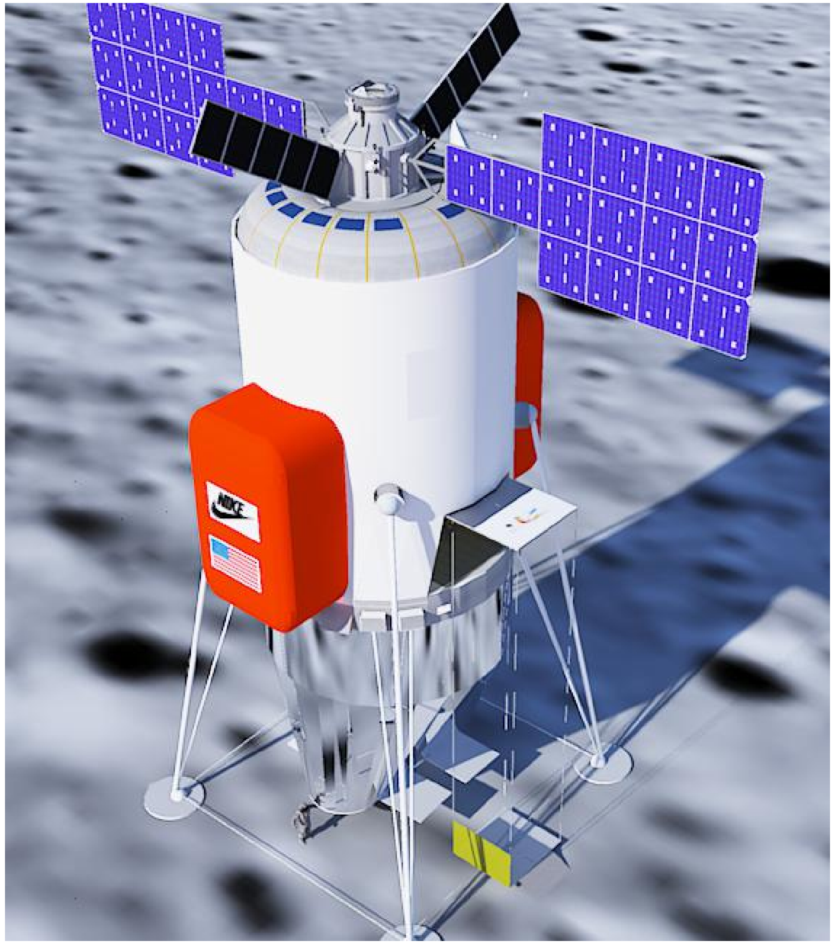
Vestal Lunar System

Additional Technical Information

Version 1.0



Summary: Key VLS (Vestal Lunar System) Features

- Based about 80-85% on HLS Starship & Other SpaceX proven tech (cost savings)
- LEO -> Lunar Surface -> LEO Operations with 100% (1200 t) LEO fill up
  - Transfer crews in LEO to and from Earth Surface using Crew Dragon and potentially Starliner and/or Dream Chaser
  - No need for SLS/Orion/Gateway (although it is compliant, so this could be a stand in HLS Starship)
- VLS is highly reusable
  - Some non-reuse in F9/CD (F9 second stage and CD trunk)
  - 2 4 T Cargo Pods left on moon surface
- Allows for a 47-50 t dry mass vehicle with 10 t crew and cargo
- Can be used as LEO Space Station / Hotel when not on lunar missions (extra revenue)
  - Can free fly away from OTV in LEO as well
- OTV by itself can be used for other mission types, such as large satellite placement into GEO (extra revenue)

$150M per person for 1 month of LEO -> Lunar Adventure?

Key Lunar Exploration System Prerequisites

- Must haves (all needed for the SpaceX HLS Starship concept as well)
  - Super Heavy + Expendable Starship can lift 120 t reliability to LEO
  - Super Heavy is somewhat reusable
  - LEO refueling is at least 95% efficient
  - Fuel boil off is less than 5% per month
  - ---> about $1B recurring per complete mission (but no SLS/Orion/Gateway needed)
- Cost reducers
  - 10x+ Super Heavy reuse (Making that cost less than $15M per mission)
  - Some Starship reuse (Making that cost drop to about $5M with 10x reuse)
  - ---> about $300M recurring per complete mission

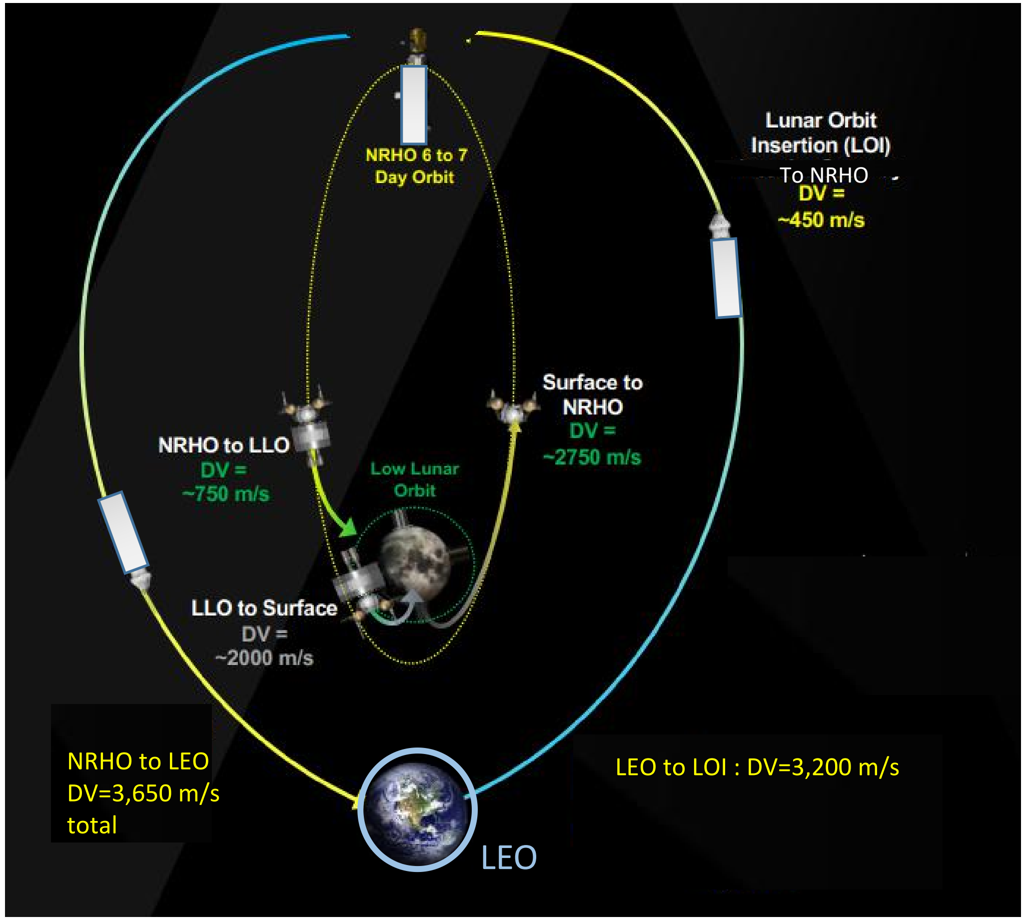
NRHO: Near Rectilinear Halo Orbit

REF: https://www.nasa.gov/sites/default/files/atoms/files/20191030-nac-heoc-smith-v3_tagged.pdf
Graphic modified to replace Gateway and SLS with Lunar Vestal elements

The NRHO is a highly inclined orbit around the moon and is considered to be in cislunar space. Cislunar is Latin for "on this side of the moon" and generally refers to the volume between Earth and the moon. Cislunar space includes LEO, Medium Earth Orbit, GEO, as well as other orbits, such as Low Lunar Orbit and NRHO, the intended orbit for the Gateway.

The NRHO is a seven-day cycle, taking the Gateway as close as approximately 1,600 km (1,000 miles) and as far away as about 68,260 km (42,415 miles) from the lunar surface. Consequently, roughly every seven days, the lunar lander can depart the Gateway to travel to the lunar surface. Because the Gateway can sit in this halo orbit, almost like it's held in place by the gravity of Earth and the moon, it requires little energy for stationkeeping or to maneuver into other cislunar orbits. The orbit is called a "halo" orbit because the tracked orbit looks like a halo around the moon.

REF: https://blog.maxar.com/space-infrastructure/2019/what-is-cislunar-space-and-a-near-rectilinear-halo-orbit



THUS:
DV From LEO <-> NRHO = 3,650 m/s each way
DV From NRHO <-> Surface = 2,750 m/s each way

Draft DV & Fuel Calculations

Needs lot of detailing, expansion and design estimation

Vestal Lunar System (VLS) DV CALCULATIONS

$$\Delta v = v_e \ln \frac{m_0}{m_f} = I_{sp} g_0 \ln \frac{m_0}{m_f}$$

<---- OTV ---->

Lander -->

1 m of tankage height = 48 t of fuel = 1.3 t of tank mass per meter

Masses in Metric Tonnes

Sequence	Mission Phases	DV Needed Per NASA Artemis	DV (m/s)	Mo	Mf	OTV	OTV Fuel Phase Start	OTV Return Fuel Reserve	Tankage (meters high)	Lander Fuel Phase Start	Lander Fuel Return Reserve	Lunar Lander Dry Mass	Crew	Consumables	Other Cargo to Moon	Cargo to Earth	Total Dry Mass
	60 TONNE DRY MASS OTV WITH ABOUT 1200 TONNE FUEL IN LEO <-> NRHO CAN TRANSPORT AND FUEL HOW MUCH LANDER AND CARGO?																
2	Lander NRHO->Surface	2.75 km/s	2751	242	115	n/a	n/a	n/a	3.05	183	56	50	0.8	0.5	8	n/a	59
3	Lander Surface -> NRHO	2.75 km/s	2745	107	51	n/a	n/a	n/a	3.05	56	n/a	50	0.8	0.2	n/a	1	51
1	OTV+Lander LEO->NRHO	3.65 km/s	3684	1317	487	75	1000	170	<- Change to make optimize DV match for each phase								
4	OTV+Lander NRHO->LEO	3.65 km/s	3806	352	126	75	170	n/a	TOTAL FUEL:		1183						
	RESULT: 75 T OTV + 50 TONNE DRY MASS LUNAR LANDER + 10 TONNE CREW & CARGO TO MOON, 1 TONNE BACK TO																

DV Assumptions (you may have different ones)

High estimate, potentially 5-10 T might be traded to Lander

<-- We are assuming that same fuel fill as HLS Starship as a direct comparison. But you can add up around 150 T to the Lander in LEO as well if needed.

The SpaceX VacRaptor Engine

$1\,\mathrm{N} = 1\,\mathrm{kg} \cdot \mathrm{m/s}^2$

F = ma ->a = F/m

F = Thrust = 1,810,000 N = 1,810,000 (kg*m/s^2)

a = 1,810,000 (kg*m/s^2) /mass of fueled vehicle (kg) = X m/s^2

Thrust	~185 t_f (1.81 MN; 410,000 lb_f) for Raptor 1
Throttle range	40–100%
Thrust-to-weight ratio	200, sea-level, goal <120, vacuum
Chamber pressure	300 bar (4,400 psi)[5] 330 bar (4,800 psi)~7 s test
Specific impulse (vacuum)	378–380 s (3.71–3.73 km/s)
Specific impulse (sea-level)	330 s (3.2 km/s)[5]
Mass flow	~650 kg/s (1,400 lb/s):[6] ~510 kg/s (1,100 lb/s), O_2[7] ~140 kg/s (310 lb/s), CH_4[7]
Dimensions	
Length	3.1 m (10 ft)[8]
Diameter	1.3 m (4 ft 3 in)[9]
Dry weight	1,500 kg (3,300 lb), goal

Lunar Lander masses at different mission phases

using 1 engine or 2 at 50% thrust

Raptor full thrust	per 1	1,181,000	N	
Force of Lunar Gravity (N)	Mass (T)	Acceleration (m/s^2)	Gs	
402500	250	4.72	0.48	
386400	240	4.92	0.50	
370300	230	5.13	0.52	
354200	220	5.37	0.55	
338100	210	5.62	0.57	
322000	200	5.91	0.60	<-First NRHO burn
305900	190	6.22	0.63	
289800	180	6.56	0.67	
273700	170	6.95	0.71	
257600	160	7.38	0.75	
241500	150	7.87	0.80	
225400	140	8.44	0.86	
209300	130	9.08	0.93	
193200	120	9.84	1.00	<- Landing burn
177100	**110**	**9.13**	**0.93**	**<- Surface launch (less lunar gravity)**
161000	100	11.81	1.21	
144900	90	13.12	1.34	
128800	80	14.76	1.51	
112700	70	16.87	1.72	
96600	60	19.68	2.01	<-Final NRHO Burn
80500	50	23.62	2.41	
64400	40	29.53	3.01	
48300	30	39.37	4.02	

Single or Double Raptor Engine ops should fall within 3 g limits

SuperDraco

Rocket engine

SuperDraco is a hypergolic propellant rocket engine designed and built by SpaceX. It is part of the SpaceX Draco family of rocket engines. A redundant array of eight SuperDraco engines provides fault-tolerant propulsion for use as a launch escape system for the SpaceX Dragon 2, a passenger-carrying space capsule. Wikipedia

Propellant: NTO / MMH

Application: Launch escape system, propulsive landing

Chamber pressure: 6.9 MPa (1,000 psi)

Thrust (sea-level): 71 kN (16,000 lbf), individually; 32,000 lbf, dual-engine cluster

Specific impulse (sea-level): 235 s (2.30 km/s)

Looks like some lower power engines needed to make a soft hovering landing on the lunar surface. The powerful Raptor would need to pulse it's way down for the "light" LSE (Lander) concept ... maybe a bad idea for the Raptor and the surface ejecta

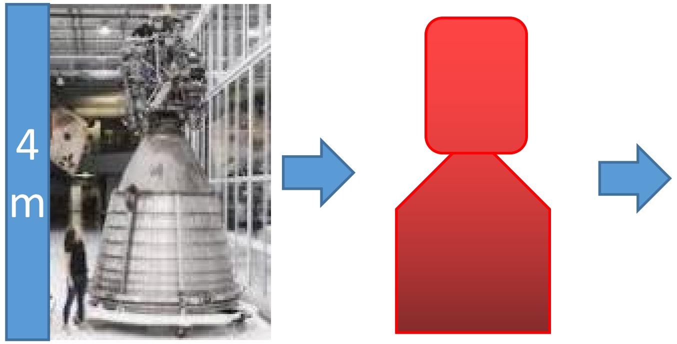
SuperDracos		Number			
	each N (kg*m/s^2)	4		fuel rate per SD	
	71,000	284,000	N	31	kg/s
			hop height:	50	m
Force of Lunar Gravity (N)	**Mass (kg)**	**Net Accl (m/s^2)**	**Kg of fuel to hop**		
161,000	100,000	1.23	559		
152,950	95,000	1.38	528		
144,900	90,000	1.55	499		

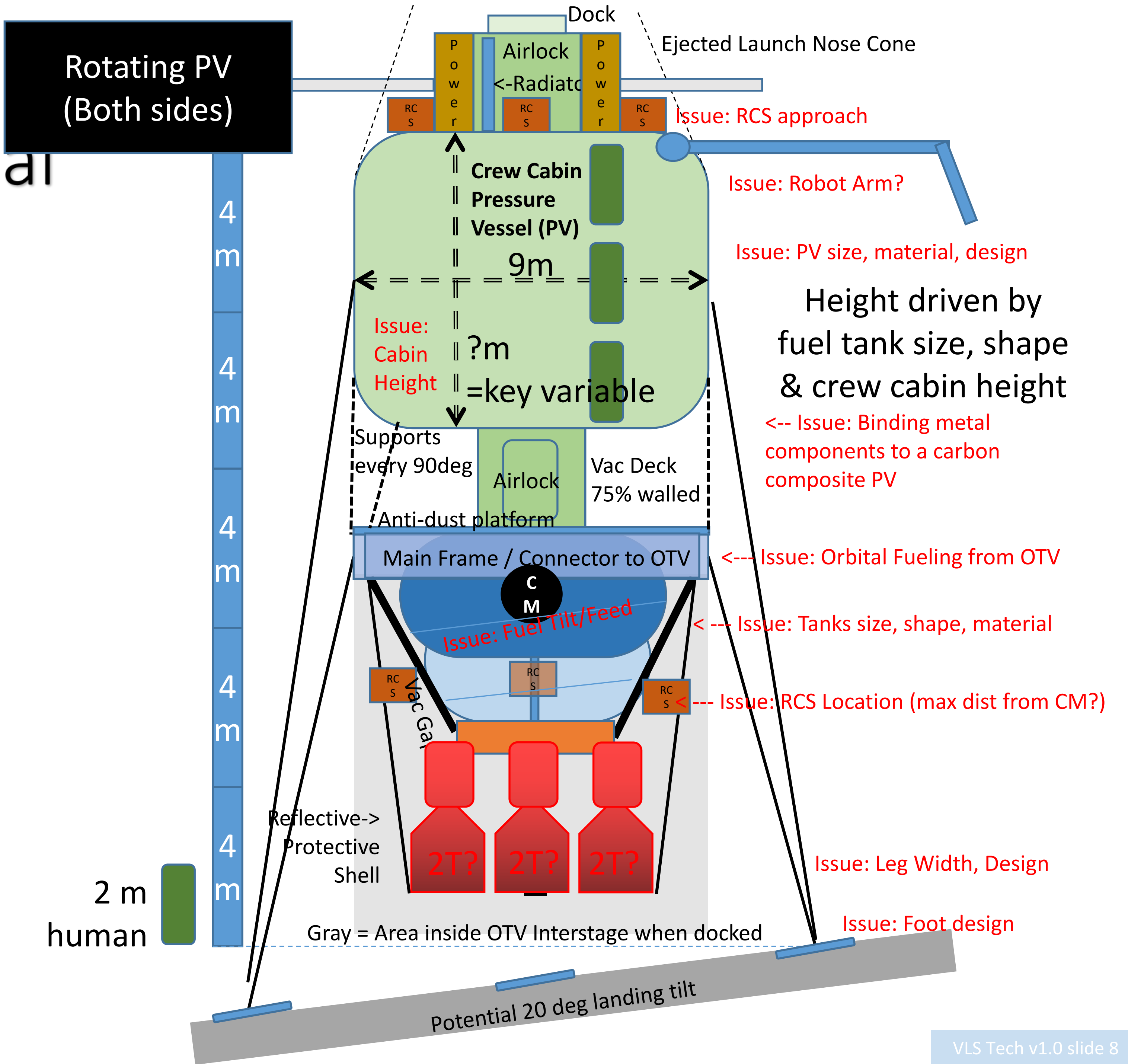
So, 4-8 SuperDracos with 2 T hydrazine between them can conduct lunar ops under 100 m from the surface. Hopefully there will be a small MethLox engine that can work to simplify the fuel mix.

VS Lunar Lander Notional Side View + Some Key Issues

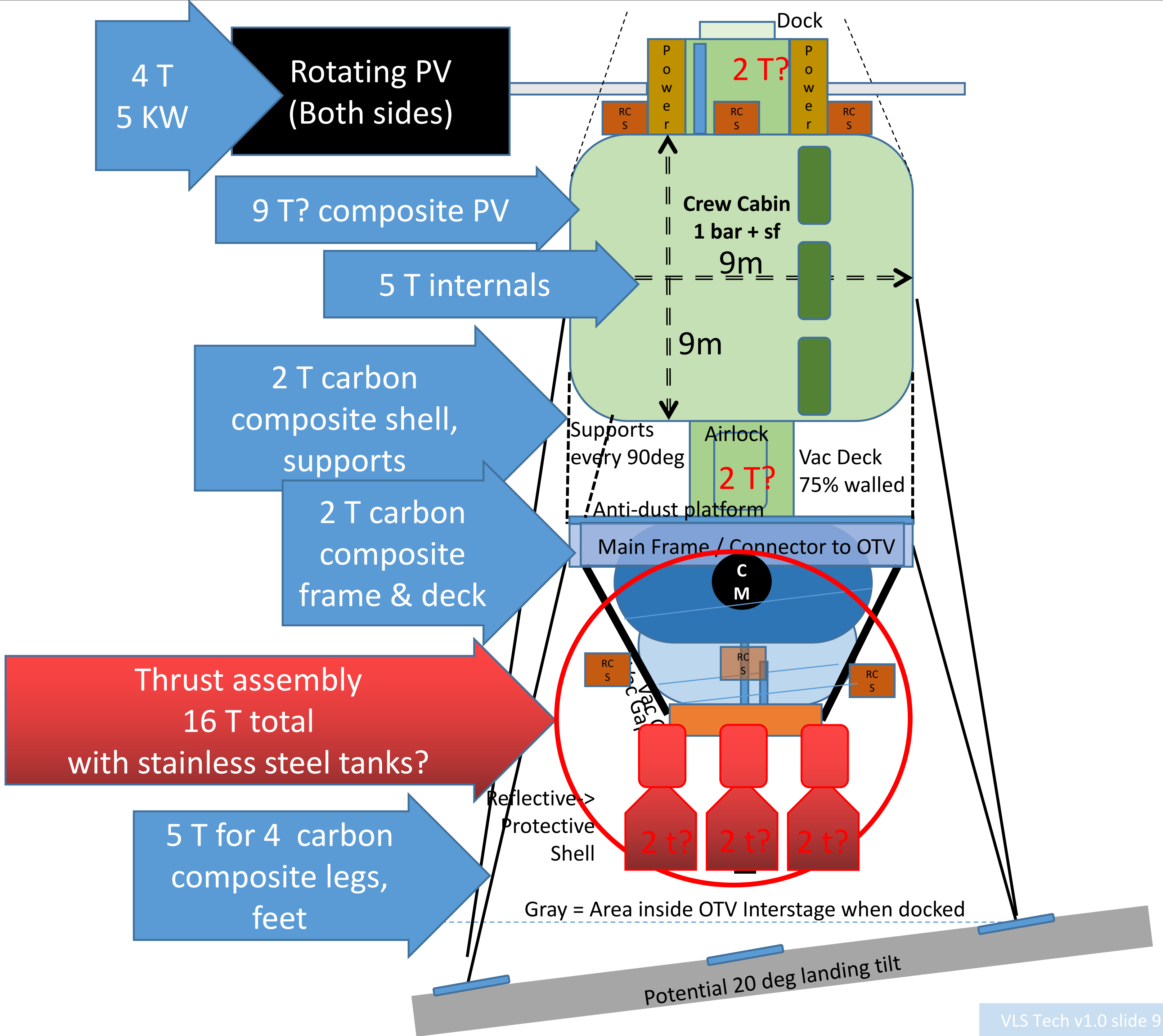
Issue: is 50 tonne dry mass possible?

Size Lander against size of VacRaptor





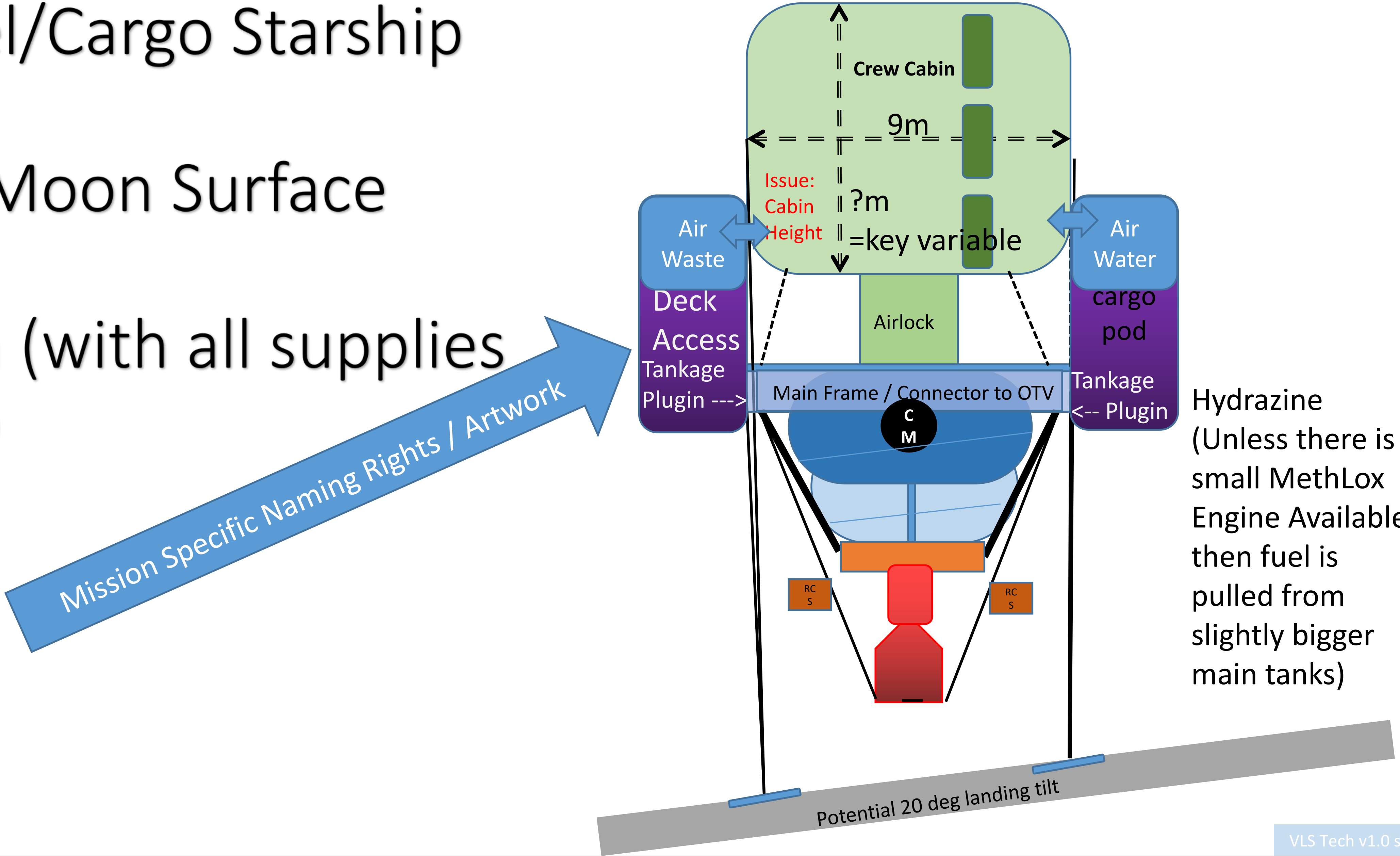
Estimating masses
47-50 T drymass
57-60 T w/ cargo



2 Cargo Pods, brought up by a Fuel/Cargo Starship

Left on Moon Surface

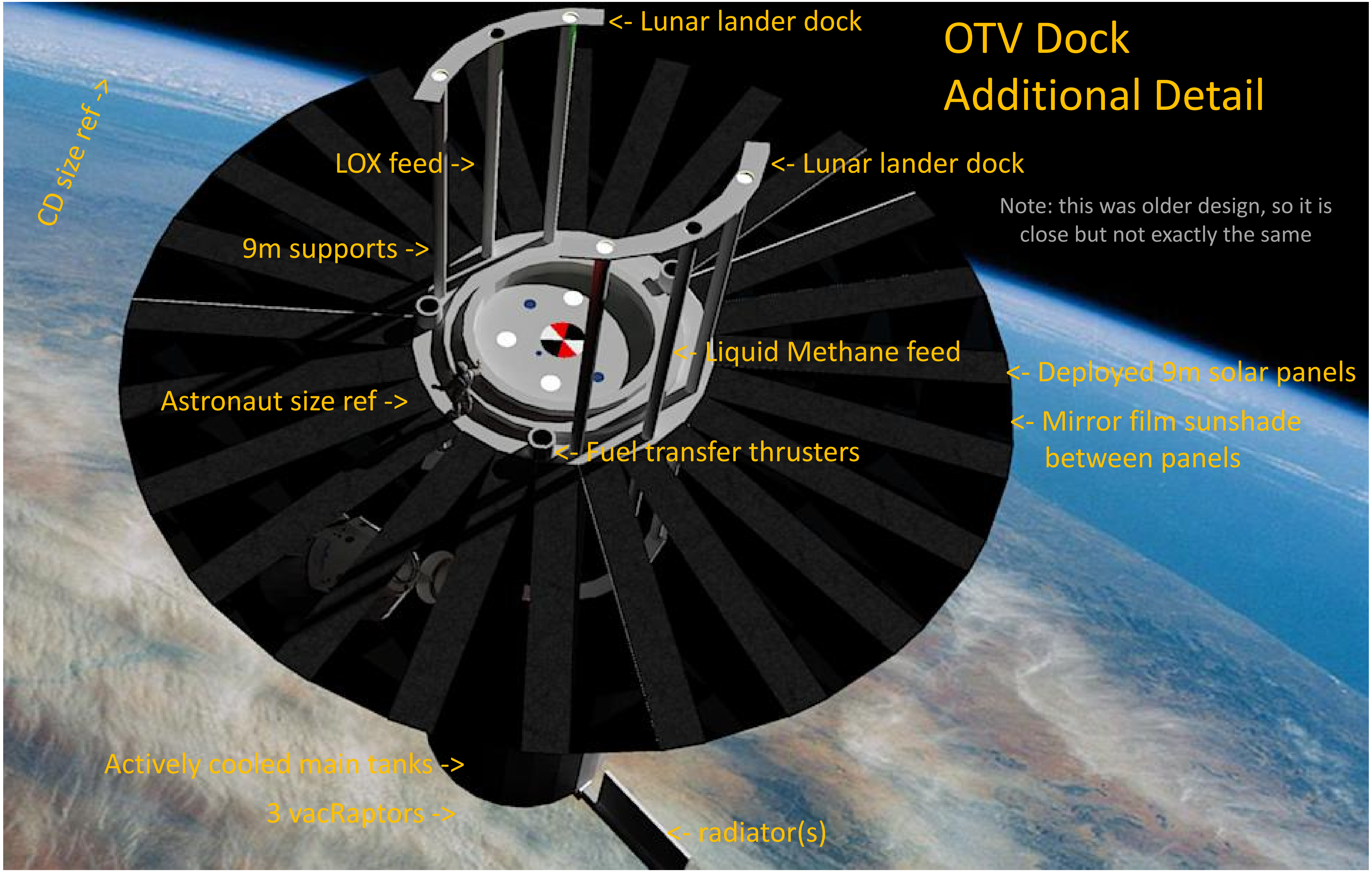
4 T each (with all supplies needed)



Hydrazine (Unless there is small MethLox Engine Available, then fuel is pulled from slightly bigger main tanks)

Why did I start thinking about this?

- I could not get over how much unused mass is going from NRHO to the Lunar surface and back to NRHO with the current SpaceX HLS Starship proposal
  - Thus HLS seems more top heavy than needed (potentially unstable on surface)
  - Thus the crew access to the surface seems much higher than needed
  - Thus the crew cabin and cargo mass is limited
  - Thus HLS Starship can’t be reused without some non-LEO refueling
  - Given that the current plan is only LEO refuel, the HLS Starship for HLS Demo-1 will be left in a near-NRHO parking orbit and a new one will be used for Demo-2 (not a good reuse story)
- I have been trying to imagine a Starship sized LEO->Lunar Surface->LEO story
  - Let’s use a proven F9/CD and then add **one** manned element for the rest of the mission
  - Yes, cutting out the $3-4B per mission of the SLS/Orion/Gateway/HLS plan is needed to make a sustainable lunar presence economically possible

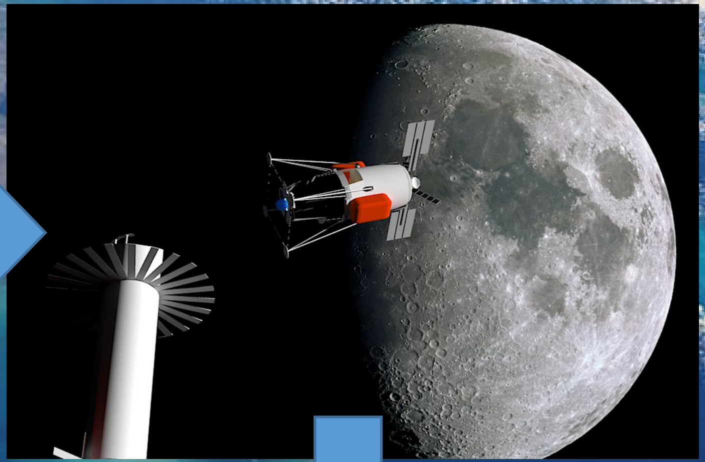


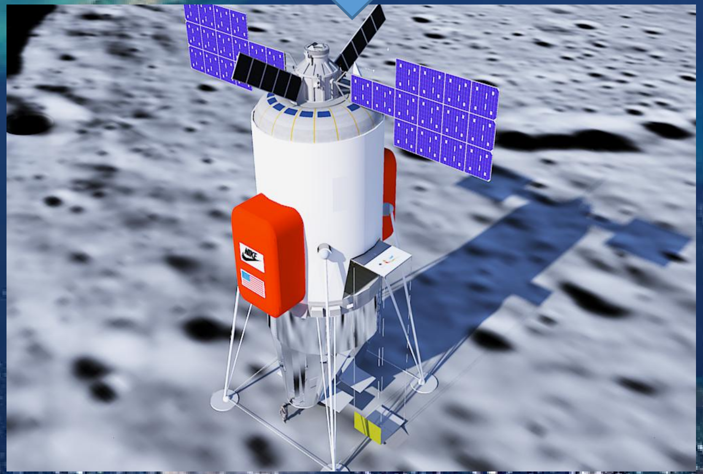
OTV Dock
Additional Detail
<- Lunar lander dock
<- Lunar lander dock
Note: this was older design, so it is close but not exactly the same
CD size ref ->
LOX feed ->
9m supports ->
<- Liquid Methane feed
<- Deployed 9m solar panels
<- Mirror film sunshade between panels
Astronaut size ref ->
<- Fuel transfer thrusters
Actively cooled main tanks ->
3 vacRaptors ->
<- radiator(s)

Vestal Lunar

LEO and Lunar tourism concept

A call for quick reviews and ideas
Non-technical ideas welcome





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