M09-0136-ABSTRACT

Title of Presentation: Advanced Chemical Propulsion

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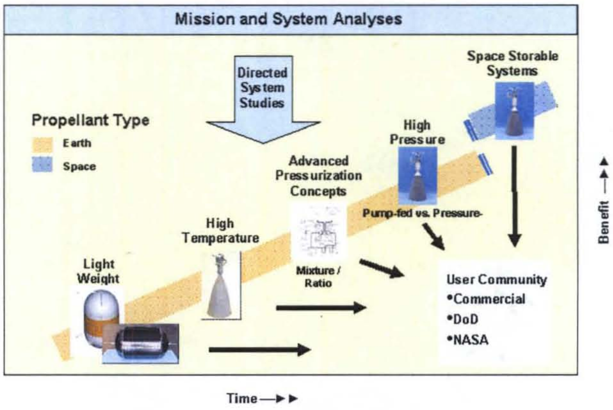
Abstract: Advanced Chemical Propulsion (ACP) provides near-term incremental improvements in propulsion system performance and/or cost. It is an evolutionary approach to technology development that produces useful products along the way to meet increasingly more demanding mission requirements while focusing on improving payload mass fraction to yield greater science capability. Current activities are focused on two areas: chemical propulsion component, subsystem, and manufacturing technologies that offer measurable system level benefits; and the evaluation of high-energy storable propellants with enhanced performance for in-space application. To prioritize candidate propulsion technology alternatives, a variety of propulsion/mission analyses and trades have been conducted for SMD missions to yield sufficient data for investment planning. They include: the Advanced Chemical Propulsion Assessment; an Advanced Chemical Propulsion System Model; a LOx-LH_2 small pumps conceptual design; a space storables propellant study; a spacecraft cryogenic propulsion study; an advanced pressurization and mixture ratio control study; and a pump-fed vs. pressure-fed study.



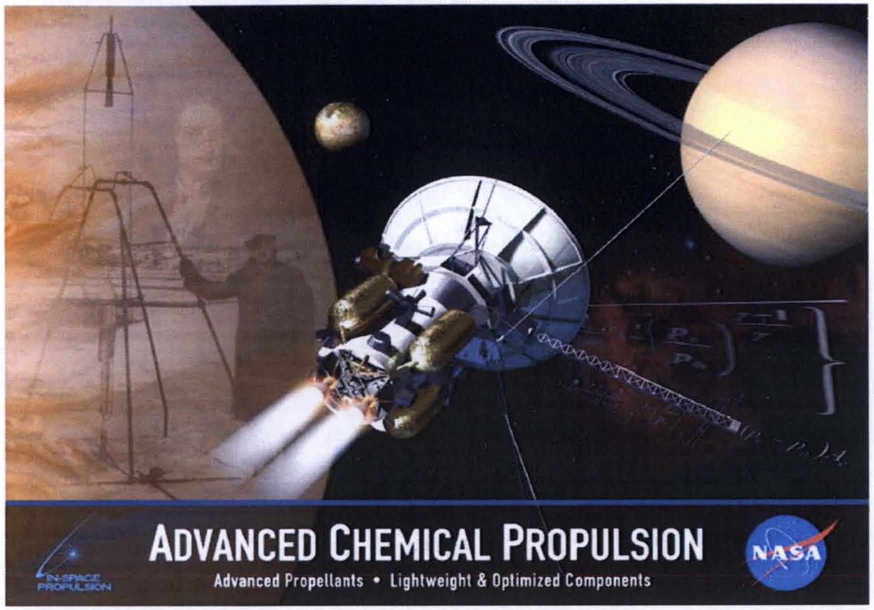
The results indicate that a strategy which starts with improvements to today's pressure-fed systems and offers steady growth to future high performance systems that operate at higher pressures and temperatures will take us from being enhancing to science missions to enabling new science. It begins with lightweight tank development to reduce the mass of a primary component that would only get heavier if we had to use thick wall tanks at higher pressures. I_{sp} gains will be obtained by increasing the combustion chamber temperature of the engine through the Cycle 3a NRA work in high-temperature thrust chamber materials. A parallel effort to explore advanced pressurization and active mixture ratio control is under way. This would replace the least reliable (and most expensive) component in the feed system, the mechanical regulator, with a simple computer-controlled bang-bang pressure regulation approach. Combined with the development of more accurate flow-rate and propellant gauging instrumentation, this allows a significant reduction in the amount of propellant residuals that must be tanked to account for instrumentation uncertainties. The next step is to realize those gains that derive from increasing the combustion chamber pressure (both pressure-fed and pump-fed engines). Finally, an evolutionary move from Earth storable propellants (NTO/N_2H_4) to space storables (LOx/N_2H_4) would yield even further gains in payload performance through higher I_{sp}. This plan is augmented by work in aluminum loaded high I_{sp} gelled propellants and Foam Core Shield micro-meteoroid protection systems.

Advanced Chemical Propulsion

Manager: Leslie Alexander, NASA/Marshall Space Flight Center

Technology Description

- Evolutionary development of chemical propulsion technologies with measurable system level benefits
    - Greater science capability through a focus on improving payload mass fraction;
    - Higher performance than SOA chemical systems;
    - Increased reliability of propulsion systems



Current Activities

- Ultra-Lightweight Tank Technology
- Cycle 2 NRA closeouts in Lightweight Foam Core Systems and Low Temperature Gel Propulsion Technology
- Alternate Pressurization and Mixture Ratio Control breadboard demonstration
- High temperature materials screening for TCA's

Approach

- Evaluate high energy storable propellants with enhanced performance for in-space application
- Optimize, design, and test cross-cutting propulsion component and subsystem technologies to reduce the overall system mass
- Develop supporting technologies that enable long-term storage of soft cryogens in low-g
- Produce useful interim products to meet ever more demanding mission requirements
- Reduce risk through ground test and demonstration.
- Leverage ongoing activities in ISPT, ESMD, DoD, IHPRPT

Key Activities

Performance Optimization of Biprop Engines

(FY2006-FY2008) High temperature thrust chamber development; Test of optimized thruster at high I_{sp}

Reliable Lightweight Tanks

(FY2005-FY2008) standard manufacturing processes and NDE for COPV(s), bonding adhesives and composite winding /lay-up on thin liners

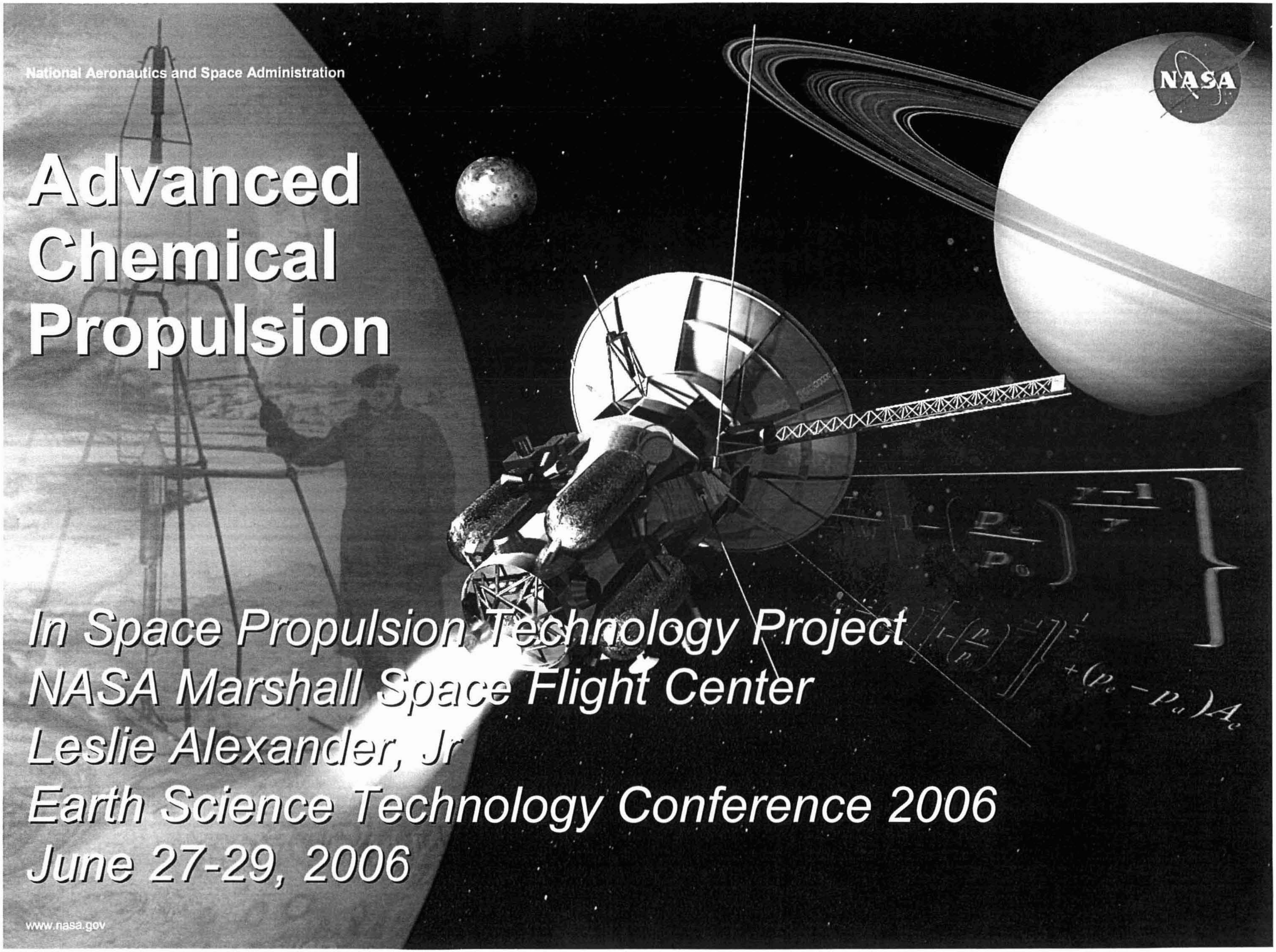
Advanced Pressurization & Active Mixture Ratio Control

(FY2006-FY2008) Verification accuracy of flow meter and mass gauging; Design and test sensor technology and subsystem hardware

M09-0136-PRESENTATION

National Aeronautics and Space Administration

NASA



Advanced Chemical Propulsion

In Space Propulsion Technology Project
NASA Marshall Space Flight Center
Leslie Alexander, Jr
Earth Science Technology Conference 2006
June 27-29, 2006

www.nasa.gov

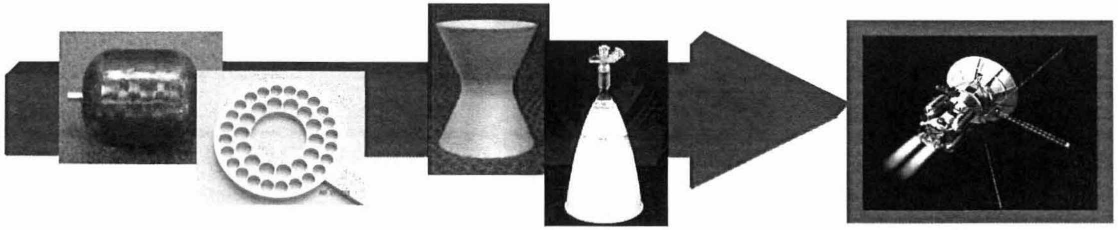
ISPT Advanced Chemical Propulsion (ACP)

Technology Objectives and Benefits

- Develop evolutionary improvements in chemical propulsion system performance that yield near-term products and directly impact payload mass fraction and cost.
  - Resulting in greater science
  - Producing higher performance than SOA chemical systems
  - Increasing the reliability of propulsion systems

Focus areas

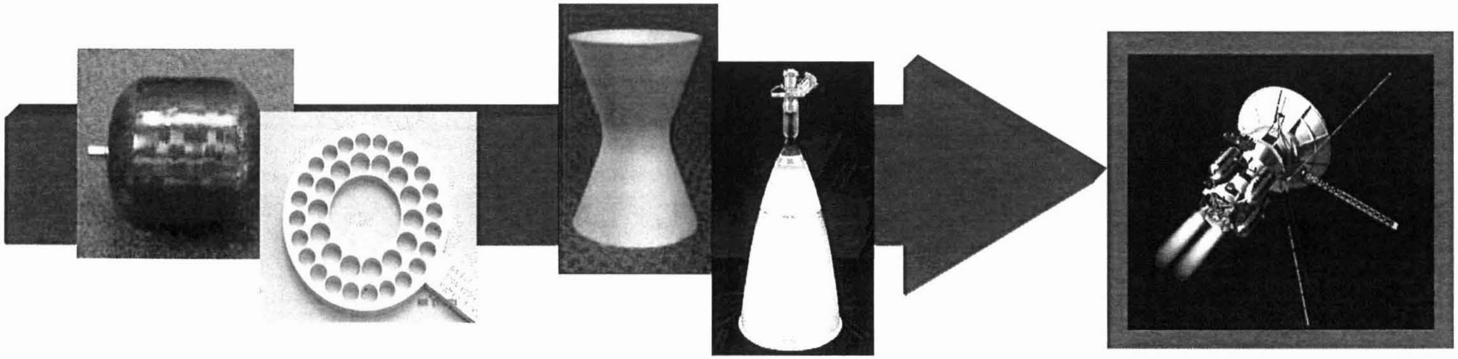
- Lightweight / optimized components - component, subsystem, and manufacturing technologies that offer measurable system level benefits
- Advanced propellants - evaluation of high-energy storable propellants with enhanced performance for in-space application



ISPT ACP Task Areas

Lightweight/Optimized Components Tasks

- High Temperature Storable Bipropellant Engines
  - Performance optimization of existing storable bipropellant engine designs and demonstration of increased Isp >335s by leveraging high temperature thrust chamber material potential
- Ultra-lightweight Tank Technology (ULTT)
  - Optimization of COPVs to decrease the mass of propellant and pressurant tanks.
  - Acceptance / margin testing to increase design allowables and reduce risk



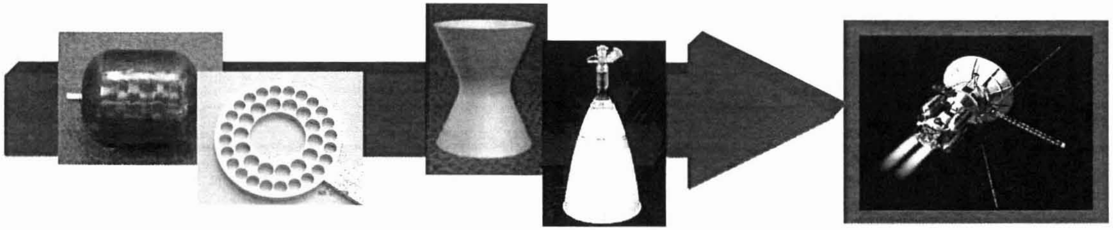
ISPT ACP Task Areas

Lightweight/Optimized Components Tasks (cont.)

- High Temperature Thrust Chamber Assembly (TCA) Materials
  - Investigation of materials and manufacturing processes, e.g. Vacuum Plasma Spray (VPS), to provide high temperature options for TCAs
- Active Pressurization & Mixture Ratio Control
  - Initial laboratory demonstration using non-hazardous fluids to simulate a small, deep space, pressure-fed propulsion system
  - Investigation to determine the accuracy of critical sensor technology in at the component and subsystem level

Advanced Propellants Tasks

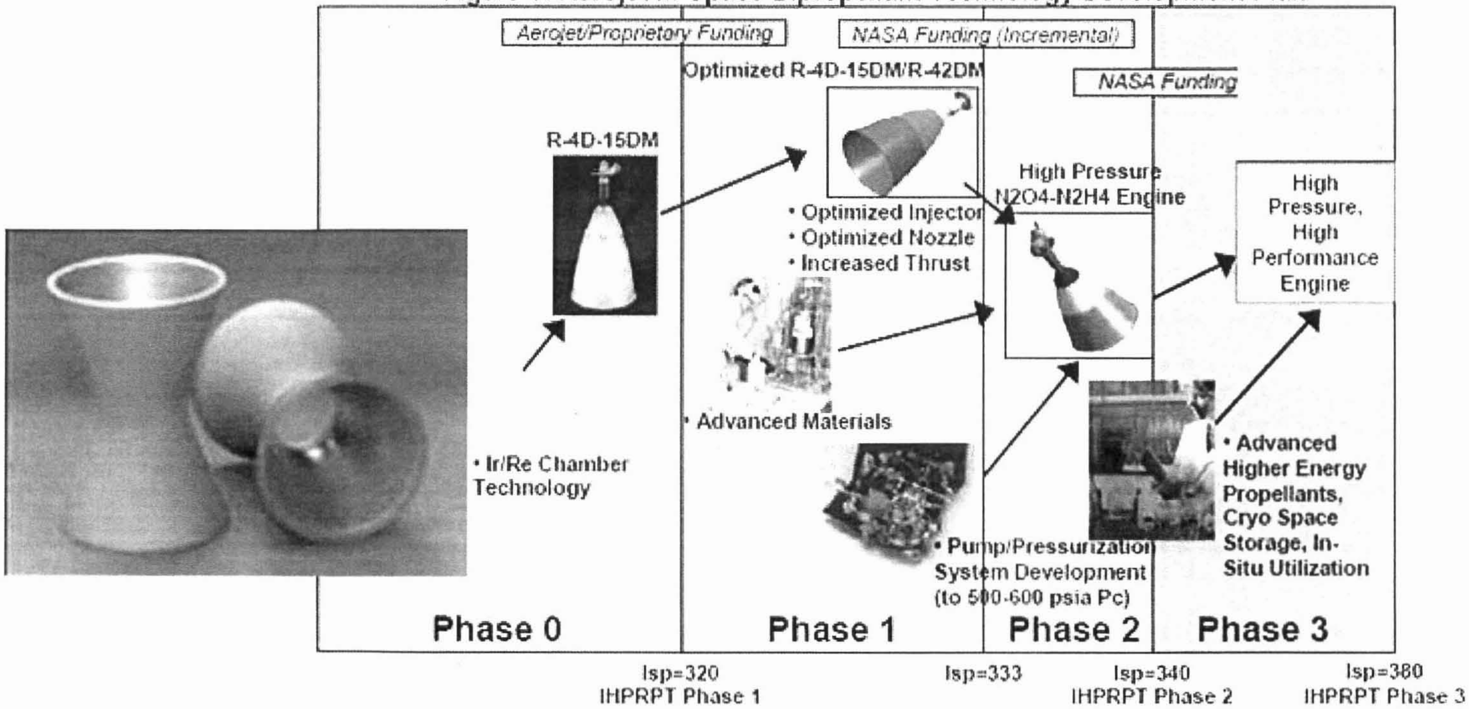
- Advanced Ionic Monopropellants
  - Assessment of high performance monoprop potential through laboratory test and simulation



High Temperature Storable Bipropellant Engines

- Objective
  - Investigation of high temperature materials and thrust chamber manufacturing processes, such as VPS and Electro-form
  - Optimization of high performance storable bipropellant engine (hot rocket)
    - Higher performance: >335s I_{sp} for NTO/N2H4 and >330s I_{sp} for NTO/MMH
    - Lower manufacturing cost with improved producibility and reliability
    - 3-10 yr mission life with >1hour operating time
  - Hot-fire test demonstration to reduce risk and facilitate transition directly to in-space product line

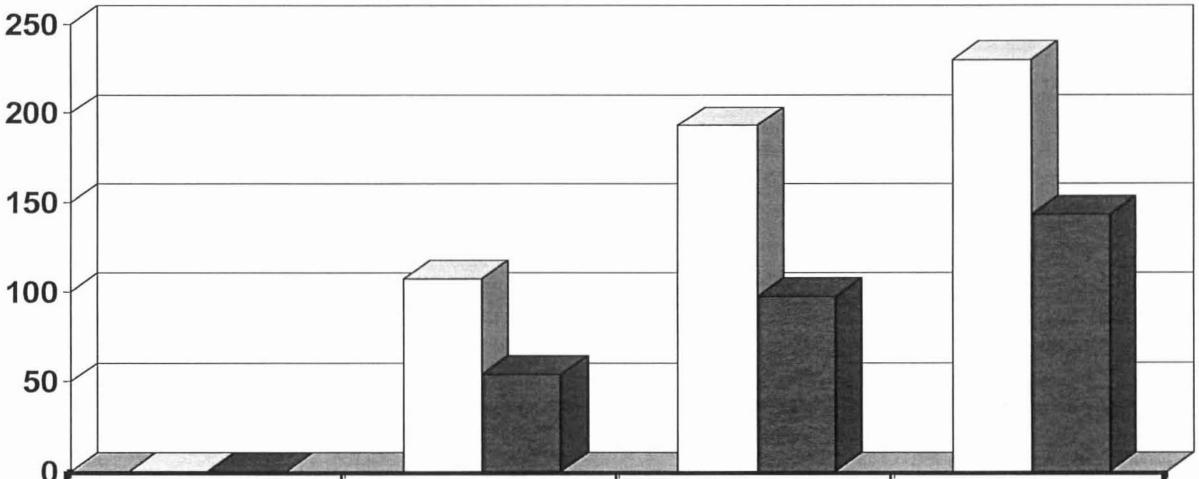
Figure 1: Aerojet In-Space Bipropellant Technology Development Plan



High Temperature Storable Bipropellant Engines

- Provide benefit for applications with medium to high ΔV and high reliability requirements
  - NASA robotic missions
  - Outer planet orbiters
  - Commercial missions such as apogee insertion of GEO COMSATs

Figure 2: Mass Savings Achievable for Europa Orbiter and GEO with High Performance,Storable Biprop Engines



Sizing Assumptions:

Europa Orbiter ☐
- 254 lbm (115kg) to Europa Orbit
- ΔV = 18045 ft/s (5500 m/s)

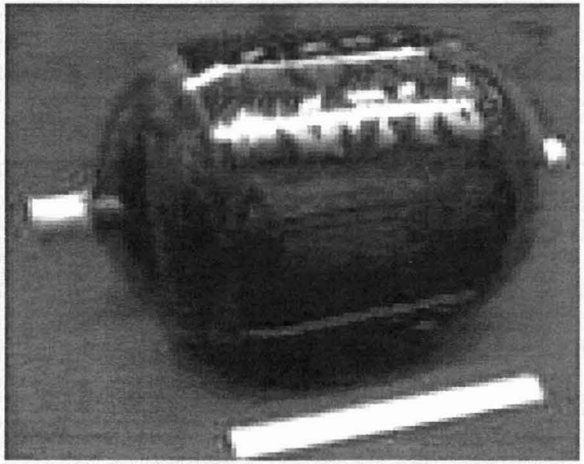
GEO COMSAT ▨
- 4513 lbm (2050 kg) to GEO
- ΔV = 6234 ft/s (1900 m/s)

	SOA Biprop (NTO/MMH)		SOA Dual Mode (NTO/N2H4)		Optimized Dual Mode (NTO/MMH)		Optimized High Pressure Dual Mode (NTO/N2H4)	
Isp, lbf-sec/lbm	320	320	327	327	330	330	335	335
Total Propellant Mass, lbm	1552	1706	1652	1657	1629	1637	1590	1602
Mass Savins, lbm	0	0	54	49	77	69	116	104
Percent Savings, %	0.0	0.0	3.2	2.8	4.5	4.1	6.8	6.1

Ultra-lightweight Tank Technology

◆ Objectives

- Decrease the mass of propellant and pressurant tanks through the development of ultra-lightweight propellant and pressurant tank technology for missions not requiring positive expulsion of propellants
- Develop a stress-rupture properties/design database that will significantly increase the allowable design stress for propellant and pressurant tanks
- Significantly reduce the tank and propulsion system dry mass for large science missions



T-1000 lightweight tank

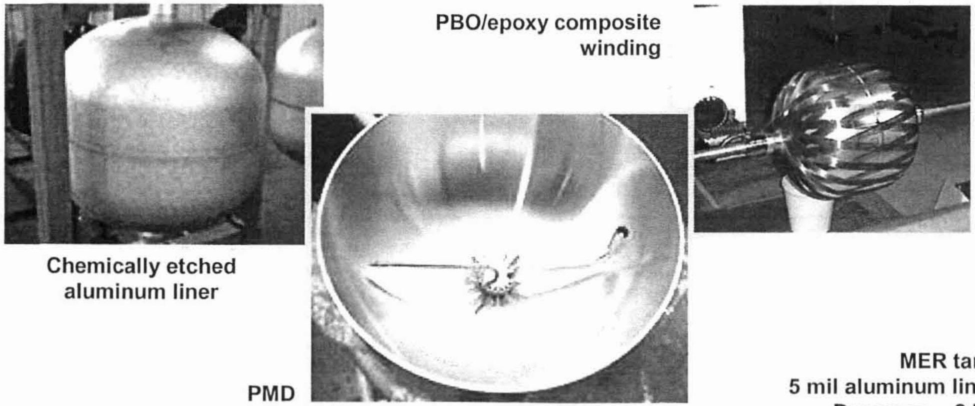
Ultra-lightweight Tank Technology

◆ Status

- Ultralight 16-in diameter aluminum lined tanks (COPVs) with a 2 kg dry mass and 30 kg capacity for N_2H_4, have been developed at JPL for MER [similar monolithic titanium MER tank mass - 5.8 kg]
- Non-destructive inspection methodology established to raise the technology maturation readiness level
- Investigated new materials and manufacturing methods

◆ Ongoing

- Validation testing of ultra-lightweight MER tanks
- Stress-rupture testing and data acquisition
- New tank designs and ultra-lightweight applications
  - Xe propellant tanks
  - Cryogenic propellants
  - Diaphragm and linerless tanks



Chemically etched aluminum liner

PMD

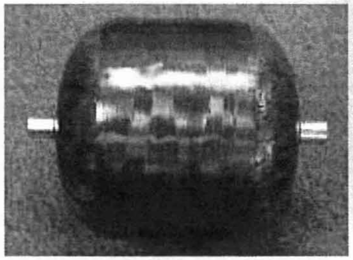
PBO/epoxy composite winding

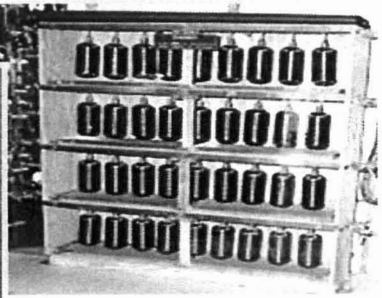
Ultra-lightweight Tank Technology (ULTT)

PI: NASA-JPL

Co I(s): NASA/MSFC, Carleton PTD, PSI, Luxfer

MER tank
5 mil aluminum liner
Dry mass – 2 kg





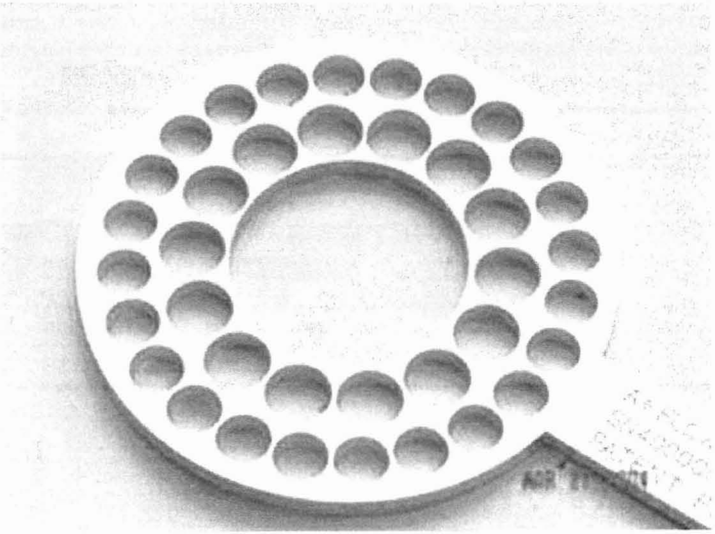
Rupture test banks

Active Pressurization and Mixture Ratio Control

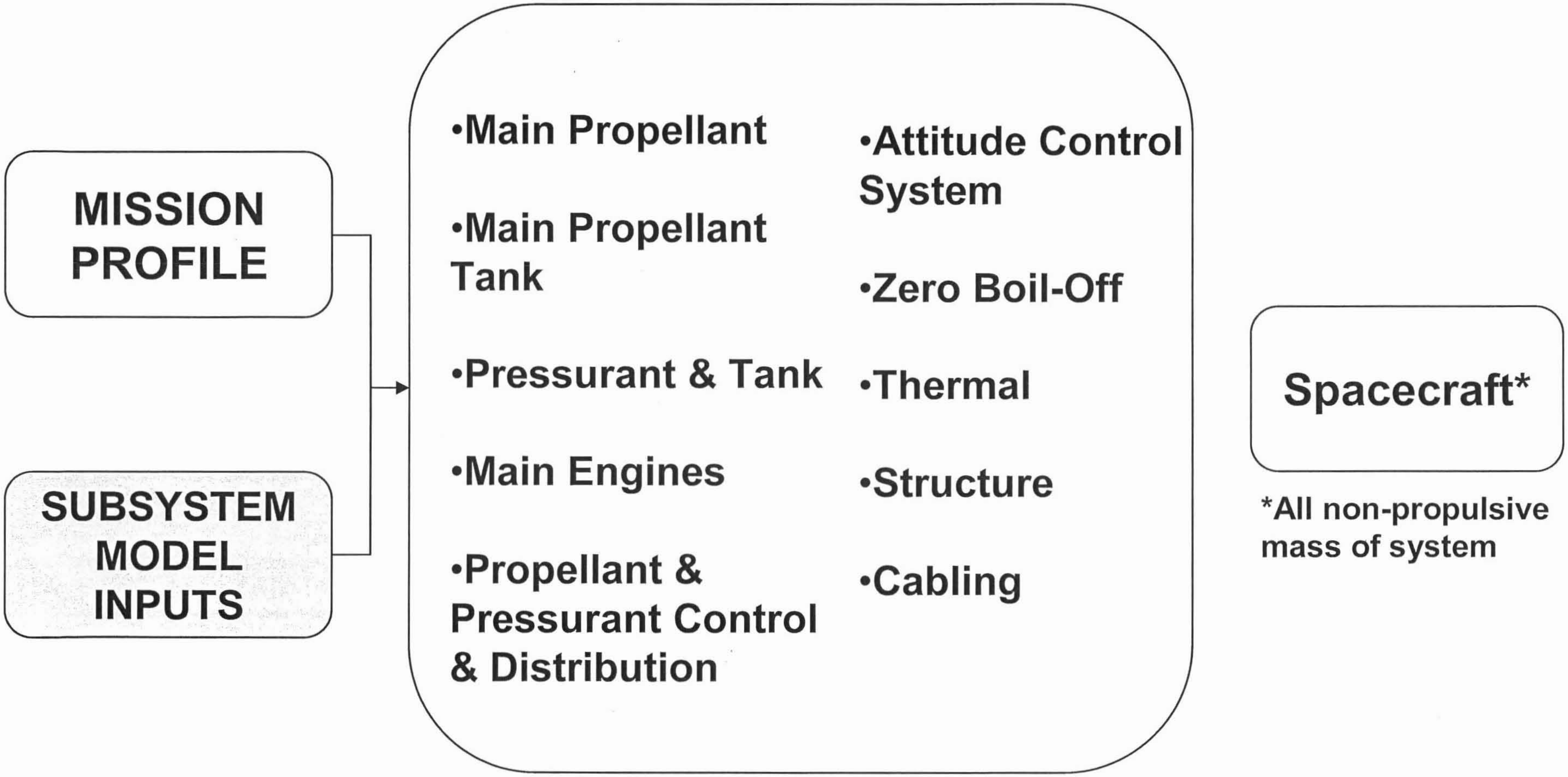
- Objective
  - Development and laboratory demonstration of active pressurization and mixture ratio control (MRC) system resulting in substantial payload gains realized through reduction of percent propellant reserves.
- Potential Benefits
  - Reduced inert mass by lessening mixture ratio variance residuals (4-6%)
  - Increased availability for scientific payload mass
    - 10-15% increase in scientific payload for lower energy missions
    - Up to 40-56% increase in scientific payload for higher energy missions
  - Detection and monitoring through balanced flow meter (BFM) and tank liquid volume instrument (TLVI) of very small leaks within propulsion system during all operational phases
  - Elimination of mechanical regulators
  - Reduced pressure drop by eliminating need for cavitating venturis
  - Decreased probability of pressurization system failure
  - Ability to detect and disregard failed sensors
  - Integration with conventional spacecraft avionics
  - Improved safety, reliability, and affordability for space access

Active Pressurization and Mixture Ratio Control

- Status
  - Study results indicate development of balanced flow metering and sensor technology could increase scientific payload mass by 10% to 56%.
- Current activities
  - Investigation of alternate technologies that would facilitate an active pressurization and MRC system to reduce propellant wet mass
  - Verifying the accuracy of balanced flow meter (BFM), tank liquid volume instrument (TLVI), optical mass gauging (OMG) and other supporting technology that would be implemented in an in-space MRC system
  - Performing a laboratory demonstration with working fluids
    - Design and test key subsystem components
    - Determine system level impacts
  - Leveraging other technology development to demonstrate and verify operational issues associated with cryogenic system mixture ratio control



ACPS Model: Overview



MISSION PROFILE

SUBSYSTEM MODEL INPUTS

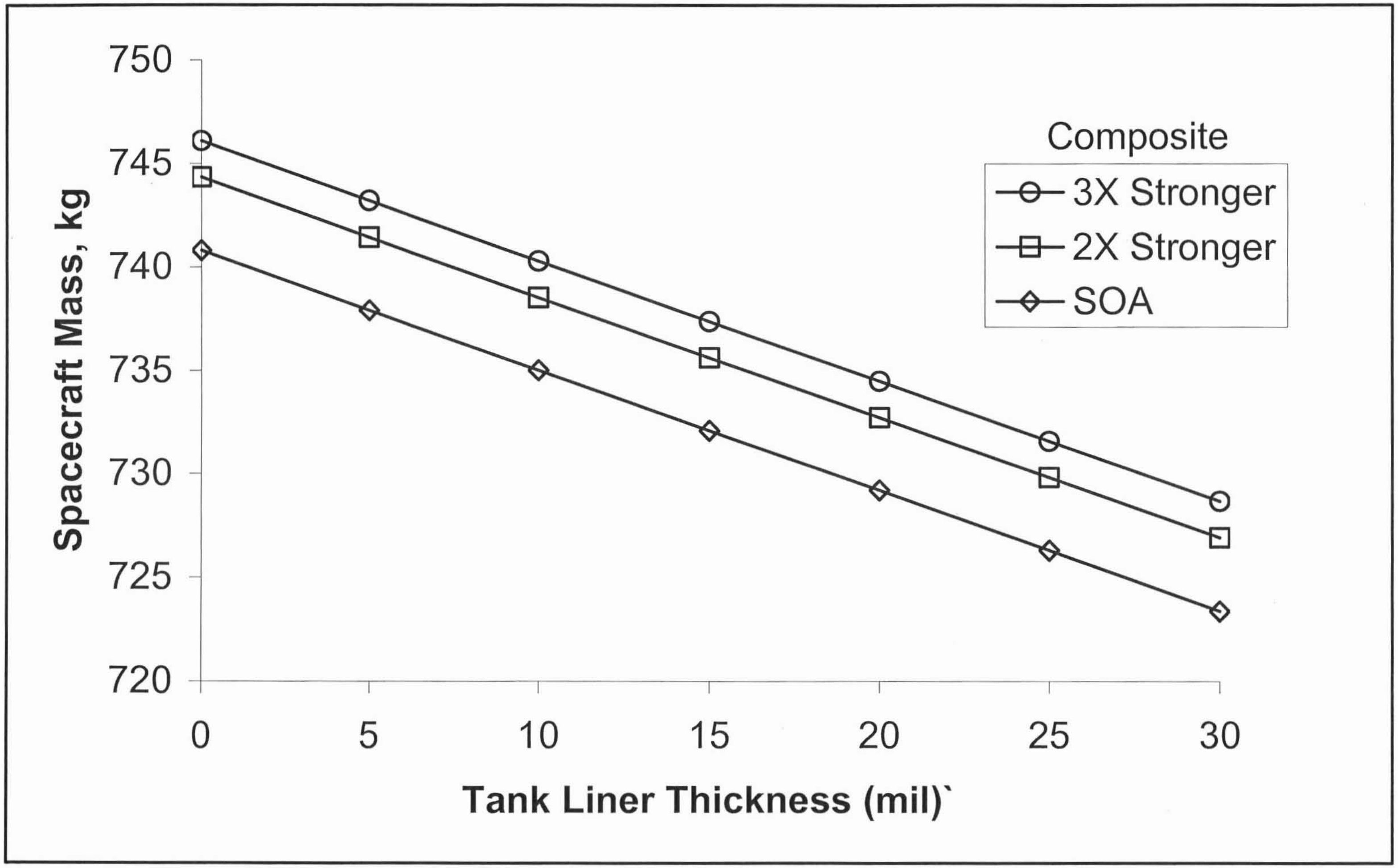
- Main Propellant
- Main Propellant Tank
- Pressurant & Tank
- Main Engines
- Propellant & Pressurant Control & Distribution
- Attitude Control System
- Zero Boil-Off
- Thermal
- Structure
- Cabling

Spacecraft*

*All non-propulsive mass of system

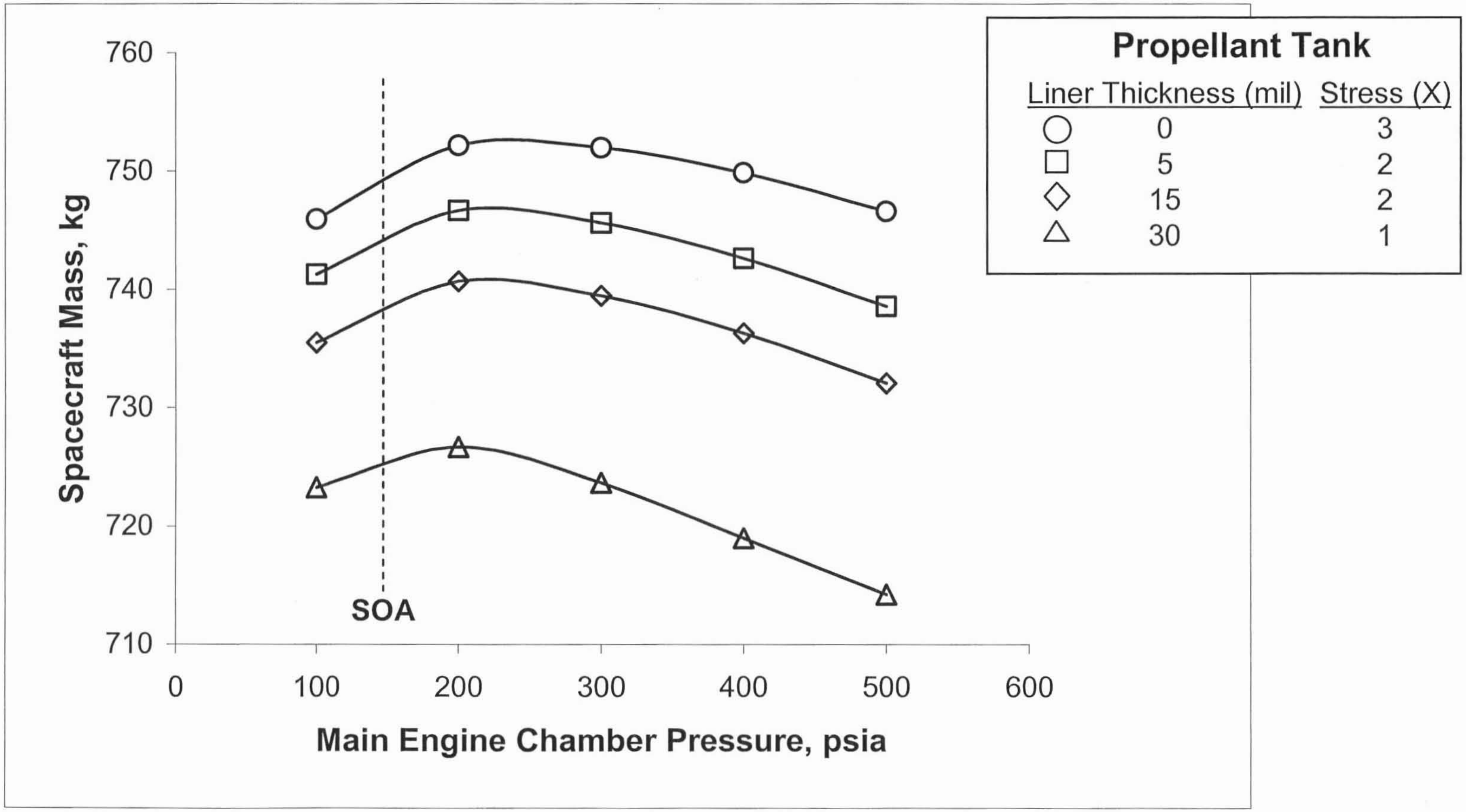
- Supports 8 different propellant combinations

Composite Propellant Tank Technology(1)



(1) New Frontiers Mission: Jupiter Polar Orbiter, VEEGA, 5.84 yr Trip Time, Mo = 1940 kg, ΔV = 2110 m/sec

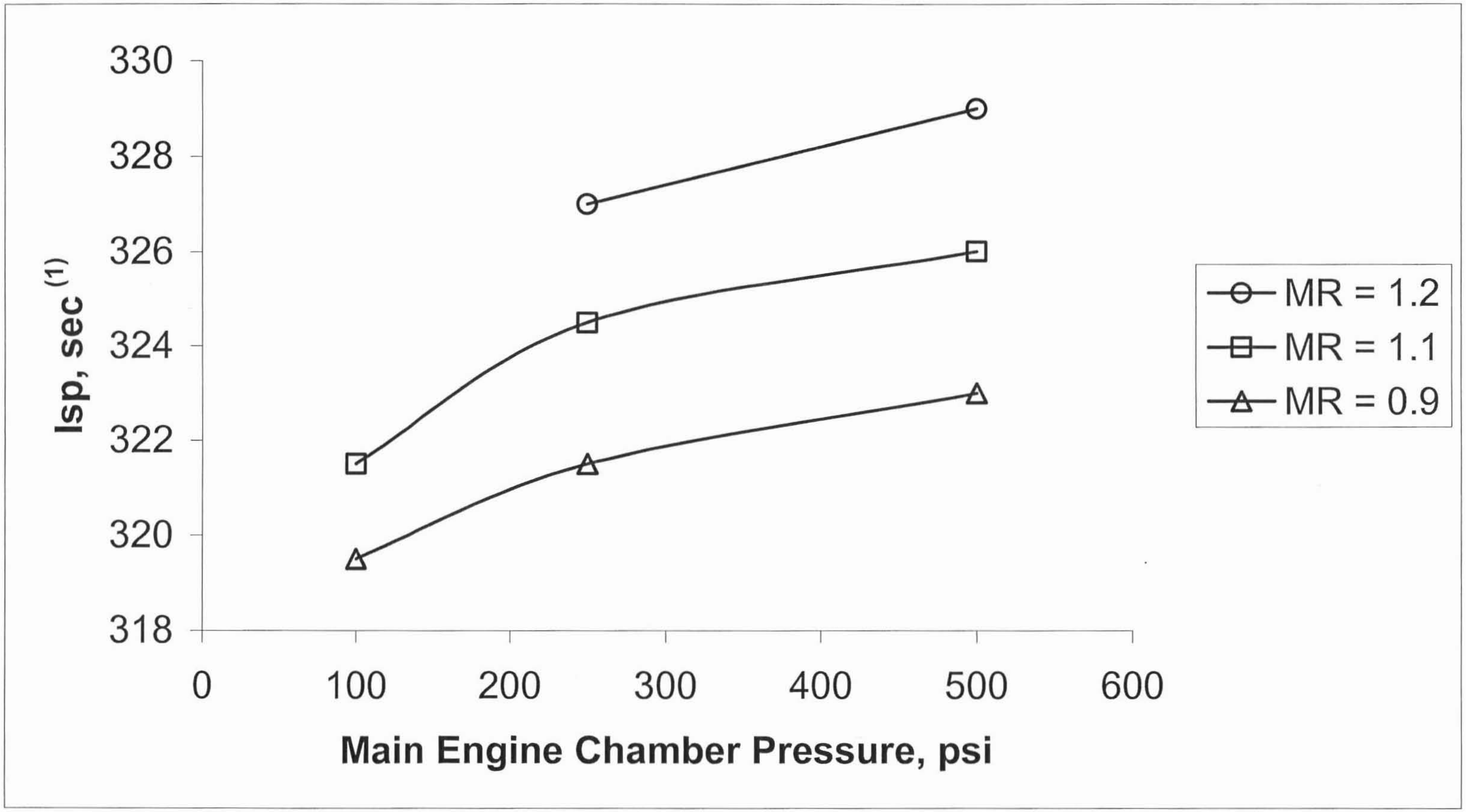
Mission Evaluation (1) – NTO/N_2H_4



- Advanced propellant tanks provide significant benefits
- The optimum Pc increases for higher strength composites
- Pc increases alone provide small benefits

(1) New Frontiers Mission: Jupiter Polar Orbiter, VEEGA, 5.84 yr Trip Time, Mo = 1940 kg, ΔV = 2110 m/sec

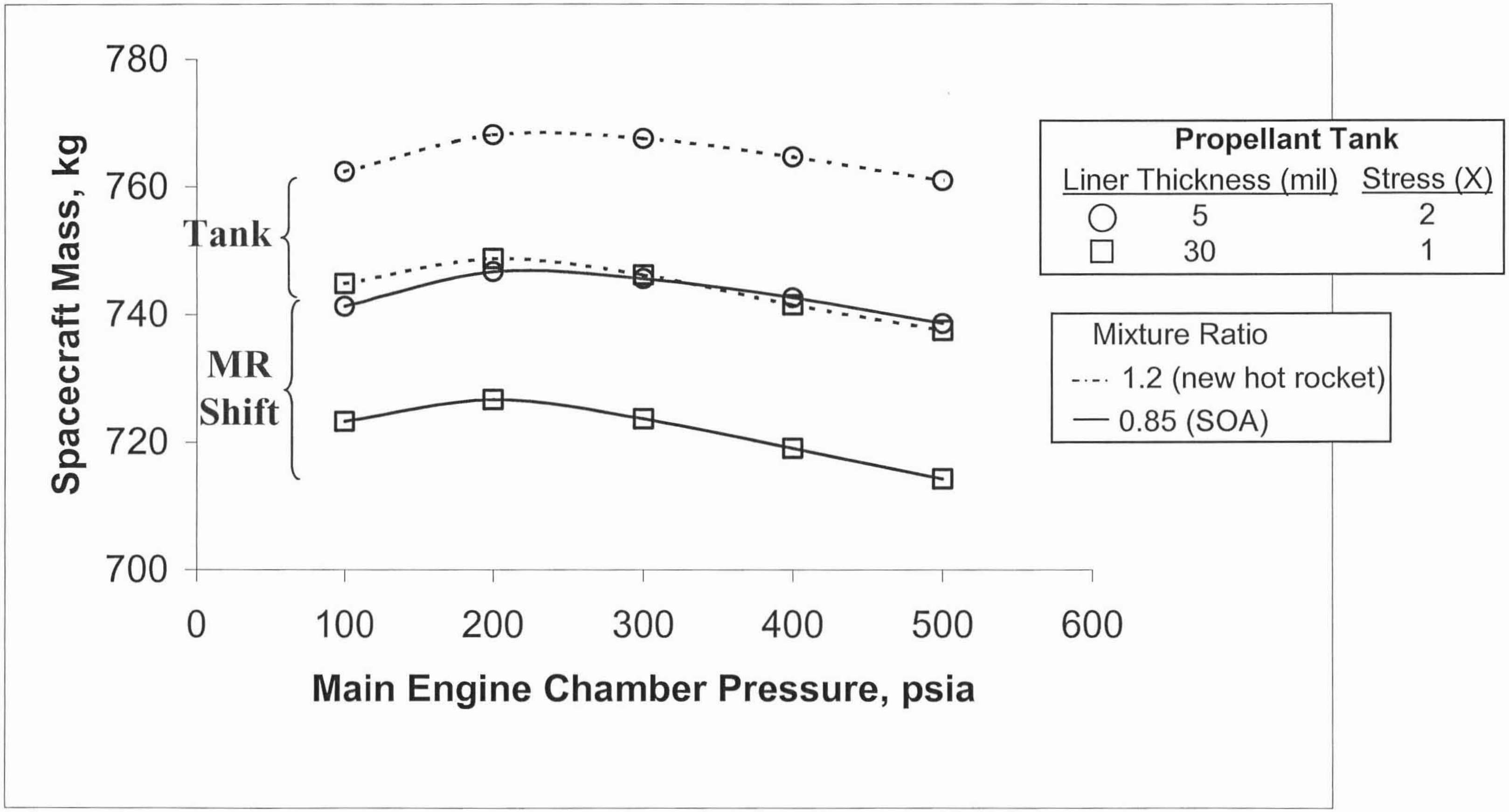
Influence of Chamber Pressure & MR Effect



Increasing either chamber pressure or mixture ratio increases the Isp of the engine (increases combustion chamber temperature as well)

(1) Data From NASA CR-195427, Vol. 1

Mission Evaluation (1) – NTO/N_2H_4



- Increasing mixture ratio has a positive effect on spacecraft mass, without tank technology additions
- Combining technologies (mixture ratio & tank) can increase payload significantly

(1) New Frontiers Mission: Jupiter Polar Orbiter, VEEGA, 5.84 yr Trip Time, Mo = 1940 kg, ΔV = 2110 m/sec

Advanced Ionic Monopropellants

Ionic monopropellant assessment

- Experimental test series completed with 5 burns of AFM-315A propellant at MSFC
- Assessment of impact of advanced monopropellants on SMD missions is in work

Motivation:

Hydrazine is considered the SOA in liquid monopropellants, yet there are new liquid monopropellant formulations in development with a number of improvements

- 'Green' propellants with very low vapor pressure and far fewer ground handling concerns/costs
- Specific impulse values 22-28% higher than hydrazine
- Density 45% greater
- Density-specific impulse 77% greater
- Delta-V 74% greater
- Lower freezing point

Advantages:

Liquid monopropellant rocket motors over bipropellant motors*

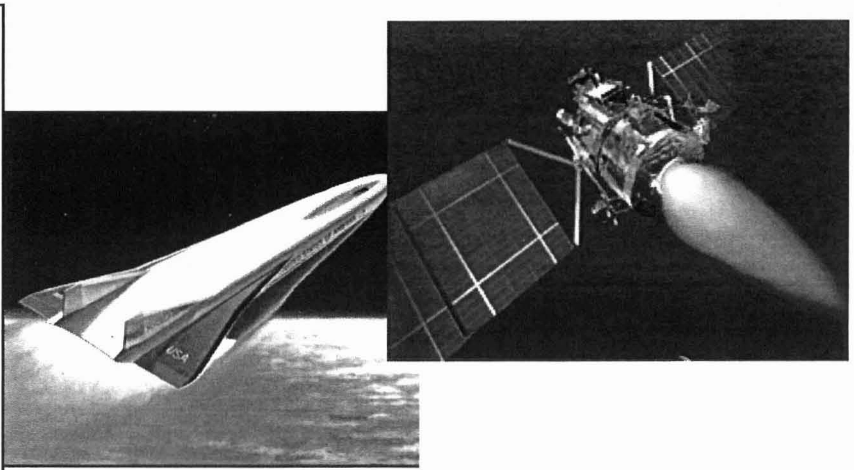
- One propellant tank with a single feed system
- Simplified injection – no need to worry about mixing of propellants
- Operation is less likely to vary with ambient temperatures
- Use of a single propellant may simplify field operations

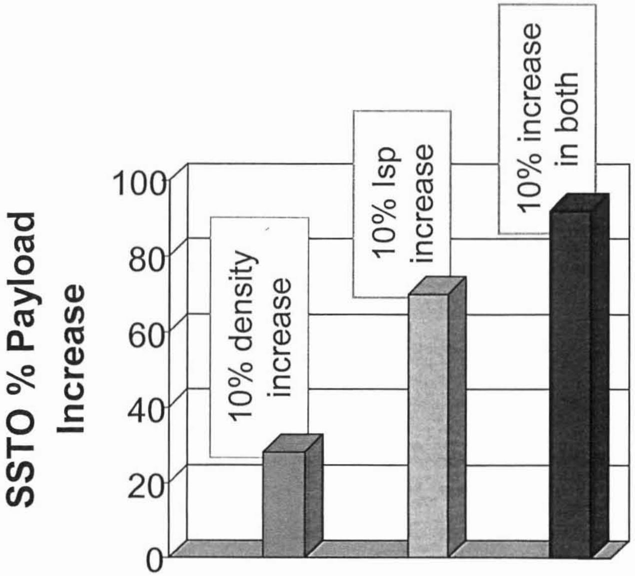
♦ *Altman, D., Carter, J., Penner, S., and Summerfield, M., Liquid Propellant Rockets, 1960

High Performance Monopropellants

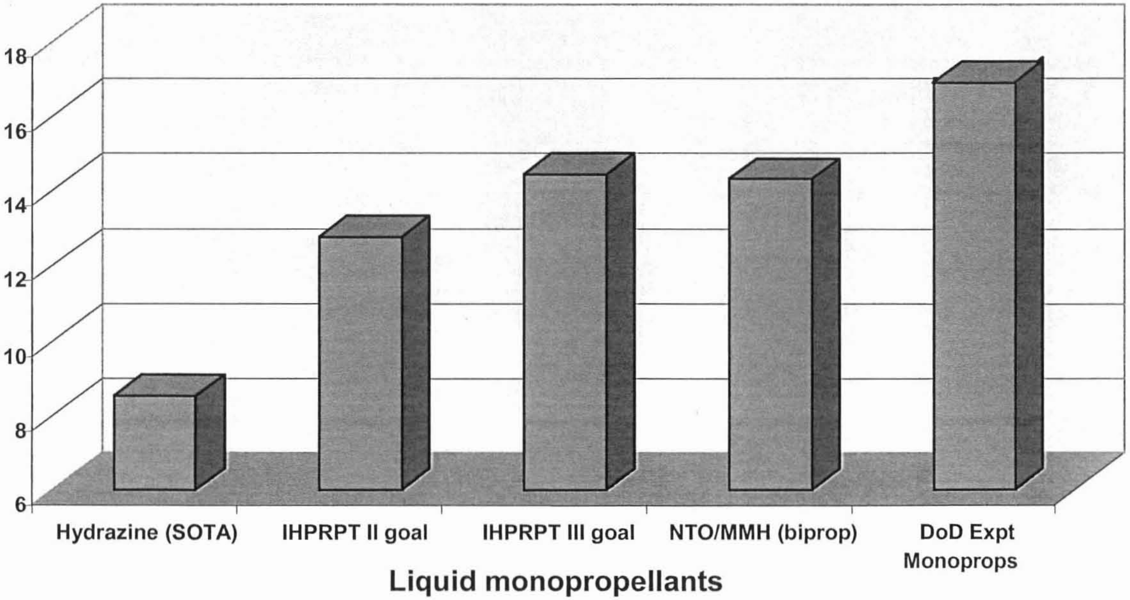
Vastly increased performance with new high energy density propellants

- Enabling larger payloads, smaller vehicles, and new mission capability
  - Highly reduced inert system mass compared to bipropellant
- Reducing the cost of exploring space
  - Smaller vehicle size and lower development costs
  - Low-toxicity, and vapor pressure 'green' propellant for lower operation cost



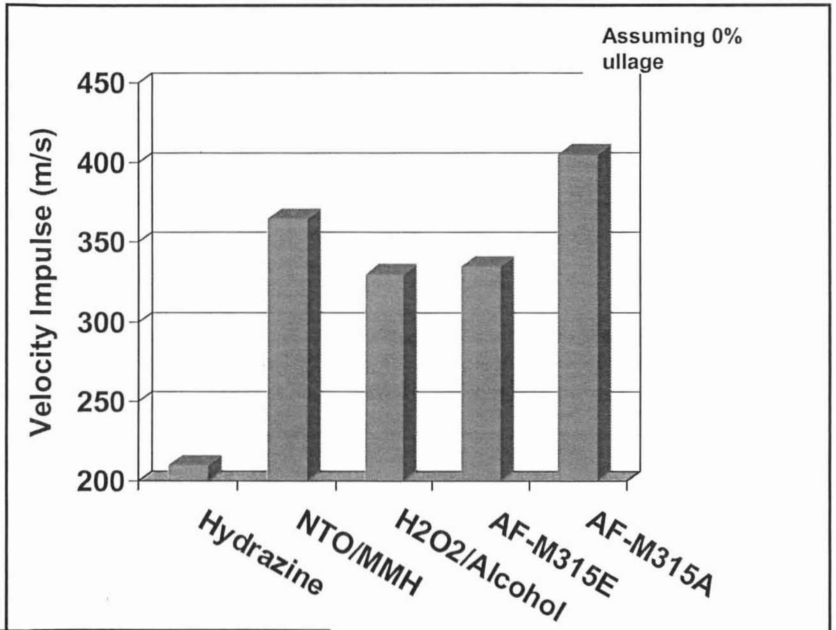


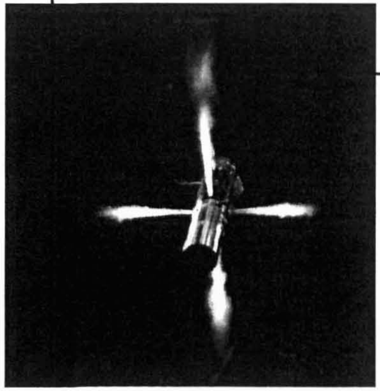
Theoretical Density Impulse (lb*sec/in3)
Isp code ran @ 50:1 expansion ratio/ 300 p.s.I. To 0.001 p.s.I.



Advanced Monopropellant Performance Payoffs

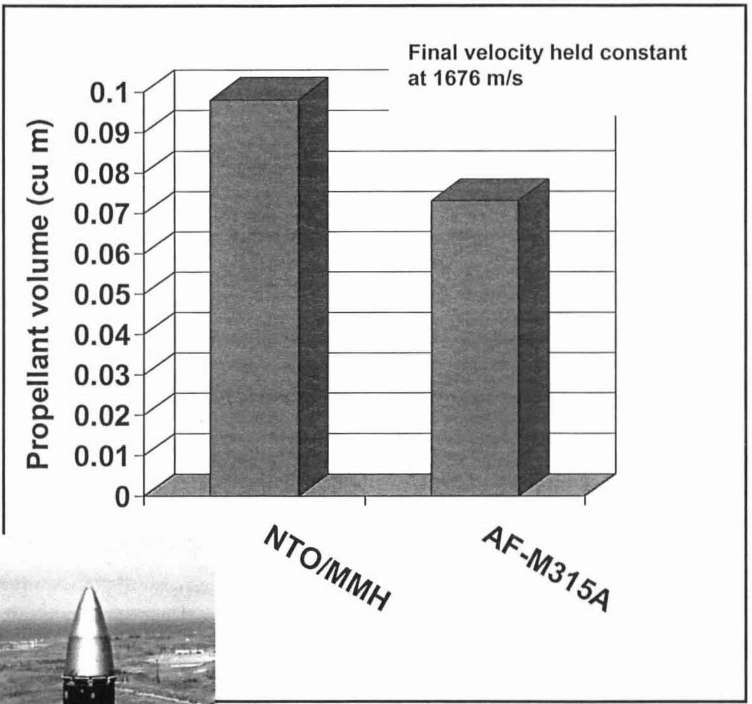
Microsatellite Trade Study





- ◆ Advanced monoprop performance can even exceed that of biprops

ICBM 4th Stage Trade Study

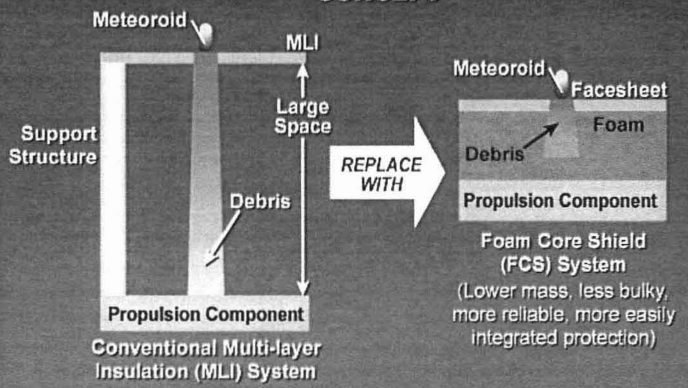


- ◆ Advanced monoprop performance allows increased range or payload over biprops

Other Lightweight and Optimized Components

Lightweight Foam Core Covers
PI: NASA-JPL; Co I: ARC

CONCEPT



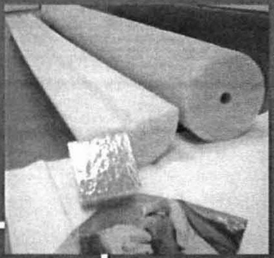
Conventional Multi-layer Insulation (MLI) System

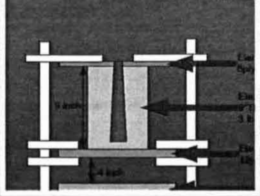
Foam Core Shield (FCS) System
(Lower mass, less bulky, more reliable, more easily integrated protection)

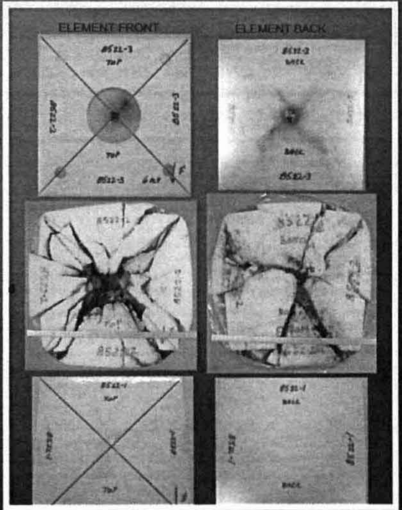
Objectives

- **Minimize the dependence on and possibly replace MLI w/Foam Core Shield (FCS) System:**
  - Reduce Mass and bulk volume of installed propulsion components
  - Provide higher reliability protection against meteoroid damage
  - Provide ease of spacecraft integration

- **Ongoing / future work w/ FCS System:**
  - Velocity impact testing and evaluation
  - Thermal analysis of FCS systems
  - Database and models development to guide design of FCS systems for spacecraft components
  - FCS and MLI performance comparison
  - Demonstration of the superiority of FCS for a Pressure Line and a Tank configuration
  - Optimization and demonstration of FCS on pressure tank and line applications



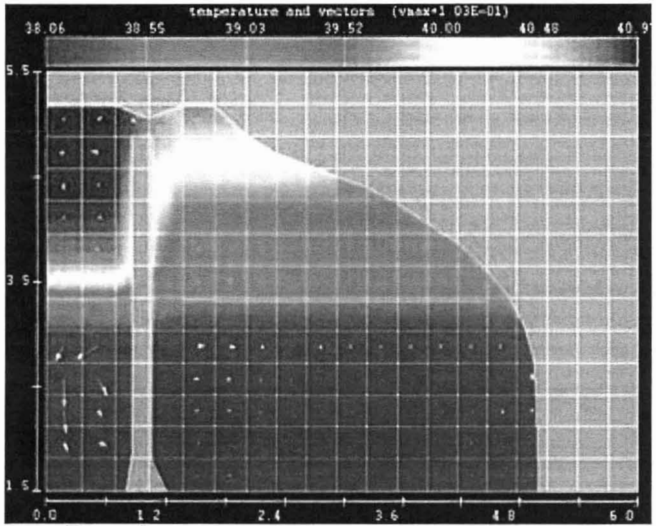




Other Advanced Propellants

Cryogenic Pressure Control in Orbit

PI: NASA/MSFC; Co-I: Boeing



Products

- Anchored analytical modeling technique for application to various missions and vehicles
- Combined test & analytical capability to support virtually all future cryogenic propellant uses in orbit
- Analytical models and documentation of data

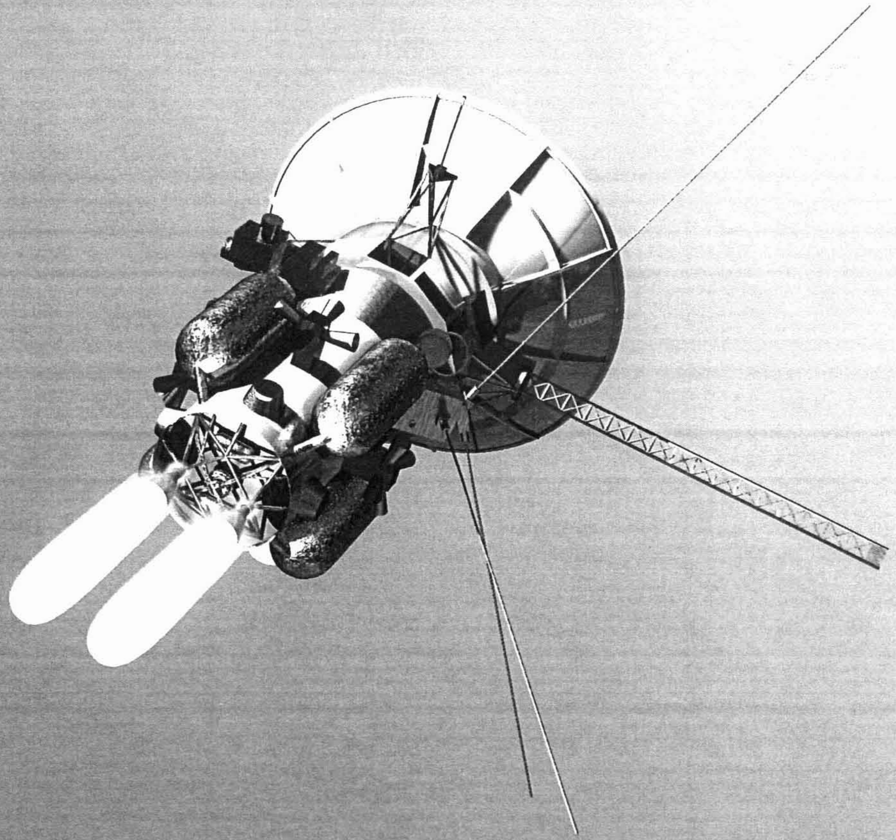
Objectives

- Develop an accurate computational thermodynamic & fluid-dynamic modeling capability for simulation of advanced cryogenic storage tanks in space.
- Techniques for pressure control within +/- 0.5 psi control band
- Demonstrate concept verification with normal gravity testing & analytical extrapolation to orbital environments

Benefits

- Deletion of APS for settling/venting, mission planning simplification
- Cross-cutting application to orbital cryo propulsion & storage
- Minimizes dependence on orbital experimentation

For additional information on **Advanced Chemical Propulsion** within the In-Space Propulsion Technology Program, please contact:



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BACKUP CHARTS

Monopropellant for Large Engines - Concept Feasibility

Objective:

- Establish feasibility of using emerging class of high performance monopropellant for large launch engines

Payoff:

New monopropellant-based propulsion approach with,

- Highly reduced inert system mass compared to bipropellant
- Smaller vehicle size and lower development costs.

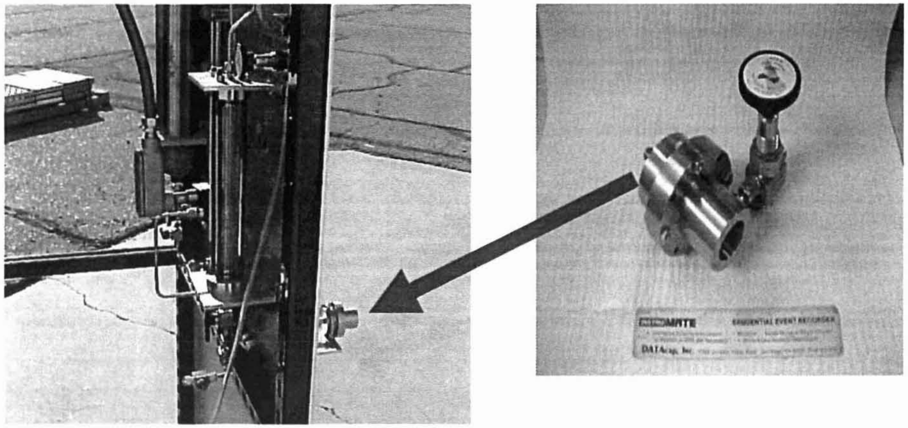
Potential Performance:

New, earth-storable monopropellant propulsion for,

- High performance; DIsp> 25% Increase over NTO/MMH
- Low-toxicity, “green” propellant for lower operation cost

Milestones:

- Quality Function Deployment analysis of propellant
  Construct propellant injector and combustion test H/W
  Propellant safety, hazard, ignition/combustion tests



Monopropellant ignition test H/W equipped with PDFM feed system and quad impinging jet injector (also, full-cone spray injector)

Status:

Completed and delivered Quality Function Deployment based assessment of new propellant replacement technology

- Ignition test hardware components production/assembly completed
- Propellant candidate formulation and characterization in progress

Collaborations:

USAF AFRL (Edwards AFB CA)
(Tom Hawkins, USAF/AFRL 661-275-5449)

Points of Contact:

John Blevins/ MSFC, Greg Drake MSFC

<u>**MSFC Trade Study**</u>

- **AF-M315 propellant in TSTO (2nd stage reaches ISS)**
- **Reduced tankage mass drives performance increase**
- **Advanced propellant provides TSTO with greater payload**