cooling water system required the installation of a retaining dam to contain and recycle water. This dam was designed to contain the capacity of the tank plus 10% for a total of 1.1 million gallons. Repairs were also required to fix leaks in the 42" pipeline supplying the flame deflector and a new 36" flame deflector cooling water valve was installed.

PROCUREMENT

Procurement of long-lead items was one of the first tasks to be initiated. The 1.6 M lbf Thrust Measurement System, hydrogen Flarestack, Liquid Hydrogen transfer system, Liquid Hydrogen 90,000 gallon tank installation, and 18" upper run lines were all designed, or specified and then procure on contracts.

Upon delivery of the items, the installation was scheduled and then executed.

ACTIVATION

Activation of a system consisted of four parts. First, performed a system walk down and audit to verify the components of the system. Second, perform dry cycle checks of valves, and perform make and breaks on the instrumentation. Third, perform leak checks of the system using inert gaseous or liquids. Four, perform a demonstration test of the system.

INSTRUMENTATION AND CONTROLS

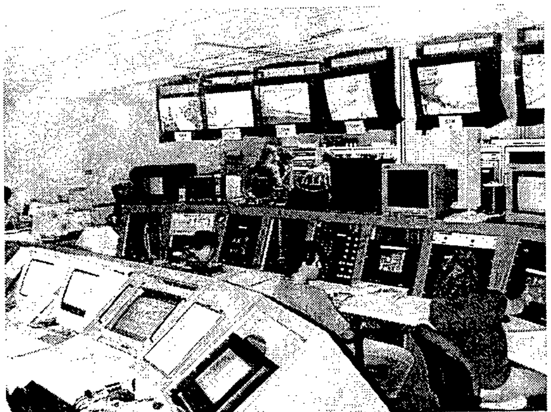

Figure Legend ?

The control room was one of the earliest systems to begin activation. Since it is common to Test Stand 2A, some equipment and wiring was available for use on Test Stand 1A. The instrumentation systems in the control room consisted of an Allen-Bradley programmable logic controller, the Cyber Data Aquisition System, FM tape recorders, and a digital strip chart recorder.

The Allen-Bradley programmable logic controller is used for facility valve control and facility data recording. Four touchscreens, located in the control room as operator interfaces, were used for Test Stand 1A. The Cyber Data Aquisition System was a digital data acquisition system for use in recording test article data as well as certain critical facility parameters. The FM tape recorders and strip chart recorder were used to record high-frequency data, such as vibration and pressures, from the test article.

VACUUM PUMPS

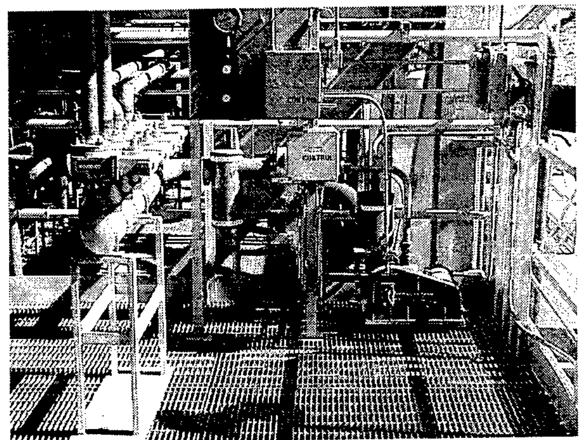

Figure Legend ?

Three vacuum pumps are used on Test Stand 1A. One pump is used to evacuate the liquid hydrogen upper run line, and the other two pump are used to evacuate the annulus space in the liquid hydrogen and liquid oxygen run tanks.

Each system has a remote isolation valve, manual isolation valve, oil trap, vacuum gauge, remote vacuum transmitter sensor, pump motor speed sensor, piping, and power to run the vacuum pumps. The remote isolation valve can be operated from the control room, and the speed sensor will close the remote isolation valve if the vacuum pump turns off, or the belt breaks.

The activation of the system included operation the remote valve and verification of the speed sensor failsafe. The vacuum reading was also monitored once the isolation valve was closed to determine the leak rate into the evacuated space.

Put legends on all pictures.

HYDRAULICS

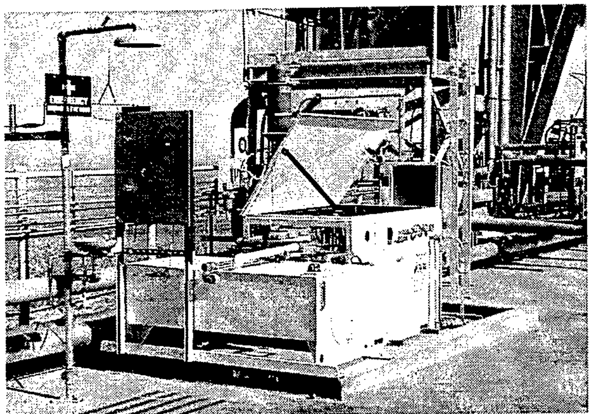

Figure Legend ?

The facility hydraulic unit controls the gaseous hydrogen cascade isolation valve, the gaseous hydrogen pressurization isolation valve, the liquid oxygen tank pressurization control valve, the liquid hydrogen tank pressurization control valve, and the turbine control valve.

The system is comprised of the hydraulic pump, reservoir, piping, power, pressure transmitters, pressure gauges, temperature transmitters, numerous accumulators, hand valves, and check valves.

The activation of the hydraulic system included leak checks, fluid sampling to meet mil-spec requirements, hydraulic valve operation, and accumulator sizing verification.

MIL-SPEC should be all capitals

FIREX

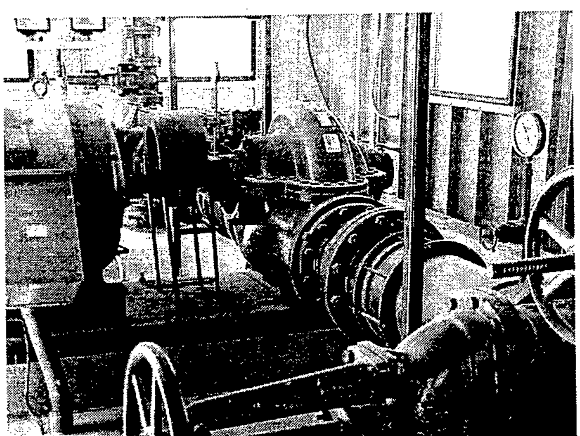

Figure Legend ?

This system is used for fire suppression on the test stand and ~~feed~~ is feed by two 400,000 gallon tanks located on a hill adjacent to the test stand.

Head pressure provides 100 psi to the firex system. A boost pump located in the area provides additional pressure if required, and can be remotely operated from the control room.

The firex system is located on all levels of the test stand, and directional nozzles are placed near the run lines, run tanks, and offload stations. Two firex cannons located on the test stand main deck can be remotely operated from the control room to provide additional fire suppression capability. The flexflow valves are controlled by closed gaseous nitrogen, and when the nitrogen is vented via solenoid valves, the flexflow valves opens. The system can be operated in a fail-dry or fail-wet mode. Fail-wet flows all levels of the firex system simultaneously.

Add sentence on how that done

Rewrite what is closed nitrogen

Checkout of the firex system was performed on the individual legs of the firex system and included flushing of the system, followed by adjustment of the directional water nozzles. A fail-wet checkout along with the boost pump was performed to very system performance. verify ?

FLAME DEFLECTOR

Figure Legend ?

The flame deflector cooling water system is used to cool the flame deflector plate from the heat generated by the rocket engine exhaust plume. The deflector was installed during the 1960's for F1 engine testing.

The system has a feed line from the 1 million gallon tank located on the hill adjacent to the test stand and several isolation valves. The flame deflector cooling water valve is a 36 in. remotely operated pneumatic valve located at the base of the test stand. A flowmeter and pressure transducers are located upstream of the 36" in. flame deflector cooling water valve.

System checkout including leak check of the water supply lines, instrumentation checkout, and 36" flame deflector valve dry cycle timing. The system was flowed and operation of the 36" valve was verified. Max flow rate was recorded at 110,000 gallons per minute.

PROPANE

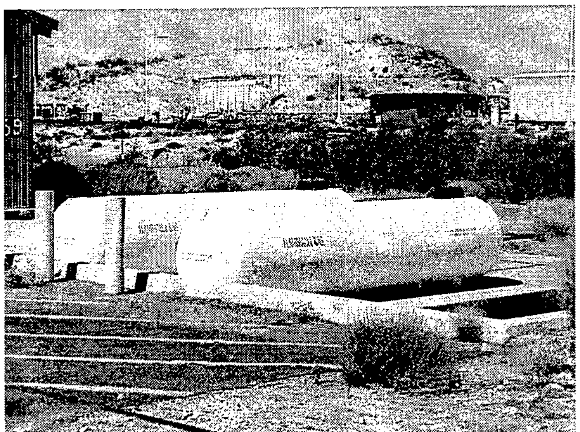

Figure Legend?

Two commercially available 1000 gallon, 250 psig propane tanks feed the Area 1-120 flarestack propane pilots. These flarestacks are located on Test Stand 1A and 2A.

Checkout of the propane system included leak checks, and final connection to the flarestack control panel. The system is regulated from the tanks supplying 25 psig to the flarestack control panel. The control panel regulator further reduces pressure to 7 psig nominal.

FLARESTACK

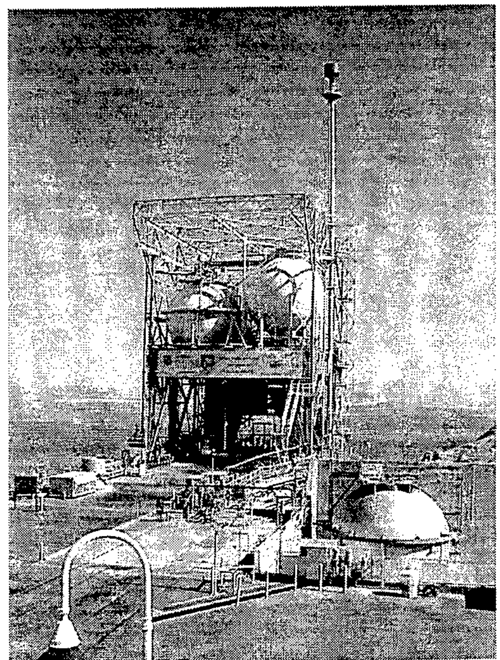

Figure Legend?

Test Stand 1A utilized two flarestacks. One flarestack is used for the pressure safety valve on the gaseous hydrogen cascade. The other is used for run tank boiloff, run line chilldown, and run tank venting/dumping.

Each flarestack uses a propane pilot to light the venting hydrogen. The flarestack also utilizes nitrogen purges to maintain an oxygen-deficient atmosphere with the flarestack piping. The flarestacks originally were purchased with a control panel, which is used for lighting and monitoring the flame temperature. The 1A main flarestack was modified for remote operation from the control room.

Activation of the system required ignition checkout of the sparking system, propane tie-in, and flame temperature verification. In addition, the IR filters on the area CCTV were used to observe the flame.

Spell out unless done earlier.

Should this be ft³ (cubic feet)?

GASEOUS NITROGEN

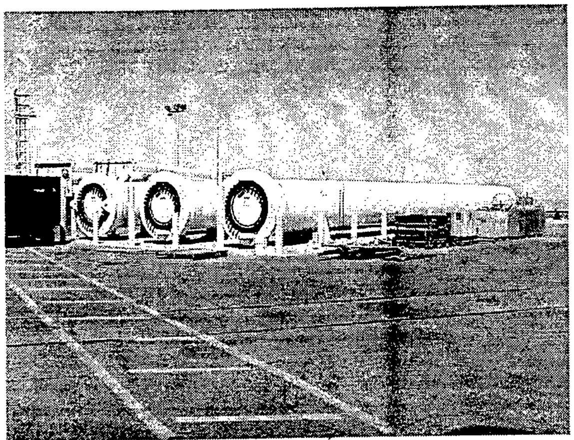

Fig. Legend ?

Gaseous nitrogen is used on the test stand 1A for facility and engine purges, LOX run tank pressurization, and valve actuation pressure.

The nitrogen is supplied by a 2850 ft3 ? 4200 psig cascade system composed of three pressure vessels. The system contains numerous piping runs, panels, pressure instruments, valves, regulators, gauges, and is located throughout the entire test stand.

Activation of the system included the pressurization of all downstream branches of the system, leak check of system, and operation of remote valves.

GASEOUS HELIUM

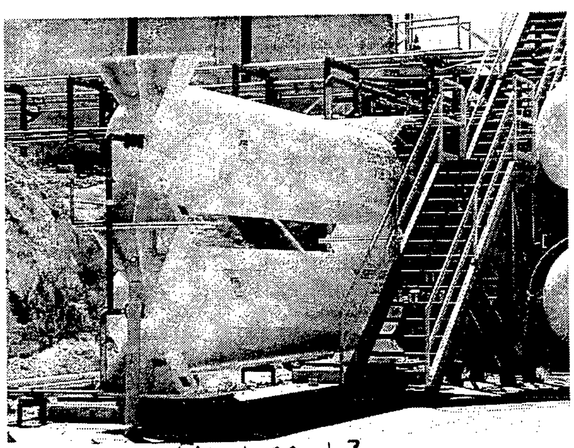

Fig Legend ?

Test stand 1A uses gaseous helium for engine and facility purges, and the engine helium spin start system.

The regulated pressure is used to purge the liquid hydrogen feed lines and various engine purges.

The helium cascade system consists of 1340 ft3, 6000 psig vessels along with numerous piping runs to pressure reducing panels. The main cascade system supplies the helium spin start tank, which is 54 ft3 and 6000 psig. This system consists of pressure instruments, gauges, valves, and regulators.

Activation of the system included the pressurization of all downstream branches of the system, and a leak check of the system.

GASEOUS HYDROGEN SYSTEM

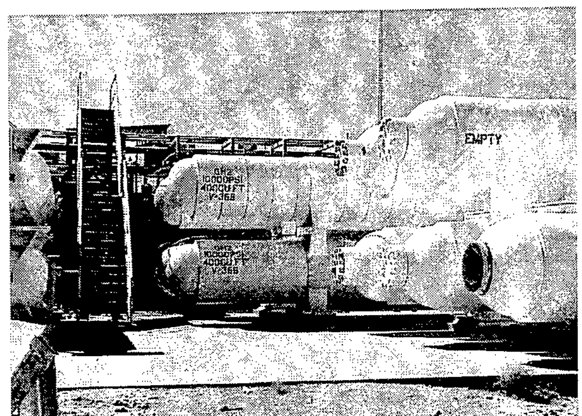

Fig Legend ?

The gaseous hydrogen system is used to pressurize the liquid hydrogen run tank for test, as well as providing a gaseous hydrogen torch for the engine main combustion chamber exit. The gaseous hydrogen torch is used to light the free hydrogen at engine start up. The gaseous hydrogen system was also used to provide turbine spin gas during turbopump testing.

The systems consists of number 1600 ft3 storage vessels, up to 10,000 psig. A number of remote pressure sensors are installed on the system for reading the pressure in the cascade, and remotely activated valves are used to charge the system for test. The system also contains a single flarestack, and gaseous hydrogen sensors for safety. This system is connected to a 10,000 psig hydrogen pump/vaporizer for charging the system to 10,000 psig, and a trailer offload station for charging the system to 2100 psig.

at pressure

During the activation the system was charged to 10,000 psig with gaseous nitrogen using the pump/vaporizer. A gaseous nitrogen blowdown was performed to demonstrate the turbine spin control system. After the gaseous nitrogen blowdown, the system was inerted with helium to support a gaseous hydrogen blowdown. The same pump/vaporizer was used to charge the vessels with gaseous hydrogen to 10,000 psig. Then a gaseous hydrogen blowdown was performed to demonstrate the turbine spin system.

LOX SYSTEM CHECKOUT

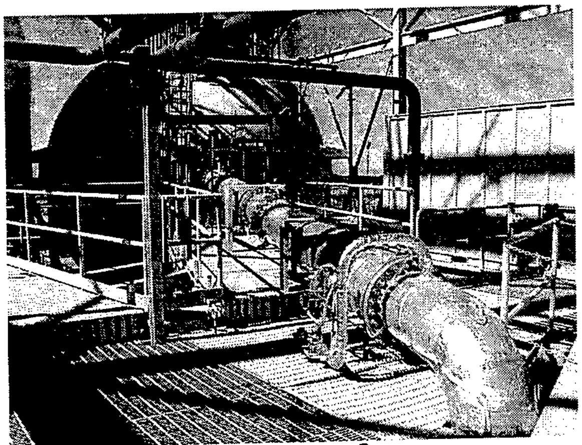

Fig. Legend ?

The liquid oxygen system is used to provide oxidizer to the rocket engine. The propellant is supplied to the engine from the run tank through the upper run line, down to the lower run line, and finally connects to the pump inlet.

The liquid oxygen run tank is a vacuum jacketed vessel with a capacity of 75,000 gallons. The run tank is isolated with a 18" ball valve and connects to the insulated 18" upper run line. The upper run line has a 18" pre-valve, which is connected to the 12" lower run line. This system contains the necessary piping, valves, relief valves, purges, and instrumentation, to perform chilldown, venting and purging operations on the run tank, upper run line, and lower run line.

Too much space

The first cryoshock of the system was performed with liquid nitrogen. This verified the integrity of the fill line, and run tank. A liquid oxygen run tank pressurization checkout test was then performed, and finally a liquid oxygen blowdown with liquid nitrogen was done to demonstrate the system performance. This system was then refilled with liquid nitrogen in support of performing the All Systems Blowdown.

lc

LH2 SYSTEM CHECKOUT

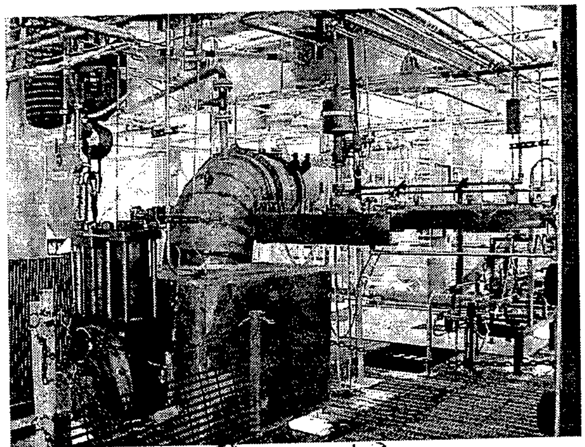

Fig Legend ?

The liquid hydrogen system is used to provide fuel to the rocket engine. The propellant is supplied to the engine from the run tank through the upper run line, down to the lower run line and finally connects to the pump inlet.

The liquid hydrogen run tank is a vacuum jacketed vessel with a capacity of 90,000 gallons. The run tank is isolated with a 18" ball valve and connects to the vacuum jacketed 18" upper run line. The upper run line has a 18" pre-valve which is connected to the 12" lower run line. This system contains the necessary piping, valves, relief valves, purges, and instrumentation, to perform chilldown, venting and purging operations on the run tank, upper run line, and lower run line.

The first cryoshock of the system was performed with liquid nitrogen. This verified the integrity of the fill line, and run tank. A liquid hydrogen run tank pressurization checkout test was then performed, and finally a liquid hydrogen blowdown with liquid nitrogen was done to demonstrate the system performance. This system was then refilled with liquid nitrogen in support of performing the All Systems Blowdown.

lc

lc = lower case

SUMMARY

LESSONS LEARNED

OPERATIONS

To reduce the possibility of transferring fluid from a full to an empty truck, use check valves on the individual truck offload stations.

Design the offload station manifold to be less restrictive using 45 deg bends, and larger manifold tie-ins.

Thrust measurement system should ~~have hard plumb tubing instead of flex hose, and have~~ multi-axis ~~thrust~~ capability.

To allow for uninterrupted vacuum service, have a backup vacuum pump tie-in with space for second pump and isolation valves.

define

To avoid down time, design in a backup HPU tie-in with isolation valves and use the same HPU fluid for all HPU's in the area.

Provide a means to repair/or secure any joined fittings on difficult-to-reach places (165 ft tall Flarestack).

Use high-speed video systems to allow for immediate video review of testing.

Have a sufficient number of spare parts, or valve re-build kits available.

Be aware of fuel/oxidizer system crossover contamination through common purge systems.

Have maintenance isolation valves and alternate tie-ins on critical components.

Simplify filter inspections by installing a borescope inspection port upstream of run line and transfer line filter elements.

When using liquid hydrogen with non-vacuum jacketed lines, have adequate drip pans for LAIR protection.

define

SAFETY/ENVIRONMENTAL

Flame deflector cooling water inoperative check valve/poor design led to a rapid closing of the 36 in. valve. This damaged the water supply line.

Plugged vent on 18 in. ball valve vent port went unnoticed due to inexperience with the valve. This resulted in a minor damage to the test stand.

Unsecured equipment (ladder) resulted in a personnel injury. Hardhat requirement policy was in place, which provided protection.

use instructions/suggestions as in other paragraphs.

Overflowing of original earthen basin dam due to inadequate communication between personnel. Resulted in an increase of environmental awareness of unauthorized water released into the desert.

OBSERVATIONS

1. Use work-around if feasible to continue progressing through build-up schedule or test operations.
2. By using parallel activities, an accelerated design/build/activate can be performed.
3. Personnel dedication to performing task.
4. Cooperation between different agencies and companies.
5. Early procurement of long lead items.
6. Benefit of using personnel who build the test stand to operate the test stand. Allows for items 1, 2, 3 above.

SUMMARY

Summarize your paper to end it