Upper Stages

(Breakout Session, Oct. 12, 10 a.m.)

Mr. Curtis McNeal, Manager, Upper Stages, MSFC

The Upper Stages Project -- a partnership between NASA, the U.S. Air Force and industry -- is developing reduced-cost technologies for potential use in 2nd Generation RLV space transportation system architectures. This session will examine peroxide-fueled liquid and liquid/hybrid propulsion systems now in development -- technologies expected to substantially lower operation costs for future transportation systems.

Briefing Objective

- **Familiarize attendees with the peroxide propulsion development currently underway**
  - **please don't propose work already underway**
- **Provide attendees with a current status of work underway**
  - **consistent with the proprietary nature of some of the work**
- **Provide contact points for teaming/partnerships**
  - Follow on work should be coordinated with initial leader of activity
  - This work may provide critical technology for a higher level system application
- **Familiarize attendees with the proposed NASA lead developments**
- **Provide a forum for answering questions**

Advanced Peroxide/RP Propulsion Roadmap

Upper Stage Technologies Project

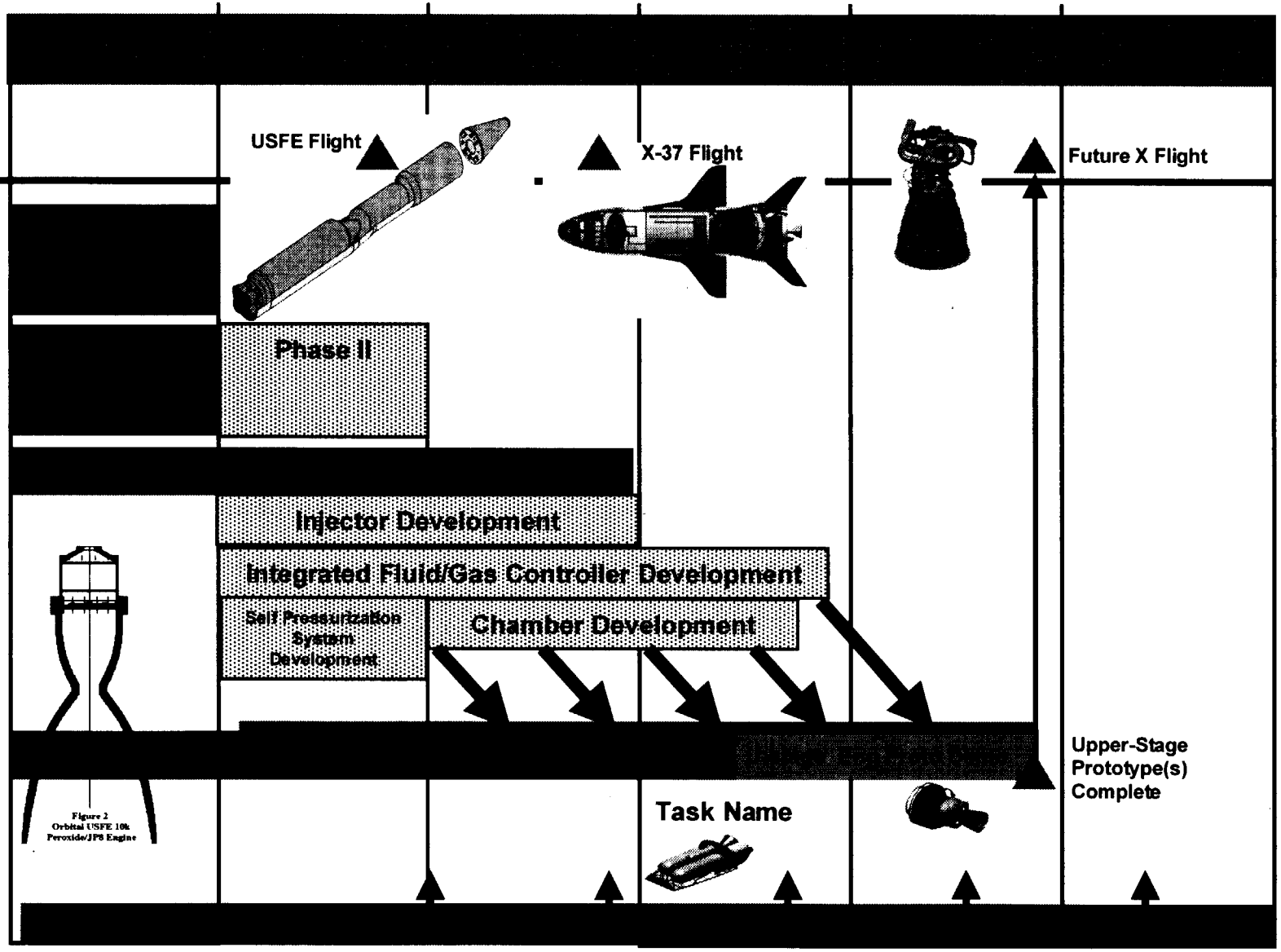
Major Milestones & Decisions

Key Tasks

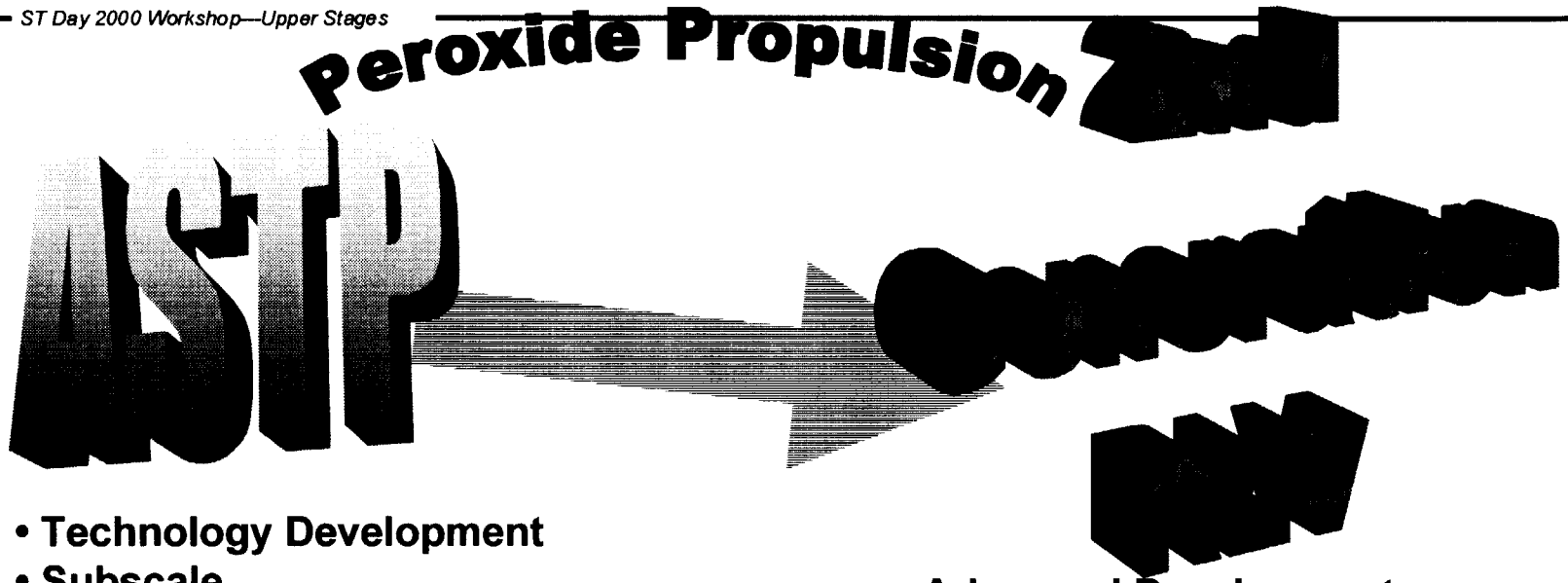
- Conceptual Design/ Vehicle Integration
- Component/ Subsystem Demo
- Integrated Demo

Objectives

- Demo needed propulsion technology to enable the next generation RLV



Peroxide Propulsion



- Technology Development
- Subscale
- 25 year horizon
- High Risk Tolerance
- Component Demonstrations
- $115M in FY01
- Get it to work

- Advanced Development
- Prototyping
- 5 year horizon
- Low Risk Tolerance
- Full System Demonstrations
- $290M in FY01 Budget
- Ensure competition

Peroxide/Hybrid Propulsion Roadmap

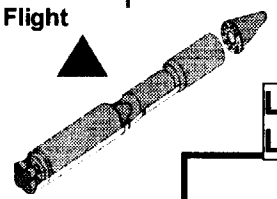
Major Milestones & Decisions

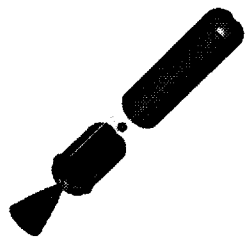
Key Tasks

- Conceptual Design/ Vehicle Integration
- Component/ Subsystem Demo
- Integrated System Demos

Objective

Mature propulsion technology to enable 2GRLV and DoD stage





USFE Flight

Leverage ongoing Liquid Propulsion Development

Requirements
Fuel Formulation
Injector/Catalyst
Motor Testing

Sub-scale Phase II

Sub-scale TCA Demo Using 98% Peroxide

Full-Scale TCA Demo

Igniter & Liquid Injection

Full-Scale Motor Fuel, Insulation, & Nozzle

Full-Scale Igniter and Injector

Self Pressurization System Development

SP Component Demo

Full-Scale Stage Demo

Prototype Stage Demo

Initiate Low Rate Production Demo

Joint Efforts | Current Efforts | Planned Efforts

Technology Working Group

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Existing NASA Peroxide Propulsion Development

Hazardous Materials Testing-FMC

Peroxide Enrichment Skid-OSC/Degussa Huls

Catalysts Development-Aerojet/P&W/TRW/Boeing/ Purdue/GK

Advanced Torch Igniter-Boeing Rocketdyne

Turbopump Development-Boeing Rocketdyne

Pressure Fed 90% Peroxide/RP Engine-OSC/GK/AAE

Integrated Peroxide Compatible Composite Common Bulkhead Structure-OSC/Aspect Engineering/AFRL

AR2-3 X-37 Engine Development Program-Boeing Rocketdyne

Peroxide Hybrid Development-LMA/Thiokol/Boeing

FMC Hazardous Materials Evaluation

Description- FMC will perform a series of industry standard tests to quantify the production, storage, and shipping hazards associated with 98% peroxide. Materials compatibility will also be determined for a limited number of samples. Work to be performed in the FMC New Jersey and Texas laboratories. FFPC.

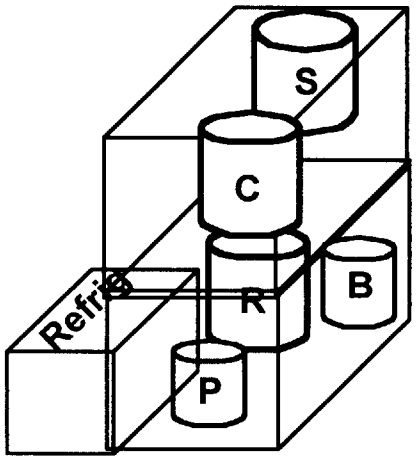
Status- Contract signed.

Contacts Mike Pinsky - 609- 951-3152

Future - This data will be used for safety analyses of advanced propulsion system designs for both Air Force and NASA missions.

Orbital/Degussa Huls Peroxide Enrichment Skid

Description-Bulk supplies of 98% concentration peroxide are needed to support NASA's research in high performance peroxide propulsion. An enrichment skid capable of concentrating commercially available product (87-90%) to 98% concentration will ensure a reliable supply until such time as a commercially viable supply becomes available. Orbital/Degussa will develop and demonstrate a safe, "turn key", portable concentrator that can produce 1000 lbs of 98% peroxide/day. The concentrator will be operated first at SSC and then at other test sites as needed to support NASA's research projects. CPIF.



Status-System Requirements established, PDR held, Hazards Analysis reviewed, CDR held, Fabrication begun, stell framework complete, tanks complete, plumbing installation underway. Checkout planned at Degussa last half of October. Installation at SSC first half of November. Operational at SSC in December.

Contacts- Dan Pauls - 334-443-2607
Stacy McMahon- 201-807-3205

Future- The skid is being installed at the Stennis Space Center where it will be operated in support of SSC conducted tests. Copies of the skid may be procured from Degussa Huls to support other requirements.

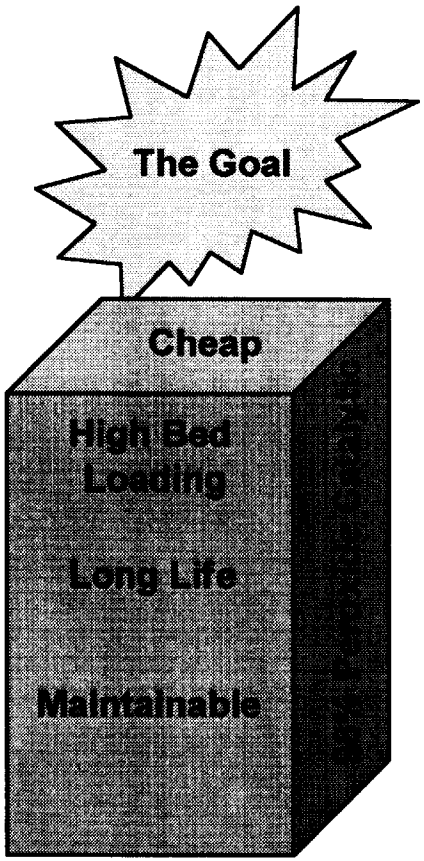
TRW Lead Advanced Catalyst Development

Description- Develop and test in a common test rig 3 potential advanced 98% peroxide catalyst. One catalyst will be wire screen based, one ceramic honeycomb based, and one pellet based. Catalyst will be tested for 1000 seconds to determine life and reuse capability. Testing to be performed at TRW facilities. FFPC

Status-All three catalysts ready for test. Test delayed by late delivery of 98% peroxide. Tests to begin week of 2 October

Contacts- TRW, William Kruse, 310-813-9268
General Kinetics, Eric Wernimont - 945-768-0166
Purdue University, John Rusek -765-494-4782

Future-Catalyst systems developed by this group will be developed into integral components in TRW engines and supplied to other industry peroxide system designers as required.



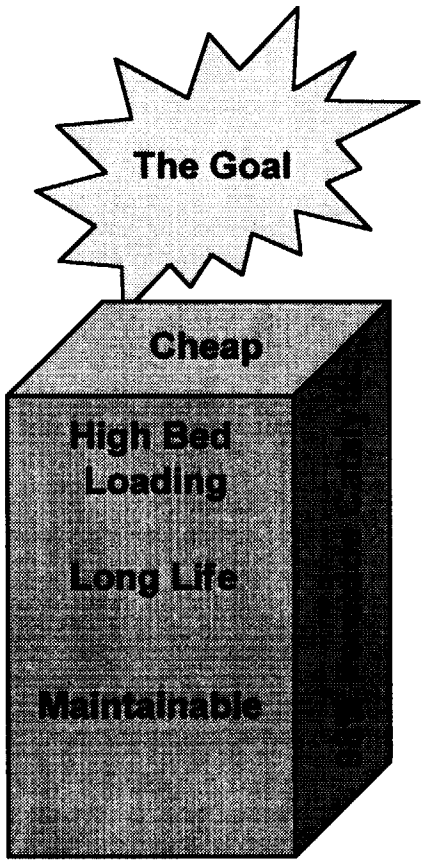
Aerojet Advanced Catalyst Development

Description- Develop and test an advanced 98%peroxide monolythic substrate catalysts. Catalyst will be tested first for its efficiency in 90% peroxide, then for long life (1000 seconds) in 90% peroxide. After successful demonstration at 90% the substrate processing will be altered for 98% peroxide catalysis and the efficiency and life determined with the 98% peroxide. Testing to be performed at Aerojet provided facilities. Cooperative agreement.

Status- in house 90% catalyst developed and tested. Life tests planned this fall.

Contact point - Adam Siebenhaar, 916-355-2535

Future-Catalyst systems developed by Aerojet will be developed into integral components in Aerojet engine systems and may be supplied to other industry peroxide system designers.



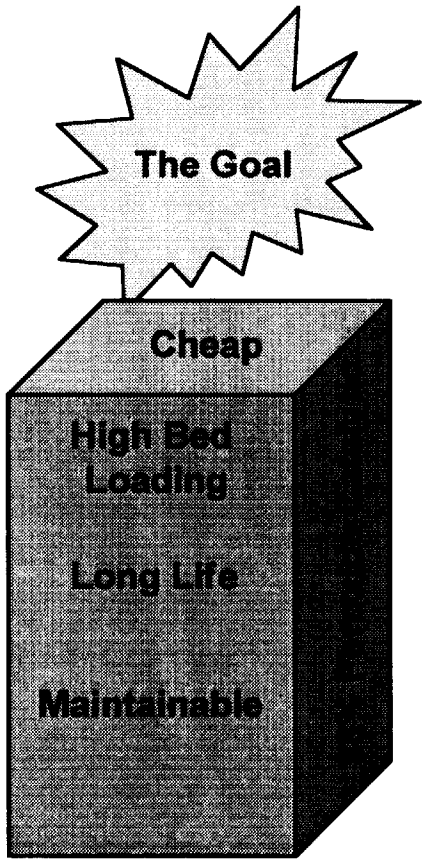
Boeing Rocketdyne Advanced Catalyst Development

Description- Develop and test an advanced 98%peroxide catalyst. Catalyst will be tested for its efficiency at Boeing facilities, and then for long life (1000 seconds min) at SSC E3 facilities. Multiple catalysts configurations are planned for test at SSC. Cooperative agreement.

Status- Catalysts development continues at Rocketdyne.

Contacts- Jeff Mays-818 586-0128

Future-Catalyst systems developed by Boeing Rocketdyne will be developed into integral components in Boeing Rocketdyne engine systems and may be supplied to other industry peroxide system designers.



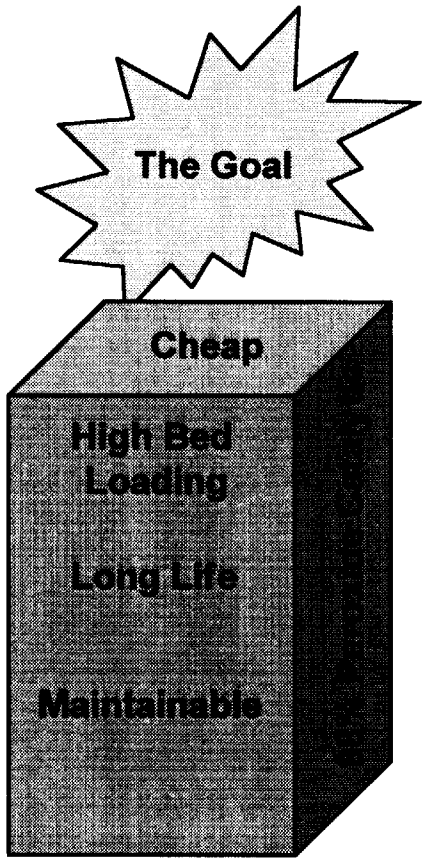
Pratt & Whitney Lead Advanced Catalyst Development

Description- Test an advanced 98%peroxide catalysts on the E3 stand at SSC. Catalyst developed by P&W IRAD funds. Multiple catalysts configurations are planned for test at SSC. Space Act Agreement.

Status- Multiple catalysts tested at the Stennis Space Center. More than one catalyst system provided successful decomposition. Best catalyst tested for more than 500 seconds without degradation.

Contacts - P&W - Jeff Breen - 561-796-7407
P&W - Bill Watkins - 561-7965840
General Kinetics, Eric Wernimont - 945-768-0166

Future-Catalyst systems developed by Pratt & Whitney will be developed into integral components in Pratt & Whitney engine systems and may be supplied to other industry peroxide system designers.



Boeing Rocketdyne Advanced Torch Igniter

Description- Develop a 98% peroxide/JP8 torch igniter with the thermal capacity to initiate thermal decomposition of 98% peroxide when it it injected directly into a main combustion chamber. Testing to be performed at SSTF. Cooperative agreement. Cooperative agreement gives NASA the right to purchase 4 of these igniters to support NASA mission requirements.

Status- Design underway at Rocketdyne

Contacts- Jeff Mays-818 586-0128
Terry Lorier - 818-586-1129

Future- Igniters of this design will be incorporated into future Boeing Rocketdyne engine systems and may be provided to other industry peroxide system designers.

Boeing Rocketdyne Advanced Peroxide/JP8 Turbopump

Description- Development and demonstration of a low cost/low parts count 98% compatible peroxide/JP8 turbopump. Pump demonstration to be performed at SSTF. Cooperative agreement. Cooperative agreement gives NASA the right to purchase 4 of these igniters to support NASA mission requirements.

Status - Design requirements established. Preliminary concept design review held. PDR planned for January 2001.

Contacts - Terry Lorier - 818-586-1129
Shawn Kurizaki - 818-586-7609

Future - Pump design can be tailored to meet a number of missions as final detail mission requirements become available.

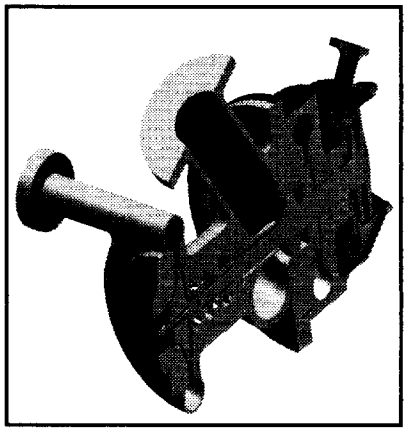


Figure 6 Peroxide Turbopump

USFE 10K Peroxide/JP8 Pressure-Fed Engine

Description- A joint AF/NASA development and demonstration of a current design practices pressure fed 90% peroxide/JP8 ablative chamber/nozzle engine. Work being performed at Orbital, GK, and SSC facilities. CPIF

Status - Catalyst bed, injector, and composite ablative chamber/nozzle all successfully developed. Two long term 140 second burns completed, Engine fluid distribution and valves, start and shutdown sequence, and purge system to be developed in 2001. Integrated engine/TVC/pressurized tank structure demonstration planned in 2002.

Contacts - Dave Crockett - 480-814-6659

Future - Engine to be used to power an upper stage flight demonstration for the Air Force in 2003.

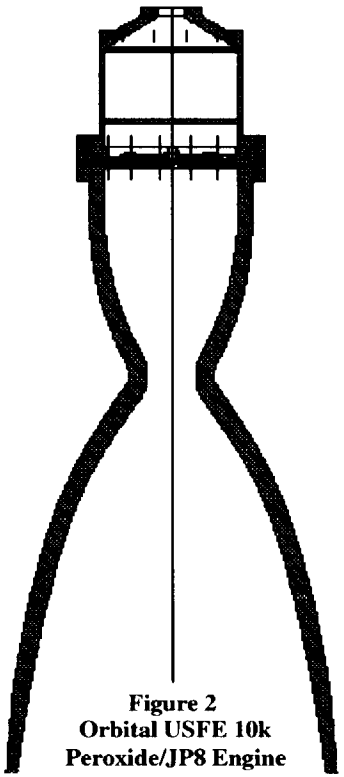
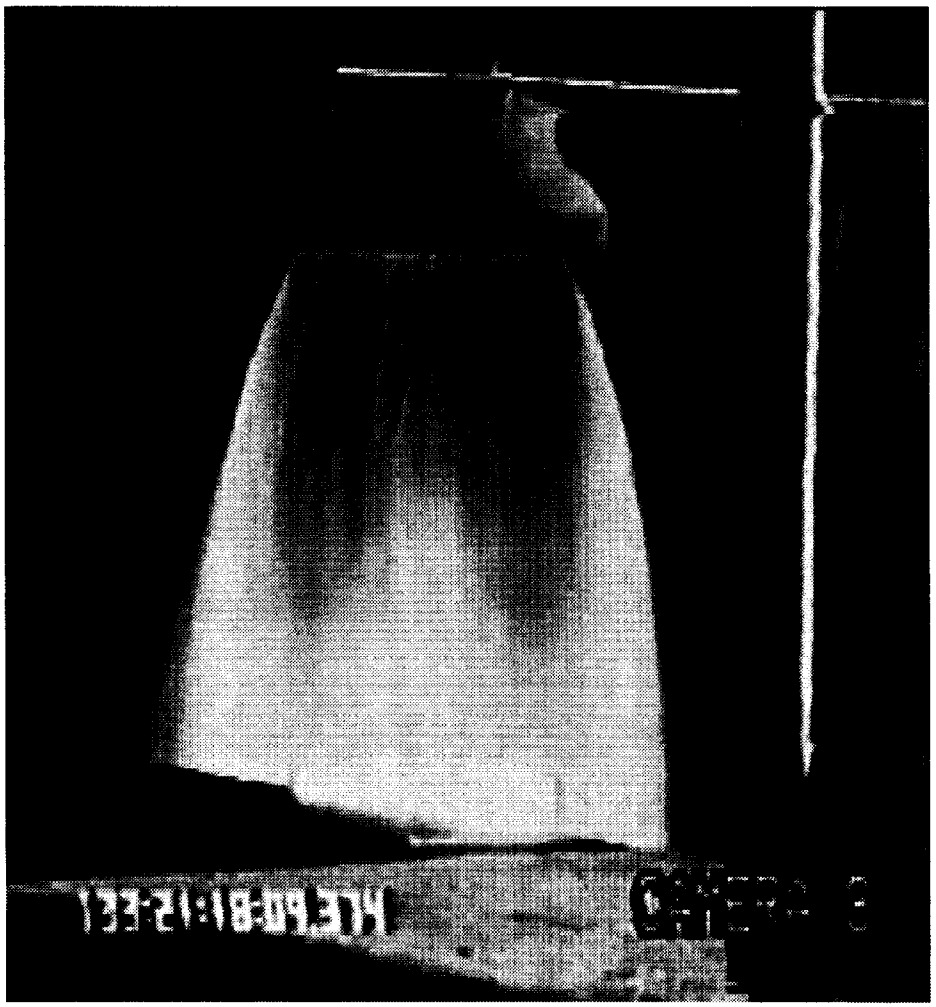


Figure 2
Orbital USFE 10k
Peroxide/JP8 Engine

The USFE 10K Peroxide/JP8 Engine

Parameter	Value
Propellants	85% HTP/JP-8
Vacuum Thrust, lbf	10,000
Chamber Pressure, psia	500
Mixture Ratio	6.0
Nozzle Expansion Ratio	40 (five for ground tests)
Chamber Contraction Ratio	7.1
Delivered Specific Impulse, s	278
Flow rate, lb/s	36.0
Burn Time, s	200
Engine Envelope	60 in. long, 40 in. diameter

Engine Component	Material	Weight Estimate
Gimbal Mount	SS304L	7
Distribution Dome	7075AL	25
Catalyst Housing	SS304L	37
Catalyst System	SS304L/Ag/Ni	39
Injector	SS304L	30
Chamber/Nozzle	F554 Fiber	103
Miscellaneous	SS304L/7075Al	17
Total		258



USFE Engine development has been successful

- conducted over 125 tests
- accumulated nearly 30 minutes of test time
- accumulated over 300 seconds of bipropellant operation using ablative chambers, including two long-duration tests of 140s and 150 s
- accumulated over 700 seconds of run time on a single cat bed without performance degradation
- demonstrated throat recession rates of less than 0.001 in/s
- demonstrated C^* efficiencies greater than 0.97 at nominal operating condition
- tested twelve different test article configurations
- tested both 85% and 90% peroxide from two different manufacturers
- demonstrated multiple restarts
- demonstrated throttling to 10% in monopropellant mode and to 20% in bipropellant mode
- maintained perfect safety record

USFE Integrated Composite Stage Structure

Description- A joint AF/NASA development and demonstration of a common bulkhead peroxide compatible all composite upper stage structure. Effort being performed at AE, AFRL, and Orbital facilities. CPIF

Status - A peroxide compatible composite material was identified in 1998, Subscale tanks were fabricated and peroxide compatibility demonstrated in 1998. A subscale composite stage structure has been designed and fabrication is nearing completion. Full scale stage structure design is planned in 2001 followed by fabrication of a full scale structure for ground test in 2002.

Contacts- Orbital Sciences- Dave Crockett - 480-814-6659
Aspect Engineering - Zack Taylor - 714-692-7779

Future - Stage demonstration provides the basis for future mission specific designs.

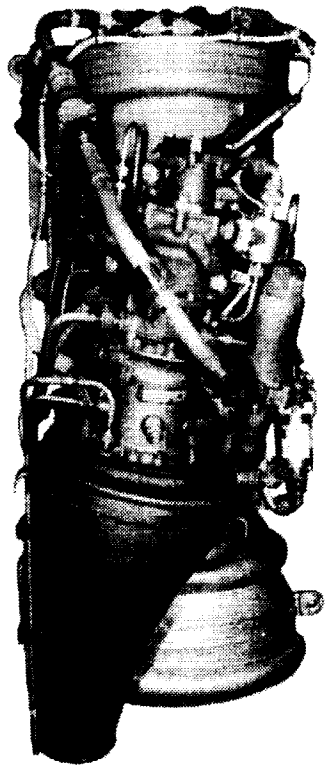
Boeing Rocketdyne AR2-3 Demonstration Program

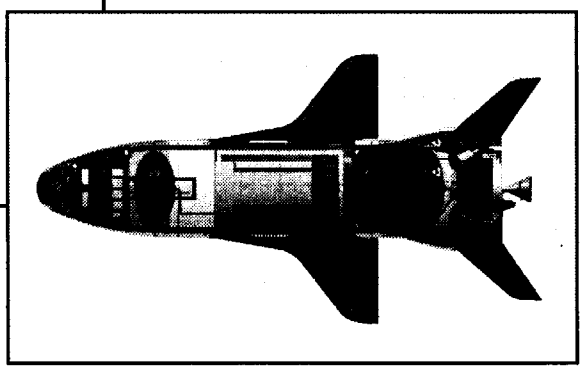
Description- A progressive development and demonstration of peroxide propulsion's application to on-orbit space transportation mission needs. The effort began with the refurbishment of an AR2-3 for initial ground test and development of control valve sequences for on-orbit operation. Two additional engines are being produced. The first engine will undergo a stringent qualification program. The second engine will undergo acceptance tests and be installed in the X-37 for flight demonstration.

Status- The initial development tests were completed in the spring of 2000. The qualification tests and the acceptance test of the flight engine are planned in early 2001.

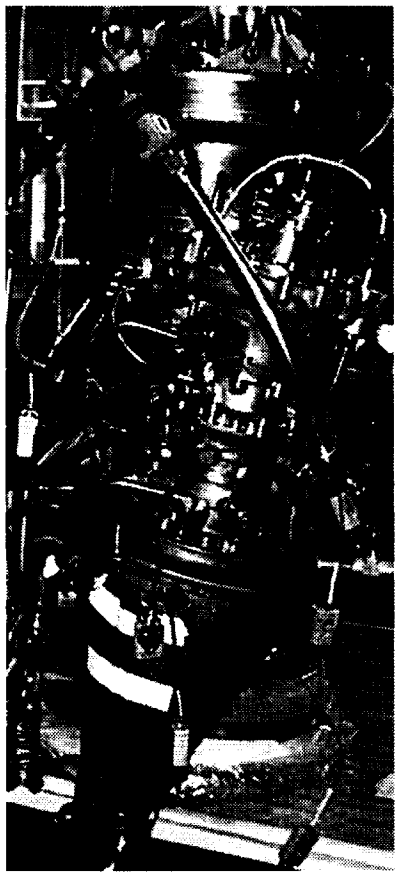
Contacts - Kathy Butler - 818-586-1158
Terry Lorier - 818-586-1129

Future - This engine will form the basis for more advanced designs which will meet future Air Force and NASA in-space propulsion needs.





AR2-3 Engine Performance.



• Propellants	90%H_2O_2/JP
• Thrust, vac (lbf)	6600
• Isp, vac (sec)	246
• Chamber pressure (psia)	560
• Mixture ratio	6.5
• Area ratio	12:1
• Length (in)	32
• Engine diameter (in)	20
• Weight (lbm)	225
• Gimbal angle (degrees)	0
• No. or restarts	multiple
• Engine life	>150 minutes

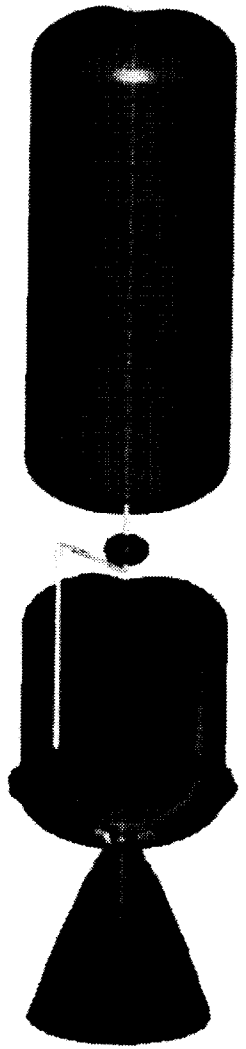
LMA Lead Peroxide/Hybrid Propulsion Development

Description- Development of design requirements, identification of technical issues, fabrication of subscale test articles, and the test and evaluation of the test articles. Work to be performed at SSC and Thiokol facilities. CPIF

Status - Basic small scale fuel formulation work complete with both Gox and decomposed peroxide. 11inch motor test articles in fab. Next test series at SSC in December 2000. Final 24inch motor test series in February 2001.

Contacts - LMA - Terry Abel -256-544-3275
Thiokol - Steve Alexander - 256-544-2582
Boeing Rocketdyne - Scott Claflin - 818-586-0329

Future - This work forms the basis for full scale design of low cost storable peroxide hybrid motors for 2nd Gen RLV expendable upper stage mission needs or Air Force and Army applications.



Proposed NASA Lead Developments

Composite Upper-Stage Tanks for 90 Percent Hydrogen Peroxide

Toroidal Upper-Stage Tank Development

Solar Thermal Propulsion: Integration and Demonstration of Critical Technologies

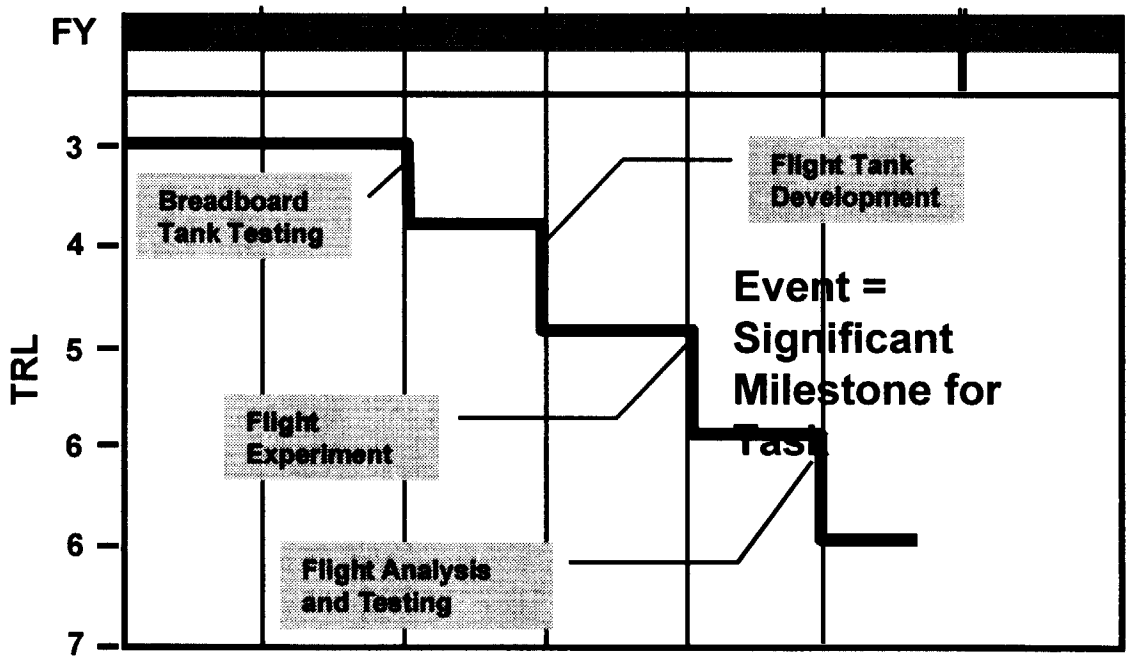
In-Space Propulsion Systems Analysis Tool Development Task

Composite Upper-Stage Tanks for 90 Percent Hydrogen Peroxide

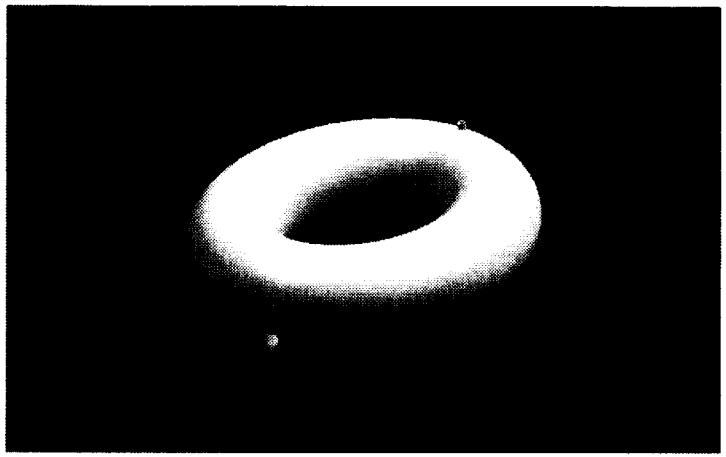
Tom Delay-MSFC

- **Products**
  - —Developmental tanks for long term storage of hydrogen peroxide. Flight experiment tank.
- **Benefits**
  - —40 percent reduction in weight compared to state-of-the-art
- **Customers**
  - —All four NASA enterprises
  - —DOD/NRO, Commercial(X–37, USFE etc.)
- **X-cutting**

- **Current State of the Art**
  - —Aluminum tanks, stainless steel tanks with liners.
- **Performance Metrics**
  - —Chemical compatibility
  - —Low mass, low permeability
- **Risks**
  - —Testing facility availability
  - —Schedule of flight vehicle
- **USG Participants**
  - —MSFC lead Center
  - —AFRL



Toroidal Upper-Stage Tank Development
Tom Delay-MSFC



- **Products**
  - —Development and demonstration of composite toroidal tanks. Flight experiment tank.
- **Benefits**
  - —75 percent reduction in weight compared to state-of-the-art
  - —40 percent increase in storage volume
- **Customers**
  - —All four NASA enterprises. DOD/NRO
- **X-cutting**

- **Current State-of-the-Art**
  - —Cylindrical composite vessels
- **Performance Metrics**
  - —Low mass, packing efficiency
- **Risks**
  - —Cost effective tooling methods
  - —Schedule of flight vehicle
- **USG Participants**
  - —MSFC lead Center
  - —AFRL