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GROUND TESTING WITH HIGH TEST PEROXIDE- LESSONS LEARNED

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ABSTRACT

Propulsion Ground Testing with High Test Peroxide (85 to 98% concentration) began at the NASA John C. Stennis Space Center in calendar year 1998, when the E3 Test Facility was modified to accommodate hydrogen peroxide (H_2O_2) in order to support the research and development testing of the USAF Upper Stage Flight Experiment rocket engine. Since that time, efforts have continued to provide actual and planned test services to various customers, both U. S. Government and Commercial, in the ground test of many test articles, ranging from gas generators, to catalyst beds, to turbomachinery, to main injectors, to combustion chambers, to integrated rocket engines, to integrated stages. Along this path, and over the past 4 years, there has been both the rediscovery of previously learned lessons, through literature search, archive review, and personal interviews, as well as the learning of many new lessons as new areas are explored and new endeavors are tried.

This paper will summarize those lessons learned in an effort to broaden the knowledge base as High Test Peroxide is considered more widely for use in rocket propulsion applications.

INTRODUCTION

John C. Stennis Space Center (SSC) in Mississippi is chartered as the NASA Center of Excellence for large space transportation propulsion system testing. This charter has led to many unique test facilities, capabilities, and advanced technologies provided through the supporting infrastructure. SSC has conducted projects in support of such diverse activities as liquid, and hybrid rocket testing and development; component testing; stage testing non-intrusive plume diagnostics; plume tracking; test technology and more. Stennis has provided testing services not only to U. S. Government agencies, but also to Commercial companies and consortia.

As different groups around the nation design the technologies for future space transportation of the future, H_2O_2 is being looked at more and more. This propellant is efficient, non-cryogenic, non-toxic and has a low operations handling cost. The growing interest in hydrogen peroxide as a propellant and the requirement for a larger-scale ground test capability to meet the needs of research and development efforts prompted the development of the E-3 Test Facility.

The E-3 Test Facility consists of 2 test cells with Cell 1 primarily used for horizontal firings of LOX and GOX hybrid motors, and Cell 2 primarily used for testing H_2O_2 and/or hydrocarbon fueled test articles. Cell 2 was brought on-line in November 1998, and has been used in support of programs primarily using 85% to 90% H_2O_2 and JP-8 propellants. Since its activation, Cell 2 has tested thrust chamber assemblies, engines, and catalyst beds. Cell 1 will be capable of testing articles using H_2O_2 after facility upgrades, which are further discussed later in this paper.

Prior to the development of the E-3 Test Facility, there was no ground testing facility in existence in the United States that could accommodate test articles that used H_2O_2 as a propellant. SSC personnel did not have experience with H_2O_2 prior to the development of E-3 Cell 2. The task of building a test stand capable of providing test articles with H_2O_2 as a propellant was a learning experience for SSC. In designing and developing the facility, the expertise of peroxide manufacturers and a small number of users was used. Documented lessons learned and guidelines from the 1960s were also used.

This paper shall provide an overview of the considerations that went into the build-up of this newly constructed test facility. It will outline the current and future capabilities and will briefly describe the programs that have been tested at the E-3 Cell 2. It will also provide the Lessons Learned that have been

encountered through the build-up and operations of this H_2O_2 test facility.

FACILITY DEVELOPMENT CONSIDERATIONS

The development of a new facility capability using commodities for which there was no in-house expertise presented several new challenges to the SSC E-3 Team. H_2O_2 is certainly not a new commodity to this industry, but it is a commodity that had not been in use at SSC. Therefore, the design and development of a new test facility capable of testing rocket engines in the 10,000 lbf thrust class was approached cautiously.

Handling/Operating Philosophy

The philosophy for handling and operating with H_2O_2 was the first primary consideration to be resolved. Manufacturers were consulted for handling guidelines with respect to safety, personnel protective equipment, and processes. SSC environmental and safety personnel were involved in ensuring environmental compliance and personnel safety.

The overall philosophy employed was to utilize industry standards and recommendations as much as possible with modifications as required for SSC unique applications. This philosophy carried over to the safety and environmental issues and approaches. The top priorities were to maintain safety of facilities and personnel coupled with being as environmentally responsive as possible. Many safety rules have been instituted at the test facility and the procedures associated with testing have been carefully written to ensure safety of personnel, the facility, and the test article.

Component Selection/Compatibility

The component selection and compatibility issues were the most critical of all considerations. Due to the lack of experience with high-test peroxide, an extensive data search was initiated to obtain current information relative to today's materials and availability coupled with data available from previous usage during the 1950s and 1960s. The selection of the types of components was easily done based on experience with test facility systems and operations, but the actual materials of construction and/or methods of fabrication played a major role in final selection of components.

H_2O_2 reacts negatively with certain materials. Components that were selected for use at E-3 Cell 2

were carefully researched to ensure that their materials were compatible with H_2O_2 .

Materials used with H_2O_2 are classified in four categories:

- Class 1: Long term storage (years; Aluminum, Teflon)
- Class 2: Short term storage (weeks; 316 Stainless Steel, Polyethylene)
- Class 3: Very short contact (hours; 17-4 Stainless Steel, Duroid 5600)
- Class 4: Catalyst (seconds; silver, carbon steel)

Everything from valves, tubing, flowmeters, and pumps to PPE, storage vessels and run tanks had to be carefully selected. The majority of components in system are 300 series, stainless steel with teflon soft goods. There will be more discussion on the considerations that must be taken when selecting components in the Lessons Learned section of this paper.

Cleanliness

H_2O_2 starts to decompose when contaminants are introduced to the system. Components for the run system that were made of stainless steel had to be cleaned to ensure that no contaminants would enter the system.

The industry standard guideline for exposure to high-test peroxide requires a nominal 2-hour passivation of 300 series stainless steel with a Nitric acid solution. This process was initially incorporated into the SSC cleaning operations. However, as components exposed to this extended acid soak were installed, it became apparent the additional acid soak was etching the surface material and significantly increasing the occurrence of stainless steel threads galling during installation.

The standard cleaning process at SSC is designed to meet oxygen cleanliness. The SSC oxygen cleaning process exposes the metal parts to a minimum acid passivation soak of 15 minutes in a 27%-34% Nitric acid at 85°F. A preliminary "rough" test was conducted with components from each of the passivation processes (15 min. Vs 2 hrs.), exposed to 70% peroxide. No significant difference was observed in the reactions generated from either component. The decision was made to delete the extended acid passivation exposure and use the SSC standard cleaning procedure for oxygen service items. The decision to delete the extended acid passivation exposure prompted the ground-rule that the peroxide run system would not be utilized for storage.

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FACILITY CAPABILITIES

The E-3 test facility is a versatile test complex that is 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. Cell 1 is a horizontal test stand, which can support horizontal thrust loads up to 60,000 lbf (120,000 lbf impulse load). Cell 2 is primarily for vertical testing with provisions for limited horizontal testing. Cell 2 can support vertical thrust loads up to 25,000 lbf thrust (50,000 lbf impulse load). The addition of a third test cell (Cell 3) is under consideration.

The facility has the capacity to deliver propellants at low and medium pressures. All propellant storage, transfer, and run systems for LOX and GOX are cleaned to cleanliness level 1XX per SSC STD 79-001. Similar systems for H_2O_2 are initially cleaned to cleanliness level 1XX and then passivated for H_2O_2 service. The JP systems are initially cleaned to a level 2X and, with exception of the final filter, are maintained at level 3.

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 (TMS) are available for use. An additional TMS unit of 60,000 lbf capacity is in the facility upgrade plan. Test cells 1 and 2 can be occupied at the same time, providing a multiple program capability. Both test cells are adequately illuminated for night time work.

Cell 1 was primarily designed to test pressure-fed LOX/hydrocarbon fuel, GOX/hydrocarbon fuel, GH_2 /GOX, and hybrid rocket motor combustion devices. JP and H_2O_2 run systems will be installed in Cell 1 as part of the facility upgrades going on in the next year. Cell 1 has two thrust positions. Both positions are capable of supporting horizontal thrust loads of up to 60,000 lbf (120,000 lbf impulse load). Additionally, Cell 1 has a small component test position capable of supporting 3,000 lbf thrust loads (6,000 lbf impulse load).

Cell 1 Future Commodity Supply Capabilities

Propellant	Press. (psig)	Temp. ($^{\circ}R/^{\circ}F$)	Flow Rate (lbm/sec)	Supply Line (in.)
H_2O_2 /LOX	3500	540/80	220	4
H_2O_2 /LOX	3500	540/80	30	1.5
JP-8	3500	540/80	40	2

Cell 2 was primarily designed to test H_2O_2 /JP-8 and rocket motor combustion devices up to 25,000 lbf of vertical thrust (50,000 lbf impulse load). At present, Cell 2 is configured to support testing of 10,000 lbf H_2O_2 /JP engines. As part of the planned upgrades, Cell 2 will be capable of testing H_2O_2 /JP engines up to 25,000 lbf vertical thrust. The upgrades will also provide the cell with the capability for testing LOX/JP engines. Cell 2 has an additional capacity to test monopropellant configuration sub-scale combustion devices, such as catalyst beds and components. Two vertical thrust takeout structures are available, mounted above the flame bucket access hole. A vertical thrust takeout structure with a 25,000 lb thrust (50,000 lbf impulse load) rating will be constructed as part of the facility upgrade plan. Mobile cranes are available to provide lifting capability.

Test articles at Cell 2 are positioned above a flame bucket that is 8ft. wide by 17 ft. deep. The flame bucket 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. The H_2O_2 is diluted with water to a safe concentration before it is pumped out and disposed of safely. After testing, leftover H_2O_2 is dumped into a facility catalyst bed in order to safely reduce the concentration of the fluid prior to disposal. The catalyst bed discharges into the flame bucket.

Cell 2 Commodity Supply Capabilities

Propellant	Press. (psig)	Temp. ($^{\circ}R/^{\circ}F$)	Flow Rate (lbm/sec)	Supply Line (in.)
H_2O_2	1200	540/80	49	2
JP-8	1400	540/80	7	1

Cell 2 Future Commodity Supply Capabilities

H_2O_2 /LOX	3500	540/80	220	4
H_2O_2 /LOX	3500	540/80	30	1.5
JP-8	3500	540/80	40	2

The SSC site-wide gas distribution system can supply each test cell with GH_2 at 4,000 psig, GN_2 at 3,000 psig, and GHe at 4,400 psig.

The facility power system provides single and three-phase power at 480VAC, 277VAC, 208VAC, 220VAC, and 120VAC. The E-3 control system is a Programmable Logic Controller (PLC). The control system provides real time control of test article coolant, propellants, and control valves. It can automatically cycle control valves through a series of predetermined states specified by the customer and it performs the test article red line and blue line limit monitoring. Facility

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instrumentation is installed for real-time display of facility processes and data recording. The facility also provides the ability to display real-time test article measurements. 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 programmable bridge type signal conditioners. The system provides 16 bits of resolution with a throughput of 250 sps. The high-speed data acquisition system (HSDAS) has a 16 bit digitizer and recorder. The digitizer is typically configured for 32 channels at 100 KSPS, but can be modified for each test article. Data processing is provided for the LSDAS and HSDAS.

FACILITY UTILIZATION

The utilization of the E-3 Cell 2 test facility has exceeded all initial expectations. The facility was developed to support one primary test program, but the capability and design has been flexible enough to support numerous programs, test articles, requirements, and configurations. The following is a brief summary of the programs that have utilized this facility, those currently in the facility, and future programs committed to using the facility.

The Upper Stage Flight Experiment (USFE) Program, Phase 1, by Orbital Sciences Corporation was the first program to utilize the E-3 Cell 2, test facility. The USFE program utilized a pressurized feed system for 85% H_2O_2 and JP-8 as its propellants. This program conducted both mono-propellant and bi-propellant tests in the evaluation of their catalyst bed and fuel injection systems. The testing ranged from low flow conditions up to nominal flows of 30-40 lbm/sec. It culminated with a successful nominal flow bi-propellant test for 140 seconds duration.

The USFE program was followed by the Boeing AR2-3 test program of their previously flight proven system. The AR2-3 test article was a pump-fed system, thus required the facility to be slightly modified to accommodate the low pressure run systems. Initial testing started with mono-propellant tests using 85% and 89% H_2O_2 . Bi-propellant tests were conducted with JP-8 as the fuel and both 85% and 89.2% H_2O_2 . Other hydrocarbon fuels may be possible candidates for use. The inclusion of these additional fuels will be determined upon program requirements and facility handling capability and compatibility of materials of construction utilized in the existing fuel systems. The USFE and AR2-3 programs used the vertical firing position with and without the available thrust measurement system.

A concurrent test program to the AR2-3 program was a catalyst bed development program by Pratt & Whitney. The implementation of this program along with the AR2-3 required the modification of Cell 2 to include a 2nd test position. Therefore, a horizontal firing position was incorporated to handle component level tests. This horizontal firing position utilized the existing propellant run systems and was reduced to the low flow requirements by means of cavitating venturis between the facility interface and the test article. Testing for this catalyst bed program ran from November 1999 to xxx 1999 (schedule I saw said 9/99 11/99). List duration.

The Boeing Rocketdyne Catalyst Bed was testing at E-3 Cell 2 The test article used xx% H_2O_2 and was testing in the vertical position. Need more info. The info added here will not be proprietary.

Currently, E-3 is under construction due to upgrades that are being implemented in order to increase the capacity of Cell 2 and to add a H_2O_2 to Cell 1.

The remainder of this section will describe some of the upgrades happening at E-3. It will be a high level description that will not describe the configuration of the test stand. There will be no diagrams.

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LESSONS LEARNED

The E-3 Test Facility was the first facility in the country designed strictly for the testing of articles using H_2O_2 . Much of the development of the facility was a learning process for SSC personnel. Information, knowledge, and experience of H_2O_2 manufacturers were heavily relied upon. Many lessons were learned in the process of putting this knowledge and experience to work at the test facility. The following are summaries of the lessons learned. They are being presented here in order to assist test article designers and test facility designers when dealing with unique requirements of H_2O_2 .

As stated earlier in this paper, H_2O_2 reacts negatively with certain materials. When designing the test stand, the selection of components was one of the most important issues. H_2O_2 manufacturers stressed the importance of this issue and SSC personnel were conscious of it during the design and activation of E-3. There were several incidents where materials in components reacted negatively with H_2O_2 even though they were selected carefully.

The remainder of this section will be describing some lessons learned. It will be partially a repeat of lessons learned from previous papers presented at conferences. There will be nothing in it describing test stand configurations. There will be no customer proprietary information.

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