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Please see attached

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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Solar Propulsion Development

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JON:

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Michael R. Holmes

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A

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Albuquerque NM

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ASAP

9-28 thru 9-30

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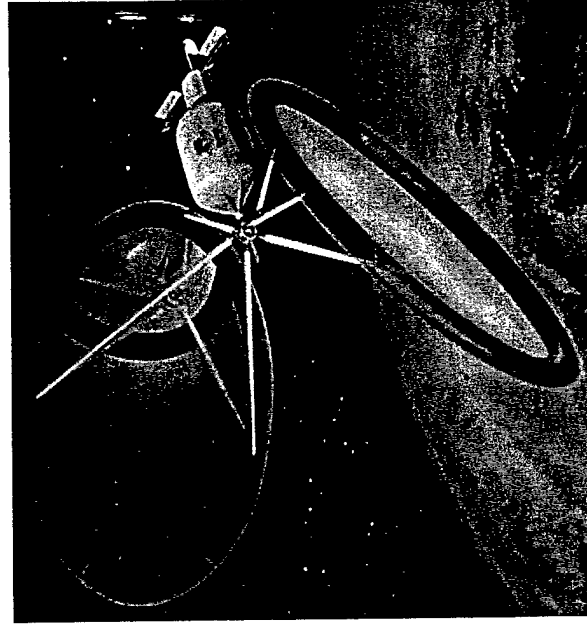
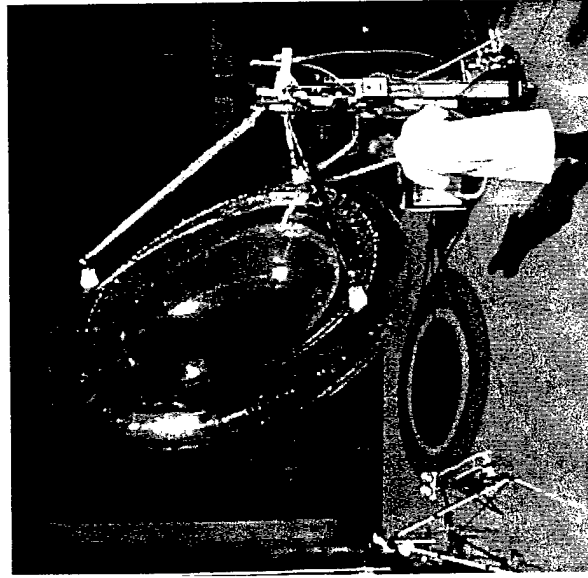
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Date assigned

27 Sep 99



AIAA Space Technology Conference and Exposition

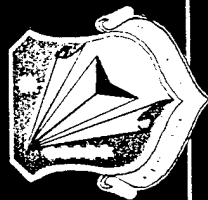


SOLAR-THERMAL PROPULSION

Dr. Michael Holmes, AFRL/PRRS

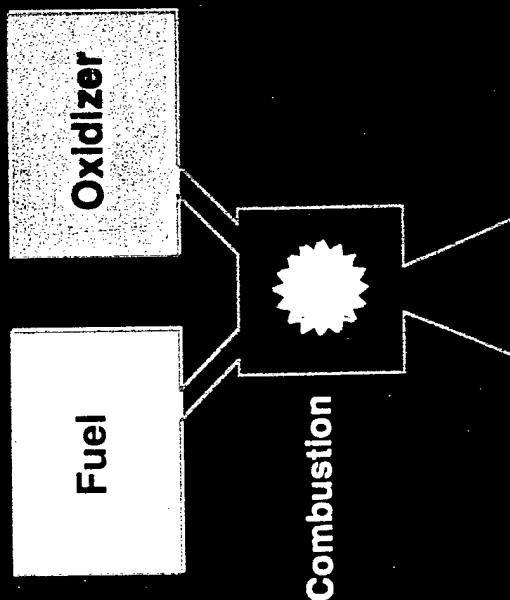
DISTRIBUTION STATEMENT A
Approved for Public Release
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Solar Thermal & Chemical Propulsion Comparison



Chemical Rocket

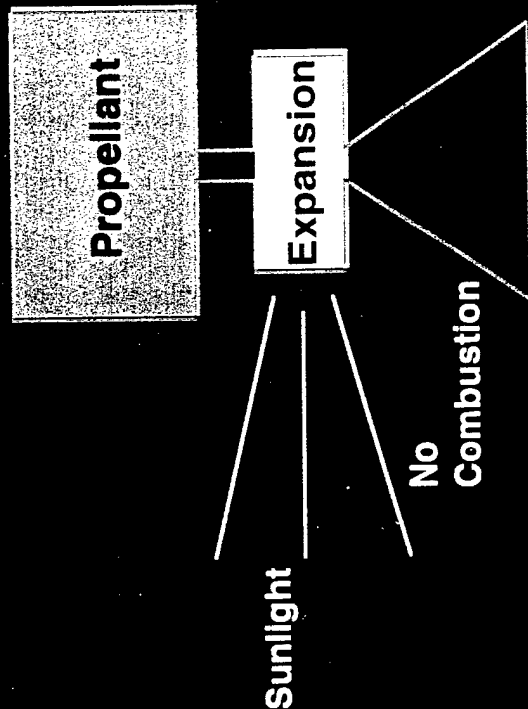
Large Acceleration
Large Propellant Usage



Inefficient, Large Thrust
Low Exhaust Velocity

Solar Thermal Rocket

Small Acceleration
Small Propellant Usage



Efficient, Low Thrust
High Exhaust Velocity

Words
on
this
slide?





Solar Thermal Propulsion Orbit Transfer Scenario



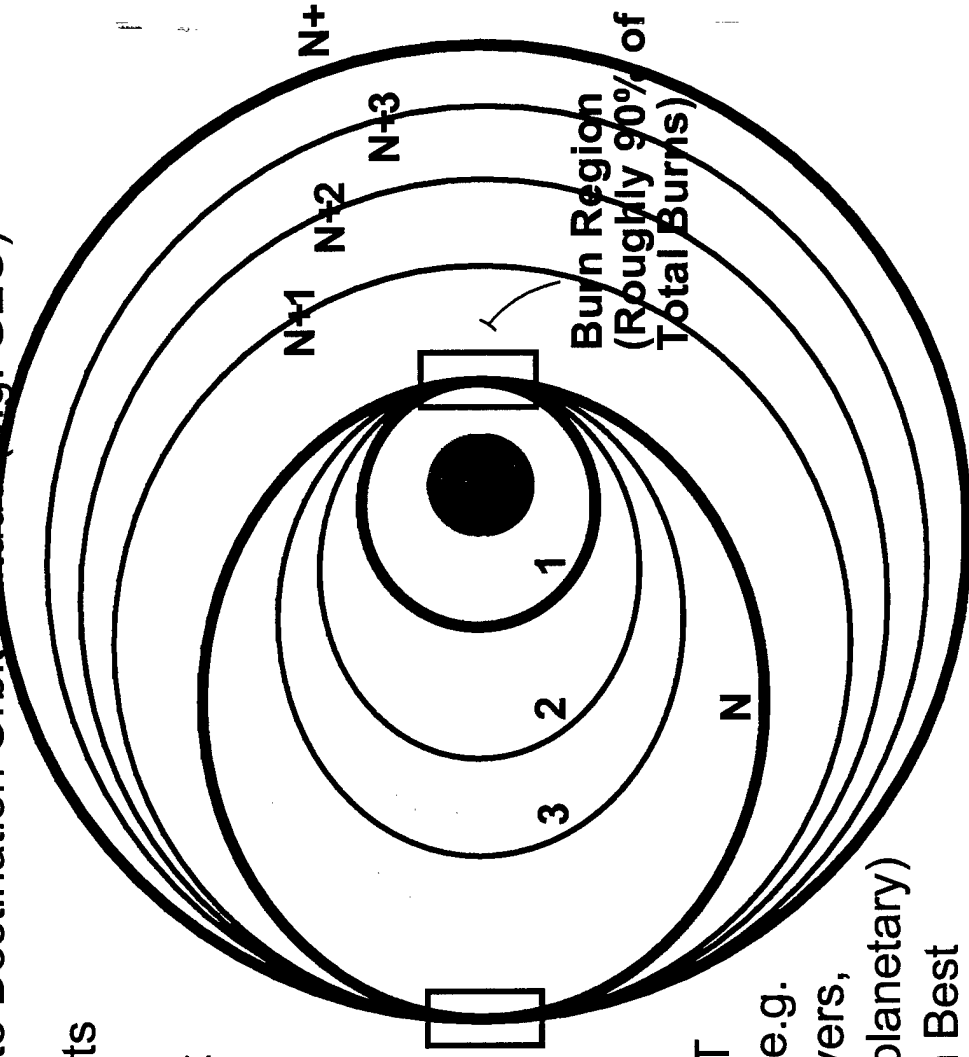
- Solar Thermal OTV to LEO by Ground Launch
- N Perigee Burns to Raise Apogee to Destination Orbit Altitude (e.g. GTO)
- M Apogee Burns to Raise Perigee to Destination Orbit Altitude (e.g. GEO)

- Trip Time = Sum of Periods of Orbits
- Higher Thrust Gives Fewer Orbits
- Longer Burns Give More Orbits but Less Delta V

- Takes a Month or Two for Solar Thermal from LEO to GEO
- Takes Many Months for Electric Propulsion from LEO to GEO

**Burn Region
(Roughly 10% of Total Burns)**

- Many Other Orbital Maneuvers NOT Limited by Orbit Period or Number (e.g. Station Keeping, High Orbit maneuvers, Orbit Control, Orbit Tweaking, Interplanetary)
- High Isp Electric Propulsion is Then Best





SOLAR PROPULSION PHASE I

Program GOALS



~~Design~~

GOALS	BASELINE	PHASE I GOAL	PHASE I ROLLUP
Isp	720 sec	792 sec 10 %	792 sec 10 %
Mass Fraction	.66	.696	.696
Dry Mass Reduction		15%	15%

Mission : LEO to GEO (250nm at 28deg) ~30day

Baseline LEO Mass Ratio

48.4%	24.9%	26.7%
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Propellant Dry Mass P/L



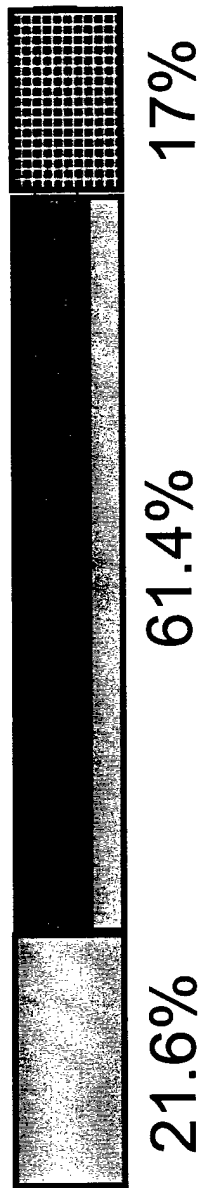
SOLAR THERMAL PHASE I PAYOFFS



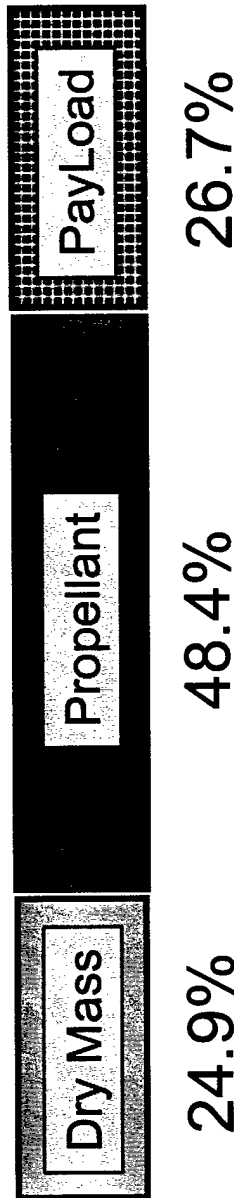
Baseline is 57% increase over chemical

Phase I is 26% increase over baseline

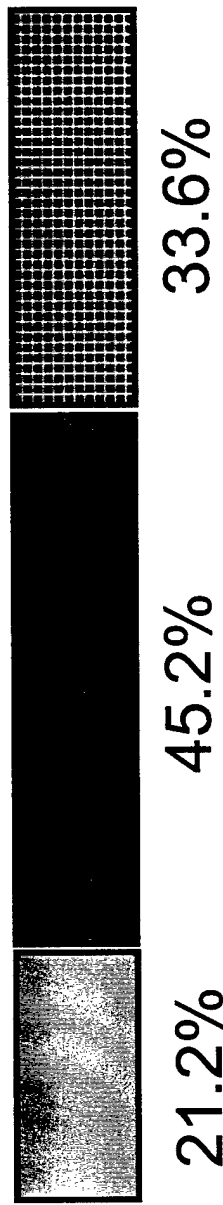
Chemical
LOX/LH2



Solar Thermal
Baseline



Solar Thermal
Phase I Goals



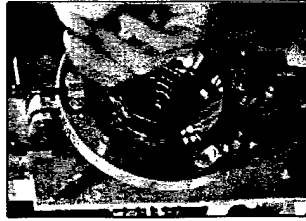
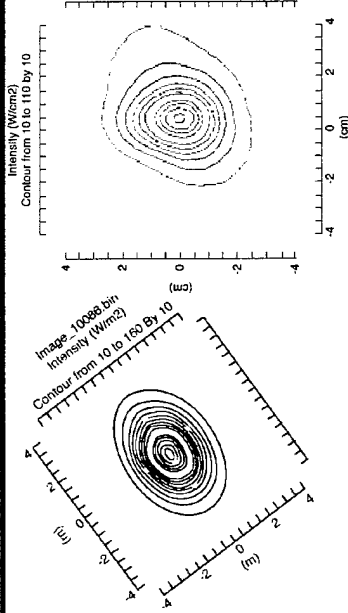


Solar Thermal Propulsion Demonstration Approach



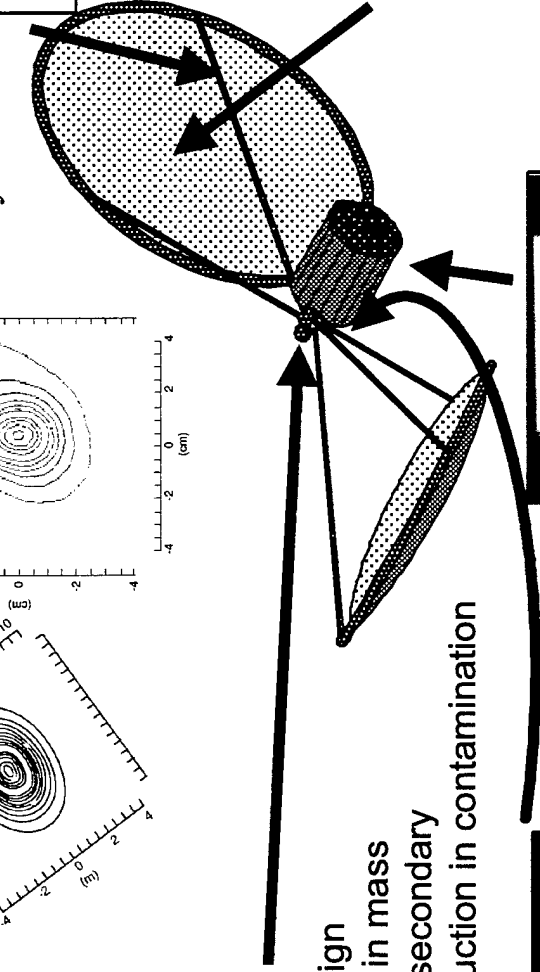
DIAGNOSTICS and MODELING

- Performance Check
- Design Tool
- Payoff Determination



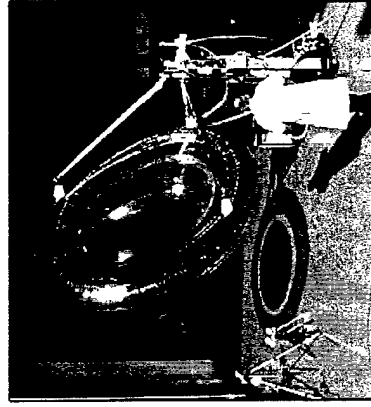
THRUSTER

- Optical wrap design
- 90% reduction in mass
- High temp moly secondary
- Significant reduction in contamination



CONCENTRATOR SUPPORTS

- Deployable rigidizing struts
- 15% reduction in mass
- Enables compact packaging
- Reduces make-up inflatable



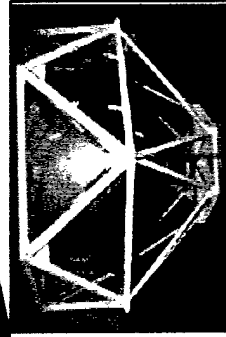
CONCENTRATOR

- Thin Film Inflatable Concentrator
- 50% reduction in mass
- 95% reduction in packaged volume



SUN-ACQUIRING, POINTING & TRACKING

- Focus sensor and control
- Reduces bus ACS

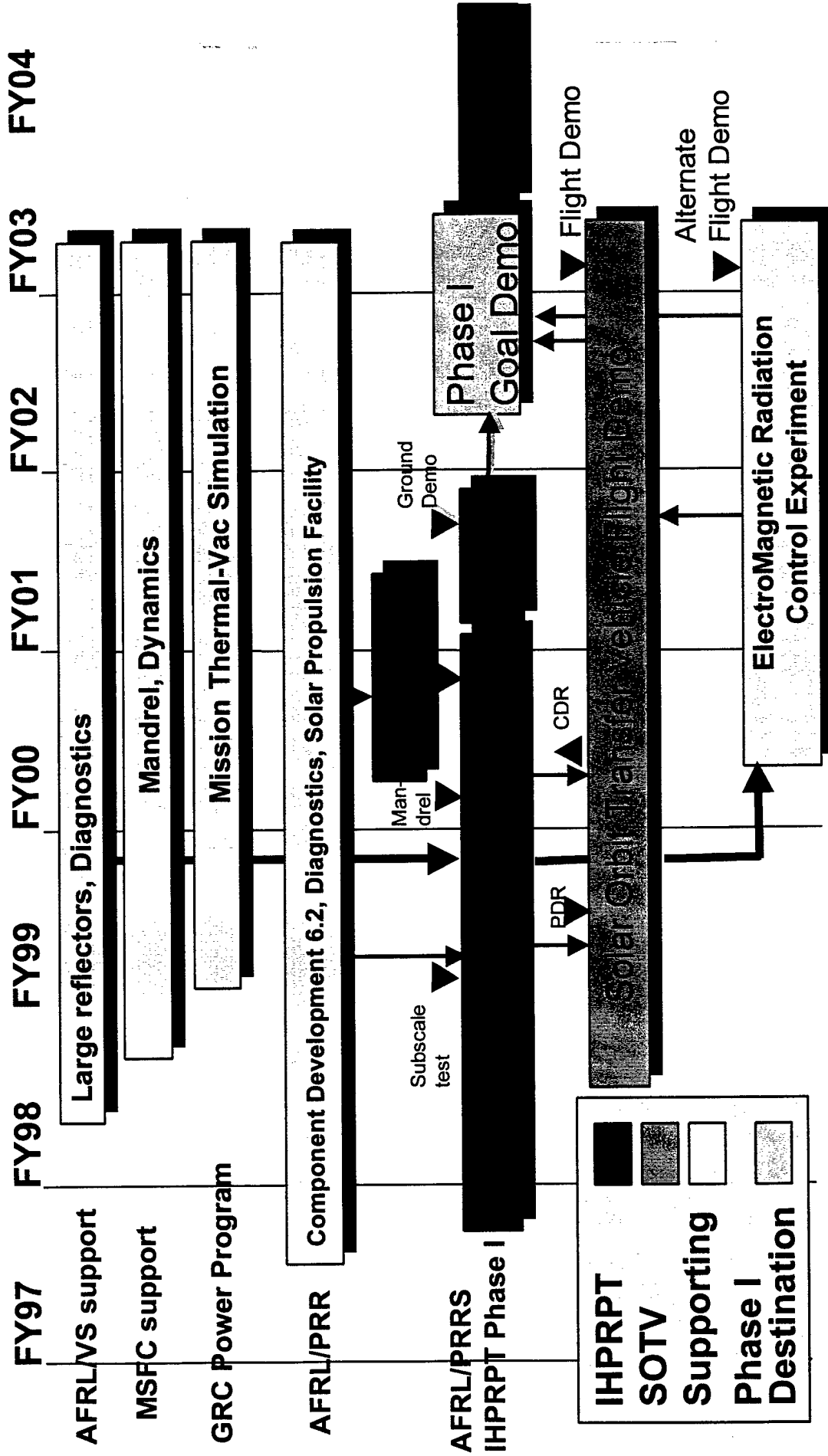


CRYO LH2 TANK & FEED

- Selective Phase acquisition
- Reduces mass
- Composite LH2 Tank
- Reduces mass



IHPRPT PHASE I SOLAR ROADMAP

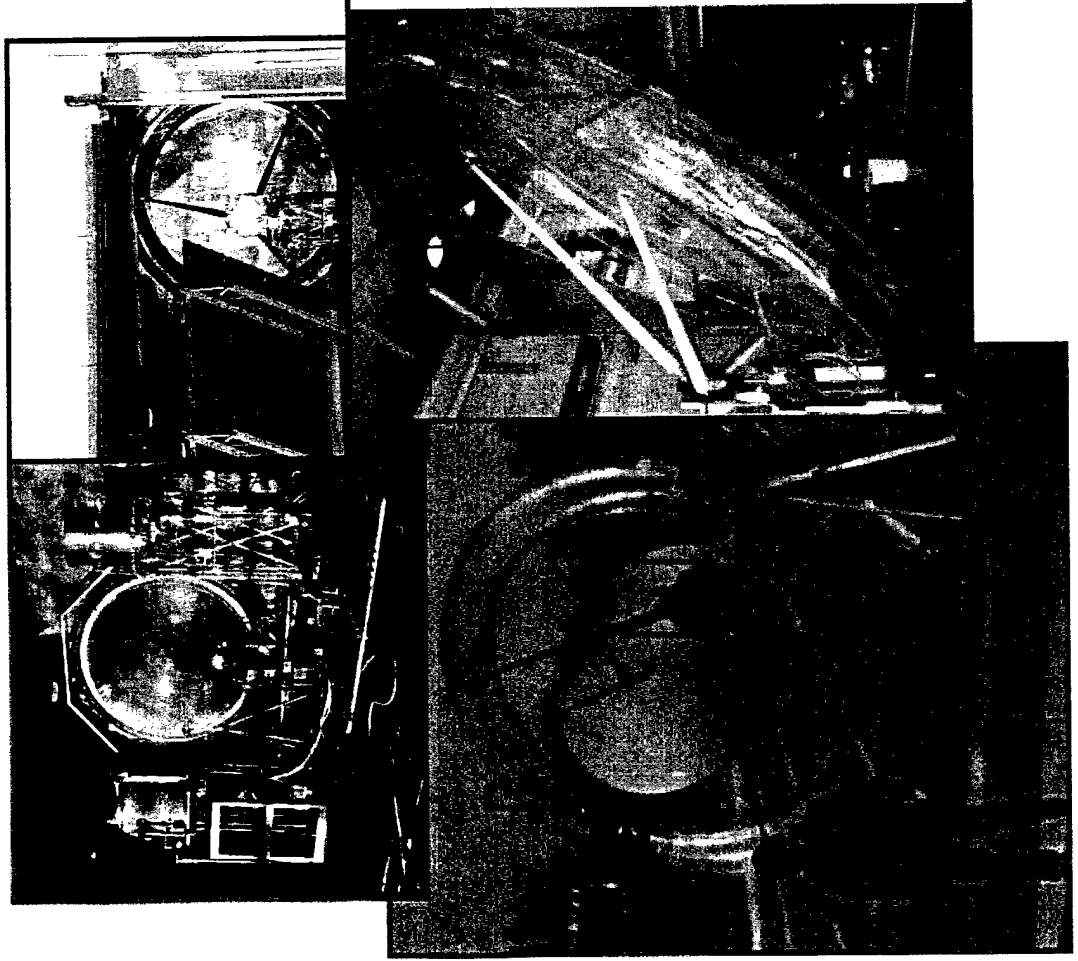




PHASE I GOAL DEMO INTEGRATED GROUND TEST OF THRUSTER AND CONCENTRATOR



- Concentrator will track sun
- Matches flux profile but not power of space system
- Thruster in vacuum chamber
- 792 sec lsp will be shown by analytical correction of:
 - 25% atmospheric loss
 - 10% window loss

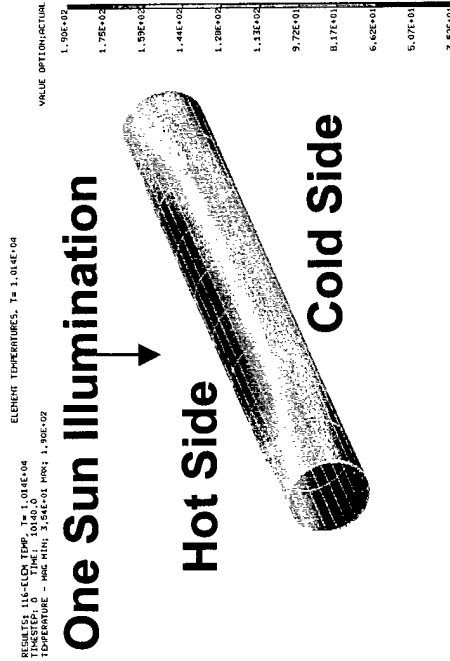




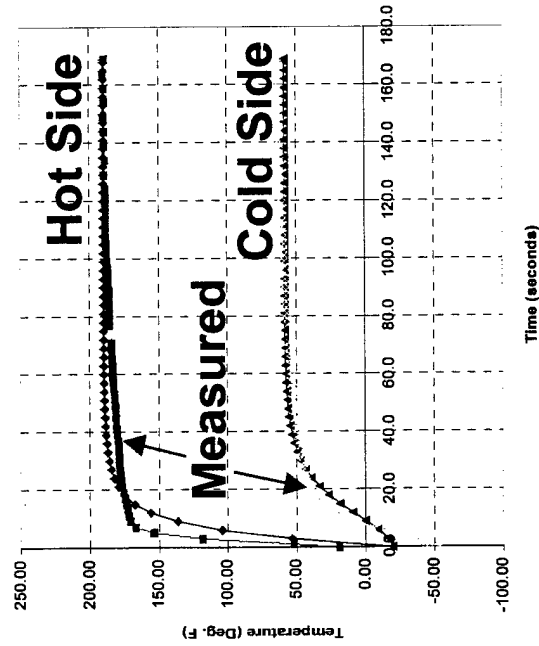
Foam Rigidized Strut Thermo-Vac Modeling

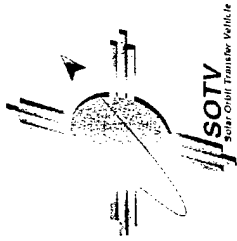


RESULTS: 16-ELON, 1PM, 1.014E+04
TEMPERATURE - HIG MIN: 3.54E+01 MIN: 1.90E+02



- Strut Illuminated in Vacuum
- Approximately One Sun
- Liquid Nitrogen Cold Walls
- Model and Measurement Match Closely (See Lower Left)
- Hot Side about 190 Fahrenheit
- Cold Side about 60 Fahrenheit
- Data to be Used in Structural & Dynamics Modeling

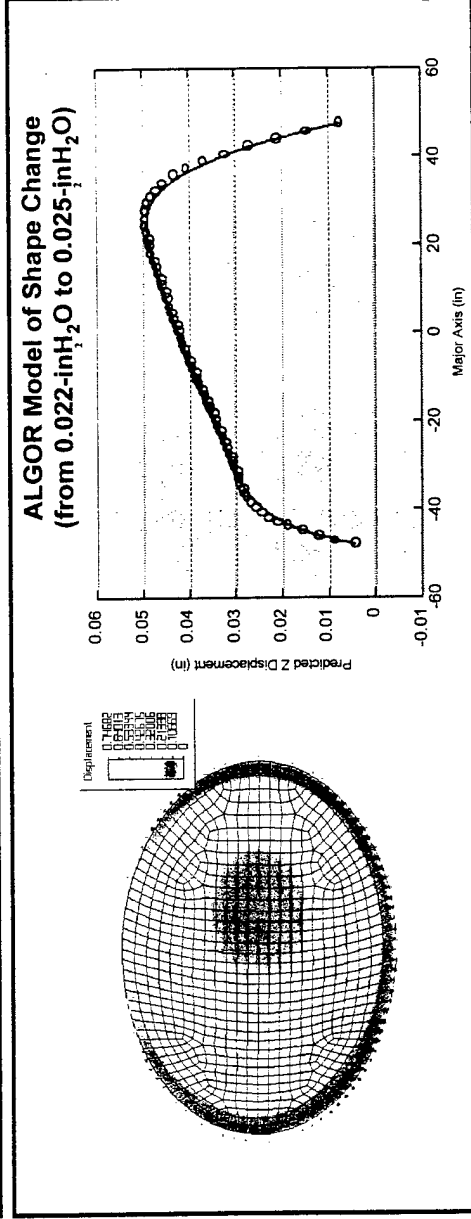
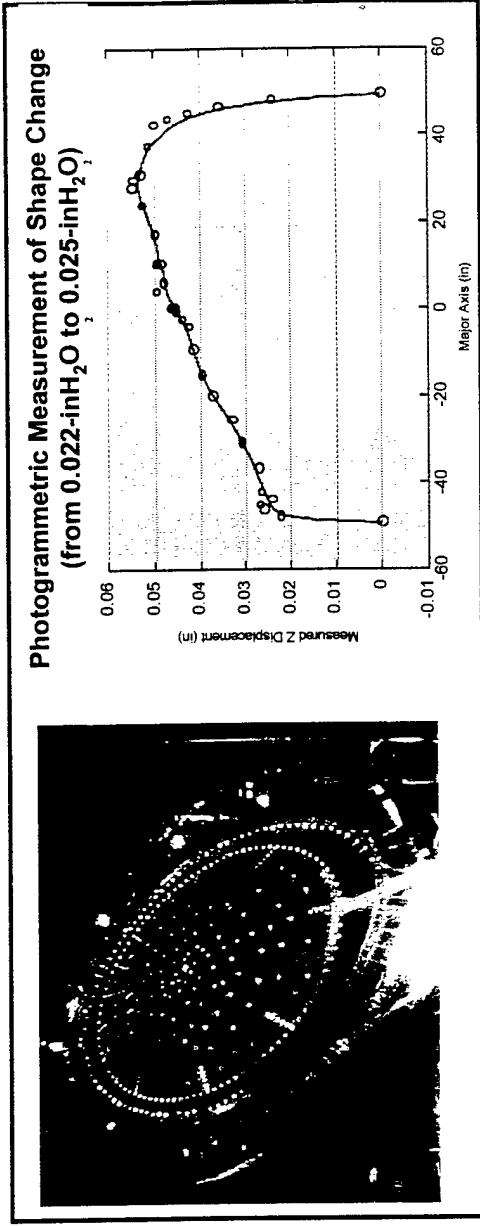




FEM Design Model Verification for TSC-6



- Used photogrammetry to measure TSC6 shape at varying pressures
- Created ALGOR model of TSC6 and measured shape change at varying pressures
- Conclusion: ALGOR model accurately defines TSC6 and may be used for optimization



Thiokol
Propulsion

Small Orbital Transfer Vehicle

STC
TECHNOLOGIES

Org/IPT - 59

BOEING

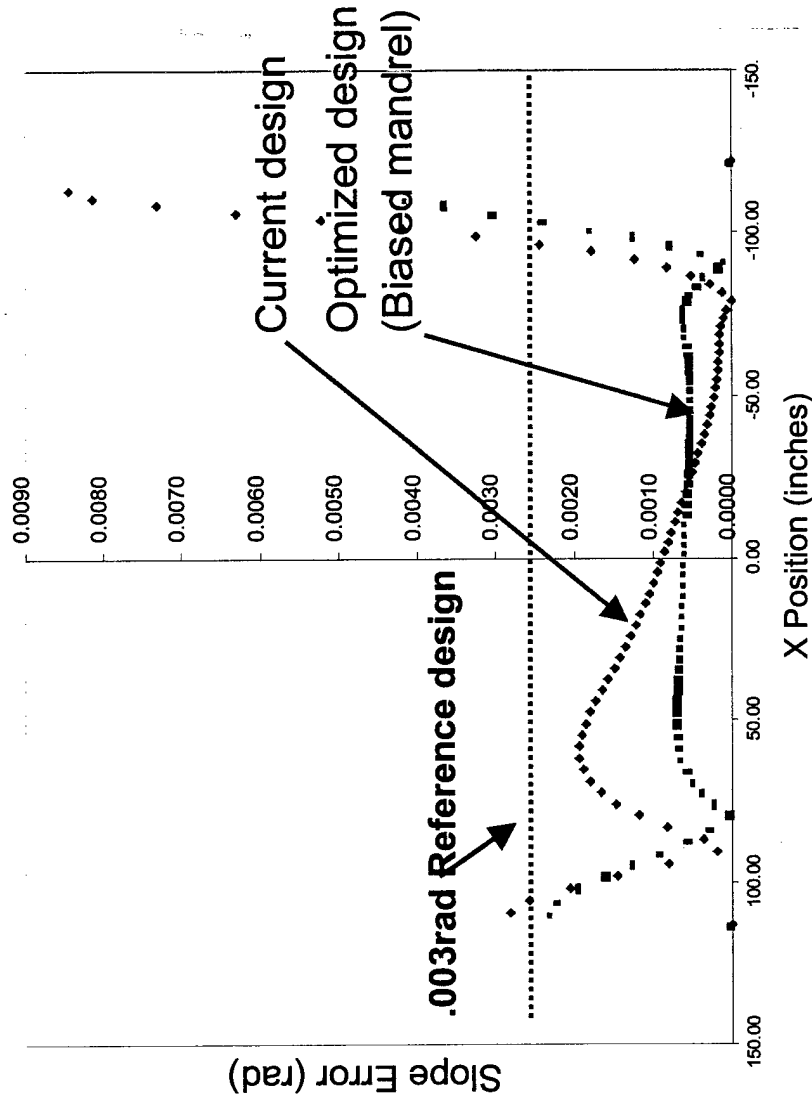


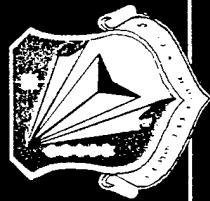
FSC Design Analysis



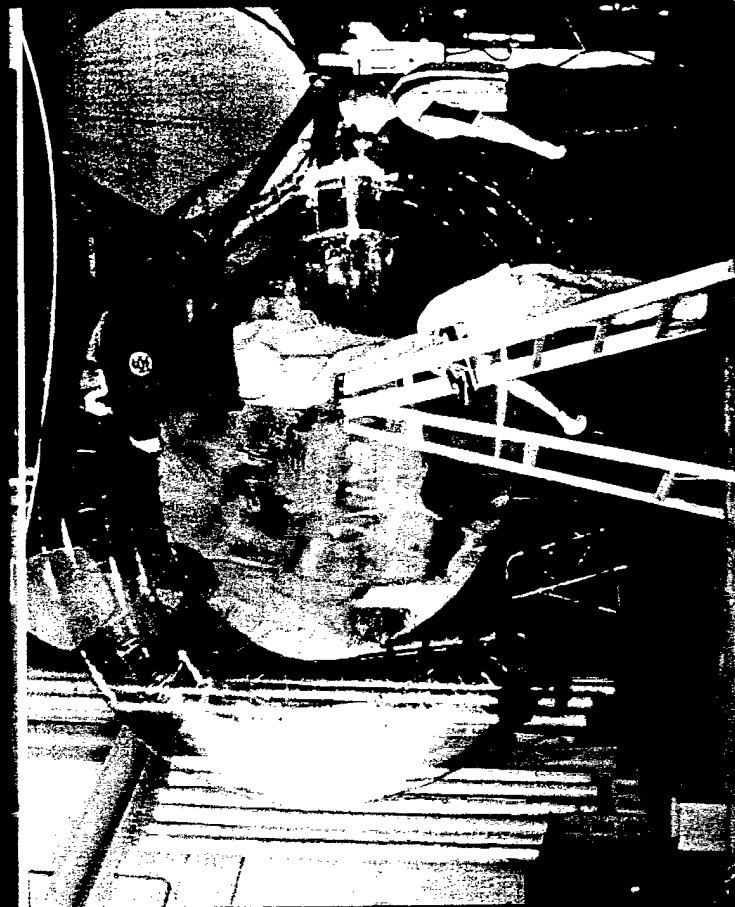
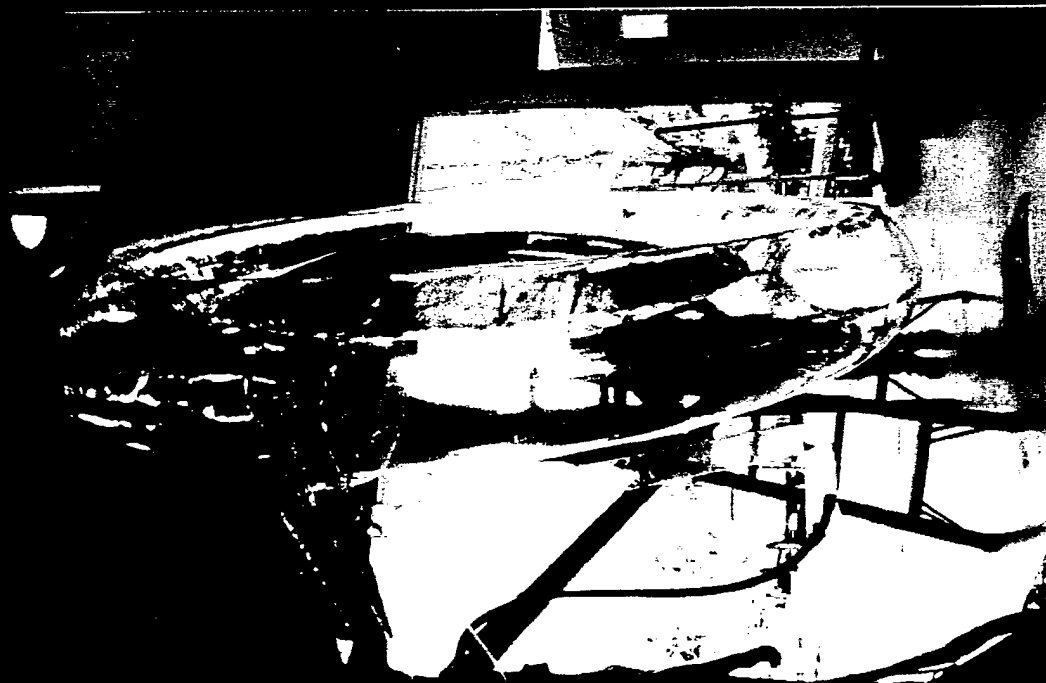
FSC Slope Error Along Major Axis

- Majority of reflector surface lies below 0.003 rad error
- FSC baseline design operates at lower pressures than those used in TSC6. The reflectivity of TSC6 indicates this is a viable design option.
- Initial shape optimization provides additional margin and improved slope error.
- Biased Mandrel 10% to 20% Greater Intensity and Power





SRS Molded Off-Axis Concentrator

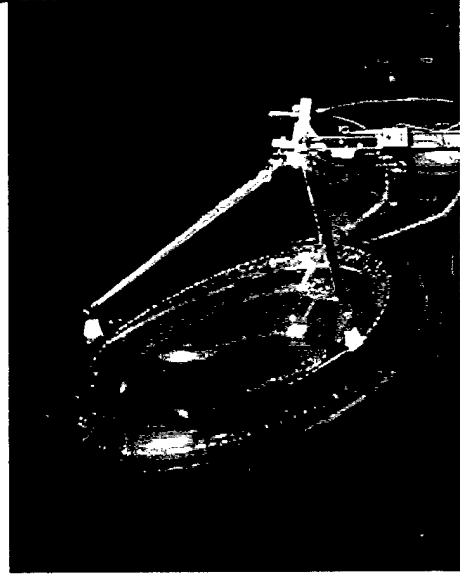
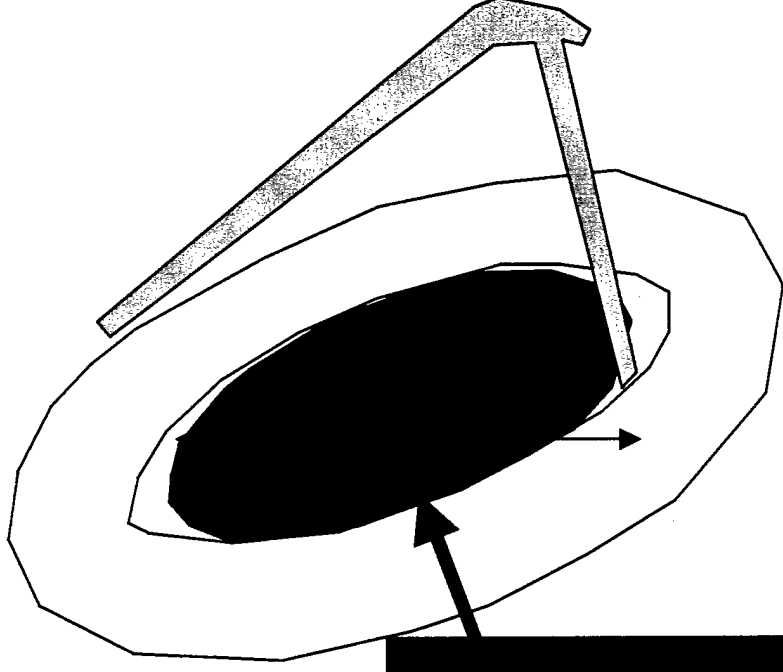




Flight Scale Reflector



- Fabrication Techniques From 2x3 m Concentrator
- About 4x6 m
- Flight Size for SOTV
- About Half Size for Minimum Operational Solar Thermal Upper Stage
- Quadruple Power over 2x3 m
- Peak Intensity About the Same



SRS Graphite Thruster

May 1, 1997

Front Side

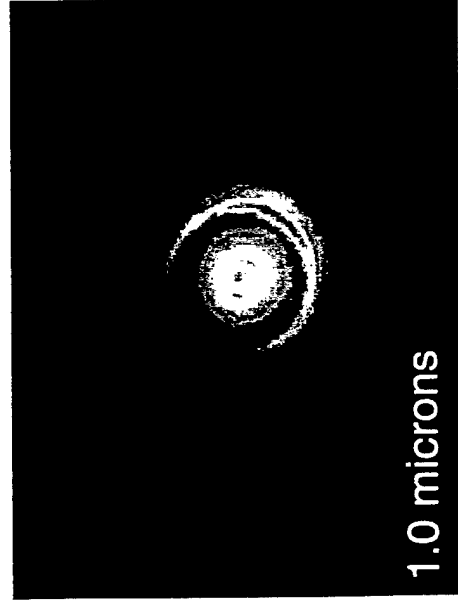
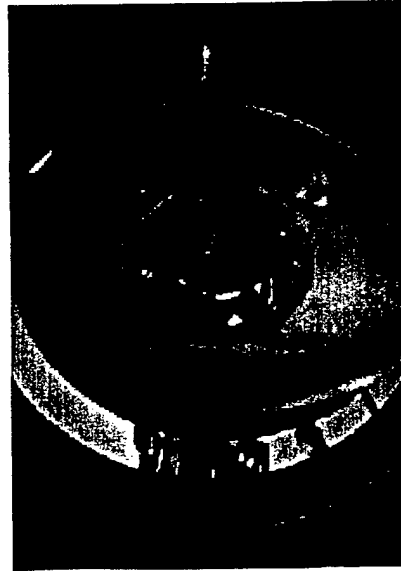
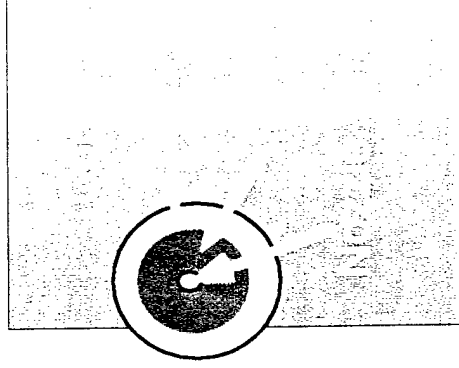
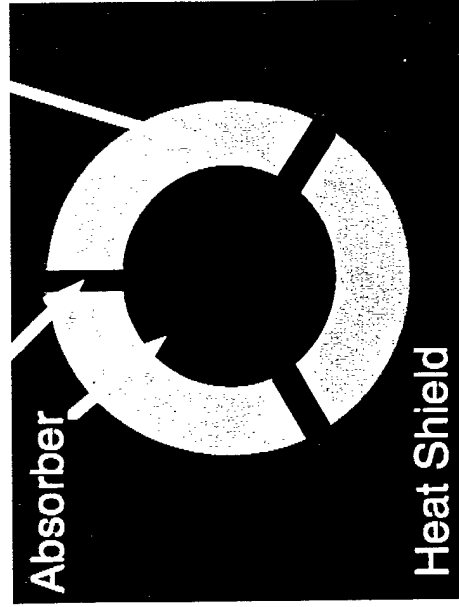
Back Side

Partch 8/98

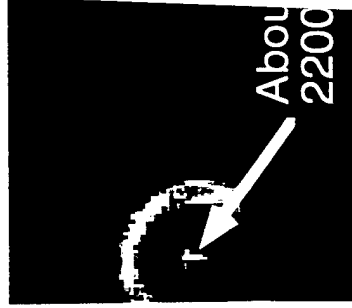
~~Heat Camera~~ ~~Nozzle Camera~~

11

Support
Secondary
Concentrator

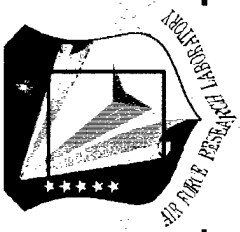


1.0 microns



About
2200

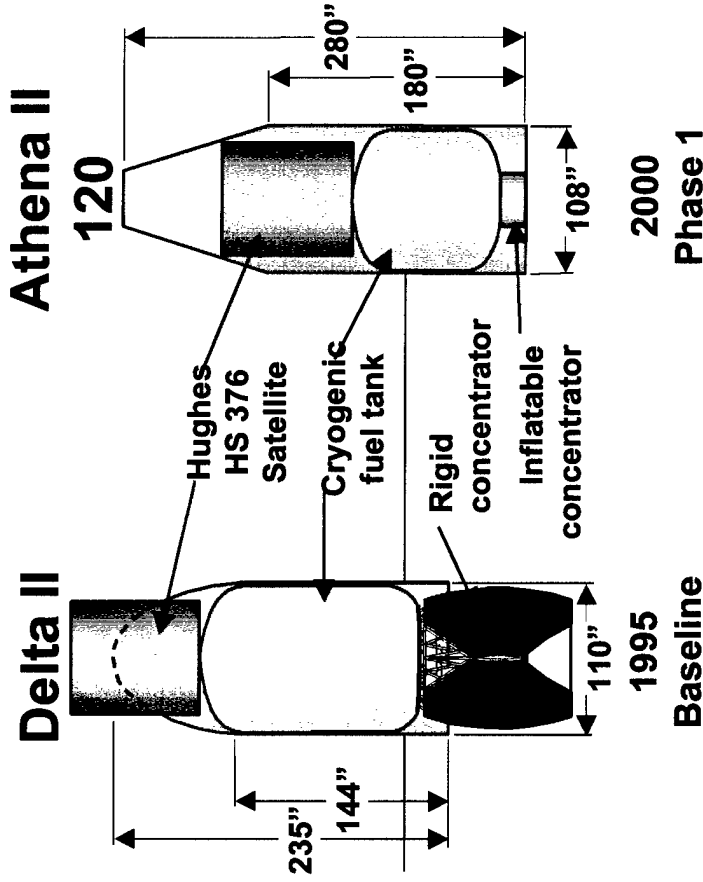
Broadband,
1.2 to 0.3 microns



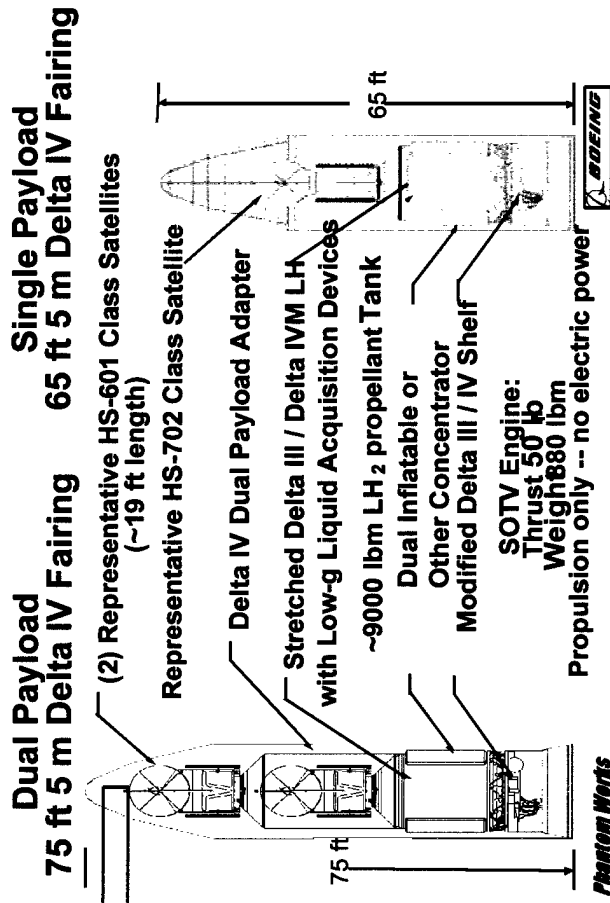
TECHNOLOGY TRANSITION OPPORTUNITIES



SOTV Packages Well on EELV/Delta IV and Athena



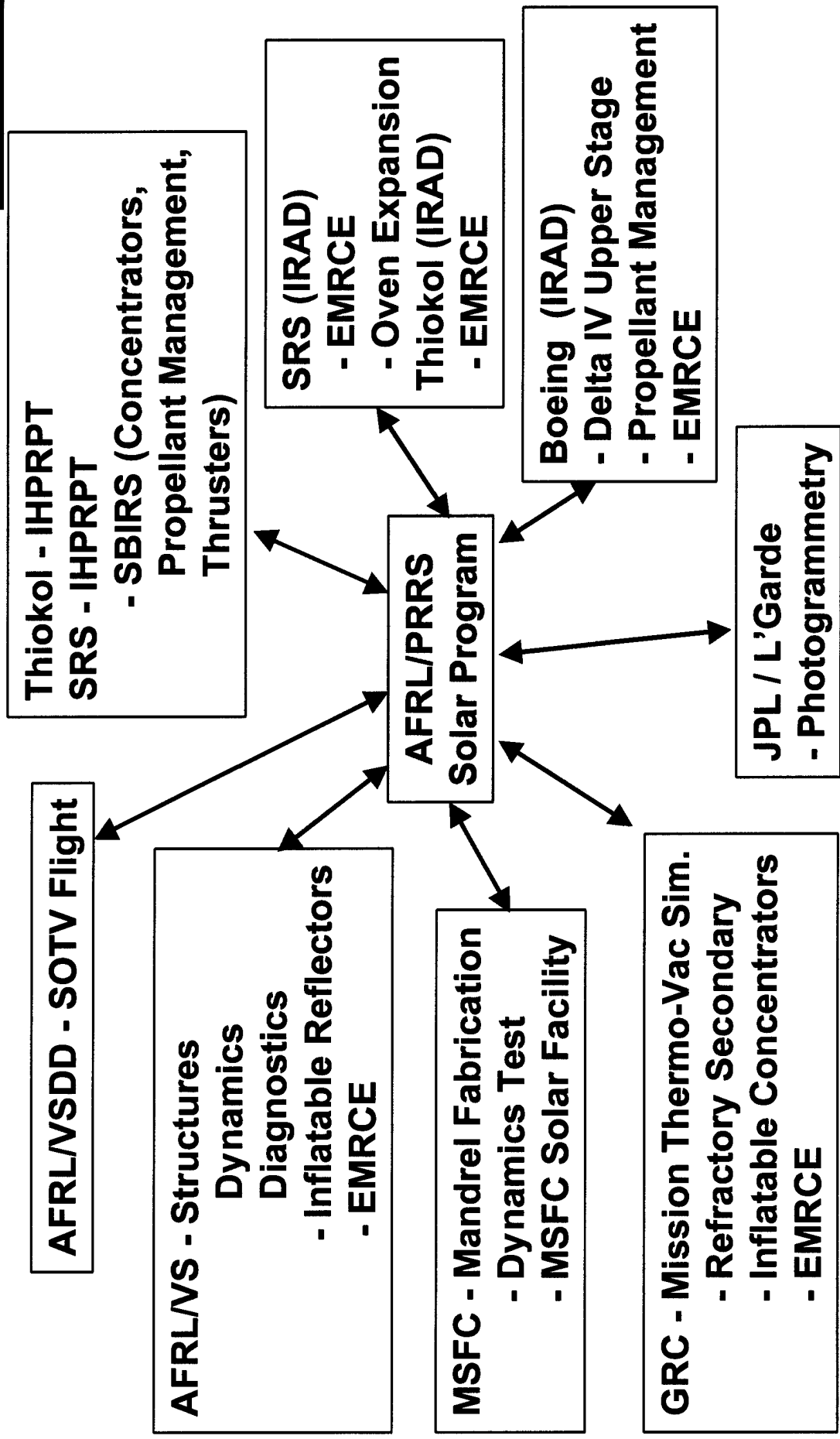
Thiokol analysis



Boeing analysis



Solar Propulsion AFRL/PR Alliances



AFRL-910-ElectroMagnetic Radiation Control Experiment

Concept



- Objective

- Deploy Inflatable 5 Meter Antenna
- Verify Precision Shape
- Verify Focused Energy
- Verify Diagnostic Techniques

- Description

- 4.88 Meter CP1 Inflatable Parabolic Metalized Reflector

- Diagnostics:

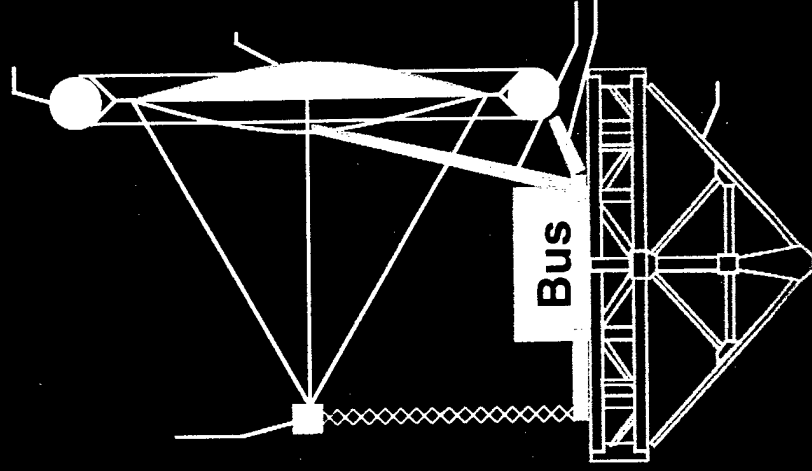
Surface Accuracy, Surface Optical Properties, Coarse and Fine Pointing Accuracy, Overall Deployment and Operational Performance

- Verify Thermal and Optical Models

- Compare to Ground Tests

- Represents Inflatables for Many Missions:

Antennas, Radiometers, Heat Shields, Solar Concentrators for Power and Propulsion, Concentrators for PV Arrays, Solar Sails





PHASE I GOAL DEMO CONCENTRATOR OPERATION DEMONSTRATED ON SPACE FLIGHT



- System demonstration of SOTV concept
- Baseline IHPRPT concentrator
- Step toward advanced space vehicles
 - EOTV, ROTV, and SSV
- Demonstrated technologies
 - Multi-burn solar propulsion
 - 0-g inflatable solar concentrators
 - Thermal storage cavity absorber
 - 0-g thermionic power production
 - 0-g cryo H2 handling
 - Flight dynamics interaction
- SOTV Launch date and funding being addressed
- Back up space flight planning continuing



Conclusions

- Solar Thermal Propulsion
Payoff

Double Payload

Or

Double Delta V