SOLAR ROCKET PROPULSION
Ground and Space Technology
Demonstration

Dr. Michael Holmes, AFRL/PRSS
Create thrust by collecting and focusing sunlight to heat and expand a working fluid through a nozzle.
Solar-Thermal System Concept

- Sunlight
- Thruster Nozzle
- Pivot Axis of Concentrators
- Thin Film Paraboloid Concentrator
- Torus: Intersection of paraboloid and Cone with Apex at Focal Point; Torus is Elliptical and Lies in Plane
- Propellant
- Payload
- Acceleration Vector
- Roll Axis
- Turntable and Receiver
- Acceleration Vector
Solar Thermal Propulsion
Orbit Transfer Scenario

- Maximum Delta V Thru Multi-Burn Transfer
- Solar Thermal OTV to LEO by Ground Launch
- N Perigee Burns to Raise Apogee to Destination Orbit Altitude (e.g. GTO)
- M Apogee Burns to Raise Perigee to Destination Orbit Altitude (e.g. GEO)

- Trip Time = Sum of N+M Orbit Periods
- Higher Thrust Reduces N+M
  – Requires More Power, or
  – Reduces Delta V
- Longer Burns Reduces N+M
  – Can Decrease Delta V by Gravity Losses
- N+M=2 for Chemical Thruster
- N+M~200 for Solar Propulsion

STP Doubles Payload in Reasonable Trip Time From LEO
## Solar Propulsion

### IHPRPT Goals

<table>
<thead>
<tr>
<th>GOALS</th>
<th>BASELINE</th>
<th>PHASE I</th>
<th>PHASE II</th>
<th>PHASE III</th>
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<tbody>
<tr>
<td>Isp</td>
<td>720 sec</td>
<td>792 sec</td>
<td>828 sec</td>
<td>864 sec</td>
</tr>
<tr>
<td></td>
<td>10 %</td>
<td>15 %</td>
<td>20 %</td>
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<tr>
<td>Mass</td>
<td>.66</td>
<td>.696</td>
<td>.722</td>
<td>.749</td>
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<tr>
<td>Fraction R&lt;sub&gt;m&lt;/sub&gt;</td>
<td>5%</td>
<td>9%</td>
<td>13%</td>
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<tr>
<td>Dry Mass</td>
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<td></td>
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</tr>
<tr>
<td>Reduction</td>
<td>15%</td>
<td>25%</td>
<td>35%</td>
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<tr>
<td>Mission</td>
<td>LEO to GEO (250nm at 28deg) ~30day</td>
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</table>
Foam Mandrel
10/29/99

Foam Mandrel on Milling Machine at NASA MSFC 10/27/99

Foam Rough Cut on 10/29/99
Flight Scale Concentrator (FSC)

- FSC Mandrel Machined and Measured (Jan 00)
  - SRS Modeled and Generated CNC Machining Code
  - NASA MSFC Machined Mandrel
  - FSC-2 Using Foam Mandrel With Teflon Coating
- FSC-1 Fabricated (May 00)
- Method Developed to Deposit, Cure, and Release Film on Foam Mandrel
- FSC-2 (Optical Quality) Currently Being Fabricated
Concentrator Deployment Repeatability Demonstrated in IT-4 & 5

- Deployment fold pattern / packaging concept verified
- Measured < 0.5 inches variation in global geometry over 4 deployments
- No difference in global geometry observed between ambient pressure and vacuum (10^-6 torr) deployment

Deployment Video:
http://www.stg.srs.com/aerospace.htm

Flight Scale Concentrator Ambient Deployment
Flight Scale Concentrator inside SPEF Chamber
AFRL’s Space Environmental Test Facility
TA-1 Tank 6 Apparatus
Thermal Vacuum Testing

• NASA GRC Tank 6 Simulates Space Thermal Environment
• Concentrator Shape and Position Verified under Mission Eclipse Cycling
Propellant Management System Experiment

- New Approach to Cryogenic Propellant Management
  - Control Tank Pressure by,
    - Remove Vapor -> Lower Pressure
    - Remove Liquid -> Raise Pressure
    - Acceleration Pulls Liquid to “Bottom” of Tank
  - Advantages
    - Large Heater Eliminated
    - Thermodynamic Vent System (TVS) Eliminated
    - Mixer Eliminated
    - Simplified Control Software
    - Lower Pressure Tank -> Lower Weight
  - Preliminary Results Very Good
  - SRS and MSFC have Models and will Compare to Data
- Thiokol Composite Tank Reduces Tank Fraction
Solar-Thermal Propulsion
Thiokol/SRS Thruster Design

• Well Tuned to Input Light Distribution
• Beam Fractionating
  – Highest Intensity at Hottest Propellant
  – Pointing Error Tolerant
  – Lowest Intensity at Coolest Propellant
• Optical Blackbody Cavity
  – Minimize Insulation
  – Secondary Mirror Cooled by Incoming Propellant
• Capable of Meeting Phase II IHPRPT Goals
• Technologies Extensible to Phase III
• Proven in Short Duration Testing (<10 hours)
• Working on 3-D Model
• Concentrator will track sun
• Matches flux profile but not power of space system
• Thruster in vacuum chamber
• 792 sec Isp will be shown by analytical correction of:
  • 25% atmospheric loss
  • 10% window loss
Key Assumptions
Solar Thermal

• Liquid Hydrogen
  – LH2 stored at 45 psi as saturated liquid
  – MLI + thermodynamic feed prevent venting
  – 6% residual

• Direct gain concept
  – No thermal storage
  – Large inflatable reflectors
  – Capable of meeting IHPRPT Isp goals
# Solar Thermal Study Assumptions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
<th>Phase I</th>
<th>Phase II</th>
<th>Phase III</th>
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<tbody>
<tr>
<td>Isp</td>
<td>720</td>
<td>792</td>
<td>828</td>
<td>864</td>
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<tr>
<td>Engine efficiency</td>
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<td>0.35</td>
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<td>Eng specific mass</td>
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<td>Concentrator eff.</td>
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<td>Conc specific mass</td>
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<td>0.001</td>
<td>0.00085</td>
<td>0.0007</td>
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<td>Tankage fraction</td>
<td>0.29</td>
<td>0.265</td>
<td>0.23</td>
<td>0.2</td>
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Efficiencies and Mass Properties can be traded!
Phase III has potential of doubling PL to GEO
Conclusion

- Solar Thermal Propulsion Payoff
- Double Payload
- Booster Step-Down
- Enable High Energy Missions