“BIMODAL” NUCLEAR THERMAL ROCKET (BNTR) PROPULSION
FOR FUTURE HUMAN MARS EXPLORATION MISSIONS

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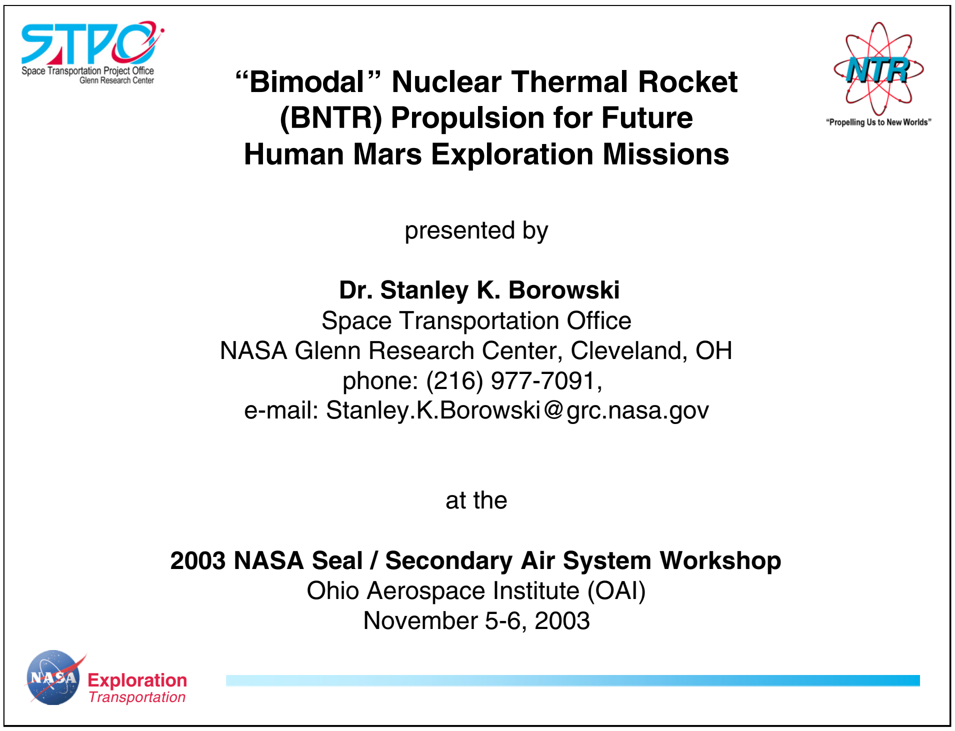

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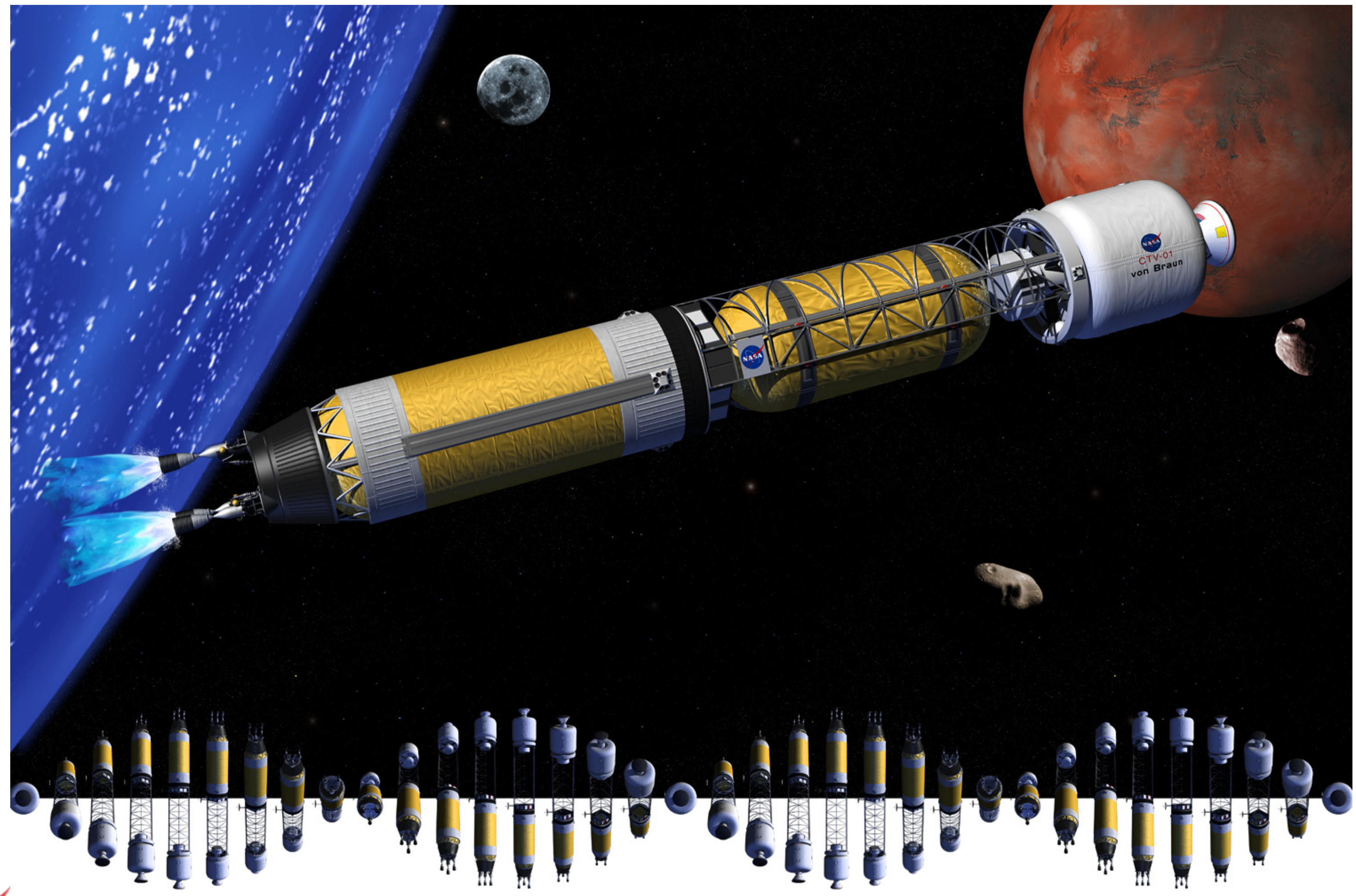
Artificial Gravity "Bimodal" NTR Crew Transfer Vehicle (CTV) for Mars DRM 4.0 (1999)

NTR
"Propelling Us to New Worlds"



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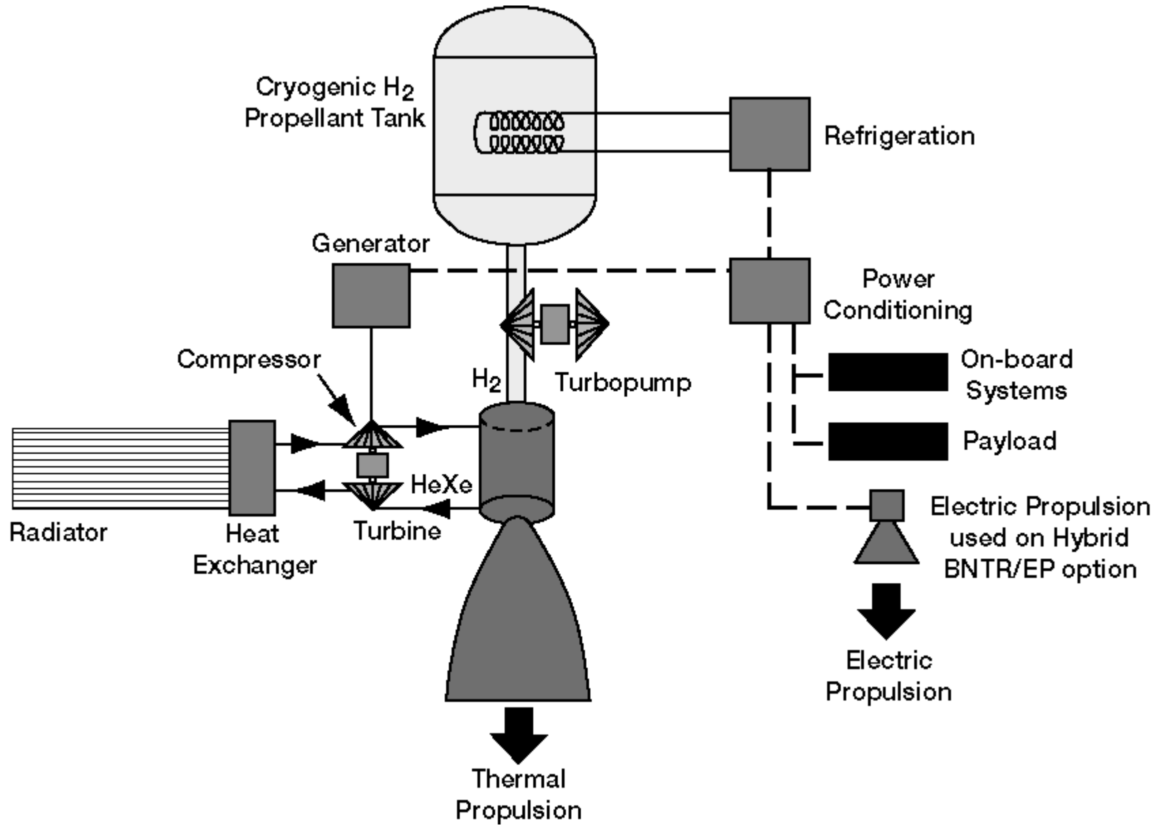
The "Bimodal" NTR (BNTR) Integrated Space Propulsion & Power System -- Smarter Systems Engineering --



- During short, high thrust propulsion phase, each BNTR produces ~340 MW_t and ~15 klb_f of thrust
- During long, power generation phase, each BNTR operates in "idle mode" producing just ~150 kW_t
- A Brayton conversion unit on each BNTR produces up to 25 kW_e to enhance stage capabilities

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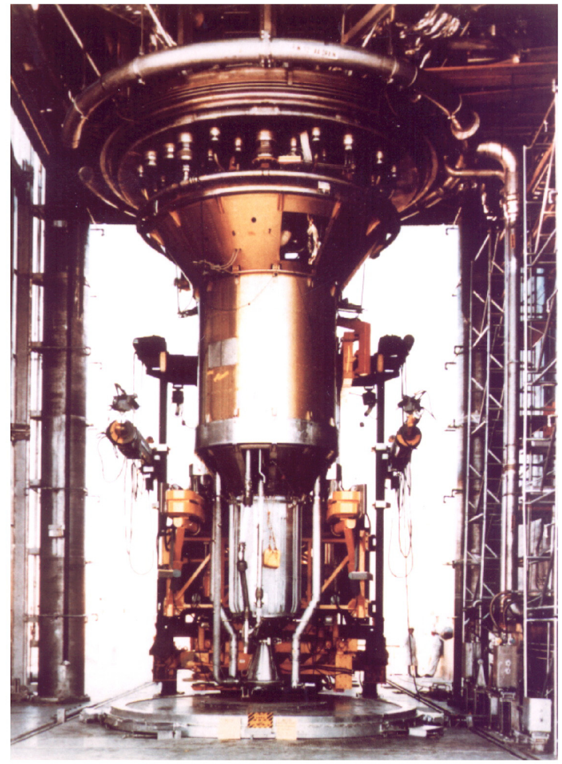
Rover/NERVA* Program Summary (1959-1972)

- **20 Rocket/reactors designed, built and tested at cost of ~ $1.4 billion**
- **Engine sizes tested**
  - 50-250 klbf
- **H_2 exit temperatures achieved**
  - 2,350-2,550 K (Graphite fuel)
- **I_{sp} capability**
  - 825-850 sec (hot bleed cycle)
- **Burn duration**
  - 62 mins. (NRX-A6 -- single burn)
  - >4 hrs. (NRX-XE -- 28 burns) (accumulated)
- **Engine thrust-to-weight**
  - ~3 for 75 klbf NERVA
- **"Open Air" testing at Nevada Test Site**

**NERVA: Nuclear Engine for Rocket Vehicle Applications*



NERVA program experimental engine (XE) demonstrated 28 startup/shutdown cycles during tests in 1969.

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Nuclear Thermal Rocket (NTR) Propulsion

What's New?

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Then (Rover/NERVA:1959–72)		Now
• **Engine sizes tested** – 50–250 klbf	Smaller, Higher Performance	• **"Current" focus is on smaller NTR sizes** – 5–15 klbf (Code S science–humans)
• **H_2 exit temps achieved** – 2,350–2,550K (Graphite)	Smaller, Higher Performance	• **Higher temp. fuels being developed** – 2,700K (Composite), 2,900K (Cermet) and ~3,100K (Ternary Carbides)
• **Isp capability** – 825–850 sec (hot bleed)	Easier to test	• **Isp capability** – 915–1005 sec (expander cycle)
• **Engine thrust-to-weight** – ~3 for 75 klbf NERVA	Easier to test	• **Advances in chemical rockets/materials** – ~2–6 for small NTR designs
• **Testing (Rover/NERVA)** – "Open Air" exhaust at Nevada test site	Environmentally "Green" For Public Acceptance	• **Small NTR allows full power testing in** – "Contained Test Facility" at INEL with "scrubbed" H_2 exhaust

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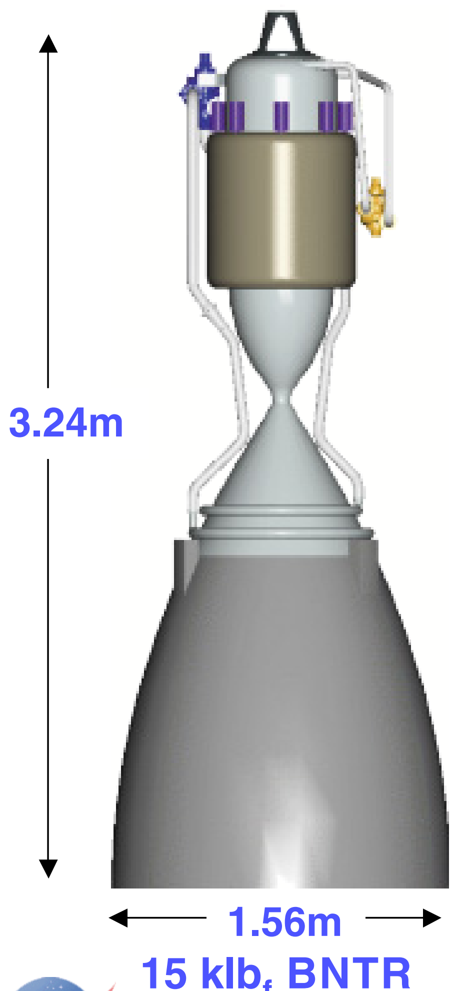
Nuclear Thermal Rocket (NTR) Propulsion
-- Key Technology / Mission Features --



- NTR engines have negligible radioactivity at launch / simplifies handling and stage processing activities at KSC
  - < 10 Curies / 3 NTR Mars stage vs ~400,000 Curies in Cassini's 3 RTGs
- High thrust / Isp NTR uses same technologies as chemical rockets
- Short burn durations (~25-50 mins) and rapid LEO departure
- Less propellant mass than all chemical implies fewer ETO launches
- NTR engines can be configured for both propulsive thrust and electric power generation -- **"bimodal" operation**
- Fewest mission elements and much simpler space operations
- Engine size aimed at maximizing mission versatility
  -- robotic science, Moon, Mars and NEA missions
- NTR technology is evolvable to reusability and "in-situ" resource utilization (e.g., **LANTR -- NTR with LOX "afterburner" nozzle**)

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"Bimodal" NTR Cargo & Crew Transfer Vehicles for 1999 Mars Design Reference Mission (DRM) 4.0

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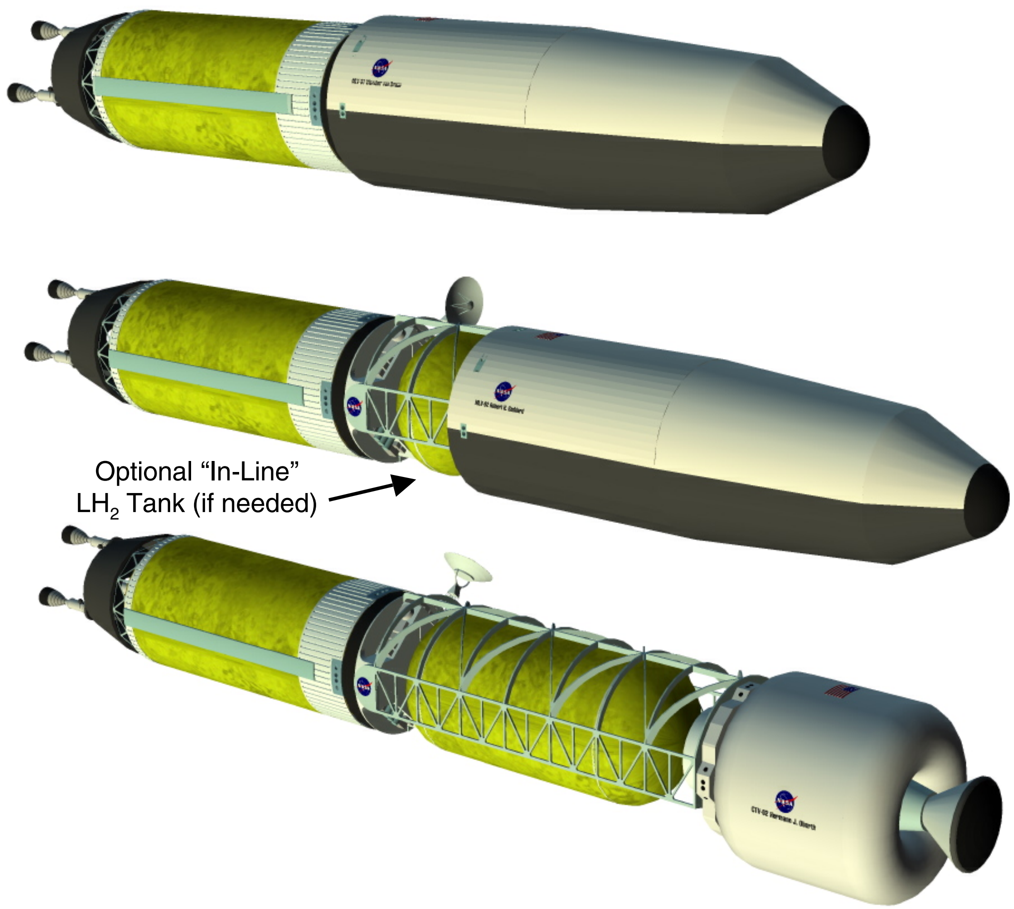
6 - "80 t" SDHLVs plus Shuttle for Crew & TransHab Delivery



2011 Cargo Mission 1
Habitat Lander
IMLEO= 131.0 t

2011 Cargo Mission 2
Cargo Lander
IMLEO= 133.7 t

2014 Piloted Mission
Artificial Gravity
Crew Transfer Vehicle
IMLEO= 166.4 t

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Modular "Bimodal" NTR Transfer Vehicle Design for Mars Cargo and Piloted Missions

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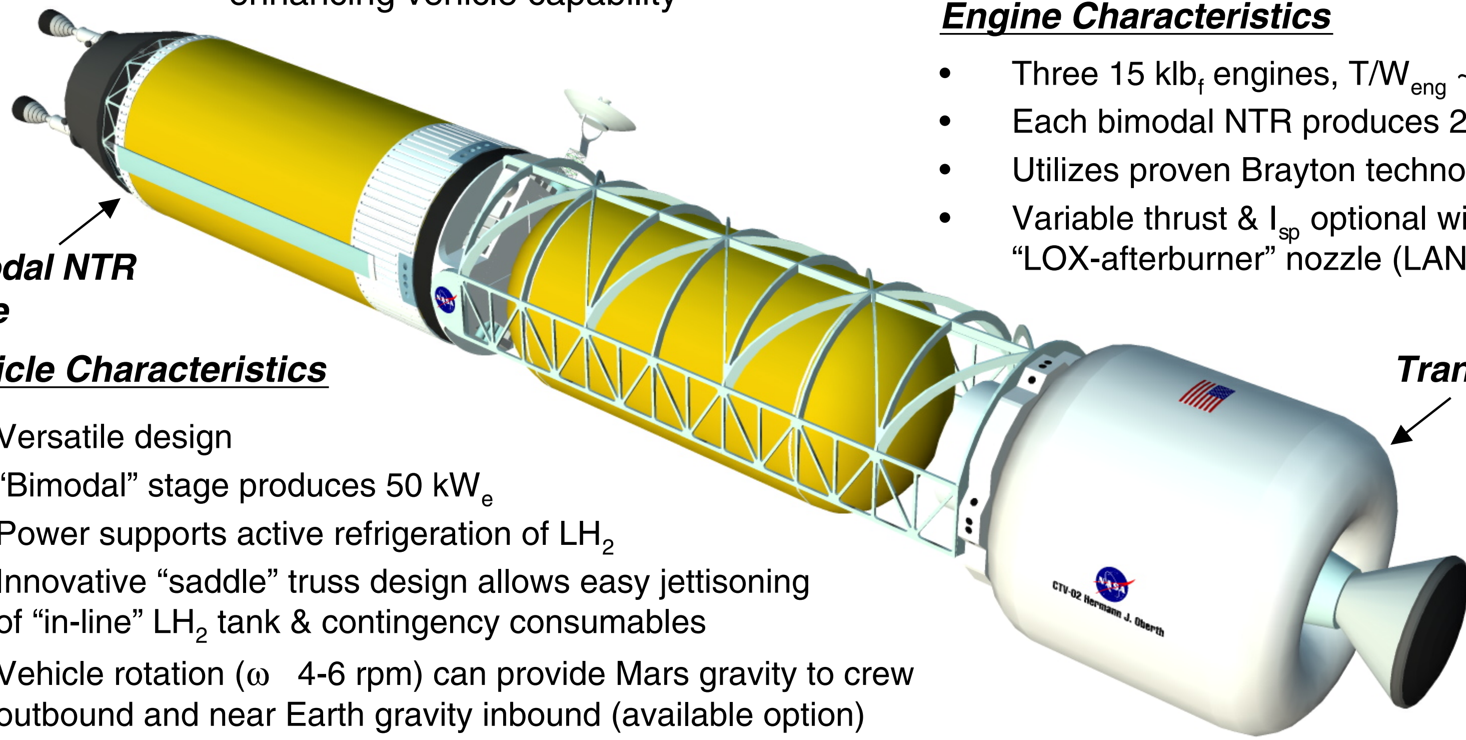
Bimodal NTR: High thrust, high I_{sp} propulsion system utilizing fissioning U^{235} produces thermal energy for propellant heating and electric power generation enhancing vehicle capability



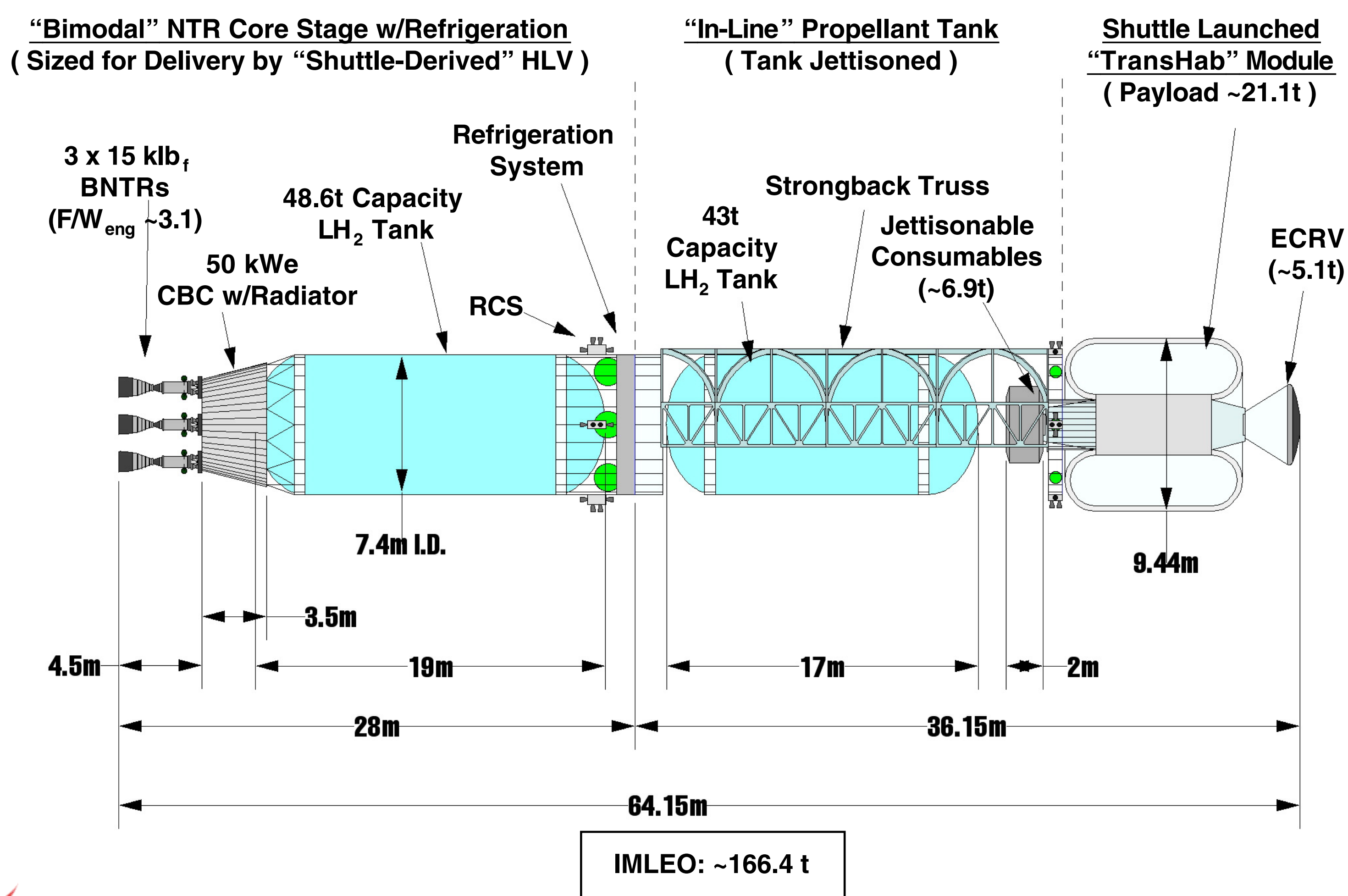
Engine Characteristics

- Three 15 klb_f engines, T/W_{eng} ~3.1
- Each bimodal NTR produces 25 kW_e
- Utilizes proven Brayton technology
- Variable thrust & I_{sp} optional with "LOX-afterburner" nozzle (LANTR)

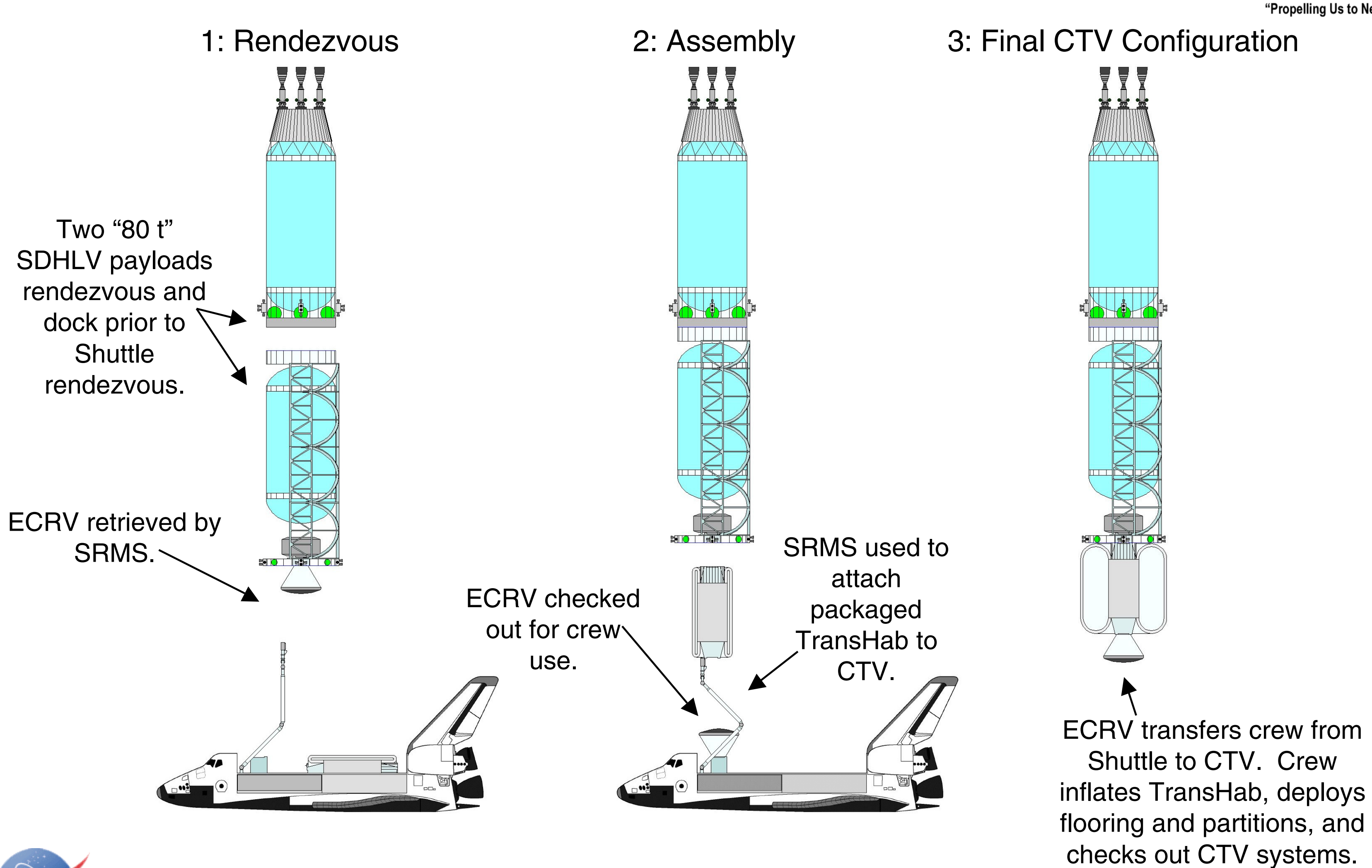
Vehicle Characteristics

- Versatile design
- "Bimodal" stage produces 50 kW_e
- Power supports active refrigeration of LH_2
- Innovative "saddle" truss design allows easy jettisoning of "in-line" LH_2 tank & contingency consumables
- Vehicle rotation (ω 4-6 rpm) can provide Mars gravity to crew outbound and near Earth gravity inbound (available option)
- Propulsive Mars capture and departure on piloted mission
- Fewest mission elements, simple space ops & reduced crew risk
- Bimodal NTR vehicles easily adapted to Moon & NEA missions

Mars DRM 4.0: "Bimodal" NTR Crew Transfer Vehicle (CTV) with Inflatable "TransHab" Module & Artificial Gravity Capability



"Bimodal" Crew Transfer Vehicle Earth Orbit Assembly Sequence



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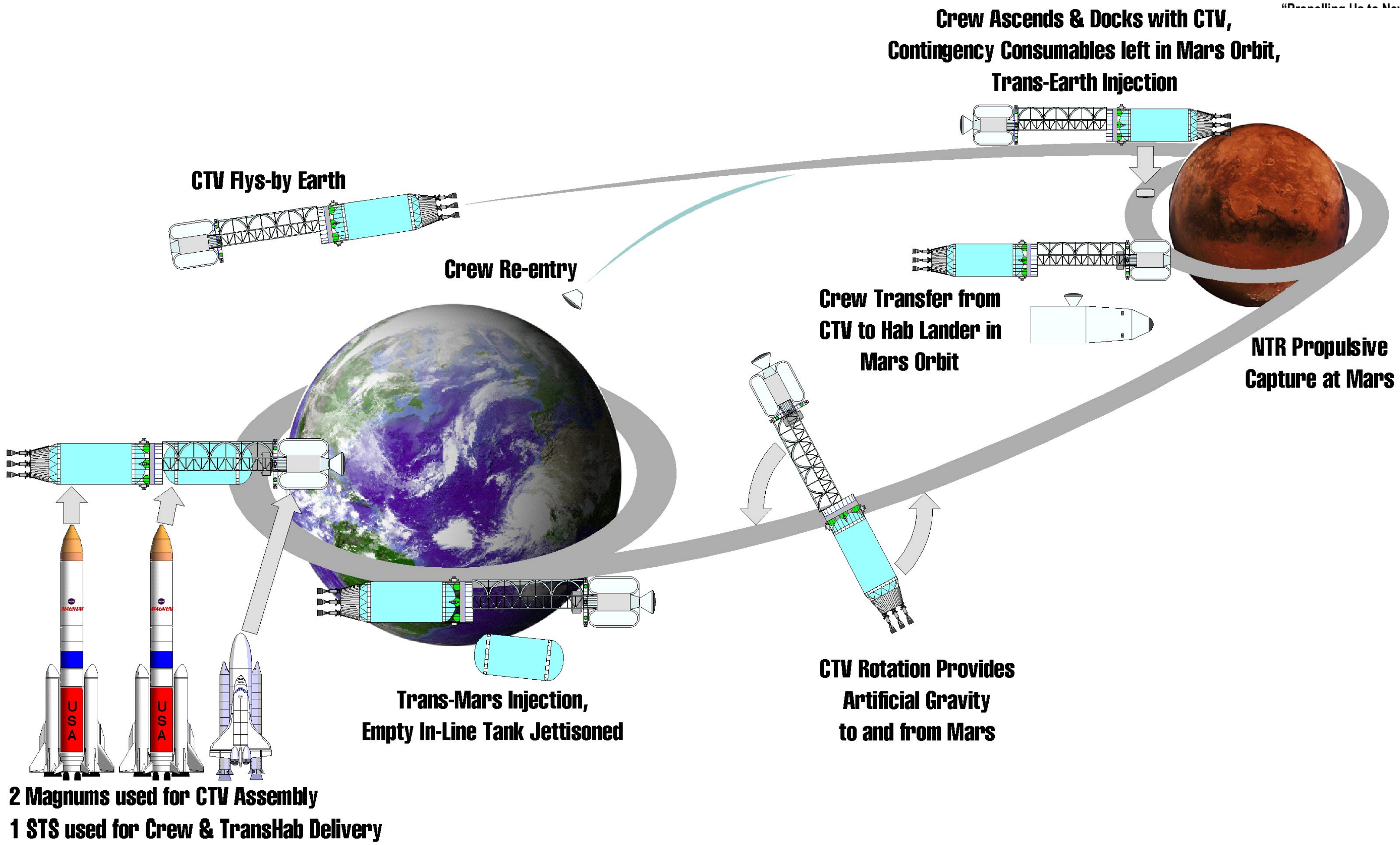
"Artificial Gravity" BNTR Mars Crew Transfer Vehicle (CTV) Mission Scenario



“Bimodal” NTR Crew Transfer Vehicle (CTV) in Artificial Gravity Mode

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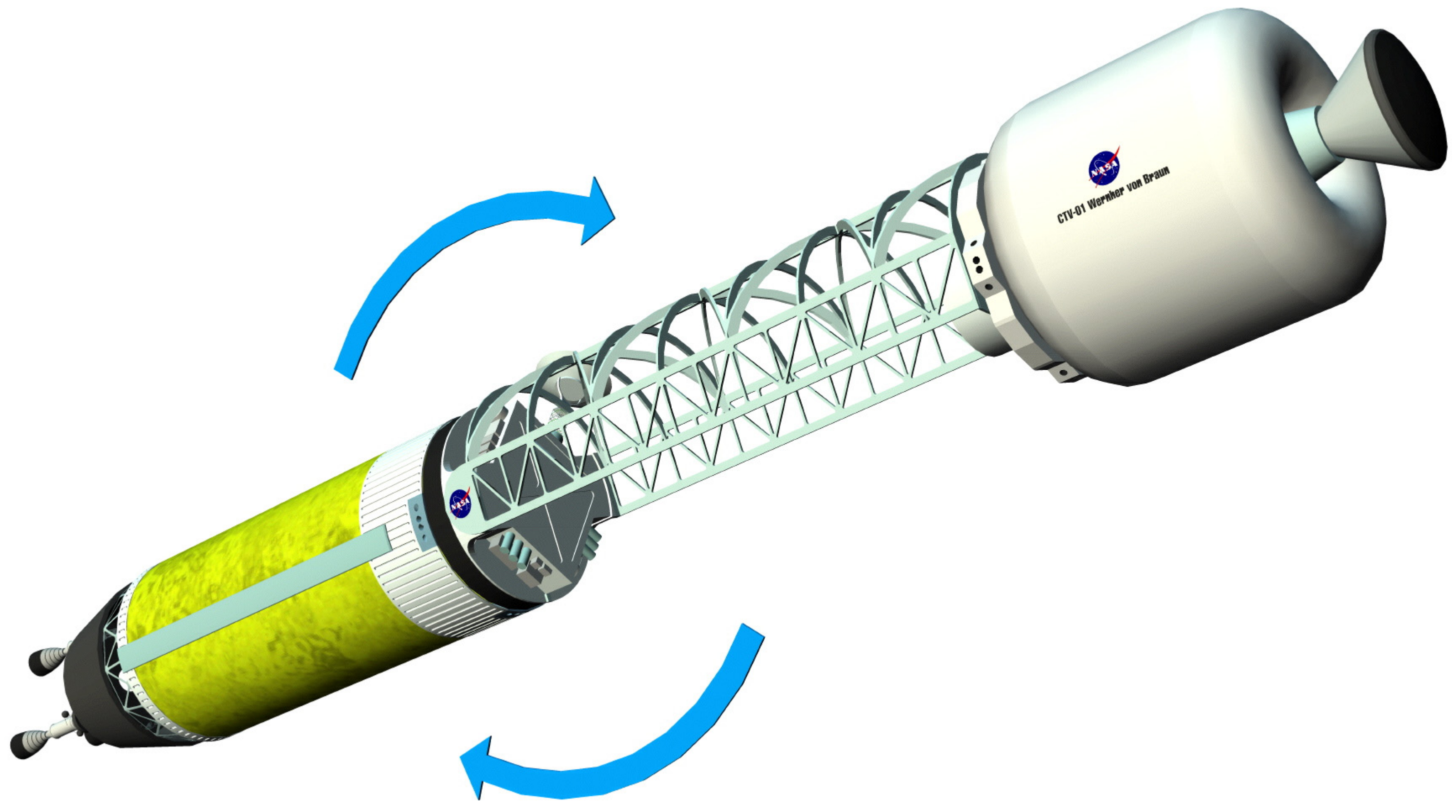

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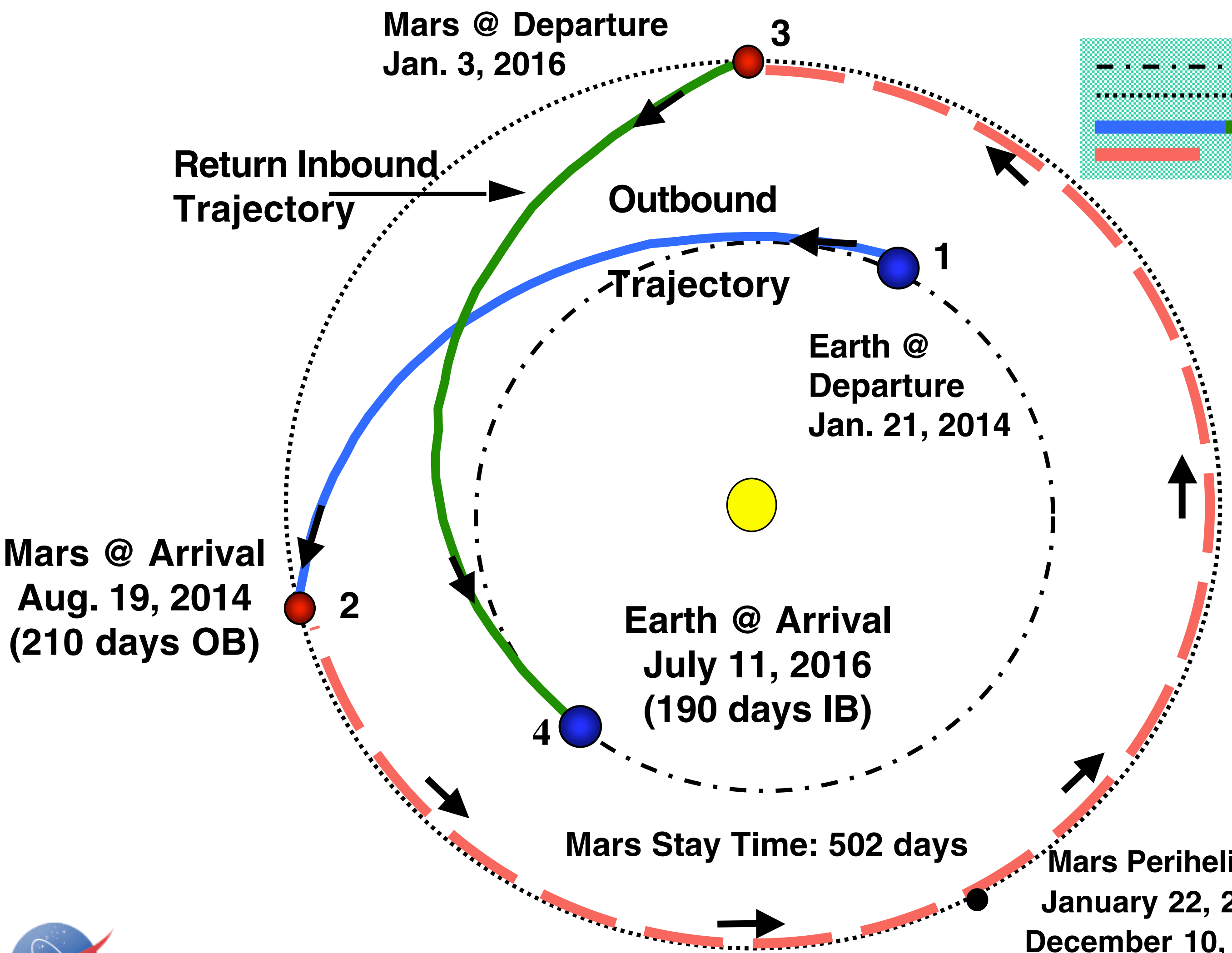
2014 “Bimodal” NTR Piloted Flight Profile (210 Day Transit Out, 190 Day Return)



Earth/Mars Synodic Period:

The proper alignment with Mars occurs every 2.13 yrs allowing the “opening” of the TMI window.

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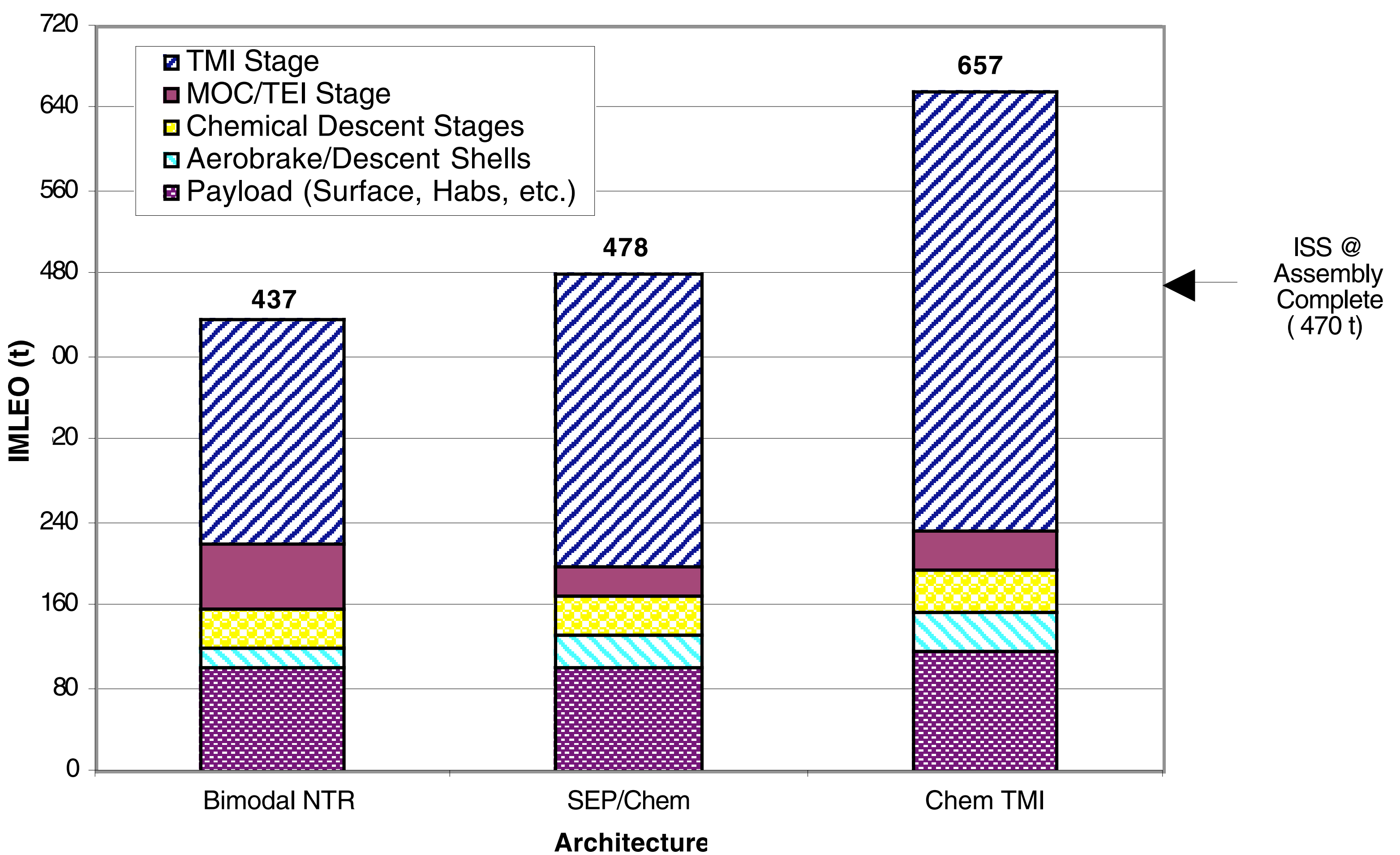
Human Mars Mission Architecture Mass Comparison

(Shown at 80 t steps)



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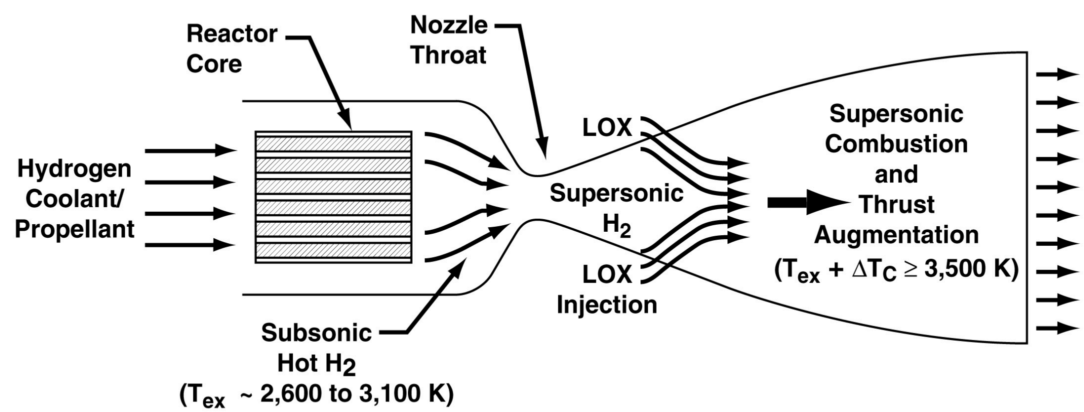
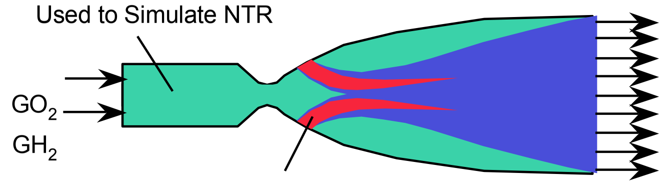
"LOX-Augmented" NTR (LANTR) Concept
--Operational Features and Characteristics--

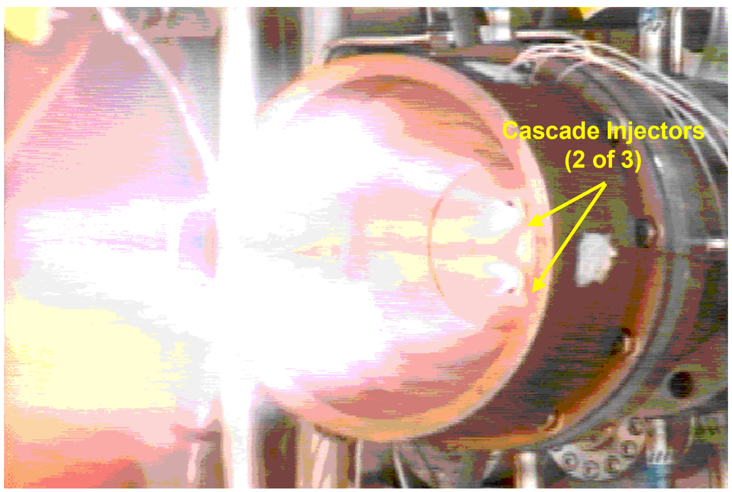


Life (hrs) T_{ex} (°K)	I_{sp} (sec) 5 2,900	10 2,800	35 2,600	Tankage Fraction (%)	T/W_{eng} Ratio
O/H MR = 0.0	941	925	891	14.0	3.0*
1.0	772	762	741	7.4	4.8
3.0	647	642	631	4.1	8.2
5.0	576	573	566	3.0	11.0
7.0	514	512	508	2.5	13.1

*For 15 klb_f LANTR with chamber pressure = 2,000 psia and ε = 500 to 1

"LOX-Augmented" Nuclear Thermal Rocket (LANTR) "Afterburner" Nozzle Concept Demonstration





Baseline H/O Thrust: 2100 lbf at 1000 psia and MR = 1.5. With GO_2 injection into nozzle, measured thrust due to supersonic combustion is 3200 lbf (~52% thrust augmentation achieved at 50:1 and MR_L~3.0)

LANTR Concept and Benefits:
- "Afterburner" nozzle increases thrust by injecting & combusting GO_2 downstream of the NTR throat
- Enables NTR with variable thrust and Isp capability by varying the nozzle O/H mixture ratio (MR)
- Operation at modest MRs (<1.0) helps increase bulk propellant density for packaging in smaller volume launch vehicles
- LANTR's bipropellant operation enables smaller, faster Moon / Mars vehicles when using extraterrestrial sources of H_2 and O_2

LANTR Test Program Objectives: (Aerojet & GRC)
- Measure thrust augmentation from oxygen injection and supersonic combustion using small, fuel-rich H/O engine with two different area ratio nozzles (@ 25:1 and 50:1) as "non-nuclear" NTR simulator.
- Use results to calibrate reactive CFD assessment of bimodal LANTR engine

Status: LANTR afterburner nozzle demonstrated
- Oxygen injection into hot supersonic flow
- Supersonic combustion in the nozzle
- Elevated nozzle pressures measured
- Benign nozzle wall environment observed
- Increase O2 consumption rate with nozzle length
- Thrust augmentation >50% measured

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Fully Reusable NTR-Powered Transfer Vehicle
"The Key to Affordable Lunar Transportation"

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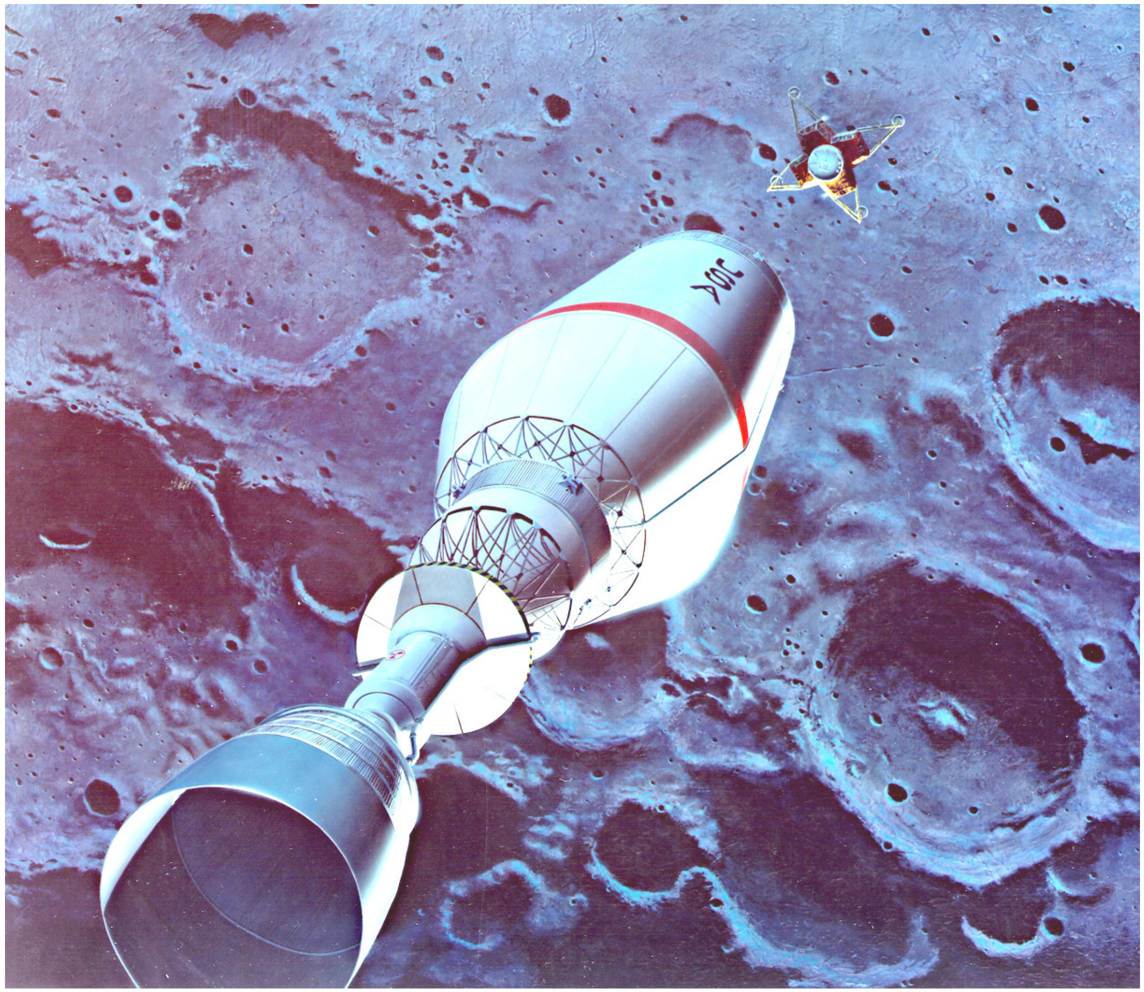

Ref: Borowski, NASA/TM 106739

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Robotic Science "Hybrid" BNTEP Vehicle

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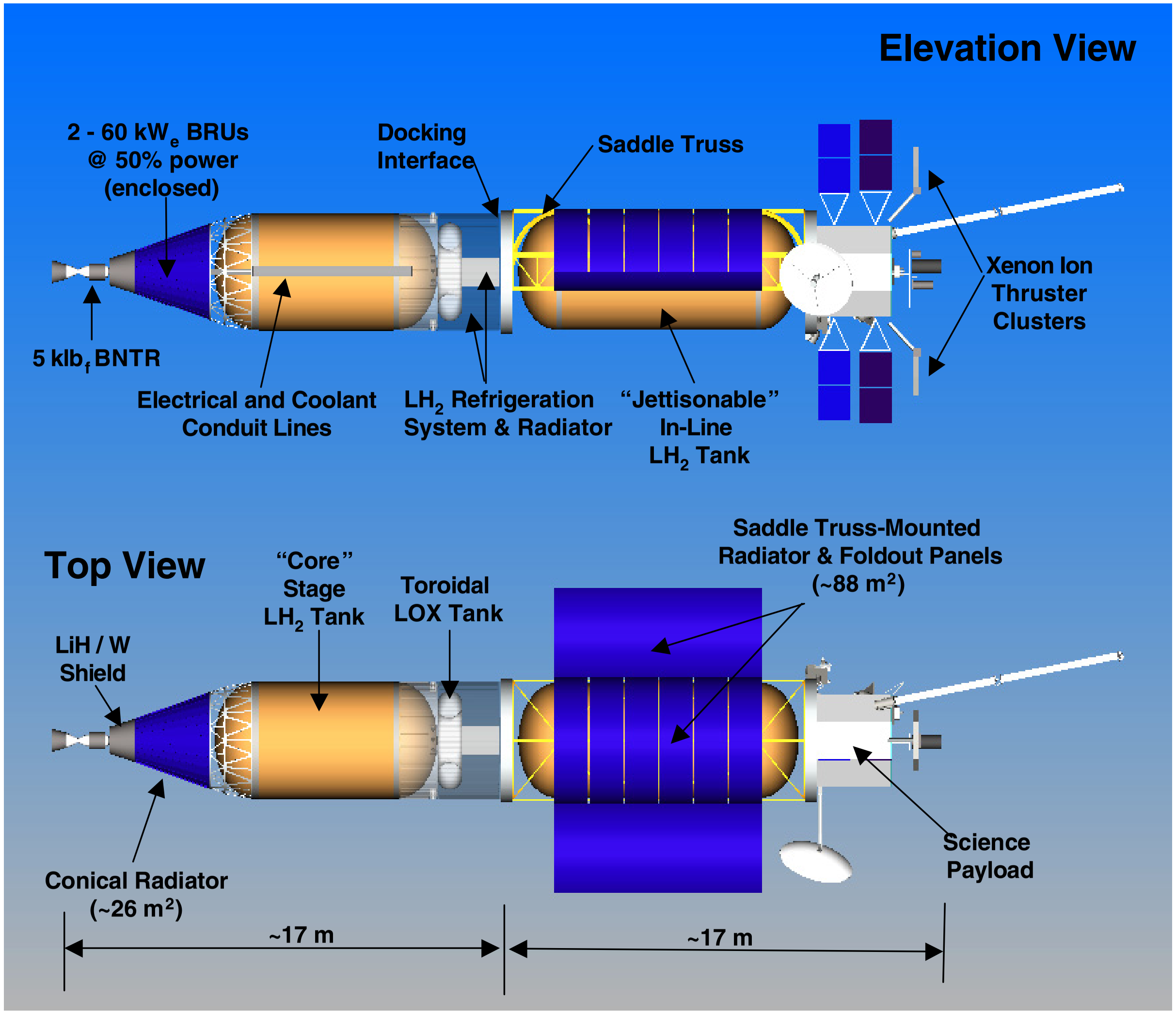

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Significant Technology Development is Underway To Support Design Definition for Future "Bimodal" NTR Human Exploration Missions

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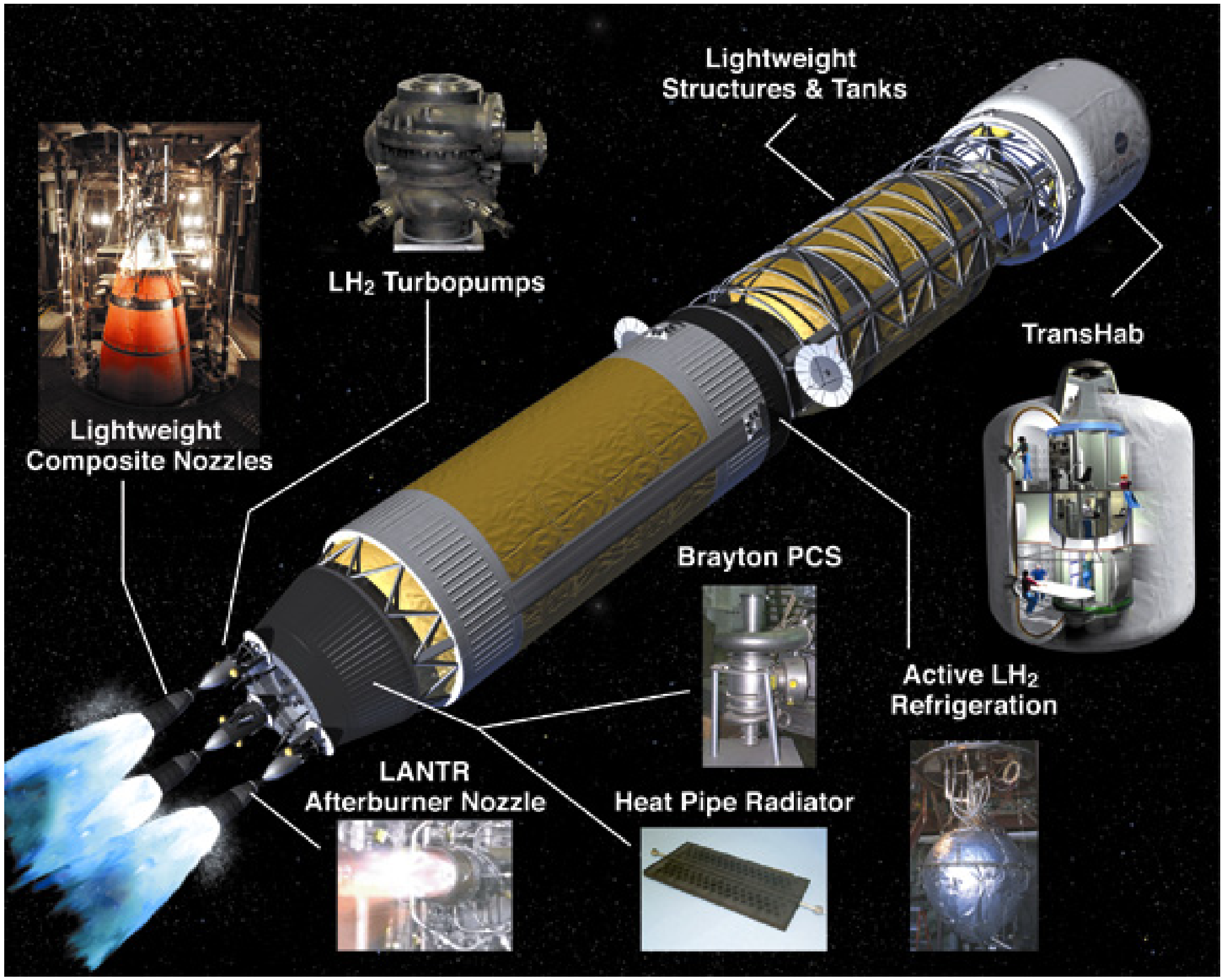

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