

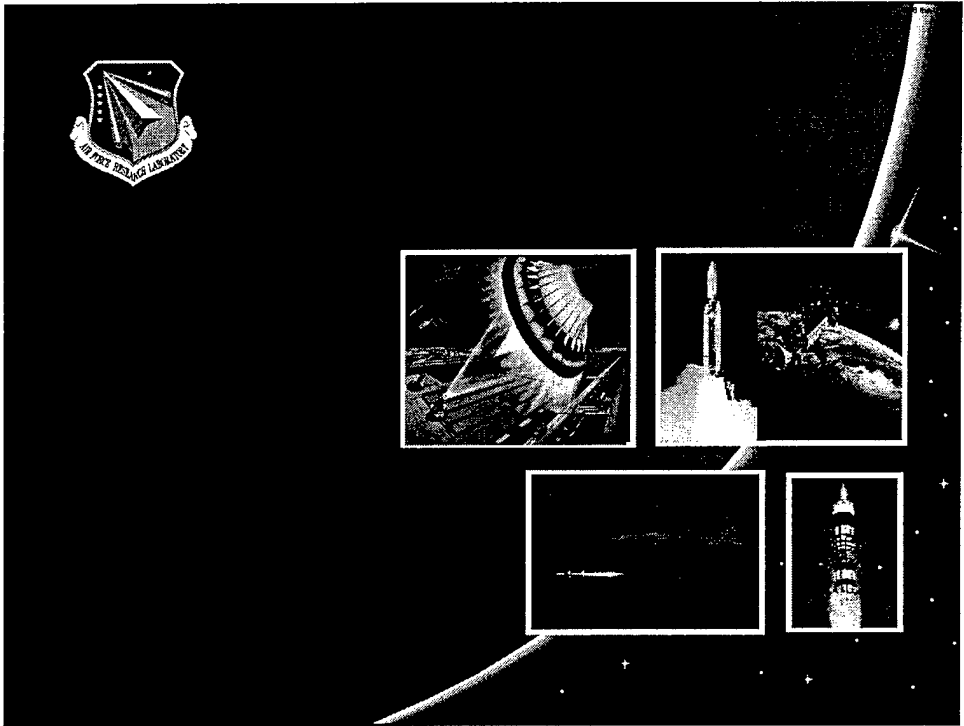
# REPORT DOCUMENTATION PAGE

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**OMB No. 0704-0188**

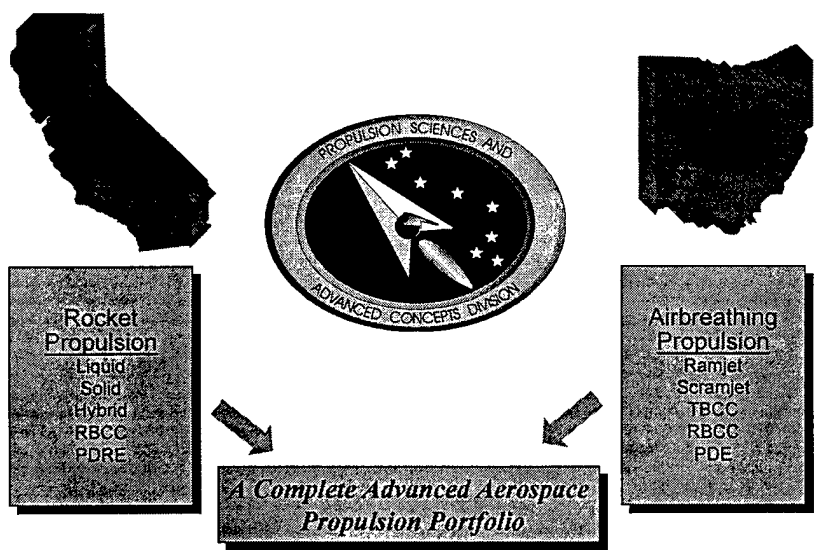
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|  |                                    |   |                                   |  |  |
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| <b>1. REPORT DATE (DD-MM-YYYY)</b>   |                                    | <b>2. REPORT TYPE</b><br>Technical Papers |                                   | <b>3. DATES COVERED (From - To)</b>      |  |
| <b>4. TITLE AND SUBTITLE</b>   |                                    |   |                                   | <b>5a. CONTRACT NUMBER</b>               |  |
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| <b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b><br><br>Air Force Research Laboratory (AFMC)<br>AFRL/PRS<br>5 Pollux Drive<br>Edwards AFB CA 93524-7048  |                                    |   |                                   | <b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>  |  |
|  |                                    |   |                                   | <b>11. SPONSOR/MONITOR'S NUMBER(S)</b>   |  |
| <b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b><br><br>Approved for public release; distribution unlimited.<br><br>MEMORANDUM FOR IN-HOUSE PUBLICATIONS<br><br>FROM: PROI (TI) (STINFO) <span style="float: right;">10 Jul 98</span><br><br>SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-1998-16<br><u>Maj MacLachlan "AFRL Propulsion Directorate Briefing for Industry (PRS input)"</u><br><b>NAECON Briefing</b> <span style="float: right;"><b>(Statement A)</b></span> |                                    |   |                                   |  |  |
| 20020823 048   |                                    |   |                                   |  |  |
| <b>15. SUBJECT TERMS</b>   |                                    |   |                                   |  |  |
| <b>16. SECURITY CLASSIFICATION OF:</b>   |                                    |   | <b>17. LIMITATION OF ABSTRACT</b> | <b>18. NUMBER OF PAGES</b>               | <b>19a. NAME OF RESPONSIBLE PERSON</b><br>Leilani Richardson |
| <b>a. REPORT</b><br>Unclassified   | <b>b. ABSTRACT</b><br>Unclassified | <b>c. THIS PAGE</b><br>Unclassified       |                                   |  | A  |

41 items enclosed

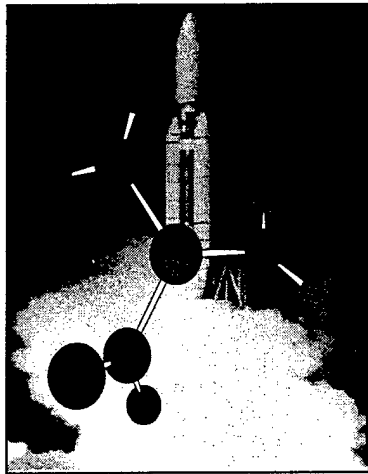


**Comprehensive Advanced Propulsion Research**





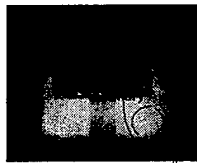
## Technical Specialties



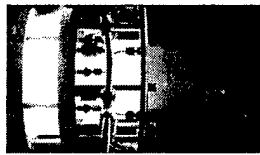
- Combustion
- Hypersonics
- Fuels and propellants
- Lubricants and mechanical systems
- Advanced components
- Advanced-concept system analysis
- Plume phenomenology



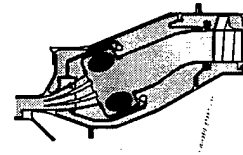
## Trapped Vortex Combustor



6.1



6.2



6.3

### ESTIMATED ADVANTAGES

- 35% Reduction in Cost
- 3.0% Reduction in Specific Fuel Consumption
- 25% Reduction in Combustor Weight
- 30% Increase in Altitude Relight
- Factor of 10 Reduction in Lean Blow Out Limit
- Factor of 20 Reduction in NOx

### TECHNICAL CHALLENGES

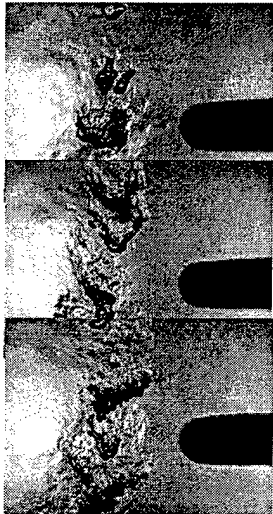
- High performance & acceptable pollutant emissions
- Flame stability
  - ★ Maintain flame stability at higher combustor flow velocities (>100ft / sec)
- Rapid fuel-air mixing
  - ★ Requires revolutionary mixing techniques

### STATUS / PROGRESS

- Preliminary modeling & experiments conducted
  - ★ Excellent performance even at high velocities (>500ft / sec)
  - ★ NOx emissions far below current technology designs
- Significant potential as a major step forward
  - ★ General Electric Aircraft Engines to pursue development



## Supercritical Combustion



*Transcritical Oxygen Drops in Nitrogen*

### PROBLEM

High-performance rocket and airbreathing engines operate in high-temperature/pressure "supercritical" fluid regime where surface tension vanishes, leading to unpredictable injection and combustion that must be corrected by trial and error

### OBJECTIVE

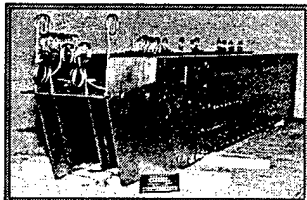
Determine the mechanisms that control the breakup, transport, mixing, and combustion of supercritical droplets, jets, and sprays, so future engines may be designed "right the first time"



## HyTech Program



*"Advanced cycle, dual mode ramjet/scramjet engines, and high temperature, lighter weight materials which allow for long range, long endurance, high altitude supercruise are the enabling technologies."*

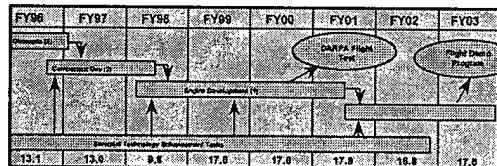


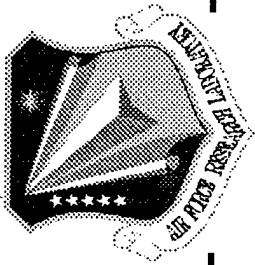
### Develop/Demonstrate H/C SCRJ Technology

- Performance: Mach 4-8
- Durability: 12 Minute
- Maturity: TRL 6 (System in Relevant Environment)

### Transition opportunity

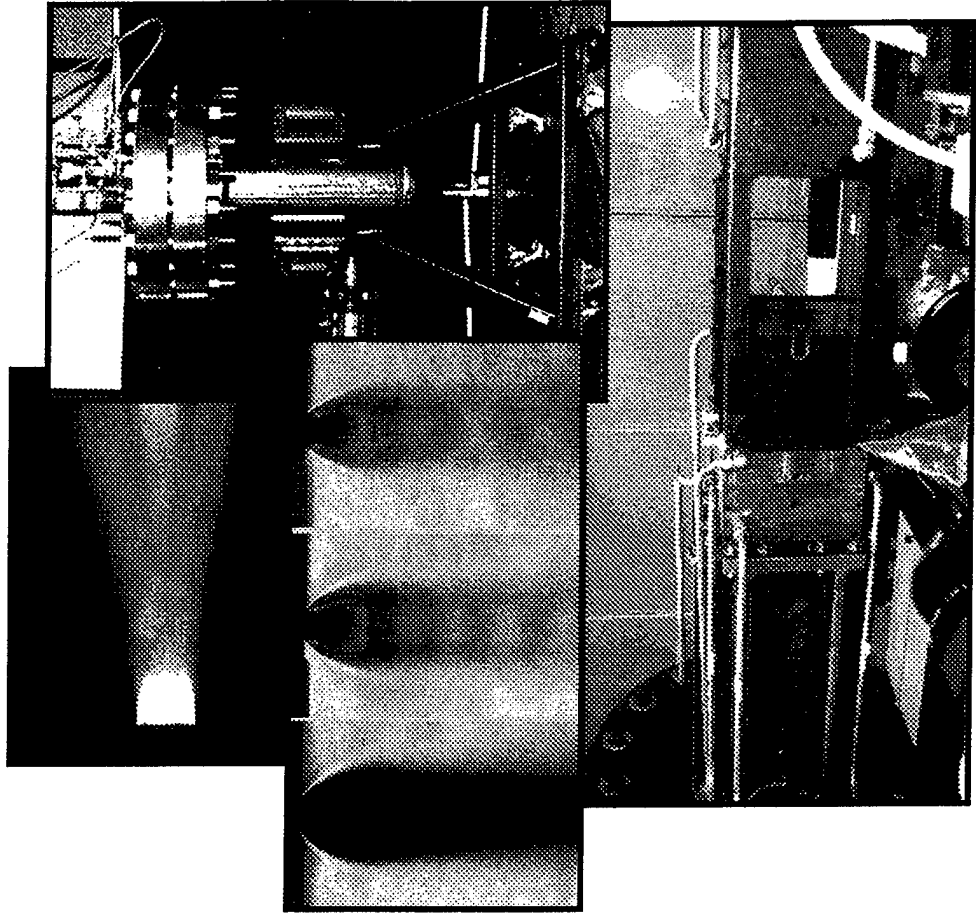
- DARPA Affordable Rapid Response Missile Demo (Heavy - fixed Mach)
- AFRL/MN Time Critical Target Technology
- Demo Program (Full function engine)
- Fast Reaction Stand-off Weapon Pgm





# Ram/Scramjet Research

- Available Facilities
  - Water-Cooled Combustor
  - Fuel Injection Tunnel
  - Direct-Connect Thrust Stand
    - Ducted Rocket
    - Scramjet
  - Supercritical Injection Chamber
- Supersonic Combustor under Development
  - Currently configured for  $M = 1.8$  crossflow
  - Ethylene fueled vitiator limited to 150 psia
  - Nominal flowpath cross section dimensions: 1.5" x 4.0"
  - Well instrumented, accessible for optical diagnostics





## Fuels and Lubrication Objectives

- **HIGHER HEAT SINK FUELS**
  - Improve Aircraft Thermal Management
  - Reduce Fuel System/Engine Fouling
  - Reduce O&M Costs
- **IMPROVED COMBUSTION**
  - Reduce Development Time and Risk (Cost)
  - Expand Engine Performance Envelope
  - Reduce Atmospheric Pollution
- **IMPROVED LUBRICATION SYSTEMS**
  - Longer Life, Higher Temperature Lubes
  - Reduce Weight/Life Cycle Cost
  - Increase Speed/Temperature Capability
  - Corrosion Resistant Bearings



### SYSTEM PAYOFF

- Improved Reliability
- Lower Life Cycle Cost
- Improved Performance
- Reduced Env'l Impact



## Vapor Phase Lubrication

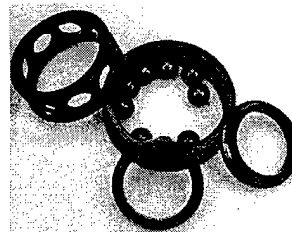
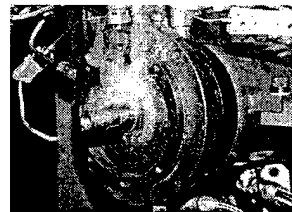
**Demonstrated, for First Time, Sustained Operation at Gas Turbine Conditions w/o Liquid Lubrication**

### KEY TECHNOLOGIES:

- Deposition & Condensate Lubricant (TBPP)
- Carbon-Carbon Composite Cage
- Solid Lubricant Coating
- Oil Mist Delivery
- Computer Modeling and Design

### PAYOFFS (Limited Life Engine):

- 90% Reduction in Lube System Weight
- 15% Reduction in Engine Cost
- Higher Temperature Capability (204 to 650°C)



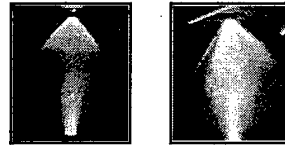
*Auxiliary Support for Magnetic Bearings!*



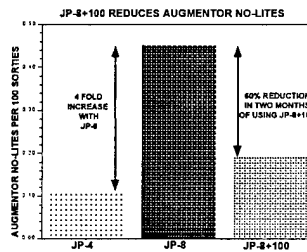
## “JP-8+100” Improved Thermal Stability Fuel

### WHAT IS JP-8+100?

- **JP-8 With Thermal Stability Additive Package**
  - Antioxidant
  - Metal Deactivator
  - Detergent
  - Dispersant
  - Added at 100 - 300 ppm
- **+100°F Increase in Stability**
  - Bulk Temp: 325°F to 425°F
  - Wetted Wall Temp: 400°F to 500°F
- **Cost Goal: \$0.001/gallon**
  - \$1.50 to Fill Up F-15
- **Specification By FY99**
  - Worldwide Use



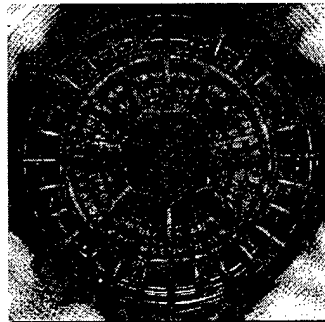
- *Coking/Fouling/Sooting Distorts Spray*
- *Causes Engine Hot Streaks and Damage*
- *Contributes to High Cycle Fatigue*



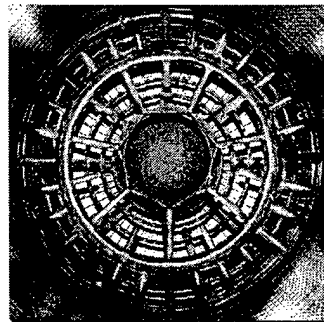
## JP-8+100 Demonstration

Kingsley Field, OR (F16/F100-200)

200+ Hours on JP-8

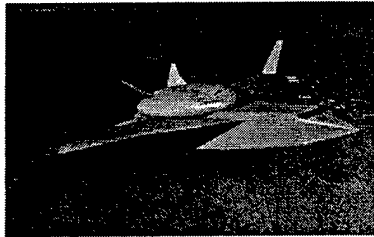


200+ Hours on JP-8  
*then*  
56 Hours on JP-8+100





## Advanced Monopropellants



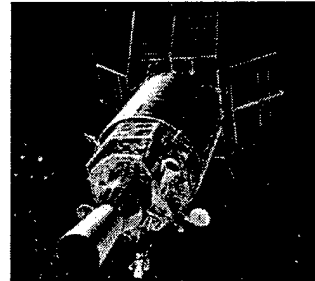
### Description:

Monopropellants for high performance, simple, easy to use, highly maneuverable military space vehicle

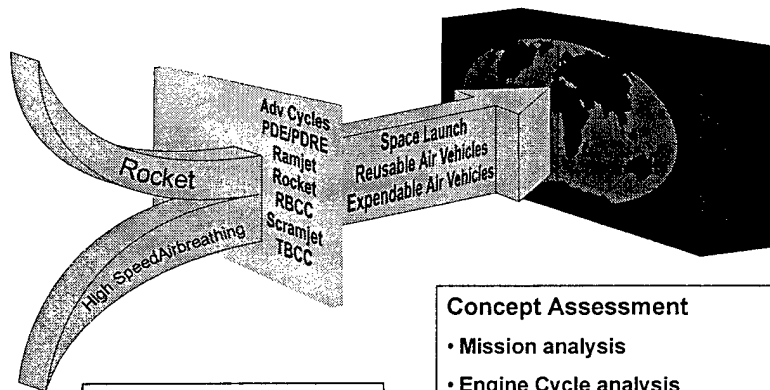
- Single propellant for entire vehicle
- Eliminates one pumping system
- Eliminates cryogenic storage/use
- Enables airplane-like operations

### Payoff:

- Simple propulsion system
- On-demand launch
- Any orbit or inclination virtually anywhere on earth
- Take off anywhere, land anywhere
- Easy to load
- Non-toxic replacement for hydrazine
- Double satellite on-orbit lifetime



## Full-Spectrum Research and Integrated Vehicle/Propulsion Assessments



### Enabling Technologies

- Lightweight materials
- Advanced propellants
- Injection & combustion

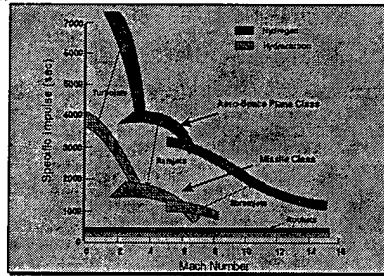
### Concept Assessment

- Mission analysis
- Engine Cycle analysis
- Tool development & modification

*One-stop "global" propulsion research & analysis*

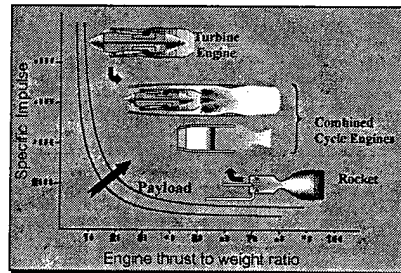
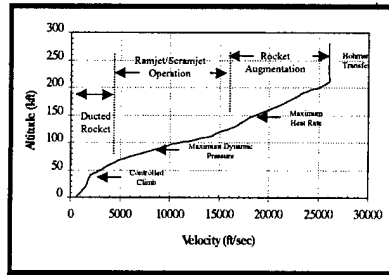


## Integrated Propulsion for Space



### Bridge Air & Space

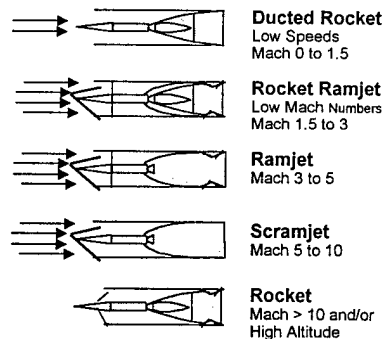
- Move to aircraft-like operations
- Global reach in 2 hours or less
- Bootstrap to spacelift



## Rocket-Based Combined Cycle

### Payoff

- Enables space launch systems that can deliver payloads for 10% of current costs
- Enables a broad range of military transatmospheric applications
  - Global Reach
  - Reconnaissance
  - Force Application
  - Space Control



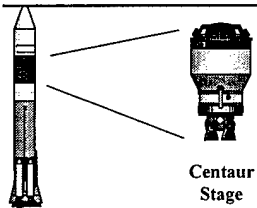


## Space Lift Concepts

- RBCC TSTO: HyperSoar
- LACE TSTO: Space Access
- Launch Assist: Pioneer RocketPlane, RASV, KST Astroliner, Maglev, X-34
  - Air Launch
  - Rail Launch
- Rocket Recoverable TSTO: Kistler K-1
- MSP Pop-Up: RLV / X-33 Derived
- Rocket SSTO: RLV
- RBCC SSTO: NASP, Vision, Trailblazer



## Performance Improvements Due To:



Atlas IIAS

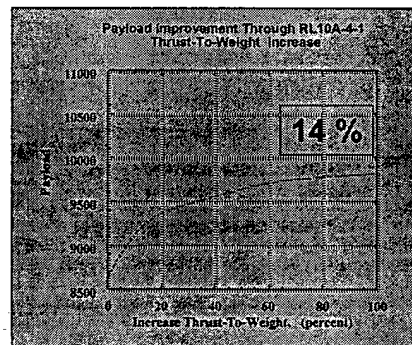
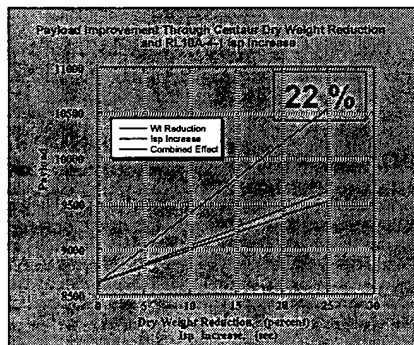
Centaur Stage

- 1) Weight Reduction
- 2) Increased Engine Specific Impulse
- 3) Increased Engine Thrust-To-Weight

Baseline Payload  
(GTO Mission)  
8625 lb<sub>m</sub>

$$\Delta V = g_0 \text{Isp} \ln \left[ \frac{m_0}{m_f} \right]$$

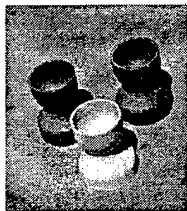
$m_0$  = initial stage mass, lbm  
 $m_f$  = final stage mass  
 Isp = engine specific impulse  
 $g_0$  = gravitational constant





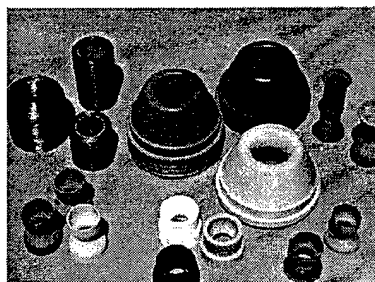
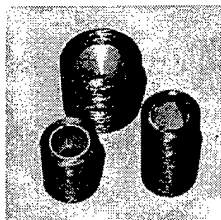
## Inverse-Processed Nozzles/Throats/Chambers

Innovation Enables High-Performance Designs



### Production Steps

- 1) Spray/Cast/Machine Liner
- 2) Fiber Wrap/Braid
- 3) Densify C-C

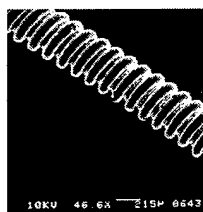


### Payoff:

- Liquids: 4000 °F radiation cooled, oxidation resistant nozzles increase booster thrust-to-weight 15% (RL-10)
- Spacecraft: Long-life (>10 hr) rhenium-lined C-C thrusters at 10% the cost
- Tactical: Erosionless throat increases AMRAAM delivered Isp by 6 sec



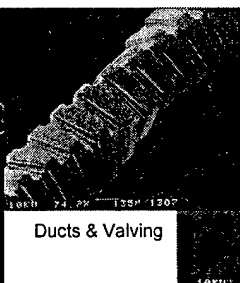
## Microdevice Fabrication and Micropropulsion



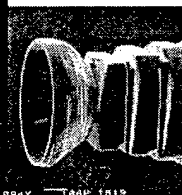
Heat Exchangers



Pressure and Temperature Sensors



Ducts & Valving



Microthrusters

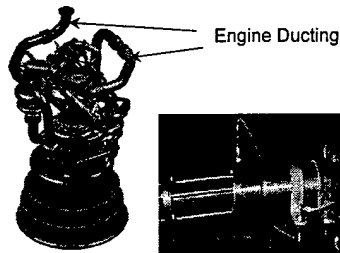
- Revolutionary method can make any 3-D micron scale shape from any material--1st reliable 3-D manufacturing method
- Will enable ultra-small satellites for sensing & exploration missions
- Thousands of micro-sensors can be imbedded in propulsion system components--enabling huge increases in system reliability



## Plastics for Rockets

Crucial to Reducing Weight and Cost

### Liquid Rocket Engines

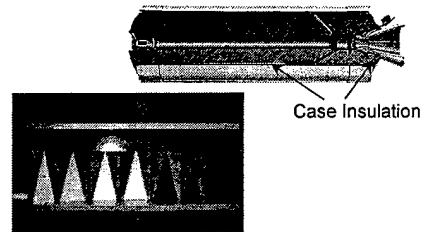


*Polymer Tube/Case Hot Gas Burst Tester*

#### Plastic Engine Ducting (SSME)

- 80% duct weight decrease
- 15% upper stage thrust-to-weight increase

### Solid Rocket Motors



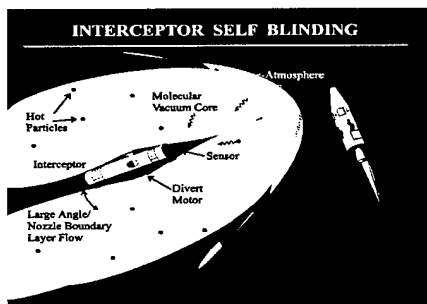
*Char Motor Polymer Insulation Samples*

#### 50% Lower Erosion Insulation

- Cuts Booster Insulation weight 44%
- Increases Booster Payload 7.4%



## Missile Plume Signatures



### *Payoff*

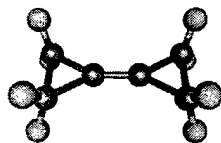
- Improved Discrimination with Countermeasures
- Reliable - All Weather Detection & Tracking
- Robust Boost Phase Intercept Capability

### *Goals*

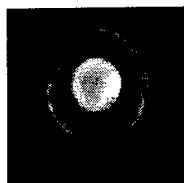
- Fulfill Identified TMD and NMD System Requirements
- Identify, and Resolve Plume Technology Deficiencies
- Transition the Use of Plume Technology From Developers to Users
- Provide Timely System Support and Consultation to BMDO/AF Programs



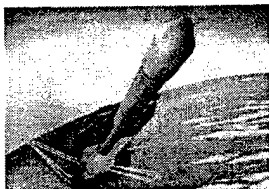
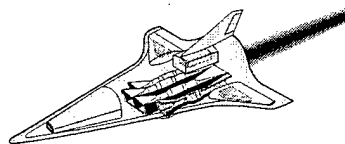
## Revolutionary Propulsion Technology



High energy-density matter (HEDM)



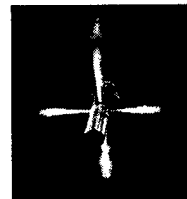
Plasma-assisted drag reduction and combustion enhancement (Ajax)



Low-cost pulsed-detonation propulsion (PDP)



Laser propulsion



Micropropulsion



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