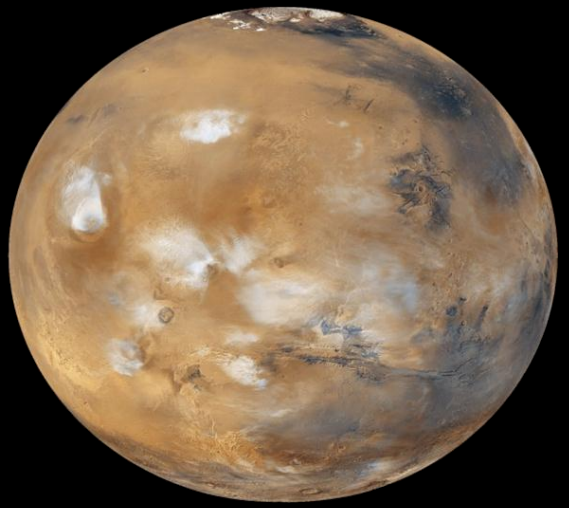
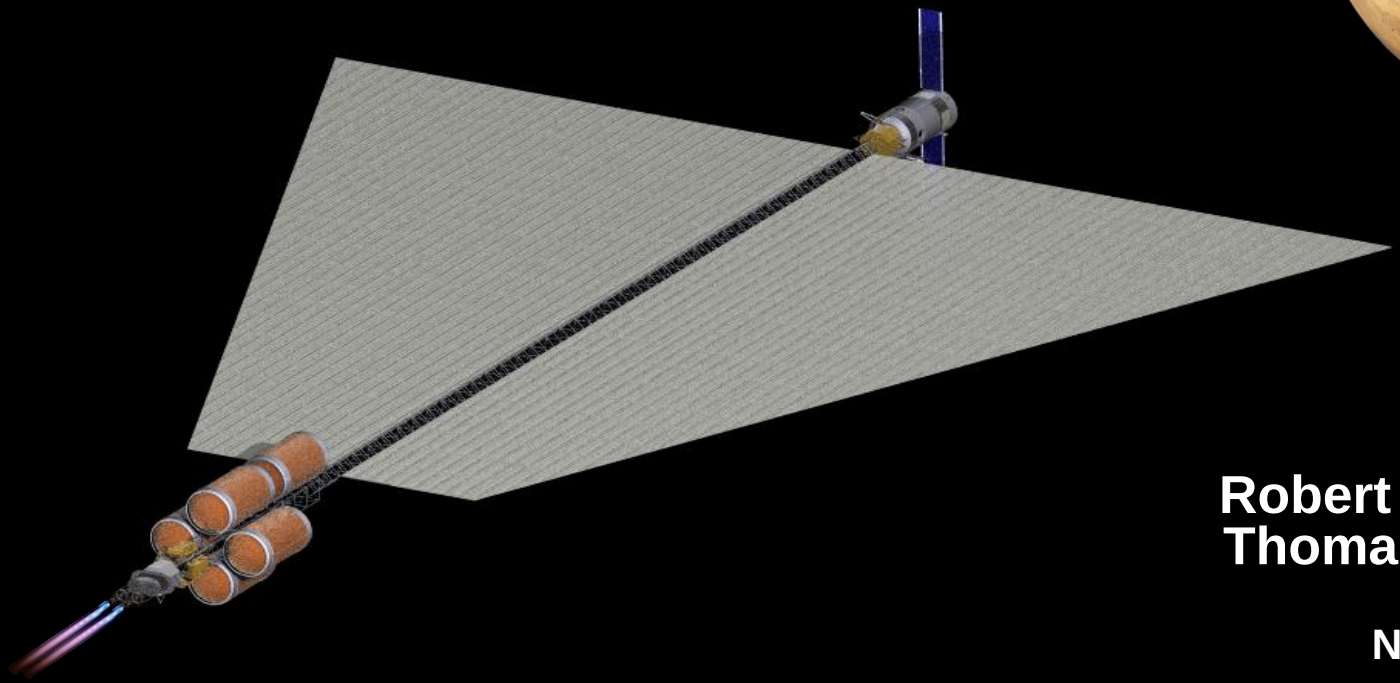
Opening The Solar System:

An Advanced Nuclear Spacecraft for Human Exploration

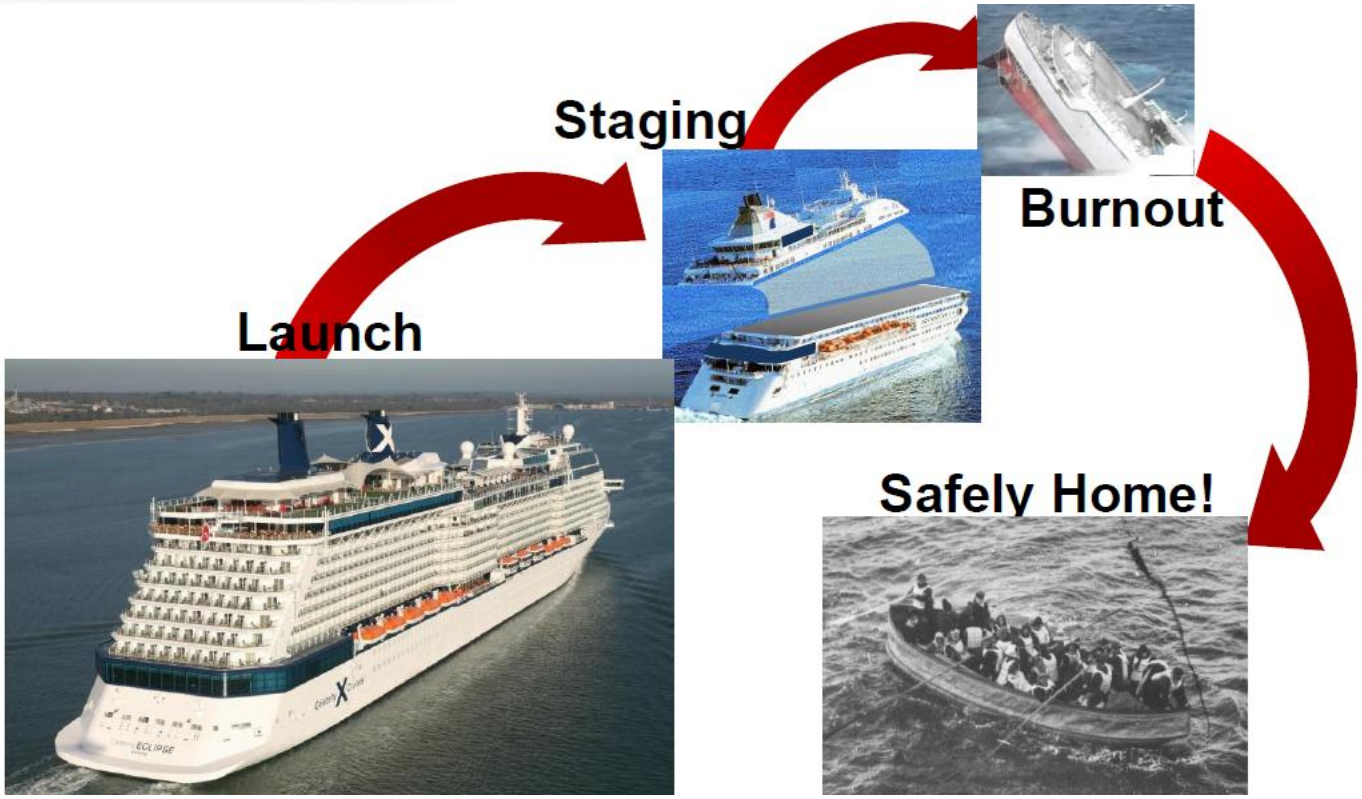




Robert Werka, MSFC
Thomas Percy, SAIC

NETS 2014

Exploration Today



You wouldn't explore the Caribbean this way, so why would you want to explore space like this?

Why This Study Is Different

- **Today's Propulsion Limits Human Space Exploration**
  - **Low performance: Leave Earth on gas tank cluster, return in a lifeboat**
  - **This approach to Exploration makes missions even to Mars extremely costly, complex and dangerous**
  - **Aerospace America (3/12): "near-to-medium term prospects for 'advanced propulsion' to create a new era of space exploration are not very good".**
- **Advanced Propulsion of Previous Studies Meant New Physics**
  - **MSFC "HOPE Study" 2003**
  - **GRC "Making 2001 Vehicle Study" 2005**
  - **APL "Outer Planet HSF Study" 2010**

Adv Prop: >30,000 sec & 1-10 mT Of Thrust = MPD, Fusion, etc.

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A Blog: "*Now, if I worked at NASA and was given the choice to work on yet another chemical launcher or a revolutionary planetary ship (propelled by fission fragment engines), I know what my choice would be.*"

Unnamed Website 2/3/10

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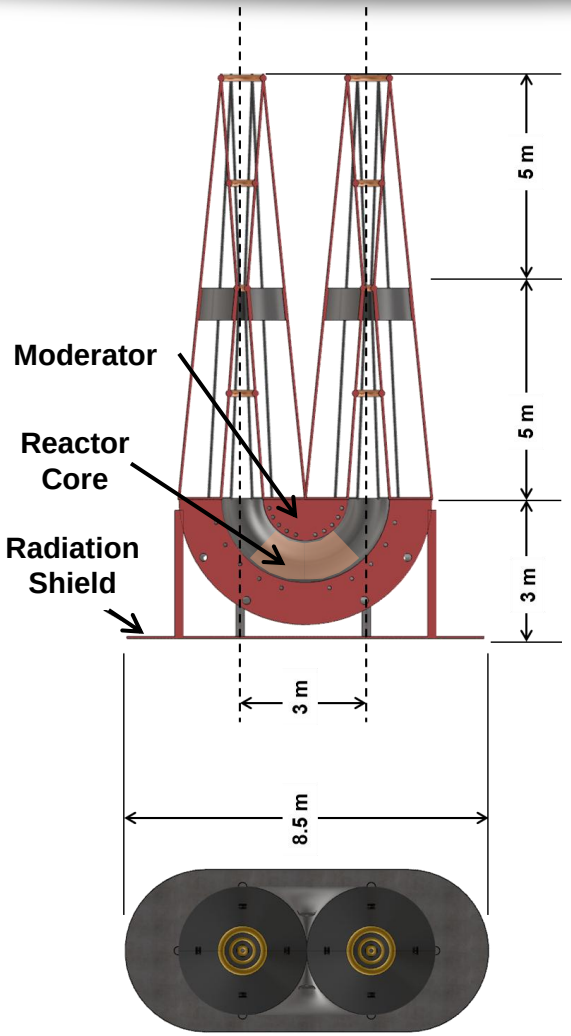
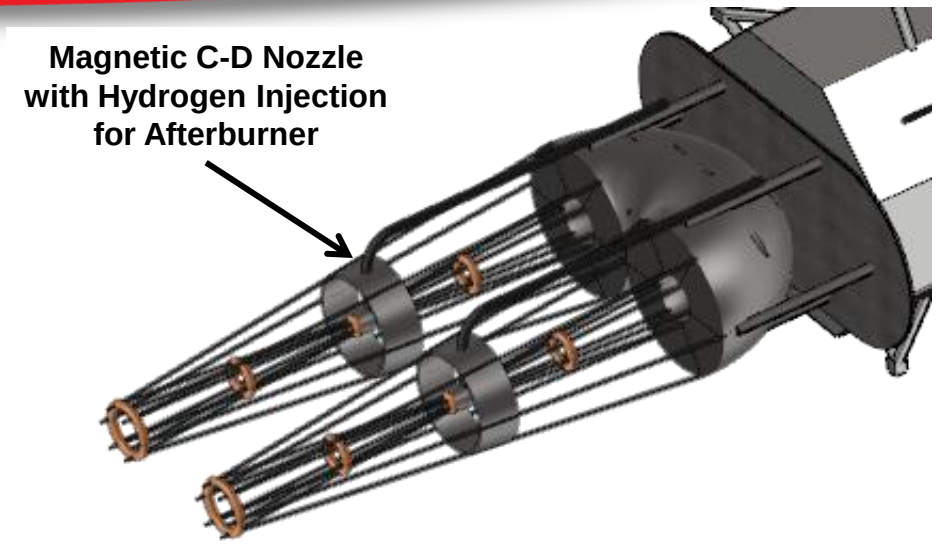
- **Fission Fragment Rocket Engine (FFRE) Not Considered Before**
  - Needs NO NEW PHYSICS
  - Adding Afterburner matches FFRE Performance to Mission Needs
  - High Power Reactor Provides High Specific Impulse & Moderate Thrust
- **Using FFRE Technology of TODAY May Make Space Vehicle Of Science Fiction Into Space Vehicle Of Science Fact**

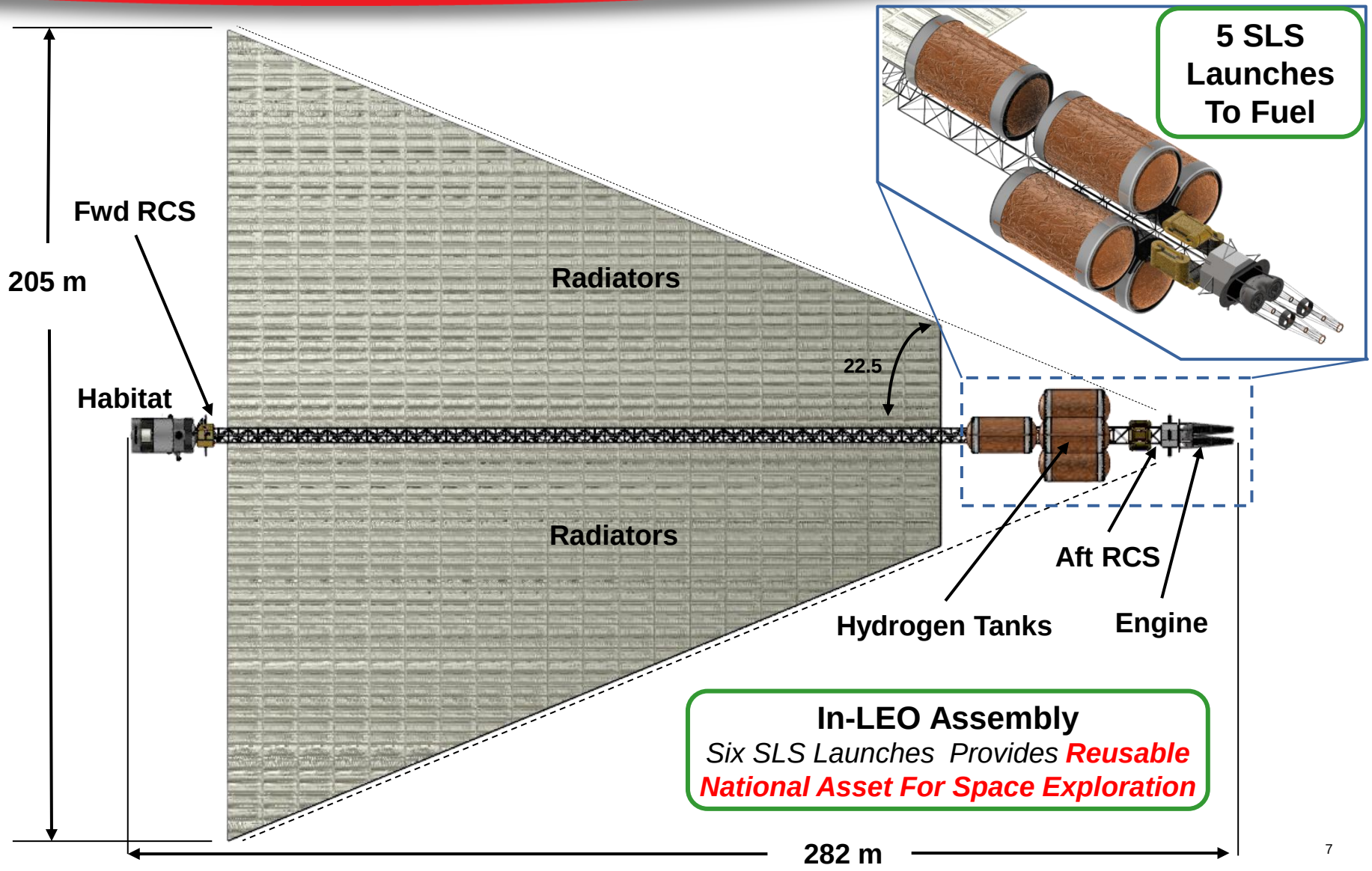
Afterburner Fission Fragment Rocket Engine (AFFRE)





- Reactor Power = 2500 MW
- Engine Mass = 107 mT + 91 mT Moderator Oil
- Thrust = 4651 N (1046 lbf)
- Specific Impulse (I_{sp}) = 32,000 seconds
- Mass Flow ($\dot{m}$) = 0.018 kg/s
  - Hydrogen: 0.0179 kg/s (140lb/hour)
  - FFs: 3.12e-5 kg/s (4 oz/hour)

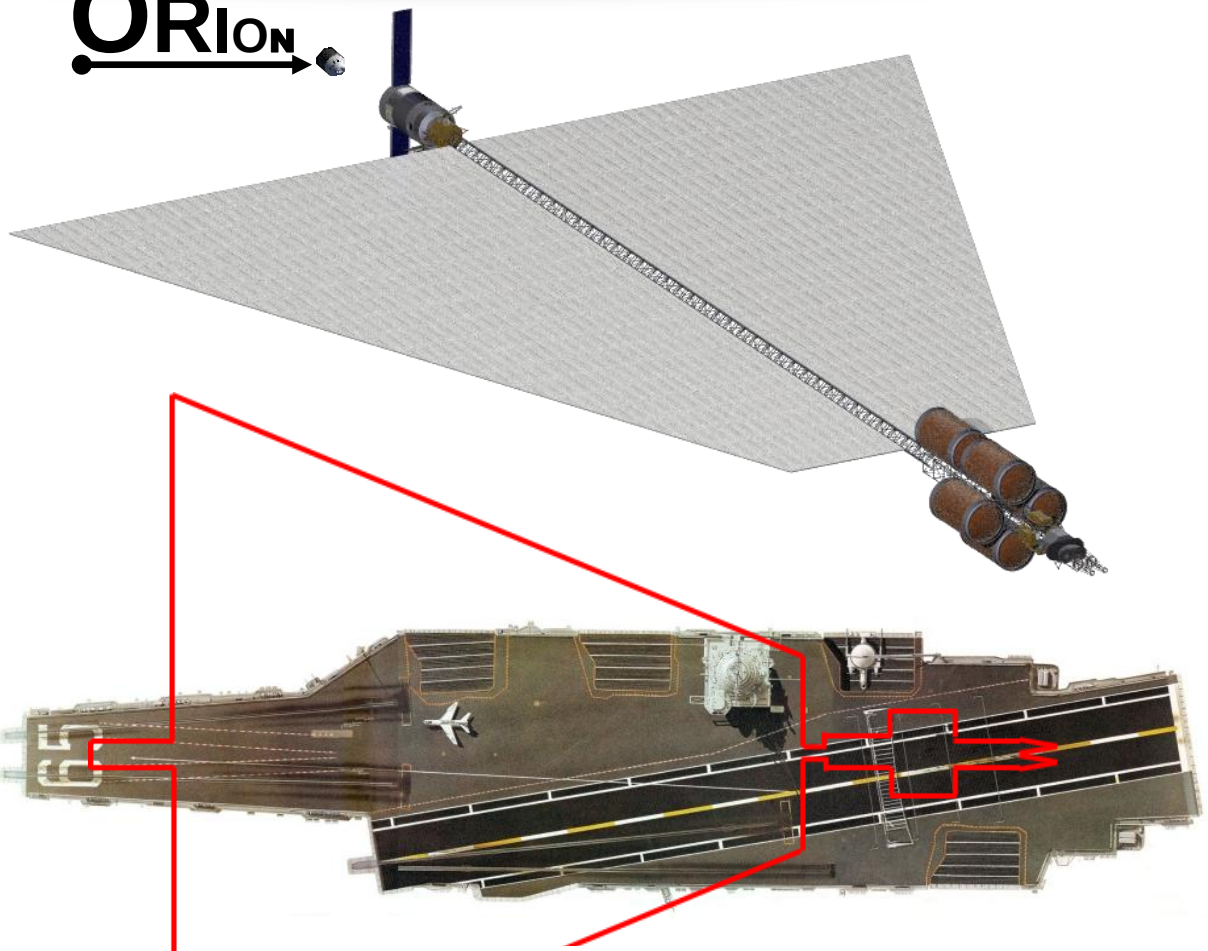
A Reusable Space Vessel



In-LEO Assembly

Six SLS Launches Provides ***Reusable National Asset For Space Exploration***

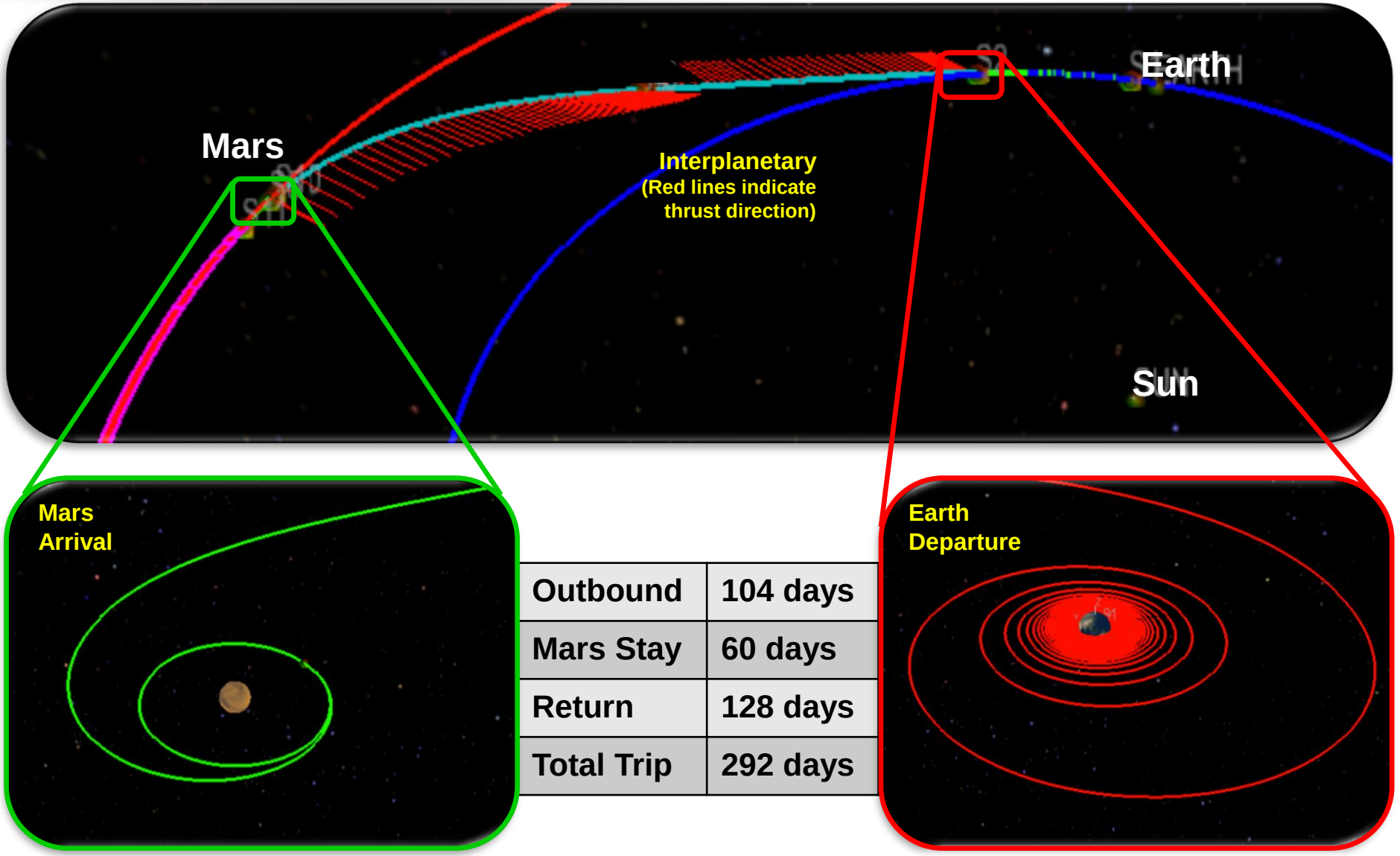
Concept Overview



Scale Comparison With USS Enterprise (World's Largest Aircraft Carrier)

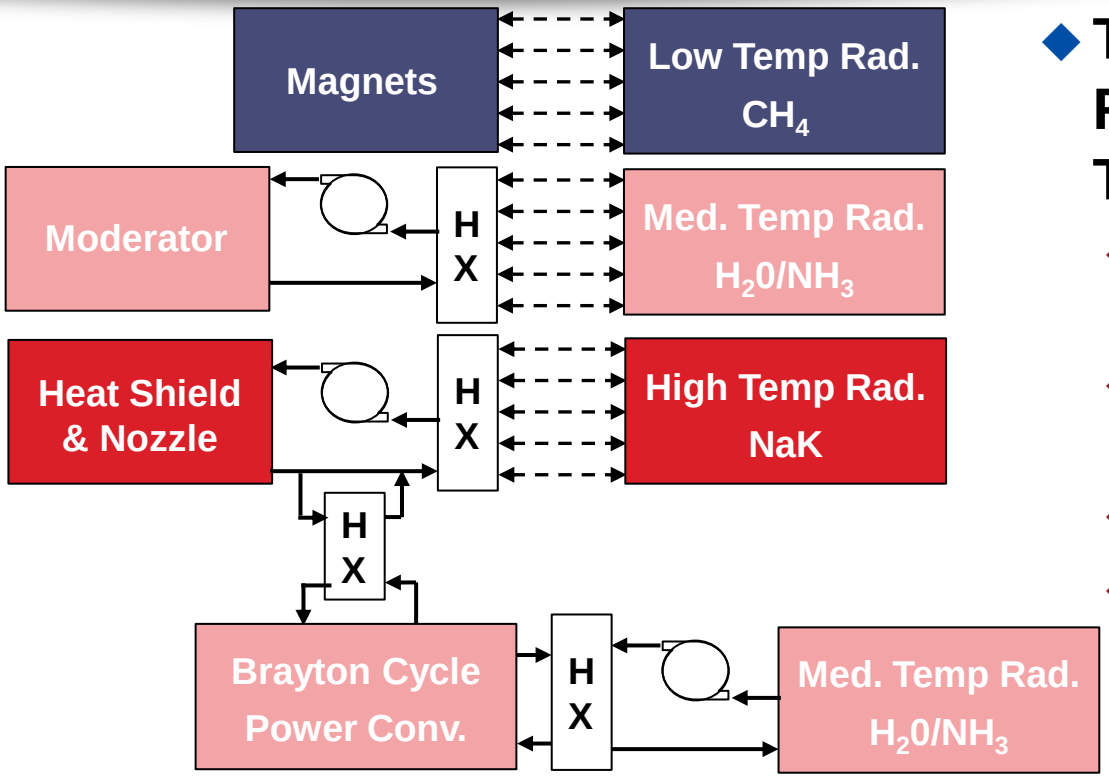
Component	Mass (kg)
Attitude Control	925
Propulsion	268961
Structures	5899
Thermal	280816
Power	6200
Avionics	3118
Dry Mass	***565,865***
Payload	170000
Plus Payload	***735,919***
Propellant	345599
Total Vehicle Mass	***1,081,518***

A Mars Mission



Outbound	104 days
Mars Stay	60 days
Return	128 days
Total Trip	292 days

Thermal Control

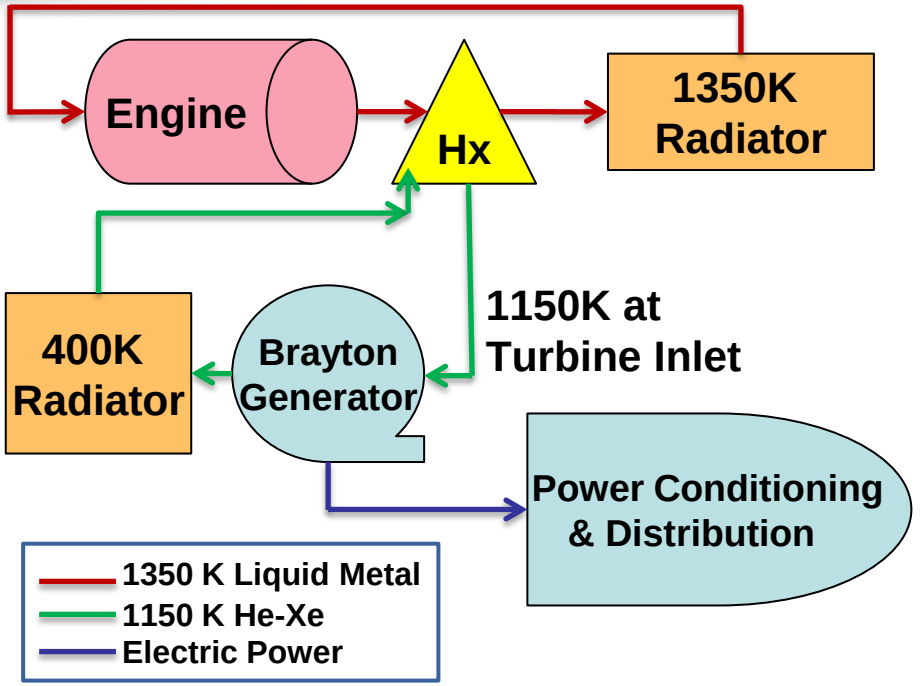


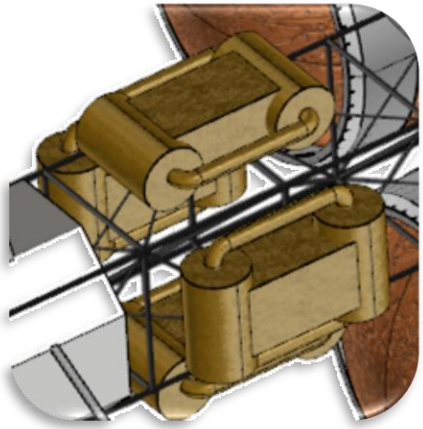
- **Thermal Challenge: Rejecting ~450 MW of Thermal Energy**
  - 4 cooling loops for different subsystems
  - Double sided radiators reduce spacecraft length
  - Most massive subsystem
  - LEO assembly like ISS

Radiator System	Operating Temp (K)	Heat Rejection	Radiator Size	Radiator Mass
Low Temp. Loop	140 K	0.40 MW	9667 m^2	71535 kg
Med. Temp. Loop	590 K	147.6 MW	11307 m^2	90455 kg
High Temp. Loop	1200 K	302.3 MW	1353 m^2	13534 kg
Brayton Cycle Loop	400 K	1.28 MW	464 m^2	3714 kg

Power

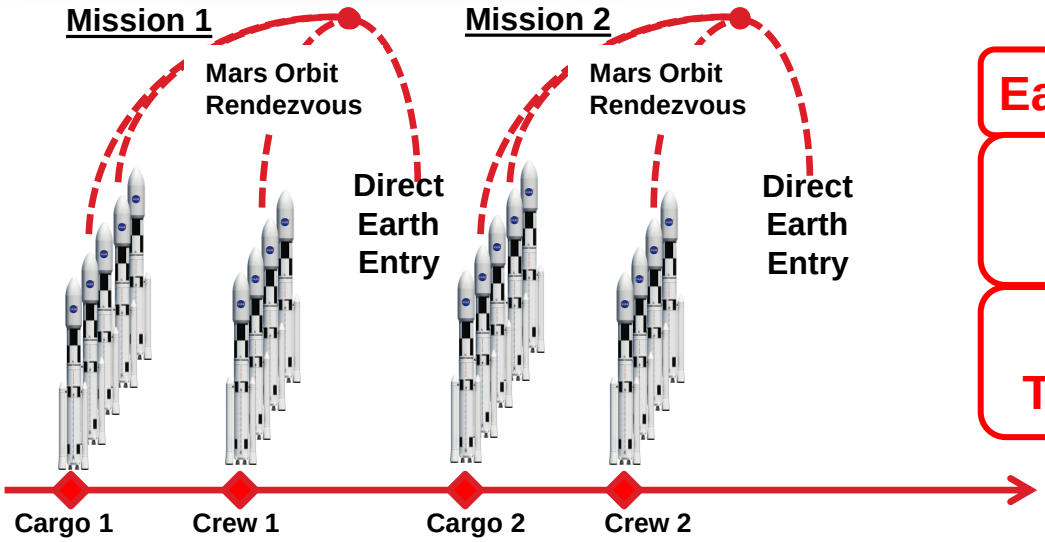
- **Use significant waste heat to produce power**
  - **100 kW Brayton power generators based on GRC concept**
  - **Carrying 3 primary & 1 spare unit**
- **Supports any conceivable spacecraft power requirement including human needs for radiation protection, physical comfort and communication**





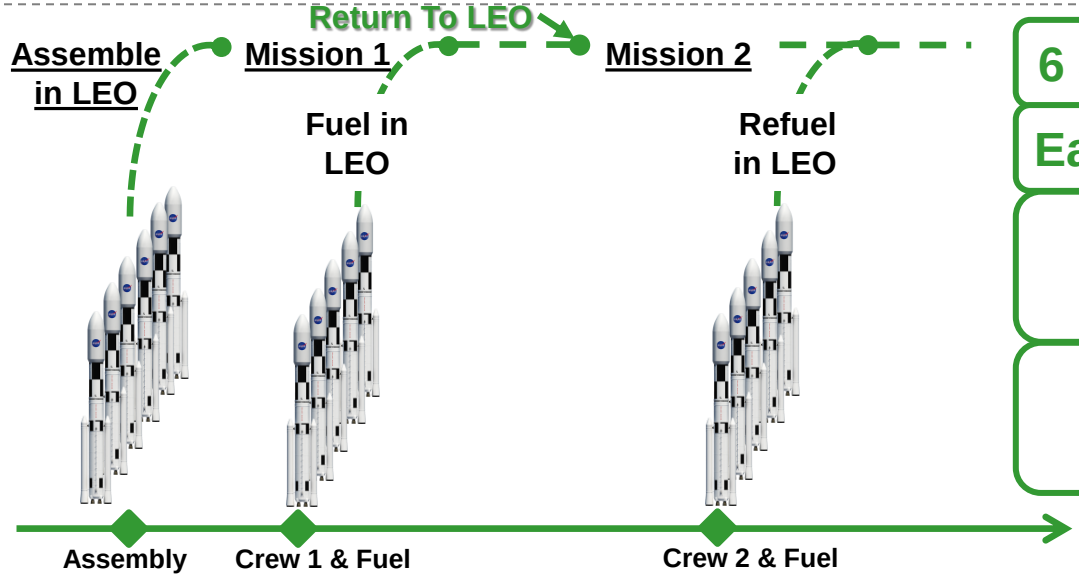
Mars Mission Comparison

Typical NTR Mars



- Each Mission: 9 SLS Launches
- Crew Deep Space Duration ~ 500 days
- All Spacecraft Elements Thrown Away for Each Flight

AFFRE Mars



- 6 SLS Launches For Assembly
- Each Mission: 5 SLS Launches
- Crew Deep Space Duration ~ 230 days
- Vehicle Reused for Each Mission

Conclusions

- **AFFRE Based On Today's Physical Principles**
  - **No Future Science Required**
- **AFFRE Can Change Space Travel Paradigm**
  - **Much Faster Trip Times**
  - **Same Vehicle Can Go Anywhere**
  - **Same Vehicle Can Carry Anything**
  - **Provides Astronaut Safety And Comfort**
- **AFFRE Allows Creation Of A Space-Based, Reusable National Asset For Exploration**