Nuclear Cryogenic Propulsion Stage Conceptual Design & Mission Analysis

Outline:

1. Stage Design
2. Interplanetary Trajectory Design
3. Launch Vehicle Utilization

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2037 NTP Mission/Architecture Stack BBC

Baseball card as of 3/22/2013 -- 4.1 SLS launches

Nuclear Thermal Propulsion -- Mars Piloted Stack

Design Constraints / Parameters:

• # Engines / Type:	3 / NERVA-derived
• Engine Thrust:	25 klbf (Pewee-class)
• Propellant:	LH2
• Specific Impulse, Isp:	900/nom. - TBD/max sec
• Tank Material:	Aluminum-Lithium
• Truss Material:	Composite
• RCS Propellants:	NTO / MMH
• RCS Thruster Isp:	328 sec (Fregat Isp)
• Passive TPS:	0.75" SOFI + 60 layer MLI
• Active CFM:	ZBO Brayton Cryo-cooler
• I/F Structure:	Stage / Truss Docking Adaptor w/ Fluid Transfer

2037 Trajectory Constraints / Parameters:

• TMI ΔV1:	1934 m/s (1813-1936)
• TMI ΔV2:	2084 m/s (1976-2172)
• MOI ΔV:	934 m/s (1029-1806)
• TEI ΔV:	1475 m/s (827-1524)
• Outbound time:	212 days (158-225)
• Stay time:	489 days (448-569)
• Return time:	220 days (195-238)
• TMI, MOI & TEI	1% ΔV Margin/FPR/other
• TMI Gravity Losses:	~377 m/s total, f(T/W_0)
• MOI & TEI g-losses:	Additional 1%
• Post-TMI RCS ΔVs:	182 m/s (>>7 burns)
• Tank Masses (C, I, D)	Details In MEL

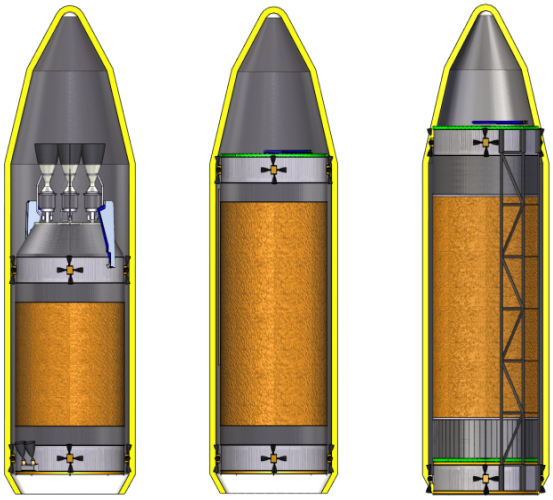
Description:

NTP system consists of 3 elements: 1) core propulsion stage, 2) in-line tank, and 3) integrated saddle truss and drop tank assembly that connects the propulsion stack to the crewed payload element for the Mars 2037 mission. Each element is delivered to LEO (~407 km circ) fully fueled on an SLS LV (183.77.00, 10-m O.D. / 9.1-m 25.5 m cyl. §). They are sized for an SLS capability of ~109 mt. The stage uses three 25.1 klb_f engines w/ either a NERVA-derived or ceramic-metallic (CerMet) reactor core. It also includes RCS, avionics, power, long-duration CFM hardware (e.g., COLDEST design, ZBO cryo-coolers) and AR&D capability. Saddle trusses use composite material and the LH_2 drop tank employs a passive TPS. I/F structure includes fluid transfer & electrical.

2037 Core stage (C)	FY13 md-trn
Engine Isp, sec	900
Inert Mass, mt	46.20
Three 25 klbf NTP Engines	12.32
Three External Radiation Shields	6.45
Tank m_inert (w/ everything else)	27.42
Usable LH2 Mass, mt	47.27
RCS Usable Prop Load, mt	15.58
Boil-off to ullage, mt	0.00
Stage wet mass total, mt (on pad)	**109.05**
Stage Length, m (engines, RCS, I/F)	~24.8
Approx. Effective LH_2 PMF / λ	0.51
2037 In-line Tank (I)	
Inert Mass, mt (w/ everything)	29.75
Usable LH2 Mass, mt	76.29
RCS Usable Prop Load, mt	2.18
Stage wet mass total, mt (on pad)	**108.21**
Engine Isp, sec	900
Stage Length, m (incl. RCS & I/F)	~25.7
Approx. Effective LH_2 PMF / λ	0.72
Saddle Truss & Drop Tanks, <$1^1/_2$ (D)	
Inert Mass, mt	28.76
Saddle Trusses (w/ everything)	6.92
Drop Tanks (w/ everything)	20.85
Usable LH2 Masses mt	84.03
RCS Usable Prop Loads, mt	4.08
Boil-off, mt	1.54
Stage wet mass total, mt (on pad)	**118.41**
Engine Isp, sec	900
Stage Length, m (incl. RCS & I/F)	~27.8
Approx. Effective LH_2 PMF / λ	0.74
Payload Mass Total (on pad)	**78.48**
Deep Space Hab (stocked)	51.85
MPCV (CM+SM, no prop)	14.49
Payload RCS/Truss/Canister	12.14
Mars stack interim total	**414.15**
Start-up/Shut-down LH2, mt (4-burns)	3.96
Crew, mt	0.79
Less mass exp. prior to TMI, mt	(13.96)
Total TMI- Stack Mass, mt	**400.99**

Launch Configurations

Four+ 183.77.0x SLS LVs (Payload launch not shown)



Core | Inline | Drop Tank

2037 NTP Core Stage BBC

(Indiv. baseball card as of 2/14/2013)

Nuclear Thermal Propulsion -- Mars Piloted Stack

Core Propulsion Stage

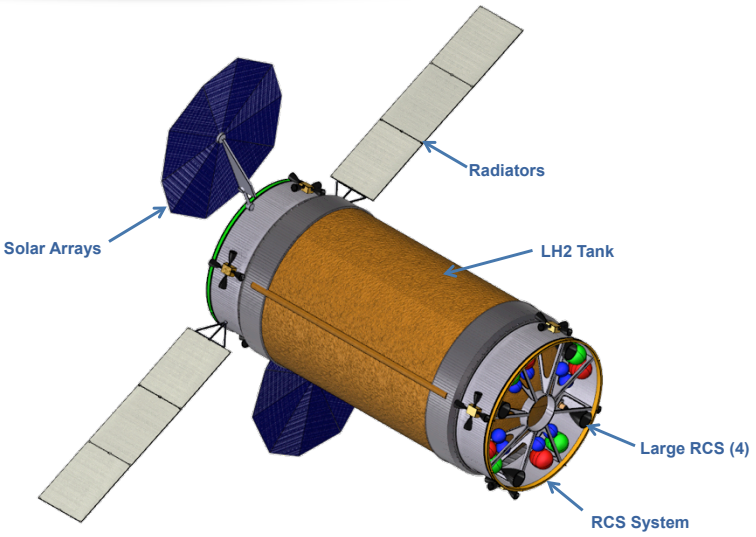
Three 25 klb$_f$ NTRs

Design Constraints / Parameters:

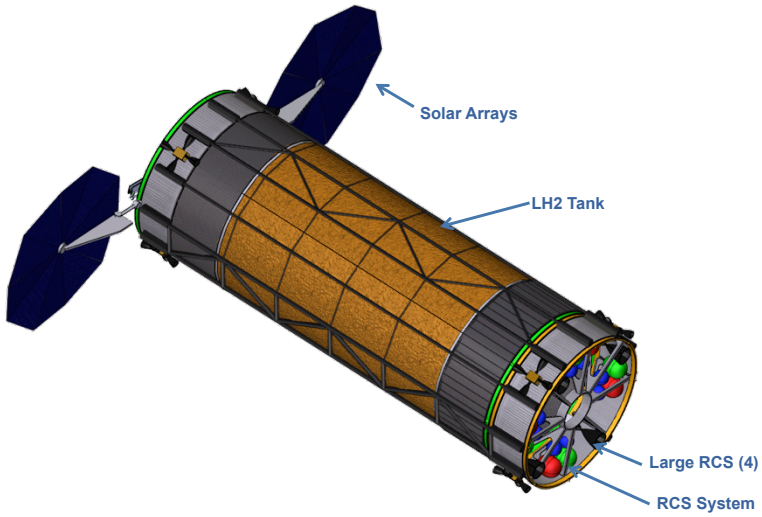
• # Engines / Type:	3 / NERVA-derived
• Engine Thrust:	25 klbf (Pewee-class)
• Propellant:	LH2
• Specific Impulse, Isp:	900 - TBD sec
• Tank Material:	Aluminum-Lithium
• Truss Material:	Composite
• RCS Propellants:	NTO / MMH
• RCS Thruster Isp:	325 sec (Fregat Isp)
• Passive TPS:	0.75" SOFI + 60 layer MLI
• Active CFM:	ZBO Brayton Cryo-coolers
• I/F Structure:	Stage / Truss Docking Adaptor w/ Fluid Transfer

	NCPS Core Stage (C)	Basic Mass (kg)	Cont. (kg)	Predicted Mass (kg)
1.0	Structures	11,765.09	1947.39	13,712.49
2.0	Propulsion	17,953.39	3705.63	21,659.02
3.0	Power	994.66	249.97	1244.63
4.0	Avionics	624.66	107.66	732.32
5.0	Thermal	2726.40	460.29	3186.69
	Dry Mass	34,064.20	6470.94	40,535.14
6.0	Non-Propellant Fluids	4457.57		4457.57
	Total Inert w/o ΔV Prop	38,521.77		44,992.71
6.1.x	Boil-off/start-up/shut-down	1980.00		1980.00
	Burn-out mass	36,541.77		43,012.71
7.1	Usable LH2	41,672.00		41,672.00
7.2	Usable RCS	16,981.00		16,981.00
	Element Mass (on Pad)	97,174.77		103,645.71
		SLS LV lift capability, kg:		100,559

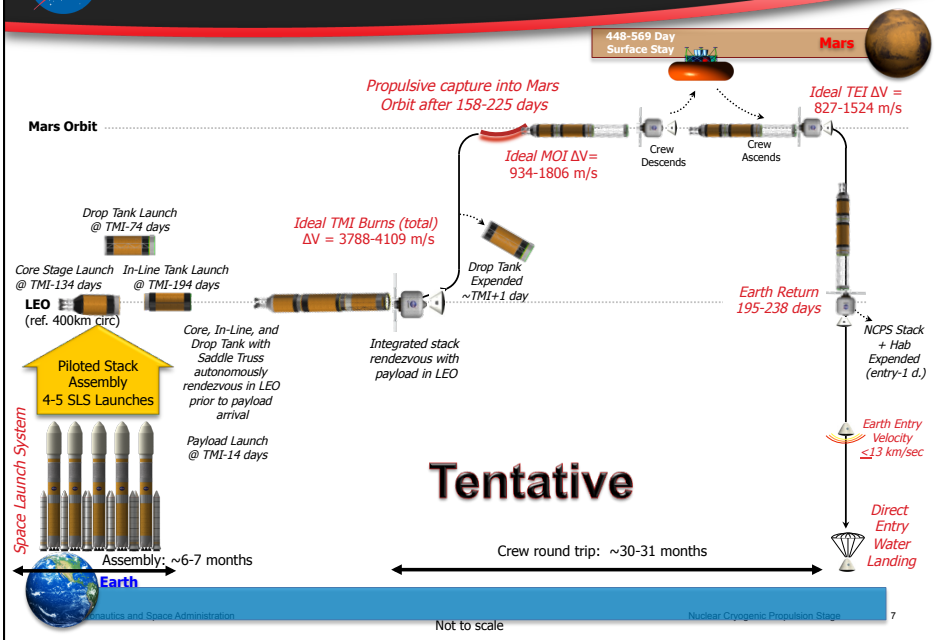
Configuration - Inline



Configuration - Drop Tank

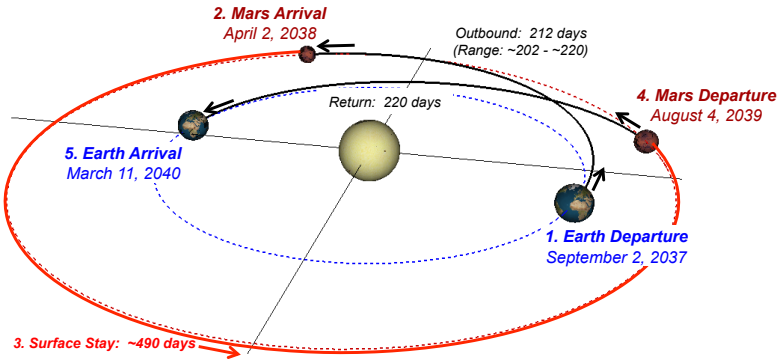


NCPS Mission Profile



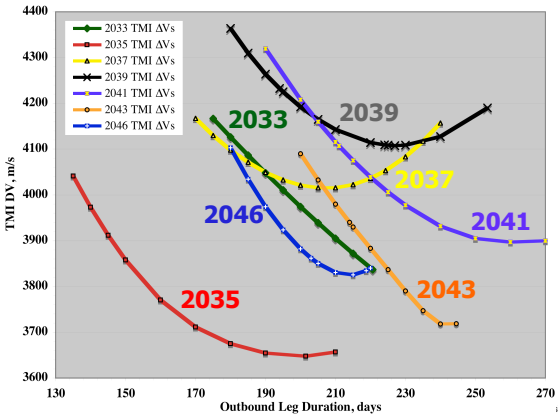
Piloted Mars Mission

- Piloted Mission (Example 2037 opportunity shown):



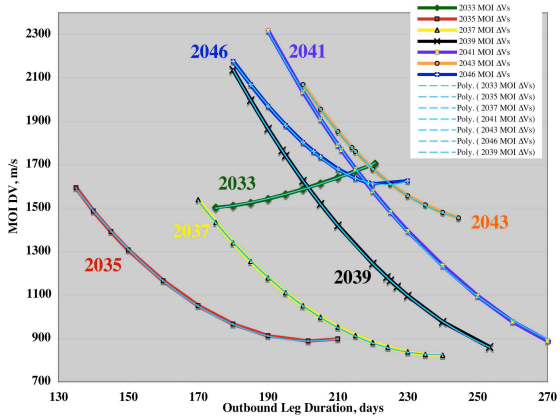
TMI ΔV vs. Outbound Trip Time

- **At some outbound TT value all curves will have a minima** (porkchop plot ridge)
- **Due to Mars' eccentric orbit, these curves are scattered all over the trade space**
- **Lowest order curve fits w/ good** (enough) **R^2 results were selected;** w/in ~1-few m/s
- **Corresponding plots for MOI and TEI exist ..** just takes time to get them documented
- **Note: Color of opportunity label matches the color of the curve it's for**



MOI ΔV vs. Outbound Trip Time

- **At some outbound TT value all curves will have a minima** (porkchop plot ridge)
- **Due to Mars' eccentric orbit, these curves are scattered all over the trade space**
- **Lowest order curve fits w/ good** (enough) **R^2 results were selected;** w/in ~1-few m/s
- **Note: Color of opportunity label matches the color of its curve**

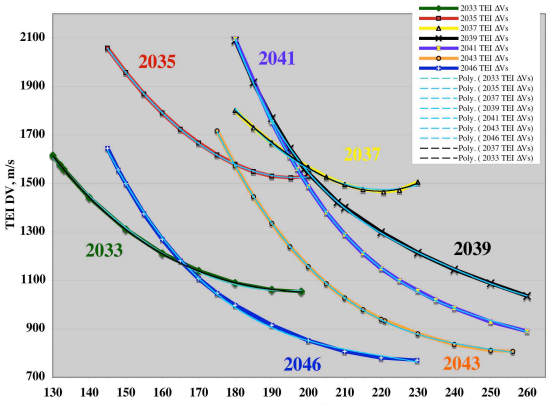


TEI ΔV vs. Return Trip Time

- **At some outbound TT value all curves will have a minima** (porkchop plot ridge)
- **Due to Mars' eccentric orbit, these curves are scattered all over the trade space**
- **Lowest order curve fits w/ good** (enough) **R^2 results were selected;** w/in ~1-few m/s

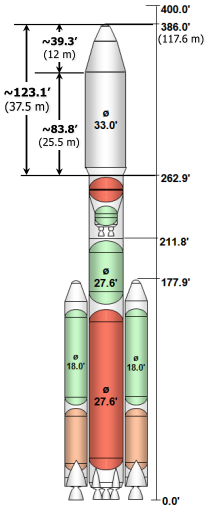
Notes:

- **Color of opportunity label matches the color of the curve it's for**
- **2-piece curve fits supercede the 1-piece curve fits for 2039, 2041, 2043, & 2046**



SLS 183.77.00 -- Mars Mission

- **Net performance: 254,034 lbm (115.23 mt)**
- 10% SLS margin reduces this capability to 115.23 mt
- HAT 5% HQ reserve reduces this perf. to 109.47 mt
- **Liquid boosters shown here are considered only as a possible option** (for the decade of the 2030s)



- **SLS LV for NCPS mission to be updated by the 190.31.xx series**

Update w/ New Launch Vehicle

	Pre-Conceptual Design w/ SLS 178.35.01	w/ SLS 183.77.01
2037 Opp. TMI/MOI/TEI:	4018 / 934 / 1475 m/s	**4018 / 934 / 1475 m/s**
TMI Gravity Losses & T/W_0:	389 m/s / 0.083 g's	**377 m/s / 0.085 g's**
2037 Trip times:	212 days (outb.), 220 (return)	**212 days (outb.), 220 (return)**
Stack mass at TMI:	413 mt	**403.3 mt**
Transportation burn-out mass: **Core Stage:** **In-line tank:** **Drop Tank(s)+Truss(es):**	108 mt 43.0 mt 27.6 mt 37.4 mt	**101 mt** **44.2 mt** **28.8 mt** **27.8 mt**
Stack LH2 Prop mass:	211.4 mt	**207.6 mt**
Non-Prop mass:	14 mt (incl. above)	~15 mt (incl. above)
LH2 prop boil-off: **Core Stage** (into ullage): **Drop Tank:**	 0.2 mt 1.54 mt	 **0.2 mt** **1.54 mt**
NCPS Launch manifest: **1: NCPS In-line tank** **2: NCPS Core Stage** **3: NCPS Drop tank #1** **4: NCPS Drop tank #2** **5: Mars Payload (DSH/etc.)**	On pad mass: (% HAT mass cap.) 103.6 mt (103%) 100.5 mt (100%) 100.6 mt (100%) ~51 mt (~50%) 80.5 mt (~100%)	**On pad mass:** (% HAT mass cap.) **108.2 mt** (100%) **109.0 mt** (100%) **109.0 mt** (100%) **~9 mt** (~10%) **78.5 mt** (~100%)
# SLS Launches:	4.5	**4.1**

Na

NCPS Piloted Stack Size, 2033 - 2046

FY13 Mission Model -- 2035 & 2037 "What if" cases

- **NCPS sizing for all opportunities in the next 15-year cycle**
  - All results are from the new(er) Mission Model informed by the ACO design activity
  - Attempted to get all cases down to 4 LVs using trip time
  - When 4.0 SLS LVs was not possible, settled on reasonable length outbound/return legs
  - The 2035 opportunity can have short(est) durations on 4.5 - 5 LVs
  - The 2037 opportunity cases have all their 'margin' used to on 4.5 - 5 LVs