Integrated LO_2-Methane for Human Space Flight

An Integrated Strategy
To Enable the Human Exploration of Mars

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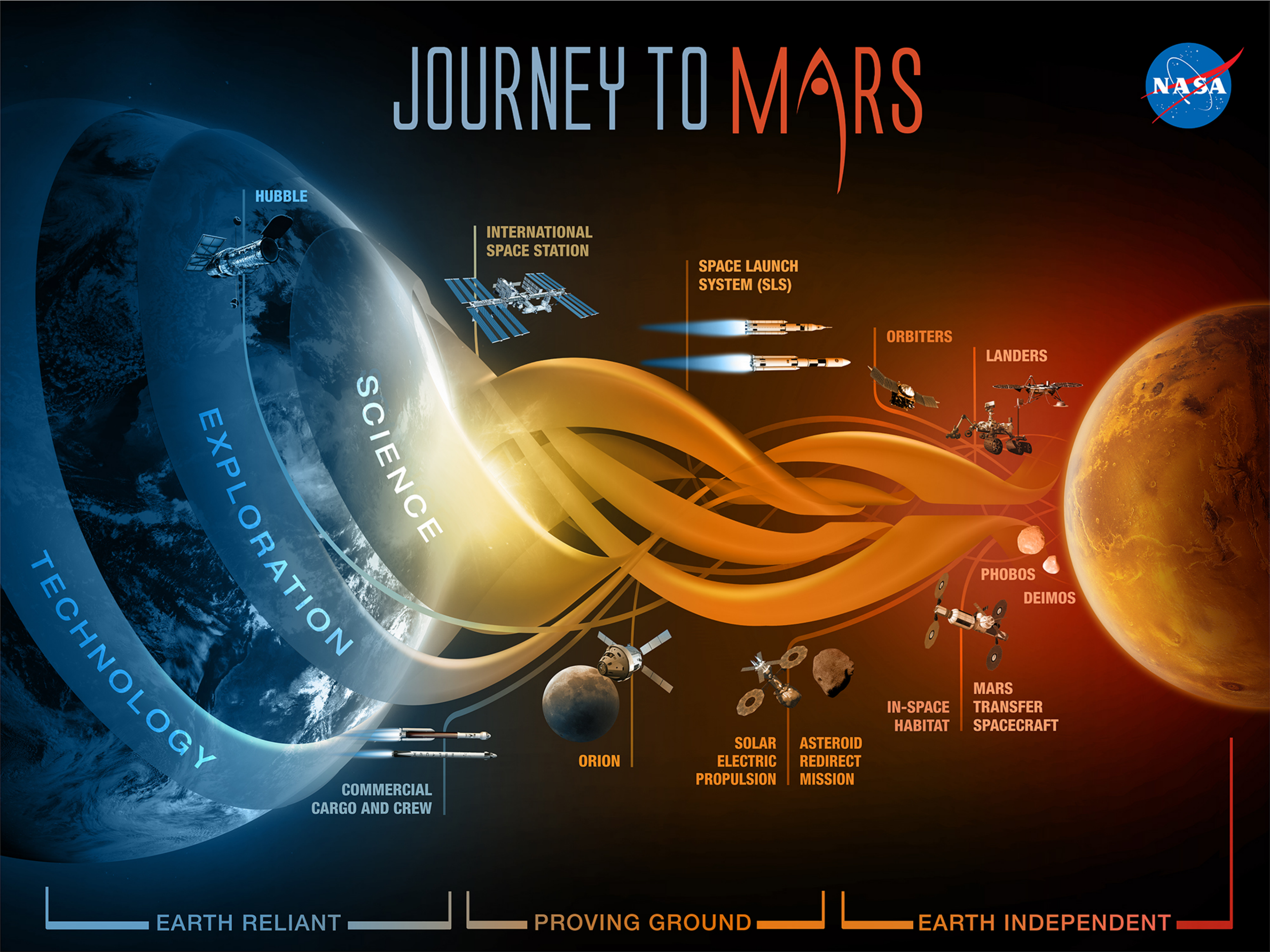
John Applewhite
Chief, Propulsion Systems Branch/EP4
NASA-Johnson Space Center,
Houston, TX


JOURNEY TO MARS
NASA
HUBBLE
INTERNATIONAL SPACE STATION
SPACE LAUNCH SYSTEM (SLS)
ORBITERS
LANDERS
SCIENCE
EXPLORATION
TECHNOLOGY
PHOBOS
DEIMOS
ORION
SOLAR ELECTRIC PROPULSION
ASTEROID REDIRECT MISSION
IN-SPACE HABITAT
MARS TRANSFER SPACECRAFT
COMMERCIAL CARGO AND CREW
EARTH RELIANT
PROVING GROUND
EARTH INDEPENDENT

JSC Energy Systems Exploration Technology Domains

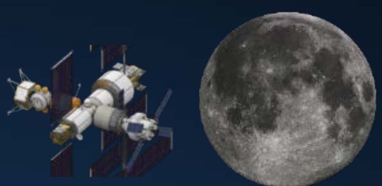
Future Missions

Where we are going

ISS

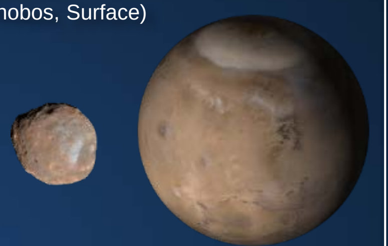
Lunar

(NRO, Earth-Moon Lagrange, Surface)



Mars

(Phobos, Surface)



Envisioned Mars Mission Elements (Mars L-8 date)

How we are getting there

Crew Transport (Orion & CC) — NOW*

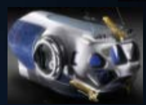
Small Power & Prop Bus — 2023

Large Enhanced Habitation & Prop Bus — NOW*

Surface Lander — 2023

Entry Decent Vehicle — 2025

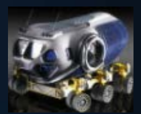
In-Space Mobility — 2025



EVA Suits — 2025

Surface Plant: Habitats & ISRU — 2023

Surface Mobility — 2025



**For cis-Lunar missions*

Needed Prop & Power Tech Advancements

Enabling

A. Transit Vehicle Power and Propulsion:
A.1 Electric (SEP)
A.2 Chemical

B. Lander/Descent Vehicle Propulsion
B.1 Integrated LOx/LCH$_4$ systems
B.2 LOx/LCH$_4$ propulsion

C. Power Distribution and Control
C.1 Radiation tolerant conversion and regulation

D. Surface Base Power Generation
D.1 Photovoltaics
D.2 Nuclear

E. Lander & Surface Mobility Power Generation
E.1 LOx/LCH$_4$ Integrated Power systems

F. Surface Habitat/Mobility ISRU & Reactant Storage:
F.1 Atmos. & Regolith proc.
F.2 Integrated Reactant Storage

Enhancing

G.1 Regenerative Fuel Cells
G.2 Battery systems

H. Power Distribution and Control:
H.1 Wiring

I. Separation/Actuation:
I.1 Pyrotechnic Systems and Firing Circuitry

Disruptive

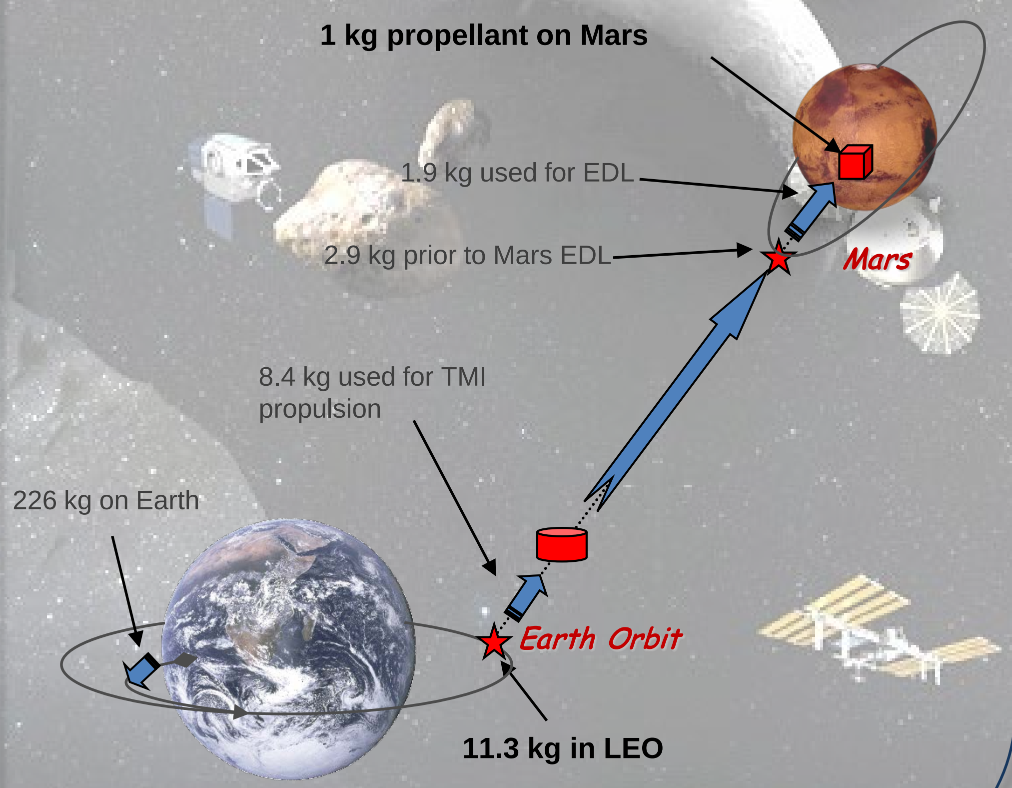
J. Advanced Transit Vehicle Power and Propulsion

Human Exploration Propulsion and Power Domains

In-Situ Resource Utilization (ISRU) and LO2-Methane for Mars

- **The Human Mars mission architecture is enabled by ISRU and LO_2-Methane**
- **Ability to produce propellant on the Mars surface has substantial 'ripple' benefits to the mission architecture**
  - *Enables a lighter ascent vehicle (MAV)*
  - *Simplifies EDL and Aeroshell design*
  - *Reduces launch requirements*
- **LO2-Methane has excellent attributes for a Mars lander**
  - *LO_2 and CH_4 (with H_2) can be produced at Mars*
  - *Improved performance over earth storables*
  - *Space storable and high density cryogens*
  - *Non-toxic, non-corrosive, self-venting*

High Mars Gear Ratio Requires Spacecraft Optimization for Mass and Size



Values shown are approximate and are only intended to illustrate gear ratio effect; actual values will vary based on specific mission parameters and architecture.

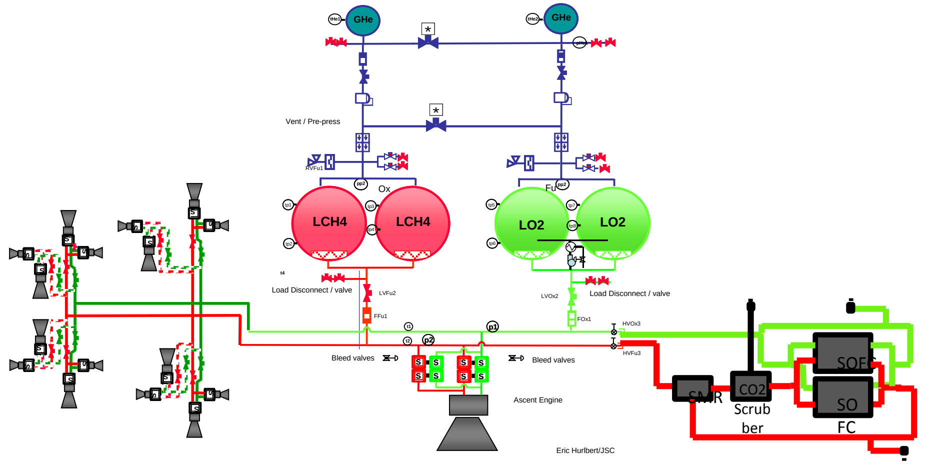
Vision for Future Human Spacecraft

Current human spacecraft have multiple fluids and little subsystem integration

- MMH, NTO, O2, N2, N2H4, Freon or NH3, water, etc.

Goal is to provide an integrated spacecraft fluid and thermal system that minimizes dry mass, complexity, and number of different fluids

- ***ECLSS:*** Oxygen storage for cabin air, suit loop, EMU recharge; thermally synergistic with high density cryogenic nitrogen storage.
- ***Power:*** Reactant storage for Solid Oxide Fuel Cell (SOFC) power generation.
- ***Thermally Efficient***: No heaters, high temperature (800C) SOFC heat rejection, reduced radiator footprint and ATCS heat load



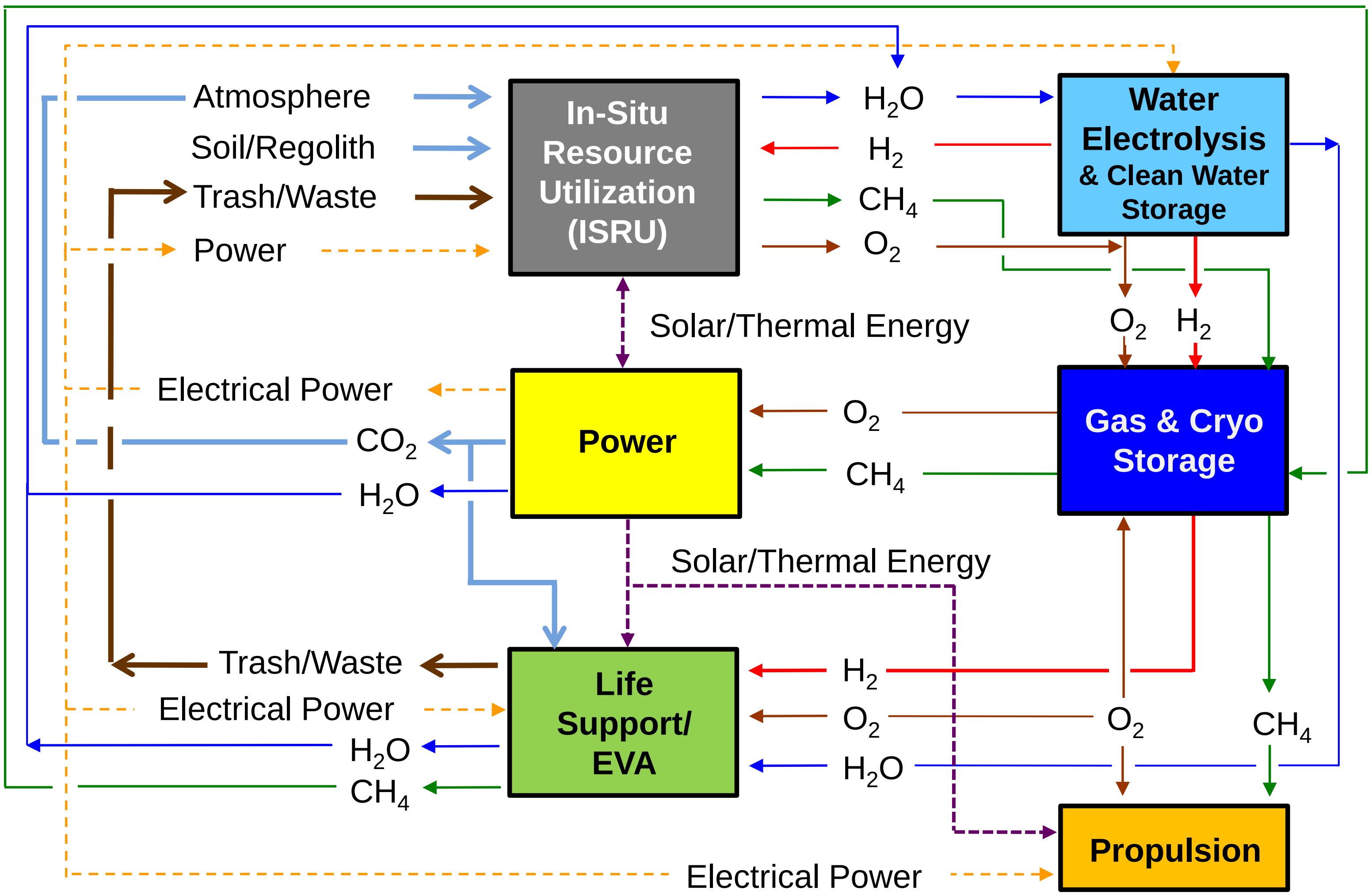
<u>Integrated Vehicle Fluids and Thermal</u>

- Supports a High Degree of Integration Across Spacecraft Subsystems
- Allows for cross strapping for redundancy with multiple common tanks and fluids

Integrated Fluids & Commodities For Spacecraft and Exploration Systems

Goal is to 'Close the Loops' Across Multiple Systems

- **Identify where common fluids, pressures, quality, and standards *are possible***
  - **Enables common storage, distribution, and interfaces**
- **Identify where common processes and technologies *are possible***
  - **Enables common hardware for flexibility and reduced DDT&E**
  - **Enables modularization of non-unique hardware for multiple systems**



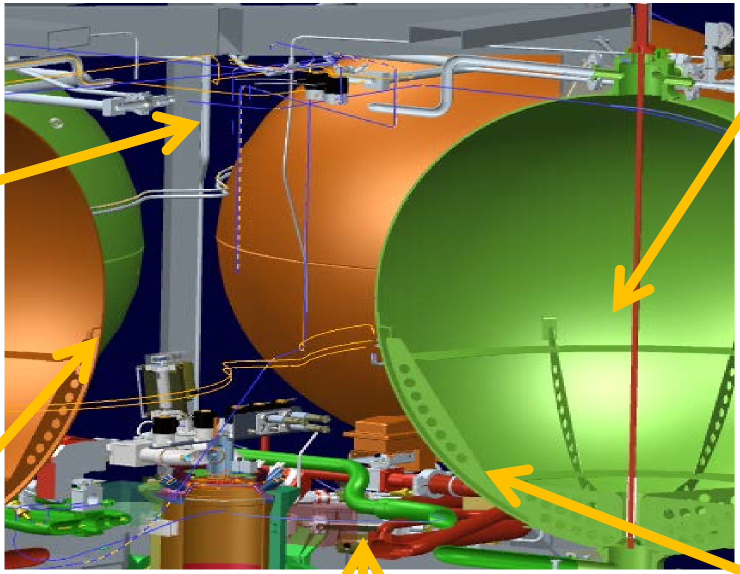
Morpheus VTB Propulsion Technical Accomplishments

System Level Operations

- Conducted 12 Hot-Fire Tests, 34 Tether Flights, 12 Free-Flights
- System Level Flight Operational Experience Gained
  - Prop System Turnaround measured in hours
  - No major issues working with LNG and Lox
    - Ie. No hardstarts/No purge run for RCS in-flight, no corrosion, little to no soot, safed quickly with GN2 post flight
- Low Cost of development, fabrication, and operations
  - Developed and Built 3 vehicles for ~500K per year procurement $90K in FY2014, + 6-7 FTE

Parallel Tank Differential Draining – Prop Management

- Capacitance probe in each tank
- Demonstrated propellant balance during free flight
- Demonstrated self-correcting behavior (passive, no liquid control valves)



Propellant Slosh Control

- Demonstrated damping of Lo2/Methane propellants

All Hardware common between O2 and CH4

- Tanks
- Valves
- Plumbing

Four RCS jets x 20 lbf(max)

- Demonstrated GNC control using Lox/LNG RCS engines
- 40msec to 30+sec pulses
- Operated in blowdown from 350 psig to 160 psig
- Operated over range of Inlet Conditions in flight
  - Gas-gas , gas-liq ., liq.-liq.
- Reliable engine and ignition obtained after a few modifications
  - Spark extend, Pc tube locations, plug mods

Gimbaled, Throttled Main Engine

- ~5400 lbf engine
- >4:1 throttle capability with simple ball valve mechanism
- >2500 sec operations, > 120 starts
- Excellent stability during main stage
- Start is stable with cold Lox and warm methane gas. Possibly unstable if liquid methane

Integrated Main Engine and RCS, Tank & Feedsystem

- Blowdown Pressurization
- RCS feedsystem mounted to tanks and TVS operated in flight
- Cryo RCS worked even in Texas and Flordia summer environment
  - Venting seen in videos is the initial chill-in from gas to liquid temps
- Tanks used purged aerogel blankets (non-flammable)

https://www.youtube.com/watch?v=1M5qS0Y3tDw