

# REPORT DOCUMENTATION PAGE

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SUBJECT: Authorization for Release of Technical Information, Control Number: **AFRL-PR-ED-TP-1998-105**  
Eric Rice (Orbitec) "ORBITEC Advanced Cryogenic Solid Hybrid Rocket Engine and Propellant Developments:  
A 1998 Status Report"

**HEDM**

**(Statement A)**



***ORBITEC Advanced Cryogenic Solid Hybrid  
Rocket Engine and Propellant Developments:  
A 1998 Status Report***

*by*

*Dr. Eric E. Rice  
President and CEO*



**Orbital Technologies Corporation**

Space Center, 1212 Fourier Drive

Madison, WI 53717

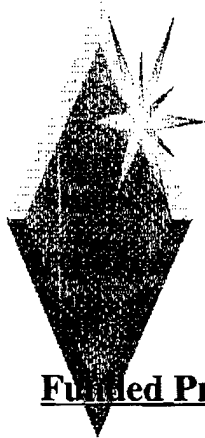
608-827-5000

<http://www.orbitec.com>

**1998 HEDM CONFERENCE**

Monterey, CA

May 20-22, 1998



# Acknowledgements

Work reported here is from several contract and inhouse R&D activities. Contributions and contributors to this work are listed below:

## Funded Projects/Organizations:

### "Storage and Delivery Device for Solid Oxygen"

USAF Contract F04611-93-C-0149

USAF Phillips Laboratory, Edwards Air Force Base, CA  
COTR Dr. Patrick G. Carrick, OLAC-PL

### "Cryogenic Hybrid Rocket Engine for Testing High-Energy Propellants"

USAF Contracts F04611-96-C-0034 & F04611-97-C-0020

USAF Phillips Laboratory, Edwards Air Force Base, CA  
COTR Dr. Patrick G. Carrick, OLAC-PL

### "Metallized Cryogen for Advanced Hybrid Engines"

NASA Contract NAS3-27382

NASA Lewis Research Center, Cleveland, OH  
COTR Dr. Bryan Palaszewski, NASA/LeRC

## ORBITEC Staff:

Dr. Eric E. Rice, Edward Bangsund, Dr. Martin J. Chiaverini, Daniel J. Gramer, Allen L. Holzman, William H. Knuth, Traci B. Mayer, E. Don Peissig, Richard Quentmeyer, William J. Rothbauer, Chip Sauer, Christopher P. St. Clair, Ronald R. Teeter, and Anton G. Vermaak.

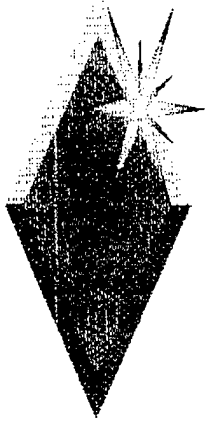
## Supporting Organizations:

Vince Weldon, Boeing-Seattle

Dan Levack, Ken Sprouse, Dave Matthews, Boeing-Rocketdyne

David Fordham and Jack Coyle, U.S. Army Badger Army Ammunition Plant





## *Introduction*

- ◆ **Overview**
- ◆ **Mark II Engine and Supporting Hardware**
- ◆ **SOX/GH<sub>2</sub> Hybrid Firings**
- ◆ **SC<sub>2</sub>H<sub>2</sub>/GOX Firings**
- ◆ **SCH<sub>4</sub>/SOX Solid Propellant Firings**
- ◆ **SCO/GOX Firing**
- ◆ **Regression Rate Summary**
- ◆ **Current R&D Activity**
- ◆ **Summary of Latest Findings**



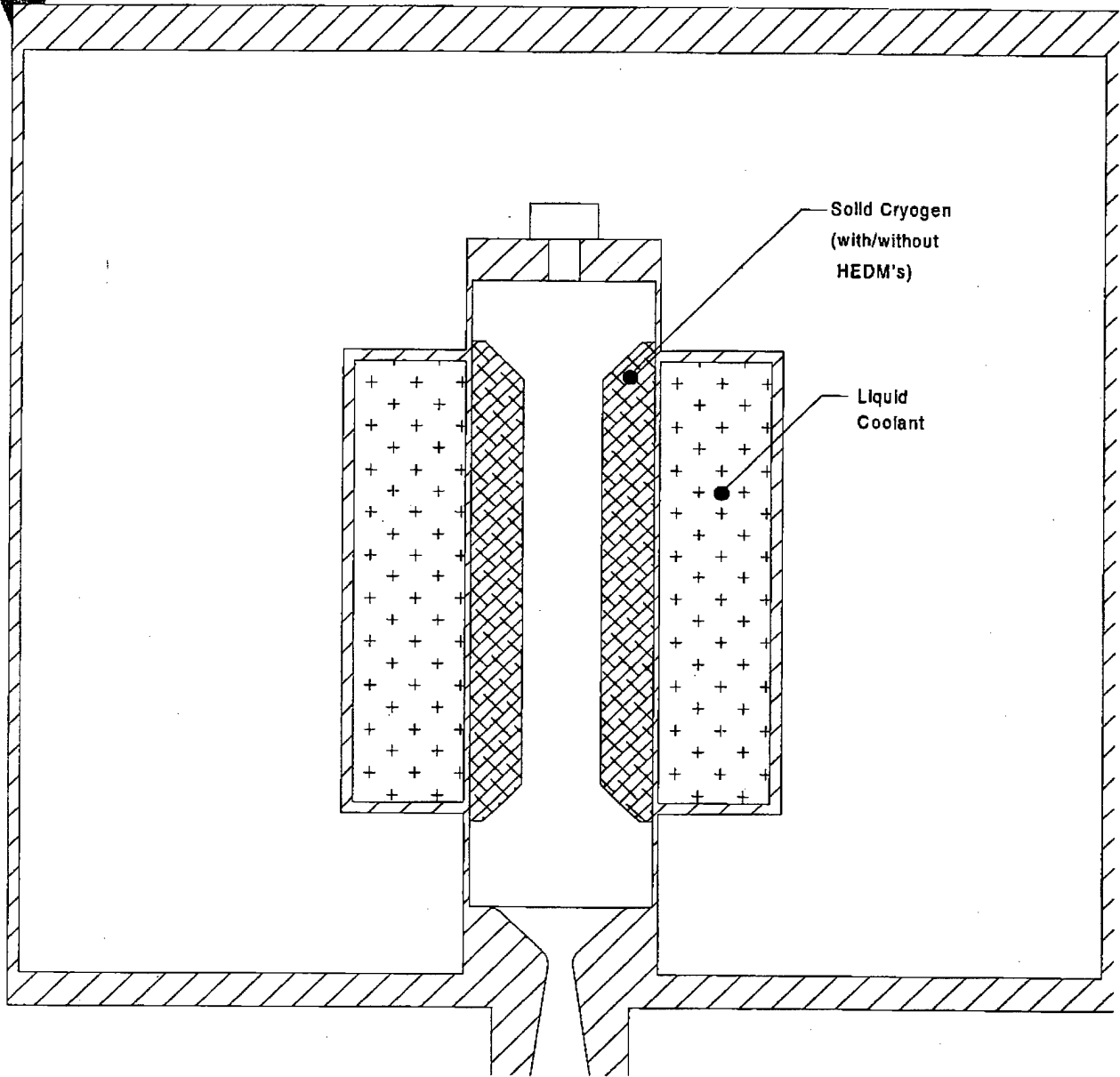
## *Overview*

**ORBITEC First Proposed Cryogenic Solid Hybrid Rocket Engine Applications to USAF/PL under SBIR Program in 1991-1992 to Support the HEDM Program**

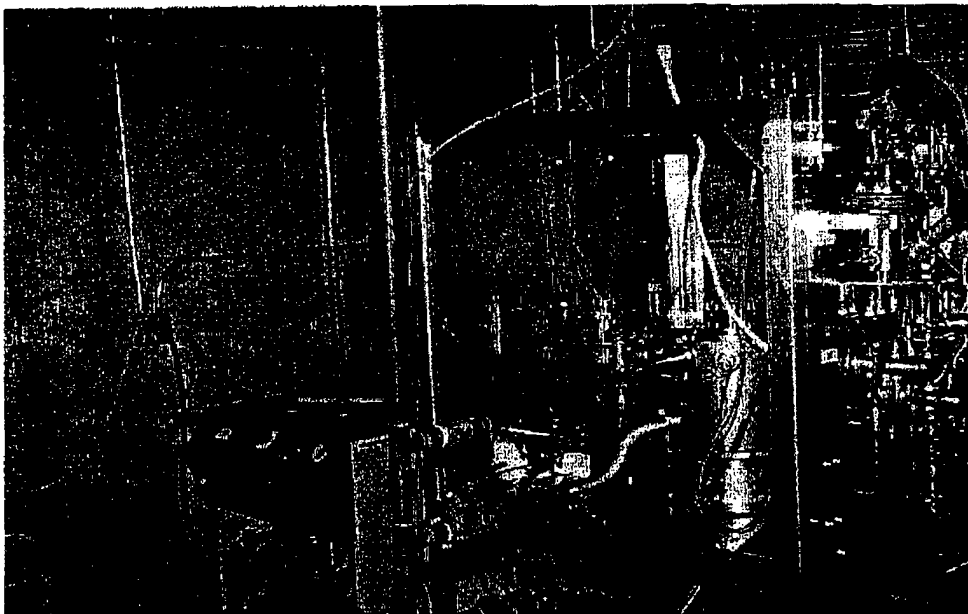
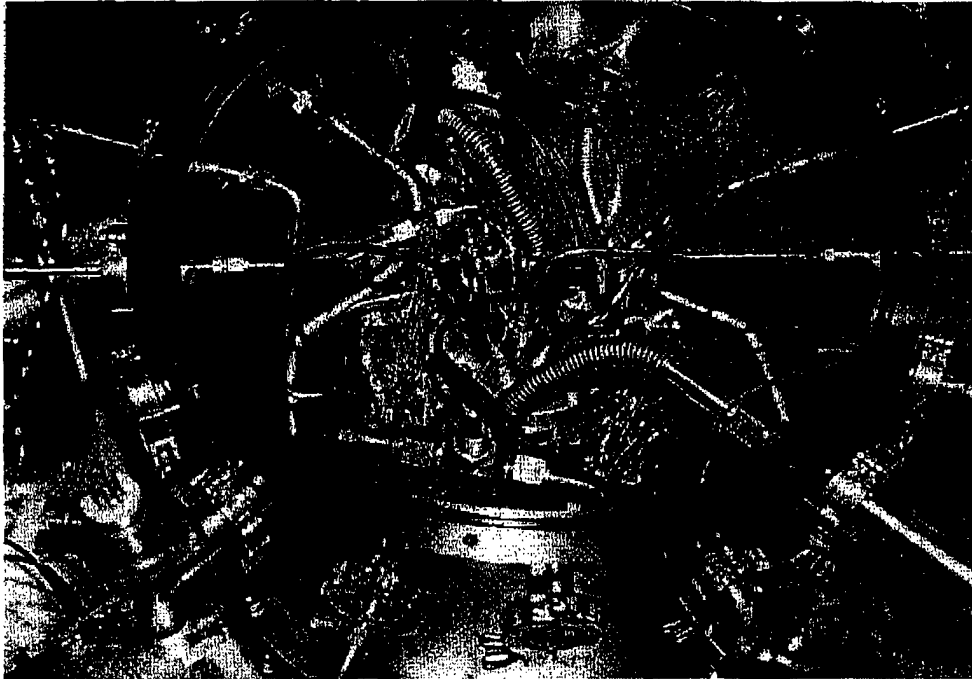
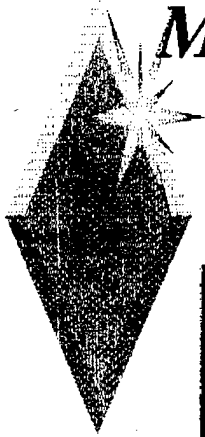
- ◆ **ORBITEC Has Had Eight Contracts in this Technology Area Under USAF/RL and NASA SBIR Funding**
- ◆ **Currently Designing, Developing, Testing, and Demonstrating Hybrid Engines for Combustion Testing of Solid Cryogenes, Including Oxygen, Hydrogen, Methane, Acetylene, Carbon Monoxide**
- ◆ **ORBITEC Successfully Fired:**
  - **First SOX/GH<sub>2</sub> Hybrid Rocket on August 21, 1995**
  - **First SCH<sub>4</sub>/GOX Hybrid Rocket on October 10, 1995**
  - **First SH<sub>2</sub>/GOX Hybrid Rocket on October 25, 1996**
  - **First SCH<sub>4</sub>-AL/GOX Hybrid Rocket on November 9, 1996**
  - **First SC<sub>2</sub>H<sub>2</sub>/GOX Hybrid Rocket on September 25, 1997**
  - **First SCH<sub>4</sub>/SOX Rocket Motor on October 7, 1997**
  - **First SCO/GOX Hybrid Rocket on January 29, 1998**
- ◆ **Plan For the First SOX/LH<sub>2</sub> Engine Firing in Larger Mark III Engine Late 1998**

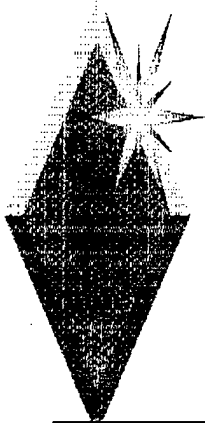


# Engine Concept Design Sketch



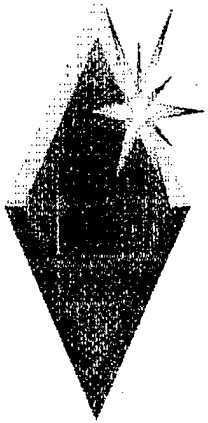
# *Mark II Cryogenic Hybrid Engine*





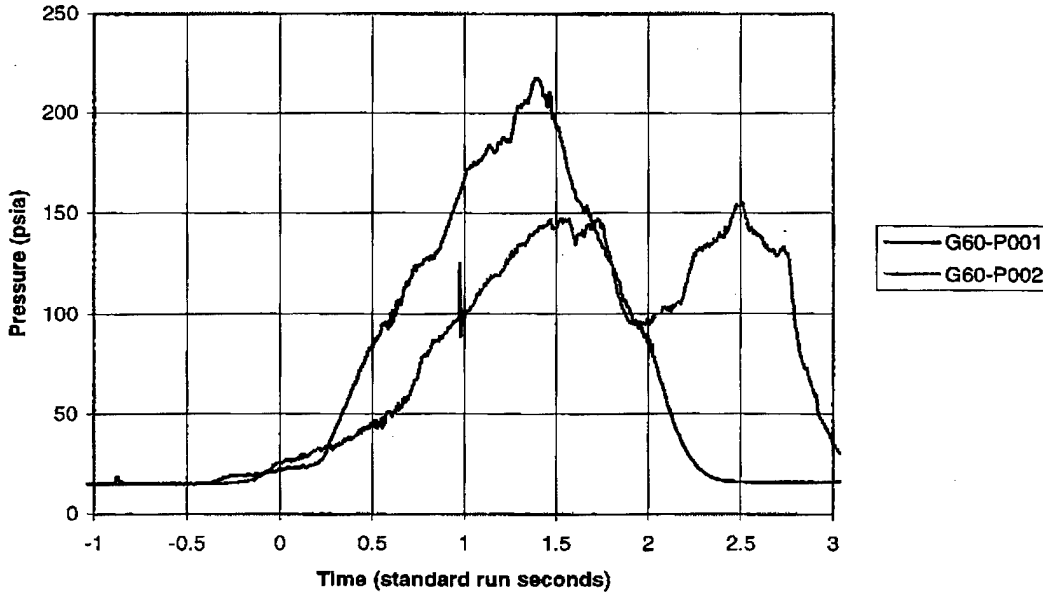
## Summary of Latest SOX/GH<sub>2</sub> Firings in Mark II Engine

Firing #	Date	O <sub>2</sub> Mass (g)	H <sub>2</sub> Mass Flow (g/s)		Peak Pres. (psia)	Duration (sec)	Avg. O/F	C* (m/s)	C* eff.	Inj. Diam. (in.)	Notes
			Head End	Aft End							
G60-P001	14 May 97	50	1.4	0.2	210	2.0	17	1210	71%	0.136	Reversed flows (head/aft)
G60-P002	15 May 97	50	0.2	1.4	150	2.9	12	1350	72%	0.136	
G60-P003	23 May 97	50	0.2	1.4	160	3.1	11	1640	85%	0.136	Installed inter-chamber restriction
G60-P004	06 Jun 97	50	0.09	1.5	130	3.7	8.5	1610	77%	0.136	
G60-P005	09 Jun 97	50	0.04	1.6	130	4.0	7.7	1710	80%	0.136	
G60-P006	13 Jun 97	50	0.09	1.5	160	4.0	7.9	1670	78%	48 h.	48 hole tube injector
G60-P007	20 Jun 97	50	0.09	1.5	140	3.8	8.2	1590	76%	Por.	Porous tube injector
G60-P008	26 Jun 97	150	0.09	2.3	210	9.7	6.4	1730	77%	Long	3" long extended injector
G60-P009	18 Jul 97	50	0.01	2.4	95	8.8	2.4	2090	82%	0.136	
G60-P010	22 Jul 97	150	0.01	2.4	160	18	3.5	2030	81%	0.136	
G60-P011	23 Jul 97	50	0.02	2.4	60	9.6	2.2	1540	61%	0.136	
G60-P012	04 Feb 98	150	3.0	0.0	110	4.7	11	1600	81%	0.136	Removed aft injector
G60-P013	05 Feb 98	150	6.0	0.0	170	4.7	5.3	2070	87%	0.136	
G60-P014	09 Feb 98	150	-	-	-	-	-	-	-	0.136	Aluminized grain
G60-P015	17 Apr 98	150	3.0	0	120	2.8	19	920	55%	0.129	Warm grain
G60-P016	22 Apr 98	150	0.09	3.1	260	14	3.3	1980	77%	0.020	Mixing plate, aft injector
G60-P017	24 Apr 98	150	0	1.75	220	16	7.0	1710	77%	0.191	Pilot oxygen flow (3 g/s)
G60-P018	29 Apr 98	150	7.5	0.0	160	3.9	4.3	1930	79%	0.191	
G60-P019	05 May 98	150	6.0	0.0	90	3.0	?	?	?	0.191	Freez. gas change, ceramic shield
G60-P020	06 May 98	150	6.0	0.0	130	6.5	3.9	2130	86%	0.191	Copper shield
G60-P021	07 May 98	100	6.0 +/-	0.0	130	4.9	3.5	2090	83%	0.191	Step hydrogen flow profile



# SOX/GH2 Firings in Mark II Engine

## Effect of Pilot Flow vs. Aft Ignition



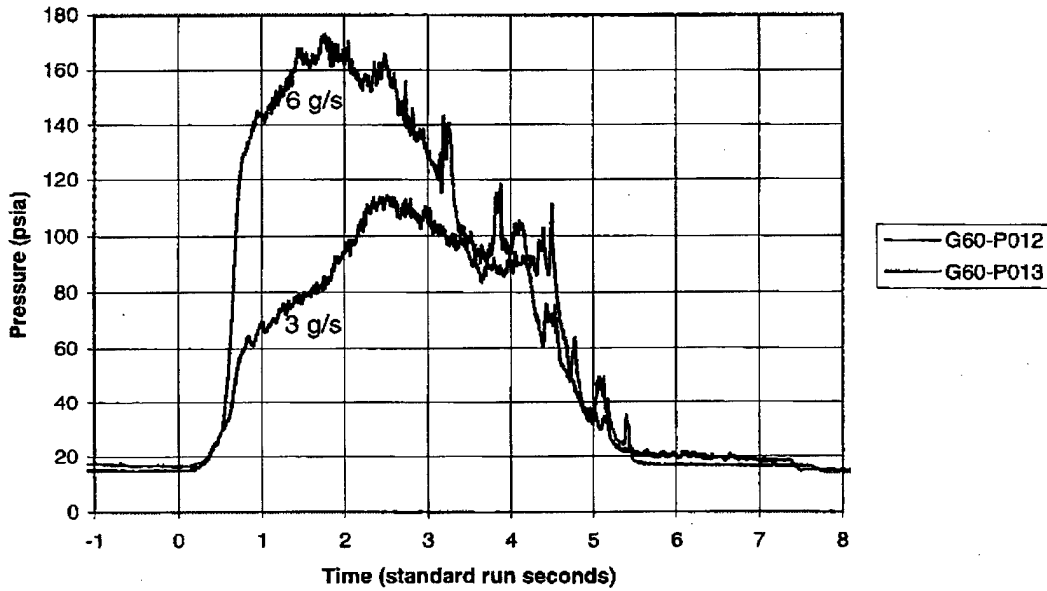
— G60-P001  
— G60-P002





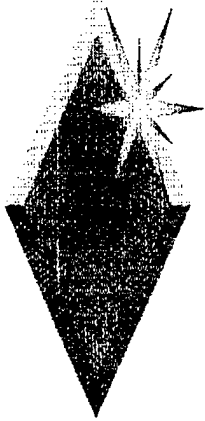
# SOX/GH<sub>2</sub> Firings in Mark II Engine

## Effect of Hydrogen Flow Rate



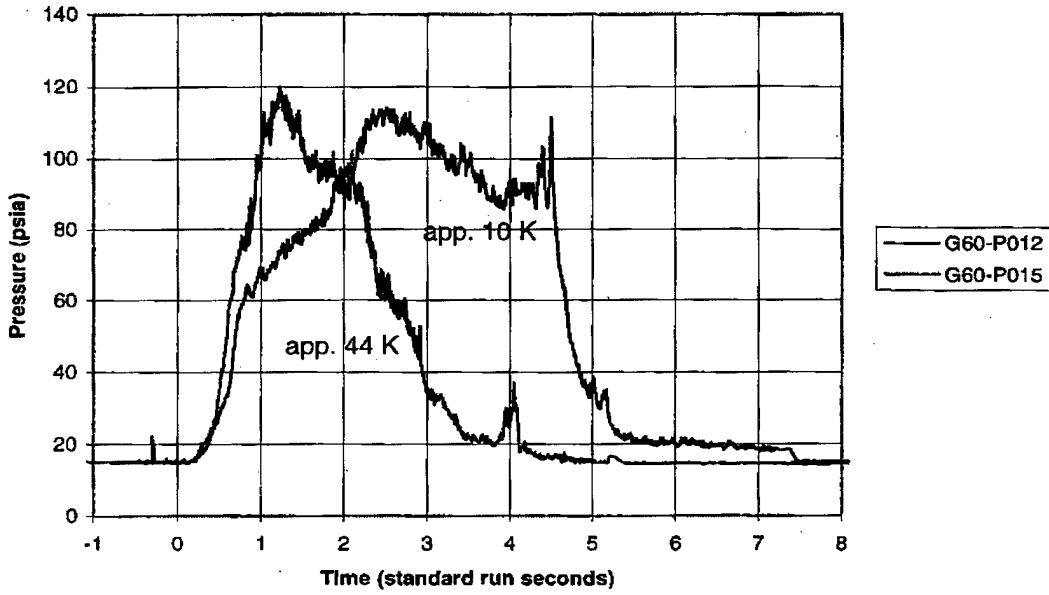
G60-P012  
G60-P013





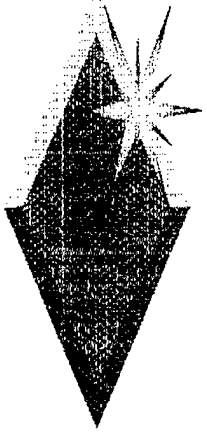
# *SOX/GH<sub>2</sub> Firings in Mark II Engine*

## *Effect of Grain Temperature*



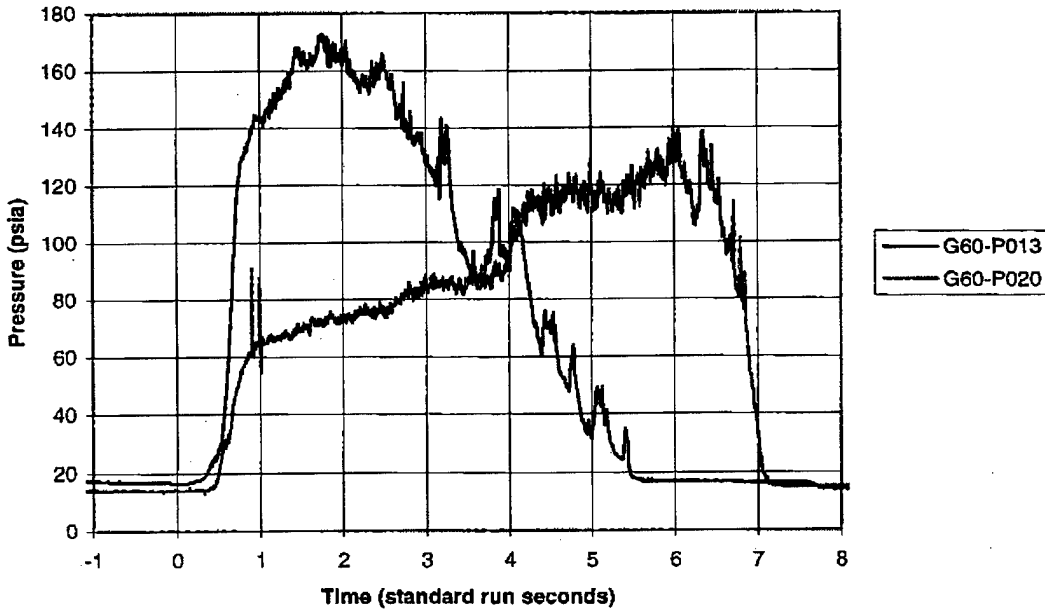
— G60-P012  
- - - G60-P015

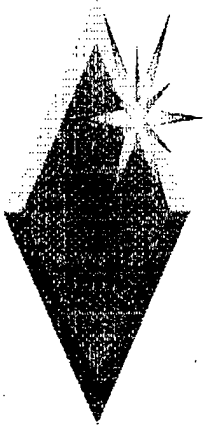




# *SOX/GH2 Firings in Mark II Engine*

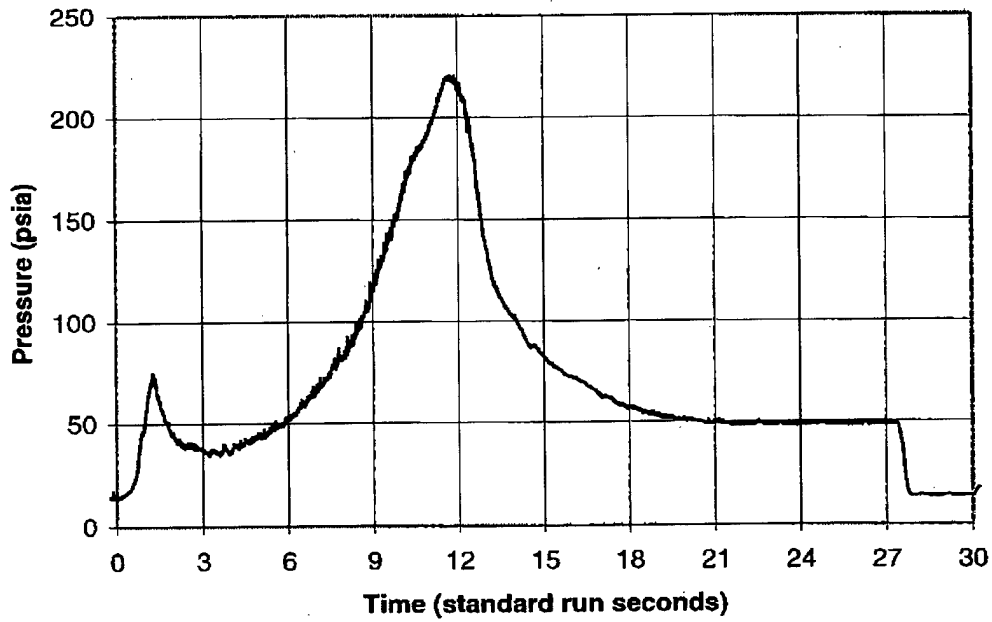
## *Effect of Injection Velocity, Grain Quality*





# *SOX/GH2 Firings in Mark II Engine*

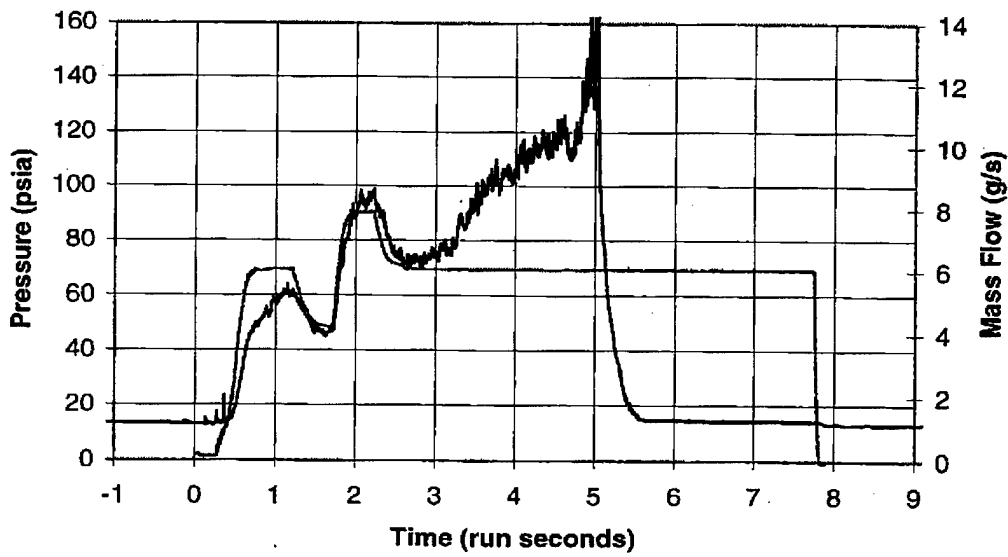
## *Oxygen Pilot Flow Test*

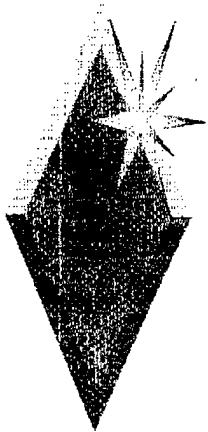




# *SOX/GH2 Firings in Mark II Engine*

## *Response to Changes in Hydrogen Flow*





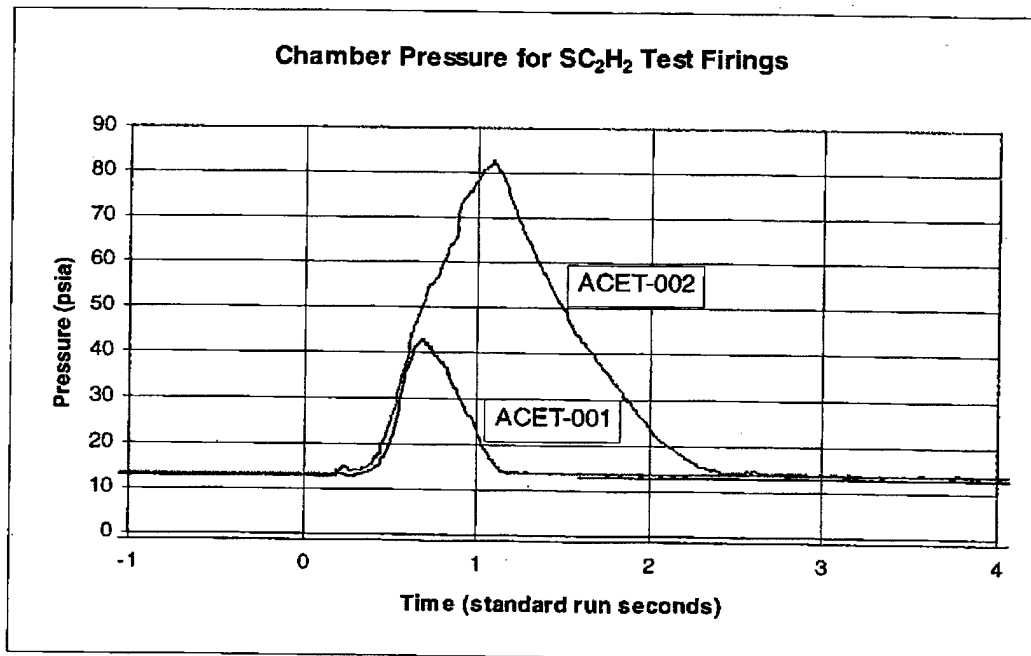
## *SC<sub>2</sub>H<sub>2</sub>/GOX Successful Firings*

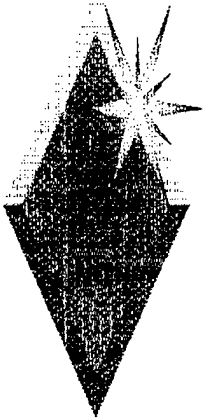
### SC<sub>2</sub>H<sub>2</sub> Test Firing #1

Date: 25 Sept. 1997  
Grain Mass: 1.0 g  
GOX Flow: 6.6 g/s  
GOX Ramp: 0.5 s  
Ignitor O/F: 2.5  
Ignitor flow: 0.18 g/s

### SC<sub>2</sub>H<sub>2</sub> Test Firing #2

Date: 26 Sept. 1997  
Grain Mass: 10 g  
GOX Flow: 6.6 g/s  
GOX Ramp: 0.5 s  
Ignitor O/F: 2.5  
Ignitor flow: 0.18 g/s





# SCH<sub>4</sub>/SOX Solid Propellant

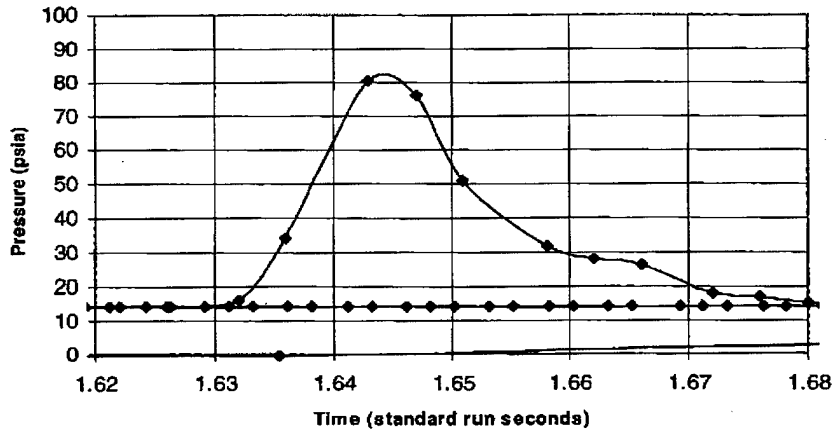
## SOM Test Firing #1

Date: 7 October 1997  
 Grain Mass: 0.6 g  
 SOM O/F: 2.4  
 Ignitor O/F: 2.5  
 Ignitor flow: 0.18 g/s  
 Tubing run to  
 transducer: app. 18"

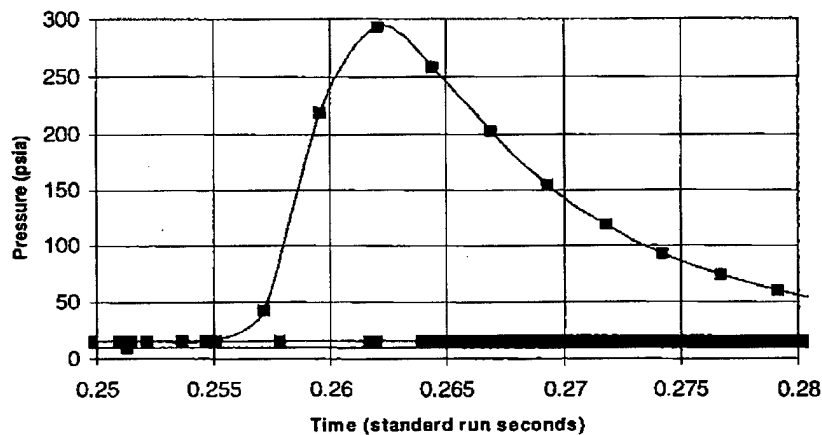
## SOM Test Firing #2

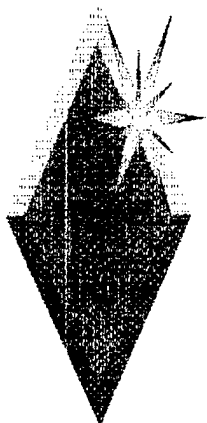
Date: 8 October 1997  
 Grain Mass: 1.0 g  
 SOM O/F: 2.4  
 Ignitor O/F: 5  
 Ignitor flow: 0.26 g/s  
 Tubing run to  
 transducer: app. 4"

Chamber Pressure for SOM Test Firing #1



Chamber Pressure for SOM Test Firing #2





## *SCO/GOX Firing*

**January 29, 1998**

Grain Mass: 100 g

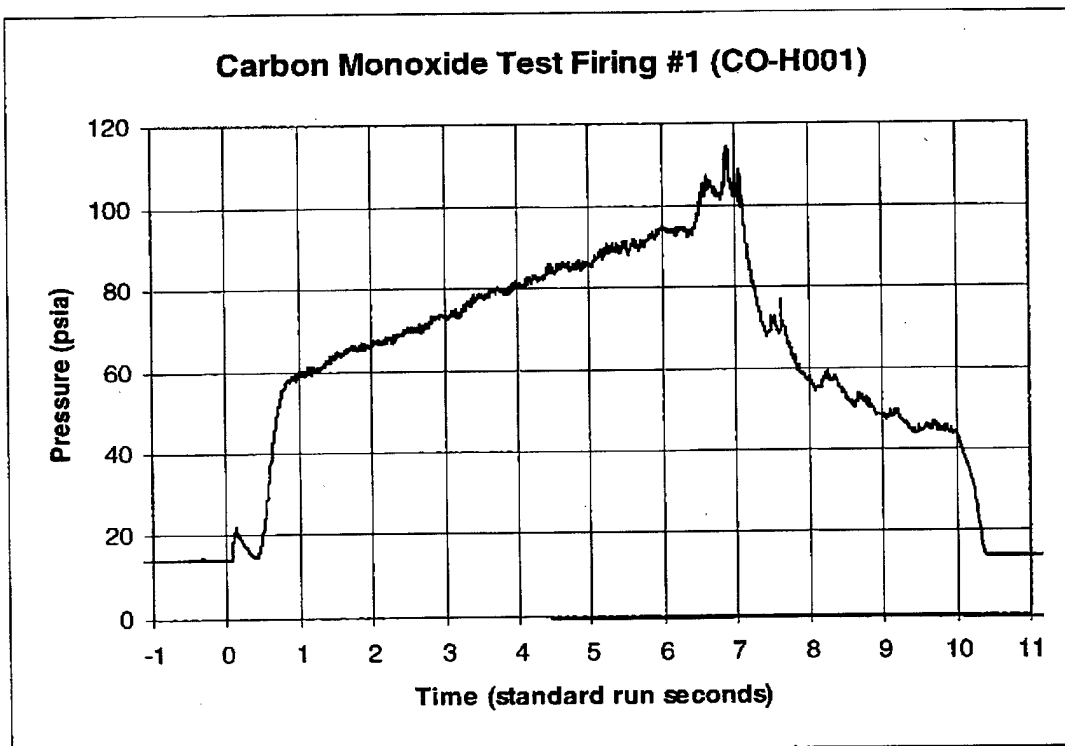
GOX Flow: 6 g/s

Average Pressure: 71 psia

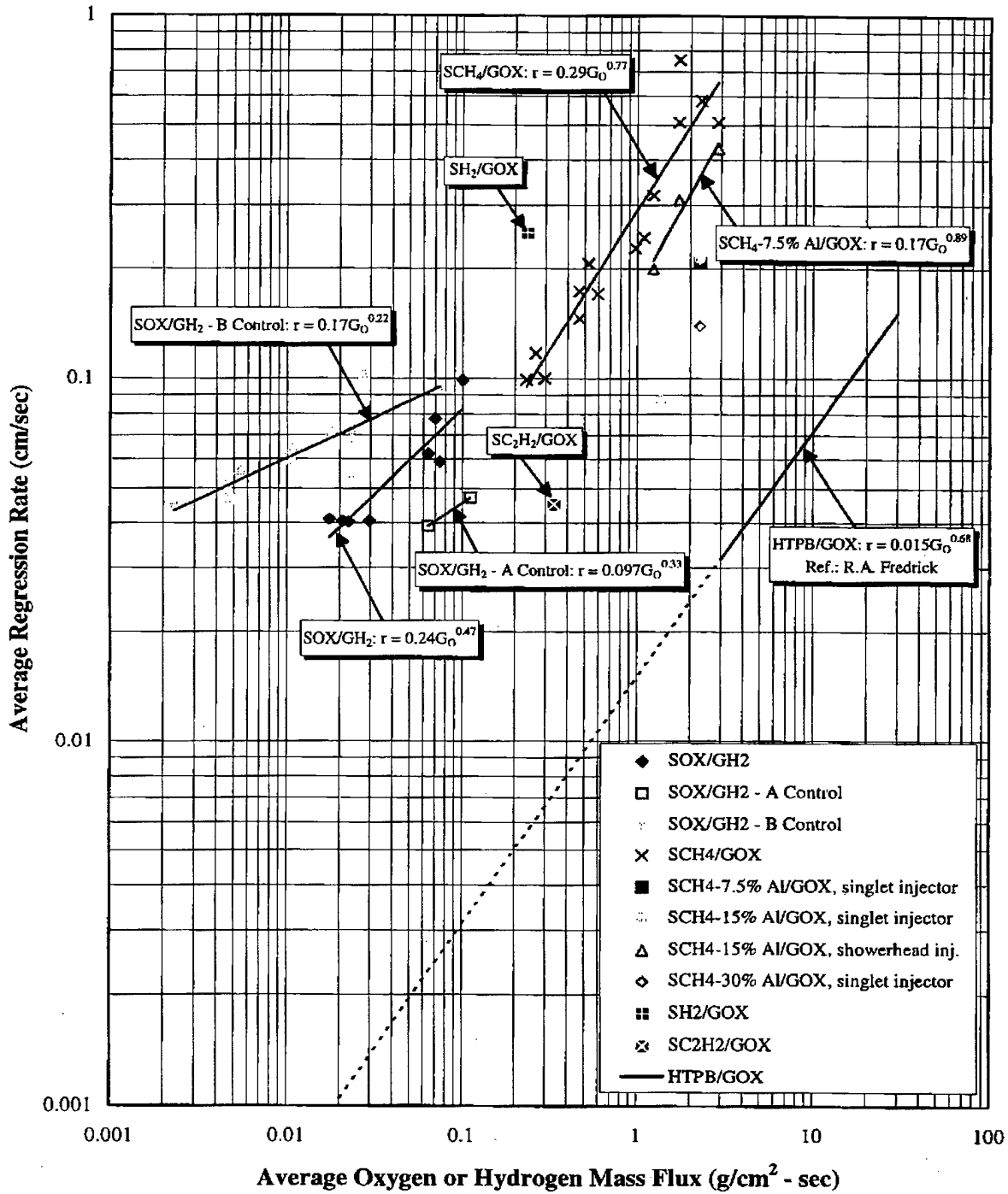
Average O/F: 0.57

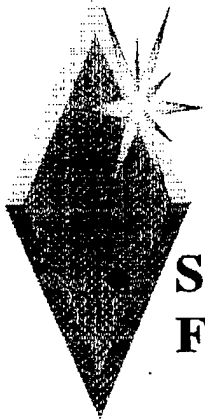
Experimental C\*: 114 s

C\* Efficiency: 83%



# Regression Rate Summary





## *Current R&D Activity*

**Sponsored by USAF/PL Under Contract  
F04611-97-C-0020**

- ◆ **Currently in Design of Systems and Approaches to Control Regression Rates to Optimize Engine Performance (O/F ratio and C\*)**
- ◆ **Mark II Engine Firings are On-going with SOX/GH<sub>2</sub> to Prove Best Combustion Control Approaches**
- ◆ **Goal Is to Design, Develop, Test and Demonstrate a Flight-Weight-Type System (Mark III) that Uses LH<sub>2</sub> for the SOX Freeze Coolant and Also As the Fuel in the Engine**
- ◆ **The use of Ozone is Also Being Integrated Into the Design Approach**
- ◆ **We are working with Boeing-Rocketdyne and Boeing-Seattle to Help Assess Our Current and Future Systems Designs and Applications**



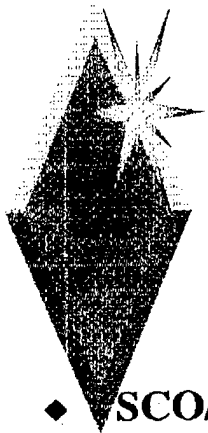


## *Summary of Latest Findings*

**O/F ratios have approached optimum values with higher hydrogen flow rates, with and without O/F ratio control measures**

- ◆ **Axisymmetric freezing of SOX and shorter ignitor burn times seemed to minimize the characteristic grain breakup at the end of the burn**
- ◆ **Injection velocity has a significant effect on regression rate**
- ◆ **GH<sub>2</sub> pilot flow control demonstrated total burning control of the engine with controlled aft injection**
- ◆ **LHe-cooled grains (to 10 K), when burned, exhibit lower regression rates and higher performance than warmer GHe-cooled grains (44 K)**
- ◆ **SC<sub>2</sub>H<sub>2</sub> may be frozen readily from the gas phase using liquid nitrogen**
- ◆ **SCO/GOX burned very well (and hot!) with a stable pressure trace and at a stoichiometric O/F ratio on the 1st Use of mixing plate between the forward/aft chamber**





## *Summary of Latest Findings (Cont.)*

- ◆ **SCO/GOX is an excellent candidate for an ISRU Mars sample return mission**
- ◆ **GOX pilot flow extend the burn time and smoothed out the pressure curve significantly**
- ◆ **Initial evidence indicates that  $C_2H_2$  is stable in the solid phase: stable burning was observed at pressures above 80 psia**
- ◆ **Fuel-rich combustion with  $SC_2H_2$  produced significant sooting**
- ◆ **Both SOM grains burned too fast for the pressure transducers to track the chamber pressure; additives may slow combustion in future tests**