AIAA-2001-3380

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37th AIAA/ASME/SAE/ASEE Joint Propulsion Conference
8-11 July 2001
Salt Lake City, Utah

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Abstract

After a decade of construction and a year of activation the E1 Ultra High Pressure Propulsion Test Facility at NASA's Stennis Space Center is fully operational. The E1 UHP Propulsion Test Facility is a multi-cell, multi-purpose component and engine test facility. The facility is capable of delivering cryogenic propellants at low, high, and ultra high pressures with flow rates ranging from a few pounds per second up to two thousand pounds per second. Facility activation is defined as a series of tasks required to transition between completion of construction and facility operational readiness. Activating the E1 UHP Propulsion Test Facility involved independent system checkouts, propellant system leak checks, fluid and gas sampling, gaseous system blow downs, pressurization and vent systems checkouts, valve stability testing, valve tuning cryogenic cold flows, and functional readiness tests.

Introduction

The E1 Ultra High Pressure (UHP) Propulsion Test Facility at the John C. Stennis Space Center, Mississippi has recently completed a successful activation program and the initial testing of a 250,000 lbf hybrid motor[1] and a 650,000 lbf lox-hydrogen engine[2].

Initial construction of the $40 million NASA complex was begun on January 18, 1989 when space agency officials cut the first tree[3]. Originally known as the Component Test Facility (CTF), the E1 UHP propulsion ground test facility covers more than 20 acres in territory and was originally scheduled to be operational by mid-summer of 1991. Designed to test high-fidelity turbo-pump assemblies for the proposed heavy-lift Advanced Launch System being jointly developed by NASA and the US Air Force, construction of the new test facility was to take two years and create about 100 construction jobs and another 100 operations jobs. By 1991 the Advanced Launch System program had become the New Launch System (NLS) program. Again Stennis' role was to provide a facility for component level testing of full-scale development turbo-pumps, to establish the pump characteristics required for refinement of the designs into flight prototypes. Activation of CTF was to begin in October of 1992 and run for two years until Oct 1994, unfortunately NLS was cancelled.

In late 1996 John C. Stennis Space Center was named Lead Center for Propulsion Test and the Reusable Launch Vehicle (RLV) program was initiated. With this announcement, came $45 million in the FY 97 budget to finish CTF, which was renamed E1. The role of the Stennis Space Center and E1 in this new program was expanded to provide a facility for component level testing of the RLV engine valves, thrusters, and turbo-pumps. Additional a third cell of E1 was reconfigured to perform horizontal firings of rocket engines. While the RLV program has faded into the background, E1's role as the preeminent ultra high pressure ground test facility has finally been achieved with the successful Hybrid Propulsion Demonstration Program's 250K Hybrid Motor test in the fall of 1999 and TRW's 650K LOX/LH Engine in the summer of 2000.

Facility Description

The role of the E1 propulsion ground test facility has evolved in the last decade from a dedicated turbo-pump test facility into a multi-cell, multi-purpose component and engine development test facility (Figure 1). E1 has the capability to deliver cryogenic propellants at low, high and ultra high pressures with flows ranging from a few pounds per second up to a two thousand pounds per sec. In addition, the facility is equipped to supply a wide range of high and low pressure gases, hydraulics, deluge water, potable water, high speed video, low speed video and 35mm photography. The data acquisition and control systems at E1 have tremendous capacities and are the state-of-the-art in number of channels and data storage.

E1 consists of three test cells capable of accommodating multiple concurrent programs, which are feed from common facility systems. Each test cell is thirty feet wide by thirty feet deep by twenty six feet high, with a structural blast wall separating the facility cryogenic tankage, support equipment, instrumentation connections, power and safety equipment. The cells are covered for protection from the elements, while the cryogenic tankage is open to the environment due to safety constraints. Cell 1's primary role is the test of pressure-fed LOX/LH2 and hybrid combustion devices which produce thrust up to 750,000 lbf, while Cell 2's primary responsibility is to test LH2 and LOX turbo-pump assemblies, either simultaneously or individually. Testing in Cell 3 is currently limited to testing LOX-rich turbo-pump assemblies and pre-burners.

E1 liquid propellant and gaseous propellant systems consist of high and low pressure liquid hydrogen, high and low pressure liquid oxygen, high and ultra high pressure gaseous nitrogen storage, high and ultra high pressure gaseous hydrogen, and high pressure helium. E1 also has low pressure liquid nitrogen storage, low pressure liquid oxygen storage and low pressure liquid hydrogen storage. A simplified E1 facility schematic is depicted in Figure 2.

Facility Activation

Due to delays in high-pressure valve deliveries and construction difficulties, activation of the E1 Ultra-High Pressure Propulsion Ground Test Facility did not begin until August of 1998. Activation of the E1 Ground Test Facility consisted of a series of tasks to transition between completion of construction and operational readiness of the facility. Activation was performed in three phases, independent system checkouts, introduction of cryogenic propellants, and combined system validation. This last phase simulated, as close as possible, the conditions during an actual test run.

Phase One, Independent System Checkouts

Phase one, independent system checkouts consisted of valve functional checks, emergency abort system functional checks and control system verification and validation. The E1 UHP propulsion test facility consists of seven cryogenic tanks, five ultra high pressure bottles, two high pressure bottles, hundreds of valves, filters, piping, instrumentation, controls and other various ancillary systems, each of which much be functionally checked, verified operation and validated for performance. A hard-wired emergency abort system is provided to manually override the control system and safely shut down the facility and associated test article systems in a predetermined sequence in case of emergency.

Ten Programmable Logic Controllers provide control to the E1 test facility. The PLC's are assigned specific tasks in the control and operation of the facility, they are connected via network that allows them to share information or tasks. Individual I/O and/or control tasks can be assigned to meet specific performance goals of a particular test program. The facility control system provides a real-time graphical display of operations in progress, which is monitored by test personnel in the test control center. A picture of the E1 test control center can be seen in Figure 3.

Meticulous end to end checkouts of the control systems were performed for each system and component. These checkouts provide functional verification of the control system, valve actuator, limit switches and/or position indicators, valve timing, interlocks and fail-safe operations. The control system validation and verification task included: visual and continuity checks to verify all wiring points, signal voltage checkouts to

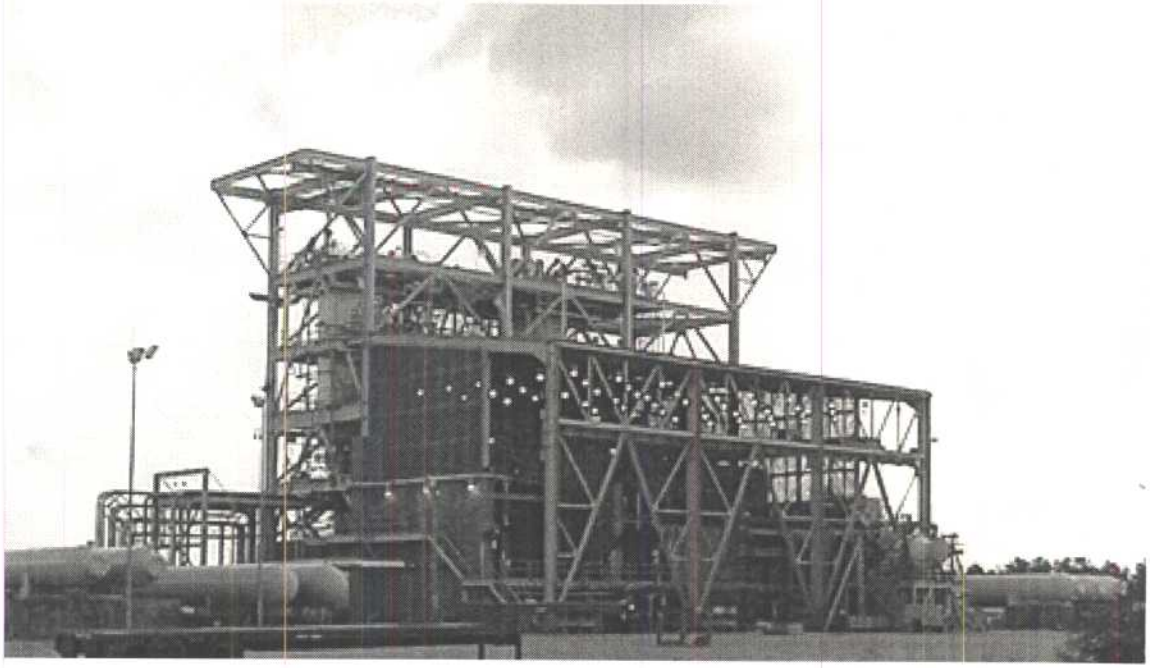

Figure 1: The E1 UHP Propulsion Test Facility

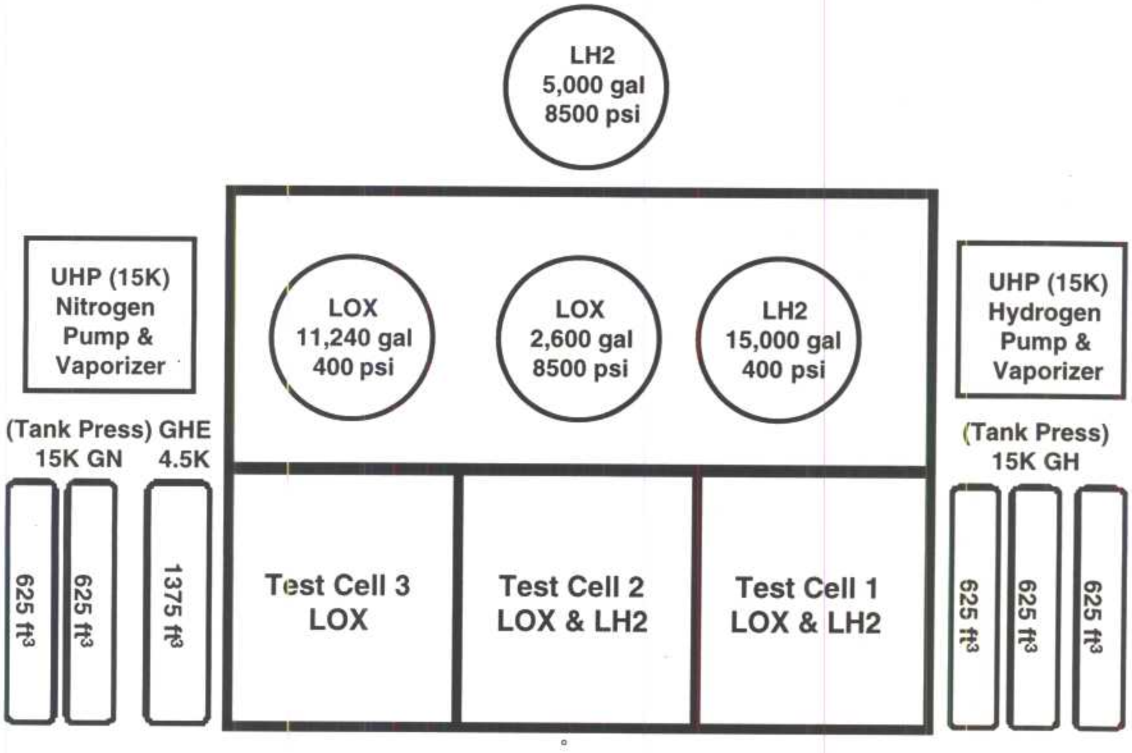

Figure 2: E1 Facility Simplified Schematic

Figure 3: E1 Test Control Center

thoroughly verify signal path, interface pin out, determine the voltage drop, validate signal timing including alarms, cutoffs, and logic signals, verification of command and feedback, etc. Individual valve functional checks consisted of manually cycling the valves and regulators. Any valve associated with the control system was cycled locally from an OPTO Cabinet located in the signal conditioning building, show in Figure 4 and remotely from the test control center.

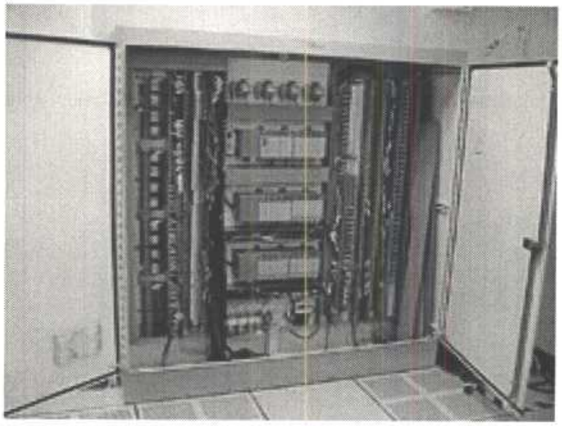

Figure 4: Signal Conditioning Building, OPTO Cabinet

Hydraulic controlled valves were functionally checked from the servo amplifiers in the signal conditioning building and remotely from the test control center. Gains were adjusted at servo amplifiers until the optimum value was reached and the gain setting was recorded for future reference. Figure 5 depicts some of the HP LH hydraulic valves. Over 200 pressure control valves, variable position valves and motor valves were cycled, verified and validated operational.

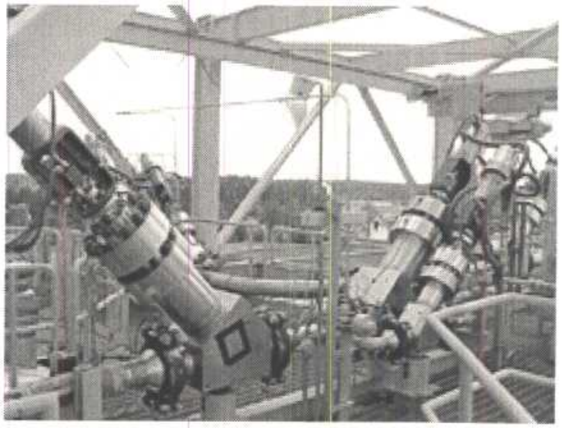

Figure 5: HP LH Hydraulic Valves

Phase Two, Introduction of Cryogenic Propellants

Phase two, introduction of cryogenic propellants, consisted of individual system cold shocks and dynamic propellant flows through each system, know as cold flows. Prior to the introduction of cryogenics each propellant system was leak checked to the systems maximum working pressure and each system was sampled for purity, particulate and moisture content. Gaseous blow downs were performed to obtain a rough system calibration and initial tuning on the cryogenic tank's pressurization and vent systems.

All cryogenic fluid systems under went a LN2 "cold shock" and a proof pressure test at operating pressures. These tests verified the function of the valves and instrumentation in addition to the system's integrity at LN2 temperatures. During the chill down and subsequent filling operations the systems were regularly inspected for mechanical binding, mechanical failure, or excessive leakage. Dynamic flow checks or "cold flows" were run on each system to verify, adjust and refine the pressurization control system. Every blow down and cold flow was recorded on the low speed and high-speed video systems for post-test playback and analysis. Currently two high-speed video cameras and ten low speed video cameras are available for recording test operations. The high-speed video system is capable of providing up to 200 images per second, available for immediate playback after test is complete.

Due to propellant temperature requirements, rapid pressurization of the high pressure tanks was desired in order to limit the amount of temperature increase in propellant due to long pressurization times. Rapid pressurization also limited the amount of pressure slump the test article sees at start up. Cold flow tests were repeated until a smooth pressurization ramp rate could be maintained until the target pressure was reached. A plot of different HP LH facility tank pressurization ramp rates is depicted in figure 6. The results of a LH cold flow can be seen in figure 7. A plot of different HP LOX facility tank pressurization ramp rates is depicted in figure 8. The results of a LOX cold flow test can be seen in figure 9.

Project oriented propellant inlet temperature requirements necessitated the need for an on-stand propellant conditioning system. The low pressure cryogenic run tanks can be used to precondition propellants. Just prior to test, the preconditioned propellants are transferred to the high pressure run tanks and lines. This lowered the facility to test article interface temperatures by 10 to 30 degrees R.

A plot of the HP LH facility to test article interface temperature before the introduction of conditioned propellant and after the introduction of conditioned

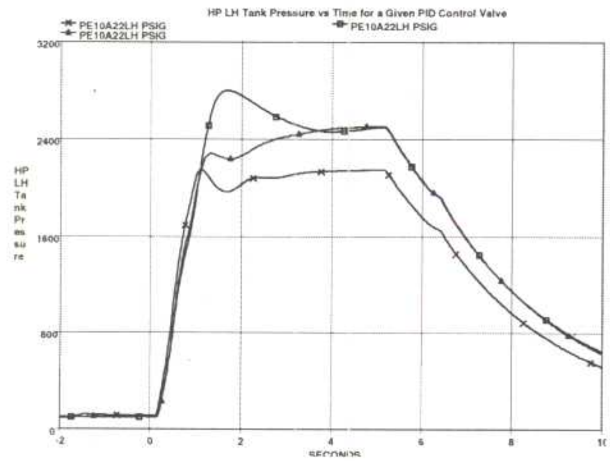

Figure 6: HP LH Tank Pressure with Different Pressurization Ramp Rates

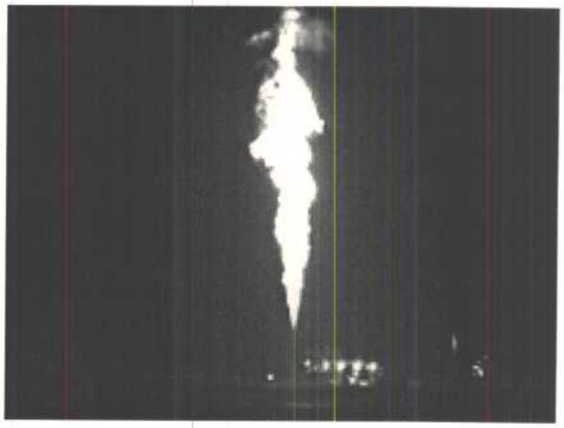

Figure 7: A Liquid Hydrogen High Pressure / High Flow Rate Cold Flow Test

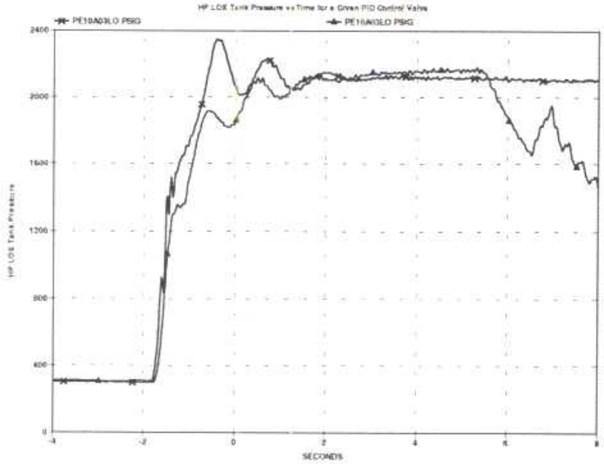

Figure 8: HP LOX Tank Pressure with Different Pressurization Ramp Rates

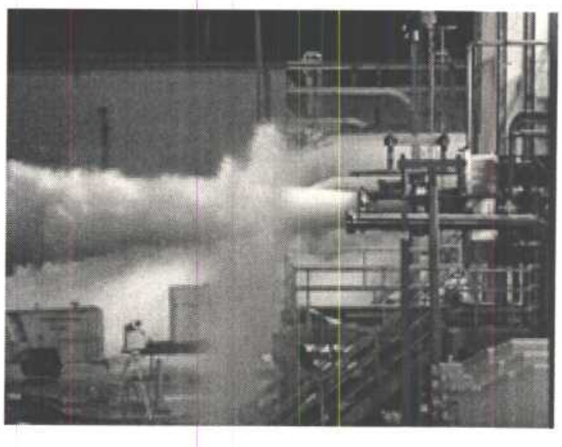

Figure 9: A Liquid Oxygen High Pressure / High Flow Rate Cold Flow Test

propellant is depicted in figure 10. A plot of the HP LOX facility to test article interface temperature before the introduction of conditioned propellant and after the introduction of conditioned propellant is depicted in figure 11. The LOX propellant was condition by bubbling Helium in the LOX for up to 8 hours prior to test.

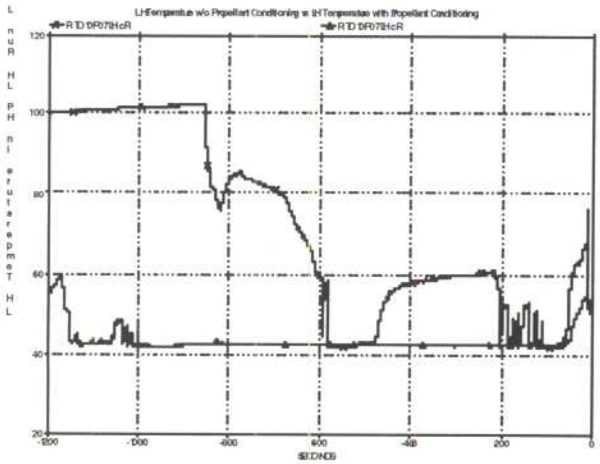

Figure 10: LH Temperature after Conditioning

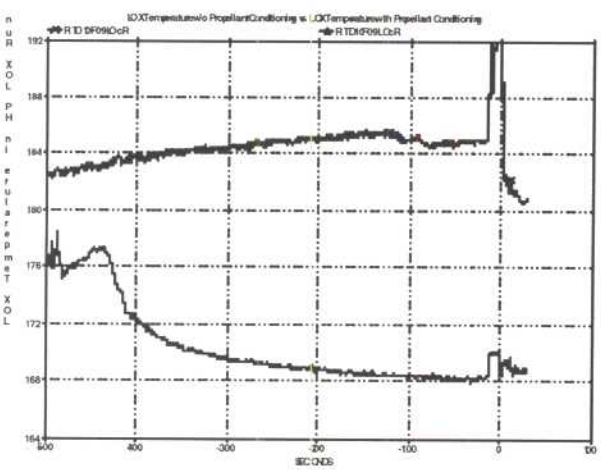

Figure 11: LOX Temperature after Conditioning

Phase Three, Combined System Validation

Phase three, combined system validation, consisted of functional readiness tests and redline system checkouts. Functional readiness tests consist of a combined simulation of all facility systems, as they would be used on test day without propellant. The redline system checkouts tested each of the facilities redlines and abort systems. While many control functions such as run tank pressurization are shared by several or all test cells, one PLC is reserved per test cell for test article or test program specific tasks. This dedicated test article programmable logic control (PLC) allows for response time of less than 30ms from any valve supplying the test article. Redline capability is provided for monitoring test specific or test article instrumentation redlines. The system provides the ability to connect up to 80 redline monitoring and shutdown (cutoff) measurements. With all inputs active, a nominal shutdown response from the PLC is 30 milliseconds , not including instrumentation or shutdown device delays. With fewer channels the response time can be reduced to less than 5 milliseconds. Multiple test sequences were developed and simulated during functional readiness testing. Using the results from the functional readiness testing and the redline system checkouts we were able to moving into hofire test with a high degree of confidence in our facility systems.

Over 210,000 gallons of LN2, 250,000 gallons of LOX, 300,000 gallons of LH and several hundred thousand cubic feet of gaseous nitrogen, gaseous hydrogen and gaseous helium were used during the activation of E1 test facility. Over 125,000 hours of labor, spread over 18 months was needed to complete the activation of the E1 UHP Propulsion Test Facility. Since the completion of activation the test stand has successfully completed two test projects.

References

1. NASA SSC Newsletter *Lagniappe*, Vol. 22, Issue 8, 25 August 1999

2. NASA SSC Newsletter *Lagniappe*, Vol. 23, Issue 9, 21 September 2000

3. NASA SSC Newsletter *Lagniappe*, Vol. 12, Issue 3, 16 February 1989

4. "Stennis Space Center Test Facilities Capabilities Handbook," Edited by R. Bruce, Third Edition, Rev 1, July 1999. (maintained by Lockheed-Martin Stennis Operations for NASA New Business Dev.)