RECENT ADVANCES IN HYDROGEN PEROXIDE PROPULSION TEST CAPABILITY AT NASA'S STENNIS SPACE CENTER E-COMPLEX

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ABSTRACT

In recent years, the rocket propulsion test capability at NASA's John C. Stennis Space Center's (SSC) E-Complex has been enhanced to include facilitization for hydrogen peroxide (H_2O_2) based ground testing. In particular, the E-3 test stand has conducted numerous test projects that have been reported in the open literature. These include combustion devices as simple at small-scale catalyst beds, and larger devices such as ablative thrust chambers and a flight-type engine (AR2-3). Consequently, the NASA SSC test engineering and operations knowledge base and infrastructure have grown considerably in order to conduct safe H_2O_2 test operations with a variety of test articles at the component and engine level. Currently, the E-Complex has a test requirement for a hydrogen peroxide based stage test. This new development, with its unique set of requirements, has motivated the facilitization for hydrogen peroxide propellant use at the E-2 Cell 2 test position in addition to E-3. Since the E-2 Cell 2 test position was not originally designed as a hydrogen peroxide test stand, a facility modernization-improvement project was planned and implemented in FY 2002-03 to enable this vertical engine test stand to accommodate H_2O_2. This paper discusses the ongoing enhancement of E-Complex ground test capability, specifically at the E-3 stand (Cell 1 and Cell 2) and E-2 Cell 2 stand, that enable current and future customers considerable test flexibility and operability in conducting their peroxide based rocket R&D efforts.

INTRODUCTION

John C. Stennis Space Center (SSC) in Hancock County, Mississippi is the NASA center for large space transportation propulsion system testing. As a result, SSC now has an inventory of many unique test facilities, capabilities, and advanced technologies provided through the supporting infrastructure, all having been developed since its establishment in the early 1960's.

SSC provides testing services not only to U. S. Government agencies, but also to commercial companies. SSC has experience in test activities ranging from the smallest sub-scale system component to large engine systems such as the Space Shuttle Main Engine (SSME).

Since high concentration H_2O_2 is an efficient non-cryogenic propellant with low operational cost, it has gained increasing consideration for use in propulsion system concepts which support the advancement of the next generation space transportation vehicles. The development of the E-Complex H_2O_2 testing facilities into a national asset has occurred due to the requirement for a larger-scale ground test capability to meet the needs of H_2O_2 component research and development efforts. The capabilities and utilization of H_2O_2 enabled E-3 and E-2 Cell 2 facilities are described below.

CAPABILITIES OF THE SSC E-3 FACILITY

The E-3 Test Facility is a versatile test complex available for component development testing of combustion devices, rocket engine components and small/subscale complete engines and boosters. The facility currently has two test cells, which can be occupied at the same time, providing a multiple program capability. Both test cells are adequately illuminated for nighttime work.

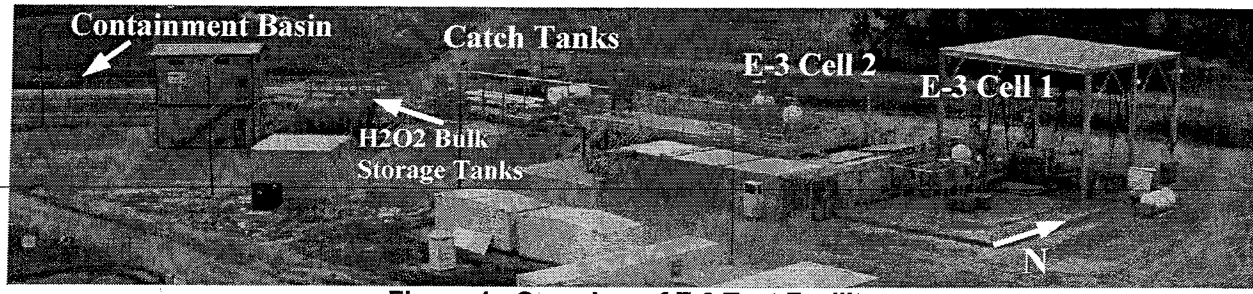


Figure 1. Overview of E-3 Test Facility

In addition to the LOX, Hydrocarbon (JP-4, JP-5, JP-8, RP-1, typical), and H_2O_2 propellant supply systems that are currently available, other amenities at the E-3 Facility include an H_2O_2 bulk storage and transfer system, H_2O_2 catch and disposal system, JP-8 catch system, a high pressure GN_2/GHe gas supply system, ancillary DI water, facility deluge and hydraulically actuated flow control valves. Figure 1 shows an overall view of the E-3 Test Facility.

<u>STRUCTURAL CAPABILITIES</u>

Cell 1 is a horizontal test stand with two thrust positions capable of supporting horizontal thrust loads up to 60,000 lbf. (120,000 lbf. impulse load). Cell 1 is 38 ft. in width by 40 ft. in length and is covered with a roof 25 ft. in height. A 5-ton overhead crane provides lifting capability up to a height of 18 ft. Figure 2 shows a view of the E-3 Cell 1 Test Stand.

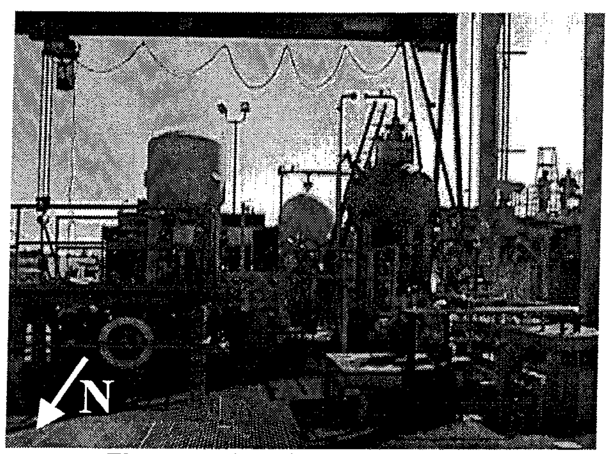


Figure 2. E-3 Cell 1 Test Stand

Mechanically configured to test H_2O_2/JP-8 rocket engine devices with up to 25,000 lbf. of vertical thrust (50,000 lbf. impulse load), Cell 2 has an additional capacity to test monopropellant configuration sub-scale combustion devices such as catalyst beds and components.

Featuring a skid-based design concept, the test article in Cell 2 is mounted on a platform that is bolted above the 8 ft. wide by 17 ft. deep concrete flame bucket with a 48 inch by 48 inch access hole provided for vertical testing. A flame deflector, located in the flame bucket, was designed and contoured to allow for long duration tests (over 50 seconds) without the use of cooling water. Figure 3 shows a close-up view of the E-3 Cell 2 flame bucket and deflector.

Two vertical thrust takeout structures are available for mounting above the flame bucket access hole. One can be outfitted with existing 10,000 lbf. thrust single axis thrust measurement system (TMS), whereas the other is shorter and stiffer, but does not have TMS capability. Mobile cranes are available to provide lifting capability. A view of the E-3 Cell 2 Test Stand is shown in Figure 4.

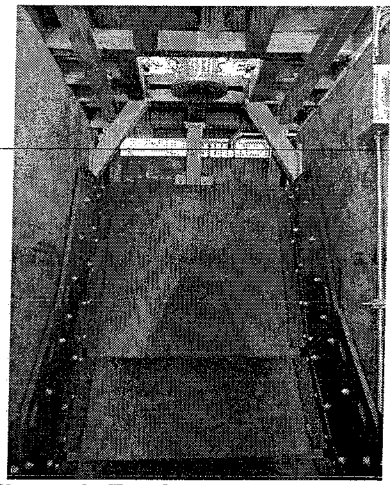


Figure 3. E-3 Cell 2 Flame Bucket

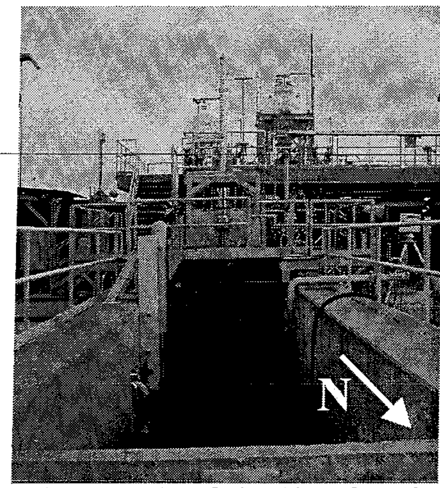


Figure 4. E-3 Cell 2 Test Stand

Single-axis thrust measurement capability is available for both Cell 1 and Cell 2. Currently, 10,000 lbf. and 25,000 lbf. thrust measurement systems are available for use.

COMMODITY SUPPLY/STORAGE CAPABILITIES

Recently completed upgrades (CY 2001-02) have increased the E-3 facility's capacity to deliver propellants at low and medium pressures up to 3,000 psig. All H_2O_2 storage, transfer, and run systems are cleaned and passivated for H_2O_2 service. The JP systems are cleaned and maintained at a commercially clean level.

JP and H_2O_2 run systems have been installed in Cell 1 as part of the facility upgrades completed in the past year. The new 4 inch H_2O_2 and 2 inch JP-8 run line construction is complete and awaiting activation. The 1.5 inch H_2O_2 run line has been designed and will be constructed at a future date. Table 1 outlines the supply capabilities for Cell 1. The flow rates listed in the table are nominal.

Table 1. Cell 1 Commodity Supply Capabilities

	Press. (psig)	Vol. (gal)	Temp. (°R/°F)	Flow Rate (lbm/sec)	Run Line (in.)
H_2O_2/ LOX	3000	500	540/80 163/-297	220/ 112[1]	4
H_2O_2/ LOX	3000	500	540/80 163/-297	30/ 15[1]	1.5
JP-8	3000	250	540/80	40	2

1 - Max LOX flow rate assumes that velocity is no greater than 25 ft/sec.

The completed facility upgrades at Cell 2 include moving the 500 gallon oxidizer run tank and the 250 gallon fuel run tank next to each other on an elevated platform 8 feet above and to the south of the test cell platform. Test articles at Cell 2 are positioned above and discharge into the flame bucket. The new 4 inch H_2O_2 and 2 inch JP-8 run line construction is complete and the system has been activated.

The 1.5 inch H_2O_2 run line has been designed and will be constructed at a future date. Table 2 outlines the supply capabilities for Cell 2. The flow rates listed in the table are nominal.

Table 2. Cell 2 Commodity Supply Capabilities

	Press. (psig)	Vol. (gal)	Temp. (°R/°F)	Flow Rate (lbm/sec)	Run Line (in.)
H_2O_2/ LOX	3000	500	540/80 163/-297	220/ 112[1]	4
H_2O_2/ LOX	3000	500	540/80 163/-297	30/ 15[1]	1.5
JP-8	3000	250	540/80	40	2

1 - Max LOX flow rate assumes that velocity is no greater than 25 ft/sec.

The flame bucket in Cell 2 is used as an emergency catch tank if H_2O_2 has to be dumped from the run tank and/or run system during testing. After testing, H_2O_2 remaining in the run tanks is decomposed by a facility catalyst bed and discharged into the flame bucket in order to safely reduce the concentration of the fluid prior to disposal.

H_2O_2 is currently supplied in 30 gallon drums. For its storage, a covered concrete pad with spill containment and deluge water coverage is located west of the test cells. As part of the facility upgrades, a remote transfer system has been integrated into the E-3 facilities in order to fill run tanks without disconnecting the operating piping system. As part of this transfer system, two tanks with usable volumes of 3500 gallons and 4000 gallons can be used to store H_2O_2 as well as remotely fill the Cell 1 and Cell 2 run tanks. Construction is complete and the system is currently awaiting activation.

Included in the completed facility upgrades, a DI water system has been installed for flushing H_2O_2 run tanks and run lines. DI water for this system is provided by flowing potable water through a portable skid of tube bank filters and then storing it in a 2,800 gallon tank. This system is assembled and awaiting activation.

The SSC site-wide gas distribution system supplies each test cell with GN_2 at 4,500 psig and GHe at 4,400 psig. Installation of high pressure inert gas storage vessels and associated piping has been completed as part of the facility upgrades. The storage system provides 150 ft^3 of inert gas at a maximum pressure of 6,000 psig and a maximum flow rate of 50 lbm/sec. Tube bank trailers can supply additional volume of inert gases if needed.

DATA ACQUISITION AND CONTROLS CAPABILITIES

The E-3 control system consists of two Programmable Logic Controller (PLC) control systems; one for test facility and STE operations and one for the H_2O_2 storage area. The data acquisition system is divided into low-speed and high-speed systems. The low-speed data acquisition system (LSDAS) has a 128-channel digitizer per cell that share 100 (50 per test cell, but patchable) programmable bridge type signal conditioners. Instrumentation measurements are sampled and stored at 250 samples per second.

The high-speed data acquisition system (HSDAS) has a high speed 16-bit digitizer and recorder. The digitizer is typically configured for 32 channels at 100K samples per second per channel, but can be modified for each test article. A video system available at E-3 includes four low speed video cameras for normal testing. There is also one portable high-speed camera capable of recording up to 500 frames per second available at the test stand

The facility power system provides single and three-phase power at 480VAC, 277VAC, 208VAC, 220VAC, and 120VAC. Uninterrupted power supply (UPS) systems provide a minimum of ten minutes of 120VAC power to test critical systems.

OTHER CAPABILITIES

Construction is complete on the E-3 facility catch system. This system directs primary H_2O_2 liquid discharges for both Cell 1 and Cell 2 to a 4500 gallon catch tank. The H_2O_2 is then sent though a catalyst bed for decomposition prior to discharge in the new 100,000 gallon concrete containment basin. The fuel catch system routes discharges from each cell to a 3000 gallon catch tank. The fuel can then be pumped into a 500 gallon portable tank and reused for additional tests. In emergency situations, H_2O_2 from the catch tank and the storage and transfer systems are routed directly to the 100,000 gallon concrete containment basin and then diluted with potable water. Figure 5 shows the E-3 Inert Gas Storage, H_2O_2 and JP-8 Catch Tanks. Figure 6 shows the 100,000 gallon containment basin.

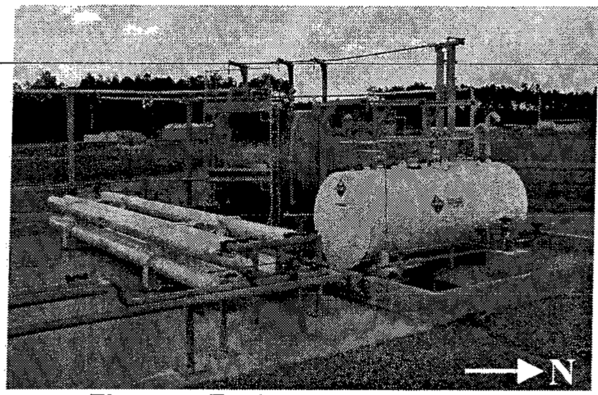


Figure 5. E-3 Inert Gas Storage, H_2O_2 and JP-8 Catch Tanks

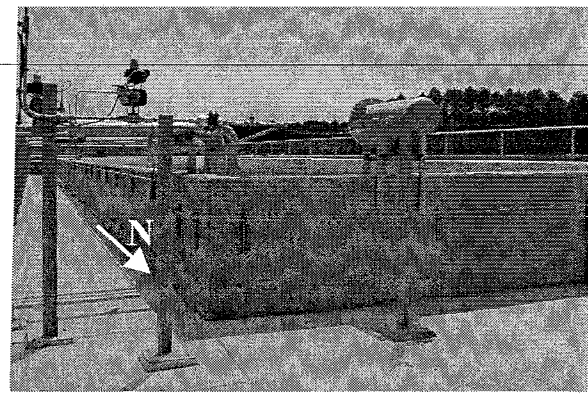


Figure 6. 100,000 Gallon Containment Basin

The E-3 deluge system covers all existing test cells, oxidizer vessels, fuel vessels, the Cell 2 flame bucket, the containment tank and all tanker fill headers. The supply system has been integrated with the E-Complex deluge water supply system as part of the facility upgrades. E-3 also uses a 6 inch potable water system for the purpose of providing deluge cooling water to two water cannons situated between Cell 1 and Cell 2. All areas can be remotely operated from the control room. In addition, the two water cannons can be locally operated. This system will limit damage in the event of a fire in a test cell or propellant storage/handling area as well as provide a means to dilute H_2O_2 in case of an emergency situation.

A 3000 psig hydraulic system has been installed this past year for both Cell 1 and Cell 2 under the facility upgrade program. The hydraulic system provides a significant improvement over pneumatically controlled valves, offering precise control for facility and special test equipment valves, improving the control of propellant flow in higher pressure test environments.

UTILIZATION OF THE E-3 TEST FACILITY

The E-3 test facility has supported technology advances in rocket propulsion devices using H_2O_2. Several different test articles have been tested at E-3 using 70%-98% H_2O_2 concentrations. The following is a brief summary of the test projects that have utilized this facility as well as those currently in the facility.

The first test project to make use of the E-3 Cell 2 facility was the Upper Stage Flight Experiment (USFE) Project by Orbital Sciences Corporation. The USFE test project utilized a pressurized feed system for 85% H_2O_2 and JP-8 as its propellants. It culminated with a successful nominal flow test for 140 seconds duration. USFE was followed by the Boeing AR2-3 test project. The AR2-3 test article is a pump-fed system testing 85% and 89% H_2O_2 and JP-8. The USFE and AR2-3 projects both used the Cell 2 vertical firing position. Figure 7 shows a picture of the AR2-3 test project.

Concurrent to AR2-3 testing, Cell 2 was also used for a catalyst bed development project by Pratt & Whitney. Cell 2 was modified to include a horizontal firing position to handle component level tests. Testing for this catalyst bed project was performed in two phases using 98% H_2O_2. Additional catalyst bed work took place with a Boeing Rocketdyne advanced catalyst bed. This work was initially performed in the horizontal position at E-3 Cell 2 using 98% H_2O_2, and then later in the vertical position in the same cell.

Recent activities at E-3 include Boeing Rocketdyne's Hypergolic Injector Program, which completed testing in April 2003. This project was the first to utilize the upgraded run line pressure capabilities in Cell 2. Figure 8 shows a picture of the Boeing Rocketdyne Hypergolic Injector Project.

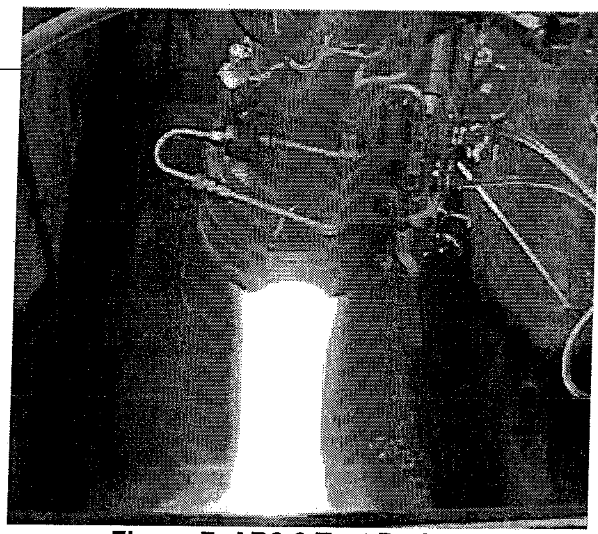


Figure 7. AR2-3 Test Project at the E-3 Cell 2 Test Stand

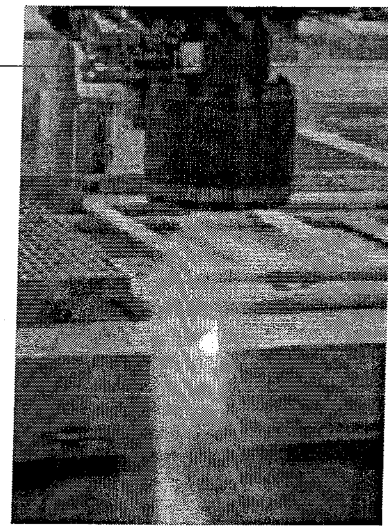


Figure 8. Boeing Rocketdyne's Hypergolic Injector Project at the E-3 Cell 2 Test Stand

CAPABILITIES OF THE SSC E-2 CELL 2 FACILITY

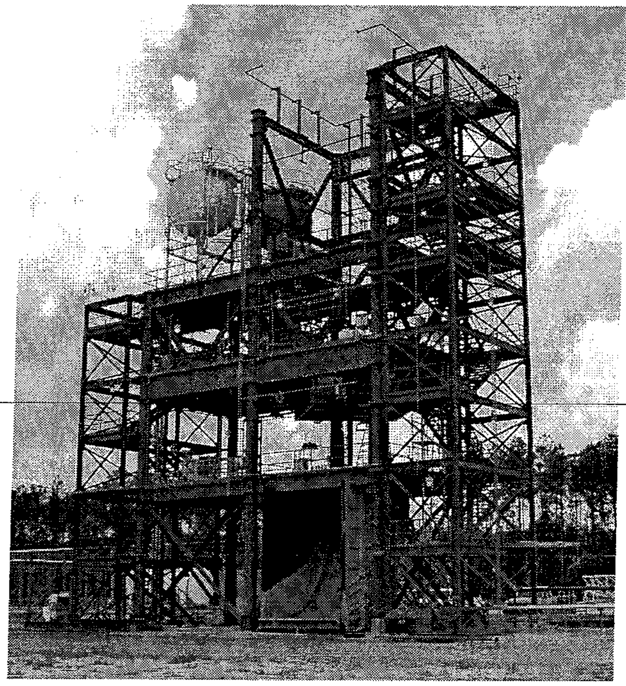
The E-2 Cell 2 test facility is capable of testing complete flight stages and "flight-like" test article stages with up to 100,000 lbf. (200,000 lbf. impulse load) thrust in a vertical orientation. LOX and RP-1 propellant supply systems are presently available at this stand along with ancillary DI water, high pressure GHe and GN_2 gas supply systems, facility deluge, and H_2O_2 drain/disposal systems.

STRUCTURAL CAPABILITIES

The E-2 Cell 2 vertical test cell runs from a rolling deck platform located 22 feet from ground level to the top of the test cell structure and measures 22' 4" x 22' 4" x 58' 10". Figure 9 shows the E-2 Cell 2 test stand. The diamond-shaped thrust takeout structure reaction beams provide a 15 ft. x 15 ft. area to accommodate test articles. Larger test articles, up to about 22 feet in diameter, can be accommodated by making structural modifications to the test cell. Access stairs are provided at both the north and south sides of the test stand. A facility thrust measurement system is available for thrusts ranging from 10,000 lbf. to 100,000 lbf.

HYDROGEN PEROXIDE CAPABILITIES

The E-2 Cell 2 test facility was not originally designed for hydrogen peroxide testing. A number of improvements were made to augment existing facilities to render this test position capable of testing hydrogen peroxide test articles.



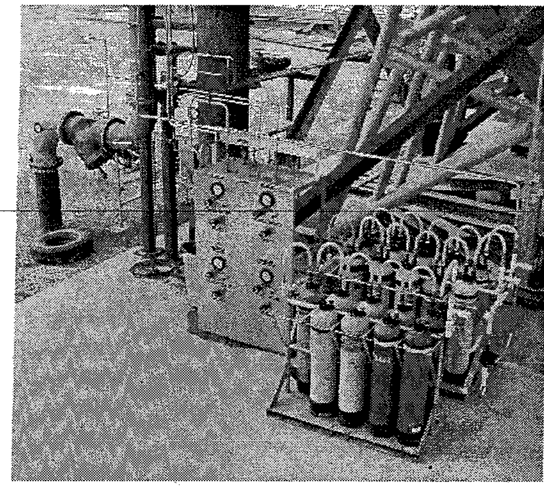


Figure 9. E-2 Cell 2 Test Stand **Figure 10. Deionized Water Filtration System**

High pressure GN_2 and GHe supplies are available at the E-2 Cell 2 facility that meet the cleanliness requirements for use with hydrogen peroxide. A portable filtration system has been installed to the current facility potable water system to produce deionized (DI) water for use with hydrogen peroxide. The filtration system, shown in Fugre 10, consists of sets of five tube bank filters that can be installed in parallel to produce the flowrate of DI water required for the test program.

The greatest challenge in modifying the E-2 Cell 2 test stand for hydrogen peroxide service was developing a system for disposing of large quantities of high-concentration hydrogen peroxide that would accommodate both routine disposal of peroxide from the test article and emergency disposal of peroxide (during incipient decomposition, for example). Other considerations for designing such a system included personnel safety from possible contact with the peroxide or inhalation of peroxide vapor, as well as environmental restrictions that limited the non-emergency discharge of hydrogen peroxide to 8% concentration.

A hydrogen peroxide disposal drain system was implemented on the E-2 Cell 2 test stand that dilutes the peroxide with potable water and flushes the resulting low concentration peroxide to a large holding pond located approximately 350 ft. from the test stand. The peroxide drain from the test article feeds into an atmospherically vented 6 inch diameter stainless steel drain line that runs just off the north side of the test stand. A 3 inch potable water line capable of delivering 300 GPM ties into the 6 inch line at the top of the stand, upstream of the high concentration test article drain. Figure 11 shows the drain system running from the test stand to the holding pond.

To decrease cost and increase versatility, the drain system line from the test stand to the disposal pond was fabricated from industrial sized hydrogen peroxide compatible PVC pipe, which is estimated to have a lifespan of several years. The pipe, primer, and cement were subjected to hydrogen peroxide compatibility testing prior to fabrication of the system. The novel use of PVC piping in this location of the drain disposal system allows for relatively inexpensive rerouting and resizing of the line if dictated by the requirements of the test article. DI water sinks and rinsing stations have been built at various levels of the test stands to provide convenient access during peroxide operations.

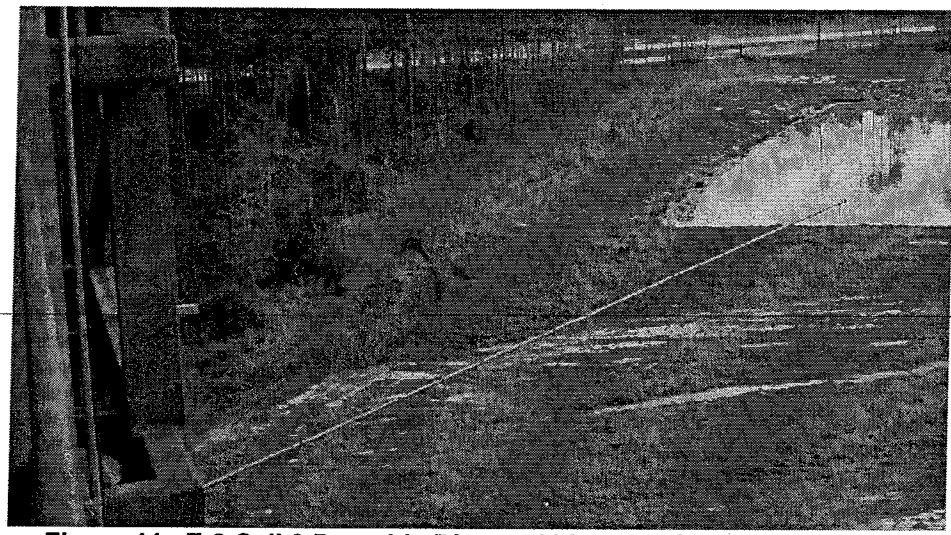


Figure 11. E-2 Cell 2 Peroxide Disposal Line and Containment Pond

DATA ACQUISITION AND CONTROLS CAPABILITIES

The E-2 Cell 2 Low Speed Data Acquisition System (LSDAS) provides 256 total channels for test article and Special Test Equipment (STE) use. These channels include 160 programmable full bridge amplifiers, 60 filter amplifiers (for a total of 220 hardwired channels), and 36 raw input channels. Total throughput is 200 sps of 16 bit data for each channel. The Inter-Range Instrumentation Group (IRIG) B time standard is also recorded on the LSDAS for time correlation between systems. The DAS end-to-end uncertainty is ±0.15%, excluding instrument and associated cabling. PCGoal is available for transmitting of near real time low speed data to an off site location.

The E-2 Cell 2 High Speed DAS (HSDAS) provides 124 channels for customer use, plus 4 additional channels reserved for IRIG-B timing. Channel throughput is 100 ksps per channel at 16 bits with a 45 kHz bandwidth. The data is recorded on Super VHS tape along with IRIG B for time correlation.

The facility power system provides 480/277 VAC three-phase and 240/120 VAC single-phase power. The 240/120 VAC, supplied from a battery-backed Uninterruptible Power Source (UPS), is supplied to the Data Acquisition System (DAS) and control system. 240/120 VAC is also available for test article use. The facility power system provides 28 VDC for valve control and 24 VDC for instrumentation transmitters. DC power is sourced from the facility UPS. 28 VDC is also available for test article use.

UTILIZATION OF THE E-2 CELL 2 TEST FACILITY

Modifications to the E-2 Cell 2 test facility were made to support the Upper Stage Flight Experiment (USFE) Program by Orbital Sciences Corporation and the United States Air Force. USFE catalyst bed and engine testing had previously been conducted on the E-3 test stand. The current USFE test article is a complete, self-contained stage that is planned to be used as flight hardware. Fuel and oxidizer tanks are within the stage. Hydrogen peroxide will be loaded to the stage from a customer-supplied fueling skid. Testing for this engine is currently being determined.

CONCLUSION

The H_2O_2 propulsion testing capabilities of the E-Complex have continued to expand over the past year with the completion of the E-3 facility upgrades and modifications to the E-2 test facility. These enhancements will enable SSC to meet the needs of current and future customers in their efforts to develop new H_2O_2 propulsion systems in support of the advancement of the next generation space transportation vehicles.

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