DRAFT

NASA HYDROGEN PEROXIDE PROPULSION PERSPECTIVE

Ronald J. Unger
Lead Systems Engineer, On-Orbit Propulsion Systems
2nd Generation Reusable Launch Vehicle Program Office
NASA/Marshall Space Flight Center

Good morning, ladies and gentlemen. My name is Ron Unger, and I am from the Marshall Space Flight Center. I serve as both the Lead Systems Engineer for the On-Orbit Propulsion Systems Project and the Lead Sub-System Manager for the peroxide component development work under the On-Orbit Project. You may be more familiar with the "Upper Stages" project term from previous meetings and contacts. A reorganization last spring brought the "Upper Stages" peroxide work under the newly-formed On-Orbit project.

Overview

This presentation is to provide the current status of NASA's efforts in the development of hydrogen peroxide in both mono-propellant and bi-propellant applications, consistent with the Space Launch Initiative goals of pursuing low toxicity and operationally simpler propellants for application in the architectures being considered for the 2nd Generation Reusable Launch Vehicle, also known as the Space Launch Initiative, or SLI.

In 1997, NASA recognized the industry-wide "great void" (CHART 1), a term my colleague Curtis McNeal coined, which existed in the development and use of hydrogen peroxide in propulsion systems. Traditional thinking in terms of environment, operations, and acceptable hazards had all been deeply entrenched during the period of the "great void," in which time hydrazines and NTO were the *de facto* propellants of choice for long-term, ambient temperature, on-orbit applications. But as part of the realization of the peroxide technology void came the revelation that peroxide also had possibilities as an on-orbit propellant, and with its low-toxicity nature, could provide operational and environmental benefits not available with the use of hydrazine mono-propellant and bi-propellant systems. Starting then in the 1997 time frame (CHART 2), solicitations and contract awards begun under the NRA8-19 and NRA8-21 procurement vehicles were initiated to bring peroxide back into a level of legitimate consideration for upper stage and on-orbit applications. This work was seen as potentially valuable and applicable to the goals of SLI, thus the work was scooped up administratively and is now managed as part of the SLI Program.

Since this conference last convened, NASA has sponsored a number of risk reduction activities for the purpose of advancing the understanding of peroxide's advantages and disadvantages that the SLI architecture contractors should consider when conducting propellant trade studies for the 2nd Generation Reusable Launch vehicle. Much of the data on the completed work are available to the US peroxide community. A number of activities are also ongoing, and will continue into the next calendar year.

Component Development

I would like to first address some of the hardware concepts that have been under development by way of NASA sponsorship.

Within the context of the SLI-initiated contracts, as well as some pre-SLI awards, Marshall has been managing a number of successful peroxide component development efforts consistent with the long-life and reliability goals of SLI.

In late 2001, through a cooperative agreement with the Boeing Company, we have successfully completed the development of a long-life catalyst/gas generator system (CHART 3). Various diameter catalyst beds were tested, along with a wide range of test parameters, such as bed loading, chamber pressure, and start conditions. The final design of the catbed and chamber has proven to be rugged and reliable, with no apparent degradation of the hardware and no chamber pressure roughness developing at the end of a long-life test series. The system has applications for powering turbopumps as well as being a hot gas source for an advanced peroxide/hydrocarbon ignition system.

As a follow-on to the development of the advanced gas generator, Boeing proceeded early this year to demonstrate the operation of its advanced ignition system (CHART 4). The igniter utilizes hot decomposed hydrogen peroxide as an ignition and oxidizer source within the torch igniter to raise the injected hydrocarbon fuel above its autoignition temperature. Various mixture ratios and flow rates demonstrated the robust design, both in igniter-only and integrated igniter tests. In these tests, the igniter was used to ignite a main injector and chamber assembly using the same fuels as the igniter, thus supporting the approach of having fewer and safer fuel storage requirements for a flight vehicle. The torch igniter demonstrated reliable ignition, survivability in its thermal environment, and stable operation.

Currently under development (CHART 5), and scheduled for testing before the end of this year at Stennis Space Center is Boeing's advanced peroxide turbopump. Again utilizing the advanced gas generator, this time to power the turbine, we plan on performing a number of tests demonstrating the throttleability and robustness of this design for peroxide/hydrocarbon applications. The hardware fabrication is nearing completion, and delivery to Stennis is expected very soon. Concurrent with the hardware fabrication is the general peroxide upgrade effort at Stennis in the E3 test complex which will accommodate the turbopump testing in Cell 1, as well as the hypergolic injector tests, to be conducted in Cell 2. I will discuss more about the injector later. To help expedite the facility preparation process for the turbopump testing, we have had a stereolithography model built of the turbopump (as shown in the chart). this model has allowed fit checks with the test hardware and running of test article feed lines prior to the actual delivery of the turbopump. This approach helped mitigate some critical schedule concerns for turbopump delivery, as well as minimize the exposure of the actual turbopump to construction and contamination hazards.

Another component effort underway is the development and test of a hypergolic injector (CHART 6). In diverting from the advanced igniter concept previously discussed which utilized an independent catalytic/hot gas ignition system, this injector concept utilizes a hydrocarbon fuel to which is added a Boeing–proprietary chemical mixture which ignites hypergolically with peroxide. The potential benefits are substantial – performance of this hypergolic injector is expected to be very near the peroxide/hydrocarbon combination, the propellants are of low-toxicity, and no separate ignition system is required. As with the turbopump, a stereolithography model is being prepared to expedite facility interface and fit checks. The injector hardware, with two distinct risk-reduction configurations, is nearing its delivery date to Stennis, also to be tested later this year in the E3 Cell 2 position.

These aforementioned components are all comparably sized for an engine system application, which would fit the expected requirements of an upper stage or Orbital Maneuvering System engine, if selected for use in an SLI architecture.

Propellant Studies

I would like to now switch to the propellant studies being sponsored by Marshall.

Marshall has several activities which either were completed this past year or are on-going both in-house as well as contracted. These studies are intended to further the understanding of the effects of manufacturing processes and purity of peroxide on catalyst beds and the fluid physics of peroxide in an on-orbit application. Additionally, we are looking at the hypergolic nature of the combination of peroxide with the aforementioned blended hydrocarbon fuel.

Completed last winter was a contract with General Kinetics (CHART 7) to study the effects of peroxide processing impurities and stabilizers as well as the effects of rapid pulsing (as in a thruster pulse mode) on the catalyst performance and life. The impurity study resulted in a new draft procurement specification (well within existing manufacturing process capabilities) for rocket-grade hydrogen peroxide, while the pulse testing showed that catalysts can hold up under representative thermal cycles in thruster applications with no apparent degradation. This risk-reduction effort was significant towards providing alternative architecture options over other traditional storable or LOX/ethanol thruster systems.

Two grants were awarded to Purdue University this past spring (CHART 8). The first actually has two distinct tasks: the study of the thermal decomposition and vaporization phenomena of peroxide injected into a flow field of peroxide decomposition products, and the vacuum ignition characterization of peroxide and the Boeing hypergolic blend. In a paper previously discussed at this conference, efforts are already underway to study and report on the phenomena of decomposition and vaporization. Marshall's funding will allow further investigation as well as the creation of a refined model describing the phenomena. The Marshall task will result in the development of a design database useful for optimizing catbed sizes, decomposition chambers, combustors, and staged combustion flow ratios, as well as increasing the understanding of the potential for combustion instability.

We are also proceeding in the planning and design of a vacuum chamber and injector to test the vacuum ignition characteristics of peroxide with the Boeing hypergolic blend at both reduced ignition pressures and varying percentages of the propellant blend constituents, which will also support the yet-to-be discussed fuel optimization tests being conducted at Marshall.

The second grant (CHART 9) that we have with Purdue is to perform a demonstration of a traditional surface tension Propellant Management Device configuration using peroxide-compatible materials. The demonstration will be conducted in Purdue's drop tower to provide for an actual zero-g environment in order to visually verify the wicking process of peroxide within the PMD.

(CHART 10) In support of Boeing's hypergolic injector development, Marshall has an in-house fuel optimization program on-going, facilitated by a license agreement between Boeing and NASA for the use and development of this fuel for SLI. We are currently in the midst of a program to test certain characteristics based on the specific percentages of constituents within the fuel to establish the optimum blend. Parameters such as ignition delay, corrosion, lubricity, cost, specific impulse, and others are being tested to help establish the optimum blend. Ignition delay tests have been completed, and lubricity testing is underway. As previously mentioned, Purdue will conduct the hot-fire specific impulse performance testing.

Material Compatibility Studies

Now to our last major area of activity. Marshall has either completed or has several on-going activities in material compatibility.

Last winter we concluded an effort with Pratt and Whitney (CHART 11) to study detonability and operating limits when using peroxide as a coolant in a combustion chamber wall. The study considered such factors as coolant channel size, heat flux, material compatibility, channel surface roughness, peroxide flow velocity, and flow pressure. This parametric study will contribute to a design methodology which precludes the decomposition and/or detonation of peroxide when used as a chamber wall coolant.

In an effort (CHART 12) more strictly in line with the testing of material compatibility and heat flux efficiency at the peroxide/chamber wall interface, Marshall has Boeing under contract to perform an extensive investigation and downselect of candidate main combustion chamber materials. The study has looked initially at such parameters as channel wall and tube wall construction for thermal management boundary conditions and structural issues, initial compatibility of the material system assessed via high-temperature immersion testing, bonding systems and passivation techniques. As part of this effort, we have completed a critical design review for a materials compatibility test fixture, along with receiving the recommendations of the four materials to be continued into the testing phase. Presently, the continuation of the fabrication of the test fixture and actual testing of the materials has been put on hold until later in Fiscal Year 03.

Concurrent with the test fixture design process, Marshall began support to the effort by initiating microcalorimetry testing on the final four downselected materials, exposing the material specimens to 98% peroxide and measuring the heat generated during decomposition as well as the rate of change of peroxide concentration. This testing is scheduled to for completion this month.

Conclusion

In summary, I have described the activities that Marshall has sponsored over this past year, but the original context of this talk was to be on a NASA peroxide perspective. Please keep in mind that the driver for the activities described is to ultimately support the 2nd Generation vehicle architecture decisions. There are competing upper stage, OMS, and thruster concepts being developed and/or evaluated, such as LOX/ethanol, that are vying for selection for inclusion in the architectures. Marshall is facilitating this evaluation by providing funding for development of these less-than-mature concepts to help reduce the risks as they are considered in the architecture trade studies. Thus, Marshall is not mandating which of these technologies to incorporate in any given architecture. Therefore, our perspective is one of open-minded consideration for all potential propellant candidates that meet the over-arching goals of the SLI program of safety and cost.

Also, without doubt, you have questions as to how well peroxide is standing up against competing concepts as the architectures develop. The pending architecture downselects, which will be contractor proprietary, as well as the upcoming cycle II contract awards prevent me from addressing any specifics.

I would like to thank John Rusek and Bill Anderson for inviting me to present this NASA perspective. I appreciate your attention and wish you an enjoyable last day at the Conference.

DRAFT

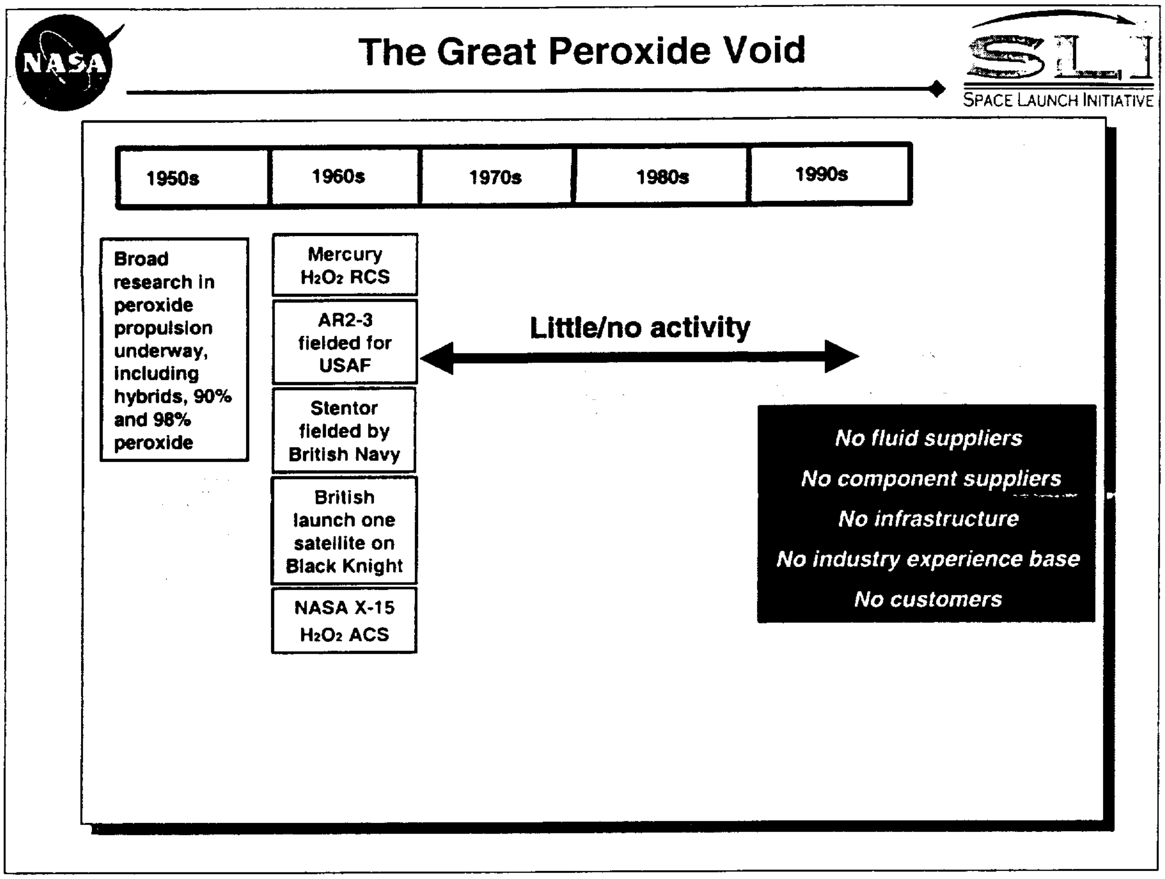


Chart 1

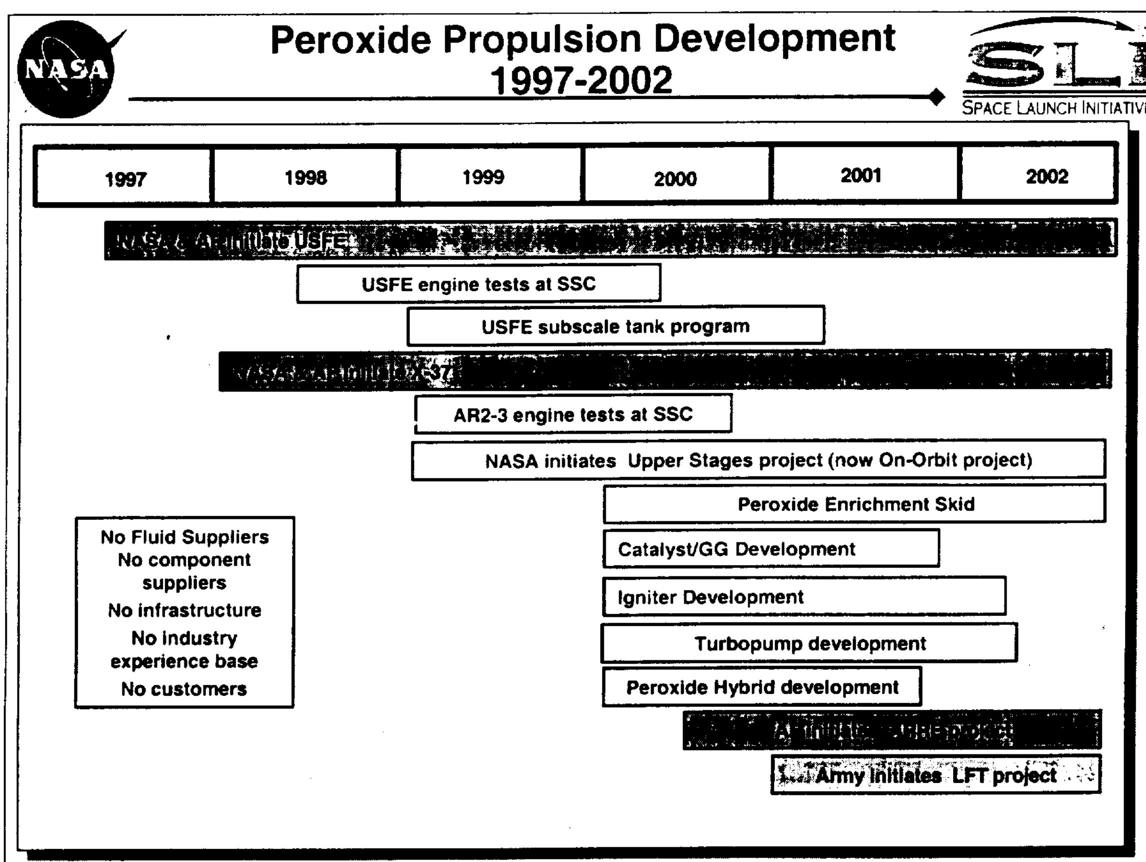
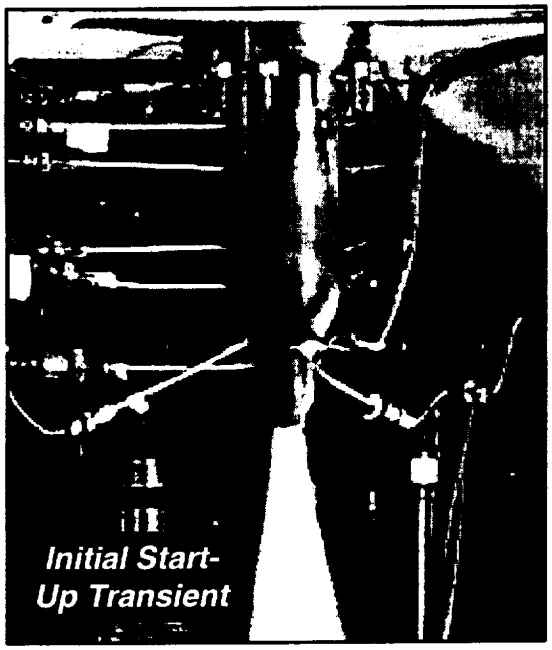


Chart 2

DRAFT

Advanced Catalyst/ Gas Generator Development

SPACE LAUNCH INITIATIVE



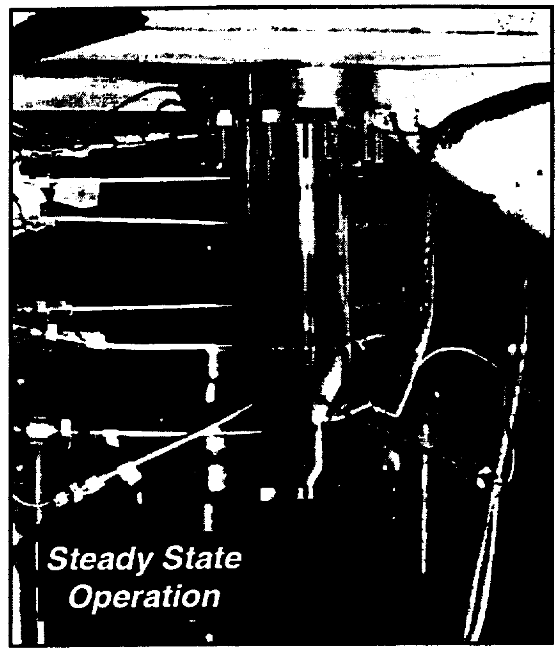
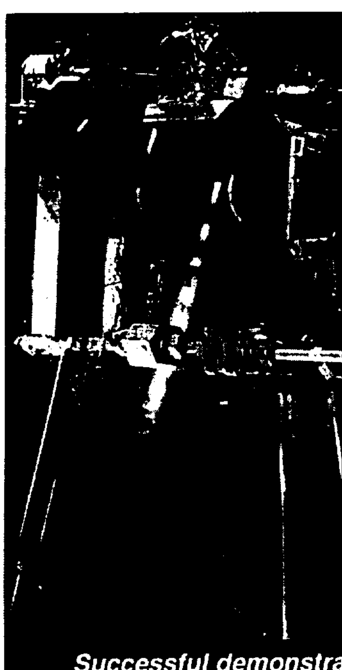


Chart 3

Advanced Igniter Development

SPACE LAUNCH INITIATIVE

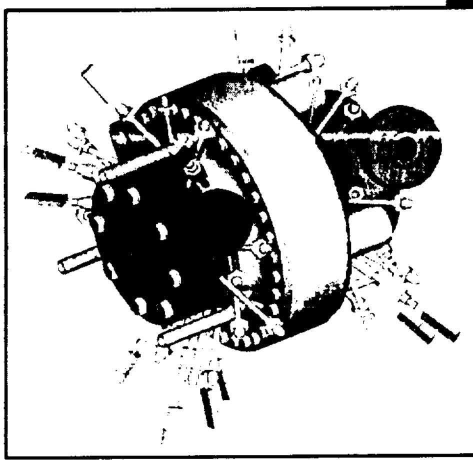


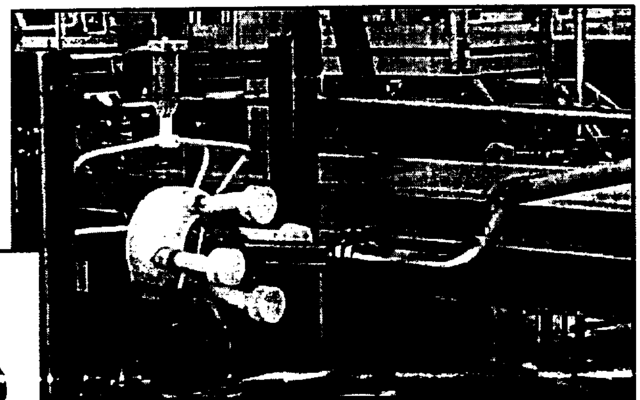
Successful demonstration of bi-prop igniter alone and integrated in a modified injector/combustion chamber

Chart 4

Advanced Hydrogen Peroxide/ Hydrocarbon Turbopump

SPACE LAUNCH INITIATIVE



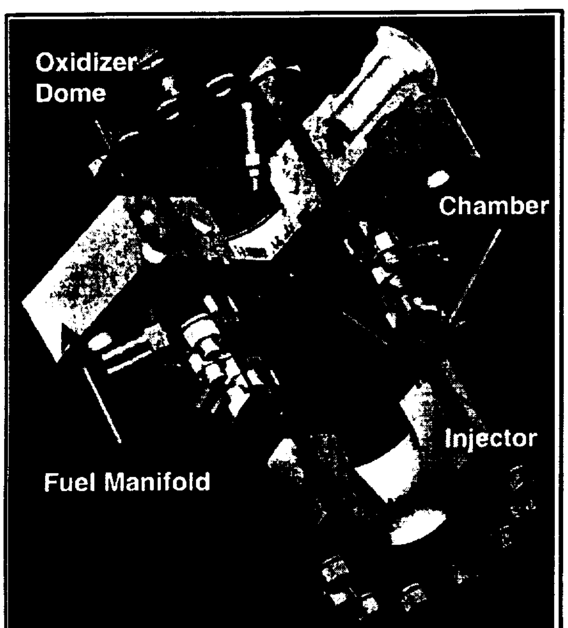


Integration of turbopump stereolithography model into E-3 Cell 1

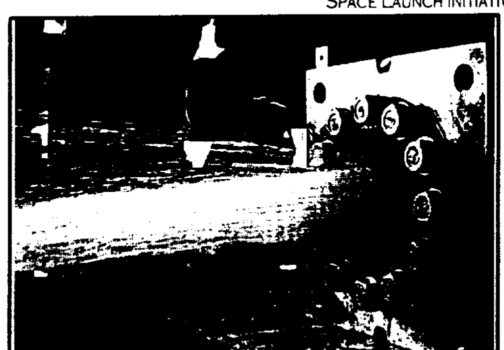
Chart 5

Hypergolic Injector

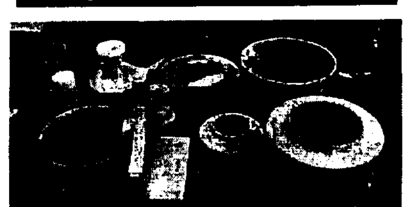
SPACE LAUNCH INITIATIVE



Hot-fire Test Assembly



Water flow test of one of two injector configurations



Stereolithography model parts to be used for facility interface checks

Chart 6

Catalyst Sensitivity and Pulse Testing

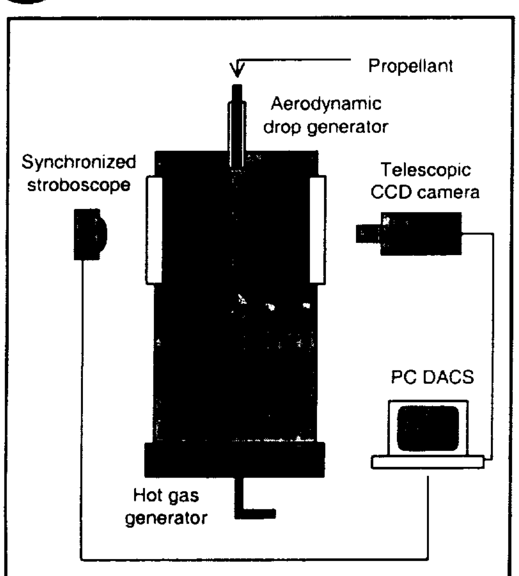
SPACE LAUNCH INITIATIVE

Test set up for catalyst sensitivity and pulse testing

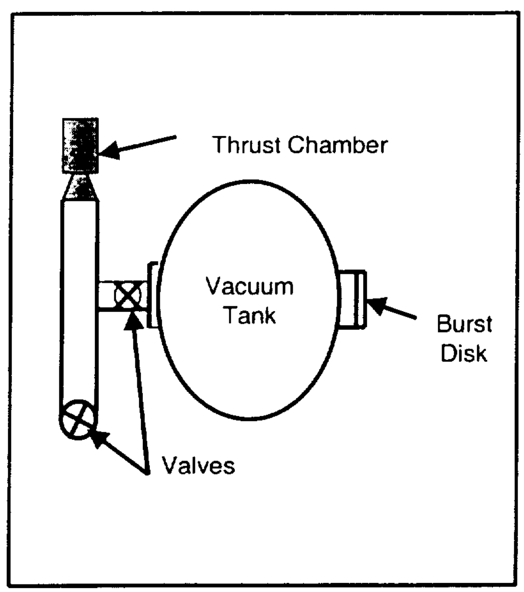
Chart 7

Thermal Decomposition/Vaporization and Hypergolic Ignition Studies

SPACE LAUNCH INITIATIVE



Will characterize the vaporization and shattering of peroxide droplets and allow creation of industry model which can be used in rocket component design using peroxide, such as injectors, catalysts, combustion chambers, etc.



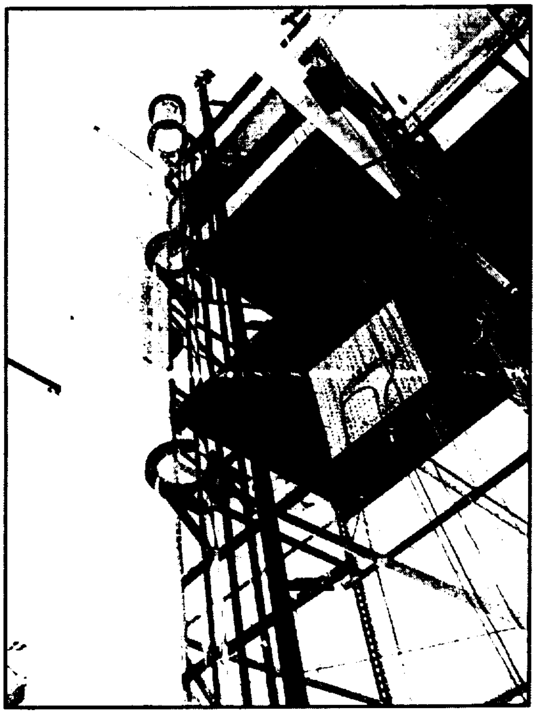
Will characterize the vacuum ignitability of hydrogen peroxide with a JP-8 proprietary fuel blend.

Chart 8

DRAFT

Zero-G Propellant Management Device Demonstration

SPACE LAUNCH INITIATIVE

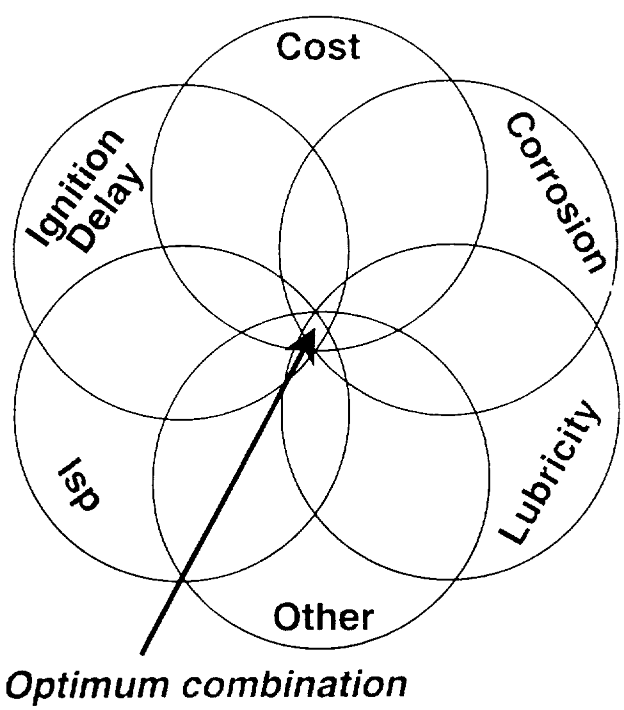


Example of zero gravity wicking effects in Purdue drop tower

Chart 9

Hydrogen Peroxide/ Hypergolic Fuel Optimization

SPACE LAUNCH INITIATIVE

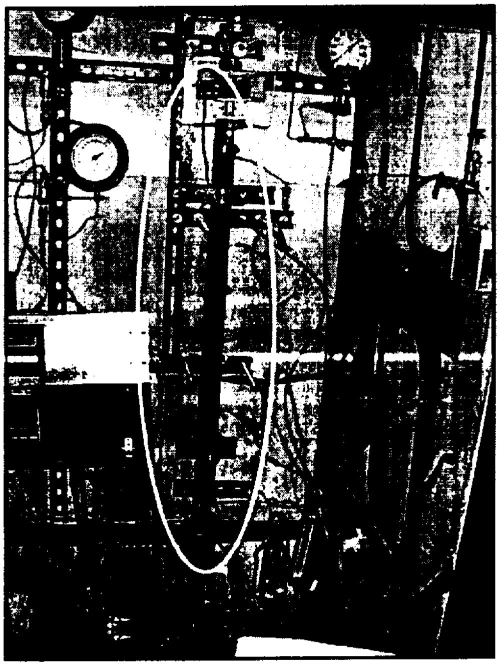


High speed video being used to determine ignition rate of hypergolic blend with peroxide

Chart 10

Hydrogen Peroxide Detonation Study

SPACE LAUNCH INITIATIVE

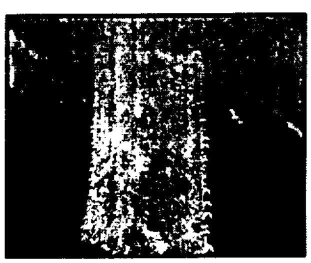


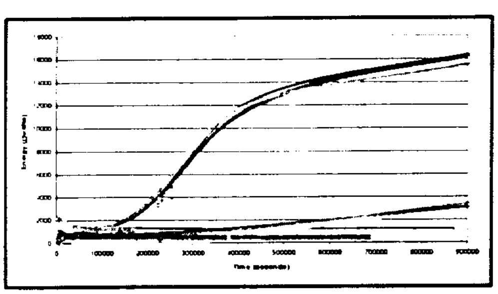
Test apparatus simulates a rocket engine chamber cooling passage

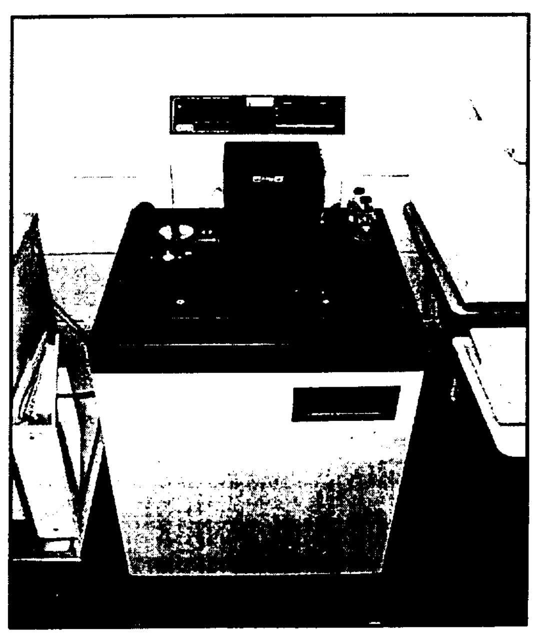
Chart 11

Main Combustion Chamber Materials Compatibility Study

SPACE LAUNCH INITIATIVE







Microcalorimetry tests are nearing conclusion on four candidate main combustion chamber materials

Chart 12