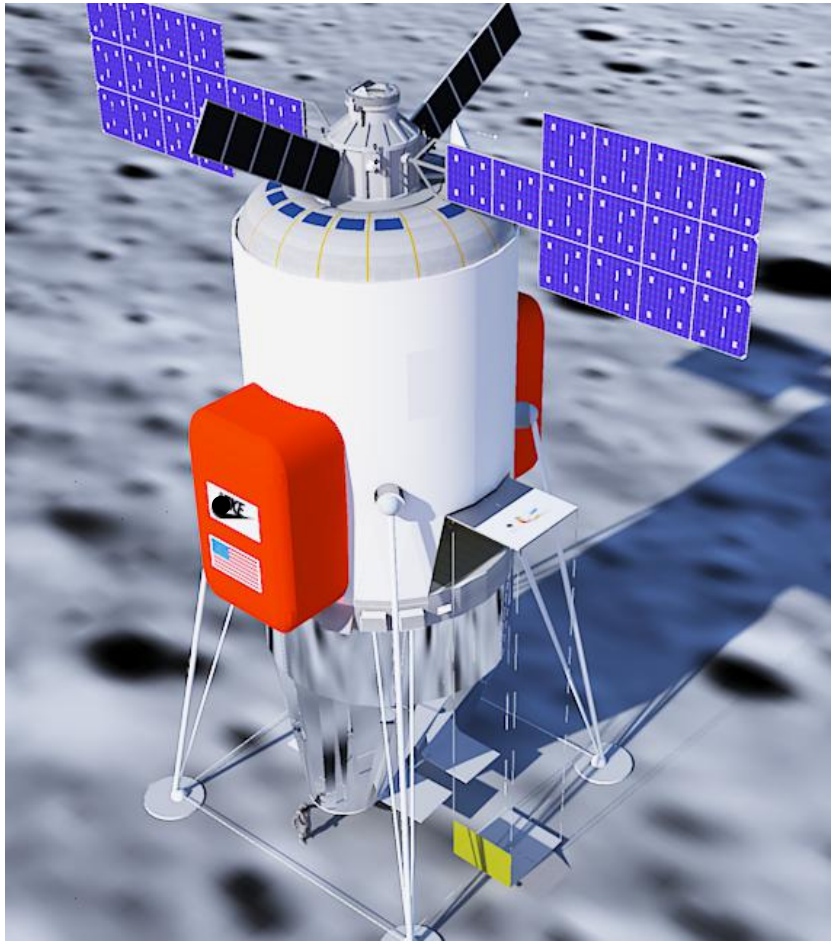
Vestal Lunar System (Concept)

LEO and Lunar Tourism

Based on a SpaceX Starship as an Orbital Transfer Vehicle (OTV)



Challenge Context and Common Terms

Challenge Context

- This is a very speculative “way out there” concept, look for show stoppers
- You don’t need to be a rocket scientist to come up with a winning idea or observation
- Assume that SpaceX would be willing to sell the Lunar Vestal Corporation anything they have developed including an HLS Starship, extra engines, cargo and fueling services, Crew Dragon services ...
- Don’t worry too much about how much something would cost. Affordability is a secondary issue
- **Safety is a key issue** from start to finish.
- The time frame for this concept might have the purchase of a proven HLS Starship in 2027 and first operations in 2030
- The depictions in this presentation are just approximations, often shadows and lighting are not perfectly aligned with the backgrounds

Common Terms

- **Orbit** is the path around a large body that keeps it in a repeating path (at least in the short term)
- **Freefall** and weightlessness are more accurate terms for the commonly used zero-gravity
- **Delta-V** (DV) is the change in velocity created by thrusters/engines using fuel. For reference the Delta-V to get into Earth Low Earth Orbit from the Surface is more than 7.7 km/s (with that velocity you can circle the Earth very 90 minutes)
- **CD =** SpaceX’s proven Crew Dragon system
- **T** = Metric Tonne = 1000 kg

Suggested comment topic are shown in gray boxes

Challenge:

This is mainly about having some fun and exchanging ideas

The Vestal Lunar System (VLS)

- A highly reusable large lunar lander for 4-8 crew members
- Only require fuel, cargo and crew transfers in LEO
- Use technologies and systems that are mature, currently in testing or can be developed in a few years, such as:
  - Use Crew Dragon, Starliner or other Earth surface to LEO systems to transfer crews (until a SpaceX Crew Starship is proven for landing crews)
  - Use SpaceX Technology now being developed for the NASA Artemis **Human Landing System (HLS)** program https://www.nasa.gov/press-release/as-artemis-moves-forward-nasa-picks-spacex-to-land-next-americans-on-moon
  - Use SpaceX Starship's main tank and engine section (with some modification) as Orbital Transfer Vehicle between LEO and Lunar Orbit and back to LEO
  - Use SpaceX's LEO refueling capabilities proven with the HLS program
  - Use SpaceX proven SuperDraco (CD abort) & Vacuum Raptor engines --->

SpaceX's Vacuum Raptor Engine

Liquid-fuel engine	
Propellant	Liquid oxygen / liquid methane
Mixture ratio	3.6 (78% O_2, 22% CH_4)[1][2]
Cycle	Full-flow staged combustion
Pumps	2 turbopumps
Configuration	
Chamber	1
Nozzle ratio	34.34 (sea-level),[3] 80 (vacuum)[4]
Performance	
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

Ref: wikipedia

VLS is about 80-85% similar to SpaceX's HLS Starship

Challenge:
Do you agree that VLS and Starship HLS are similar? If so how similar?

Current SpaceX HLS Concept

VLS

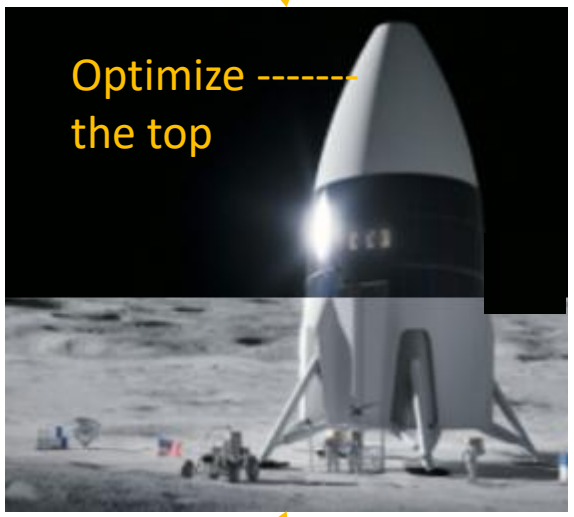
Reuse for the Vestal Lunar System

Use the HLS cabin components, but perhaps a Aluminum or Carbon Composite shell, Pressure Vessel, frame ...

Add interstage,
fuel connects,
lander connect latches

The same insulated main tanks and engines stay in NRHO, with some added active cooling

Only this lands



Use about the same legs, about the same tank design, 3 VacRaptors

REF: https://www.nasa.gov/press-release/as-artemis-moves-forward-nasa-picks-spacex-to-land-next-americans-on-moon

The key technical differences from HLS Starship

- HLS Starship is one large piece, VLS allows the main tanks and engines (OTV) and return fuel to disconnect in lunar orbit to allow modified HLS Crew section to act as a separate Lunar Lander to continue to the lunar surface. The Lunar Lander then returns to lunar orbit to reconnect with OTV that returns the reconnected system to LEO.
  - The VLS OTV adds a “dock” that allows disconnection and reconnection to the Lunar Lander as needed, as well as MethLOX fuel connections.
- The VLS OTV adds a reflective sunshield, solar array and radiator to allow for active cooling that should reduce the fuel boil off during a 1 month mission.
- The VLS Lunar Lander uses SuperDraco thrusters for soft landing on the moon.
- The VLS Lunar Lander has low cost cargo pods that are brought to LEO and left on the Lunar Surface. They carry mission specific items, water, fuel ....
- The VLS Lunar Lander adds a tracking solar array/radiator for more power.

VLS schedule of events for a 1 month mission

- First mission only: unmanned OTV+Lander System Launch to LEO/Initial Deployment
- In LEO: Fuel & Cargo Transfer (while unmanned over month, 8 - 12 Unmanned Starships)
- In LEO: New Crew Arrival (In Crew Dragon, Starliner or Dream Chaser)
- In LEO: A week of training, fun in freefall, sightseeing (also space sickness adaptation)
  - Crew Checkout Operations
- Departure/transit to Lunar Orbit (3 days)
- Separate OTV and Lunar Lander in Lunar Orbit (NRHO)
- 2 Day Lunar Surface Close Flyby
- Landing sequence
- Surface Activities
- Launch from surface, return to OTV in Lunar Orbit (NRHO)
- The Lander docks with OTV, OTV with Lander returns to LEO
- CD Returns to Lunar Lander, Crew Departure with up to 20 kg of lunar material each

Challenge:

How would you breakout the crew between Vestal Lunar trained staff and lightly trained space tourists? The reference breakout is 2 VL Staff and 5 tourists.

First mission only:
Unmanned OTV+Lander System Launch to LEO

Landing legs under pods (yellow)

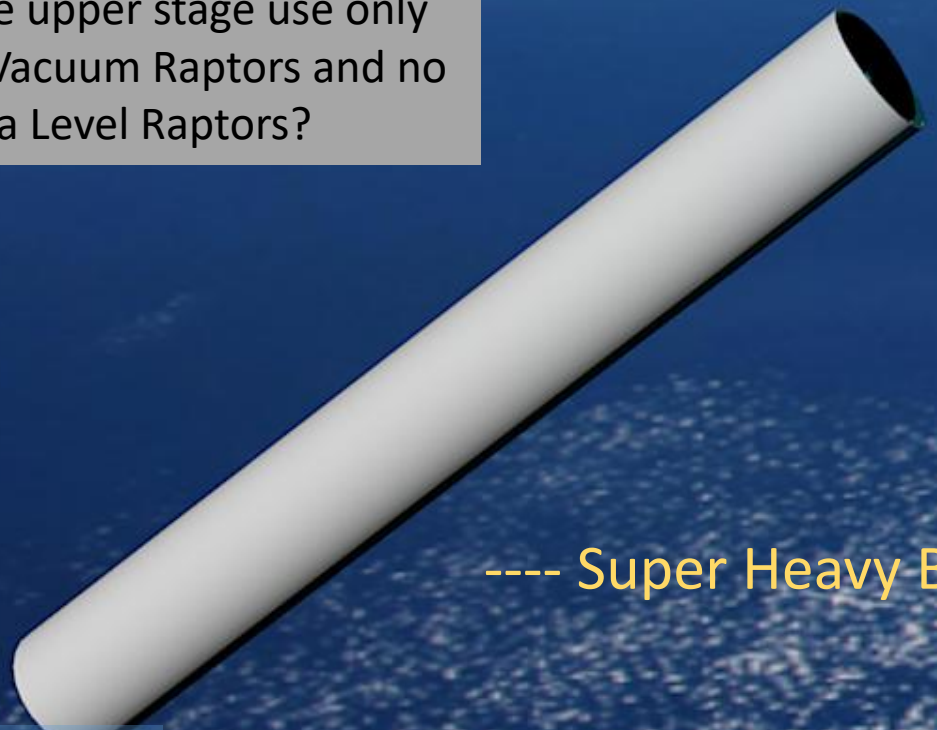
Pods will be ejected in about 20 seconds ----

Challenge:

Can the legs and node be covered in this way? Can the upper stage use only 3 Vacuum Raptors and no Sea Level Raptors?

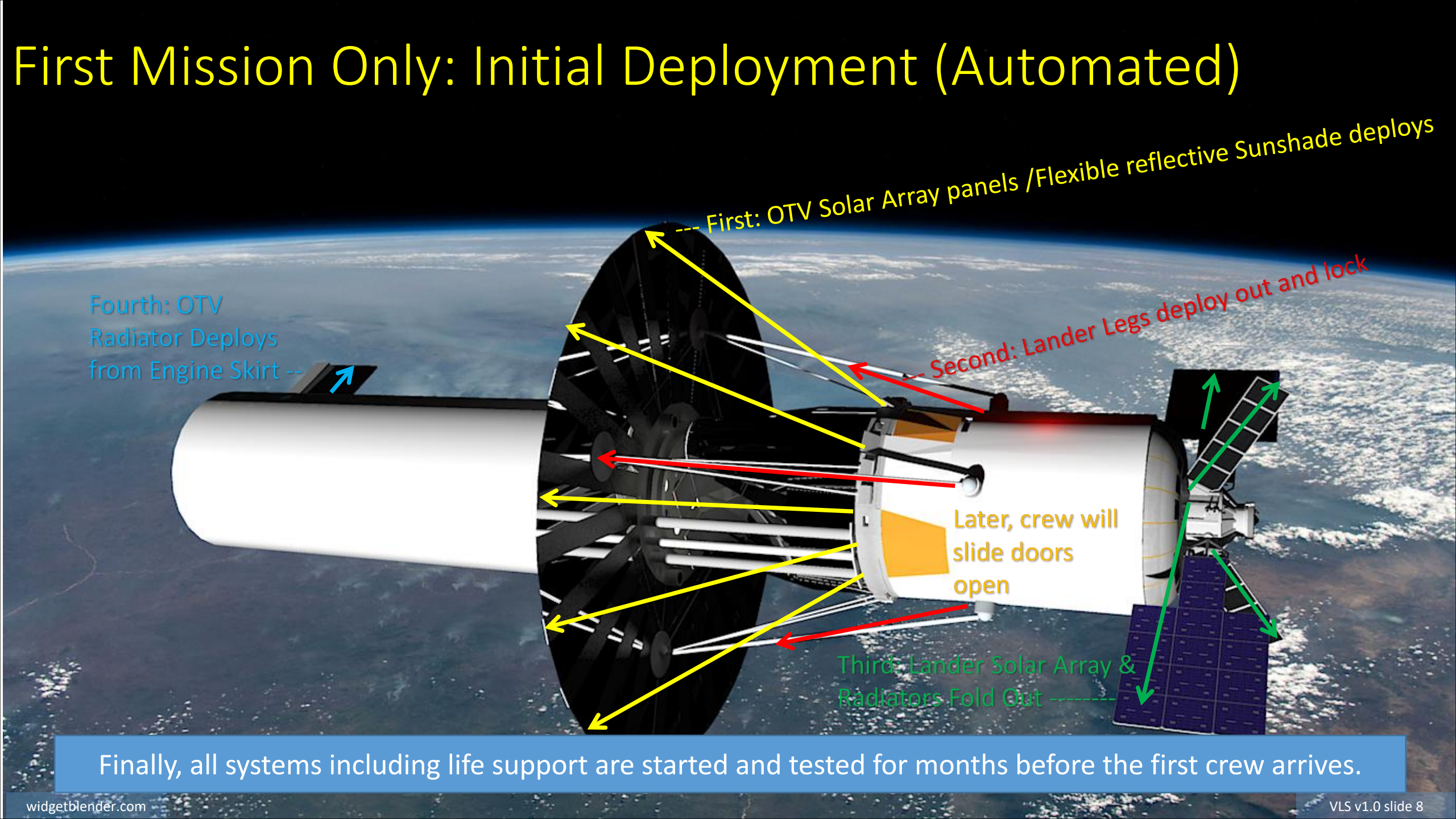
Nose cone fairing (yellow) will be split and ejected in about 40 seconds

---- *Upper Stage fires engines to get to LEO*



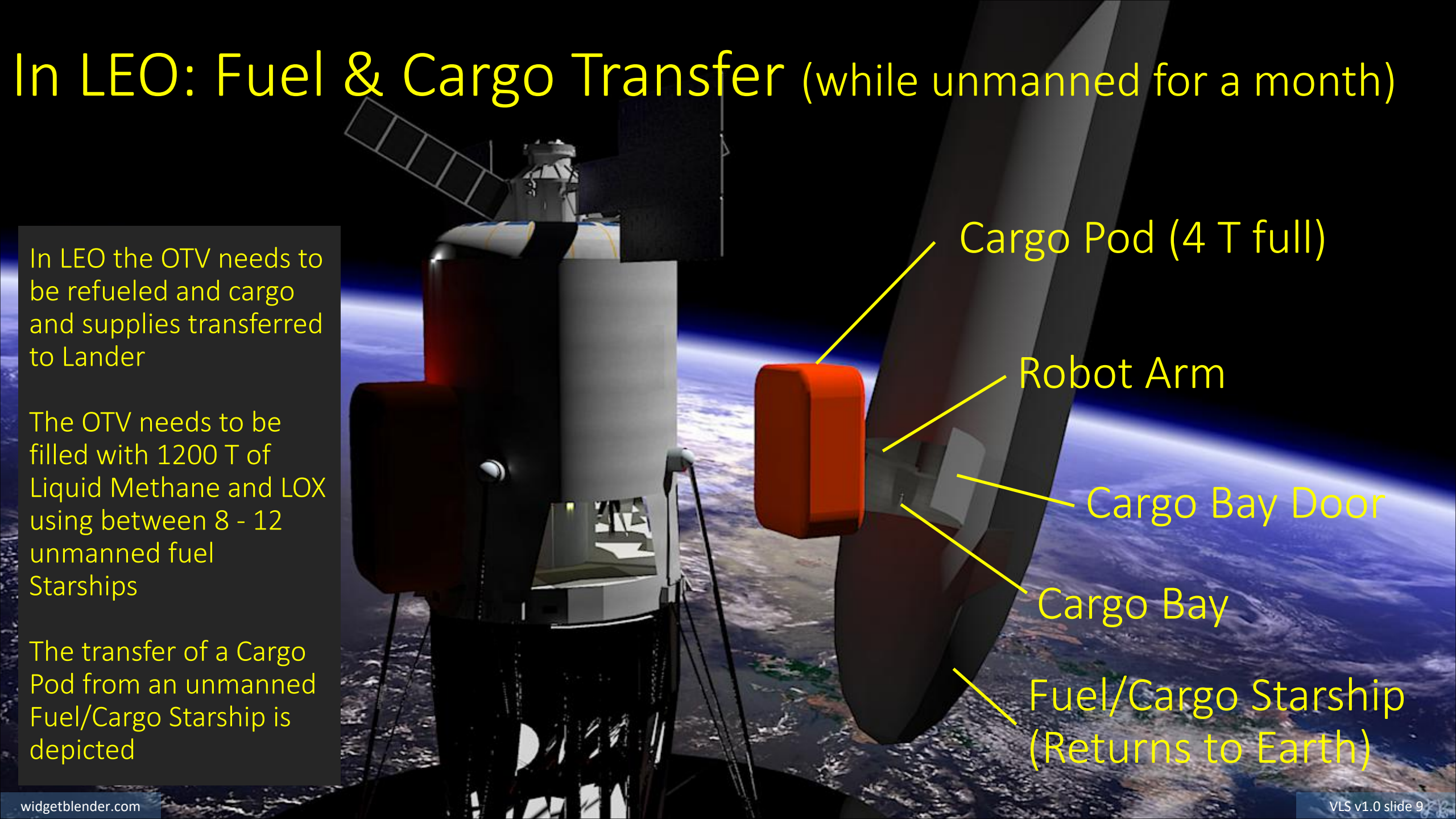
---- Super Heavy Booster falling back toward Earth for recovery

First Mission Only: Initial Deployment (Automated)



Finally, all systems including life support are started and tested for months before the first crew arrives.

In LEO: Fuel & Cargo Transfer (while unmanned for a month)

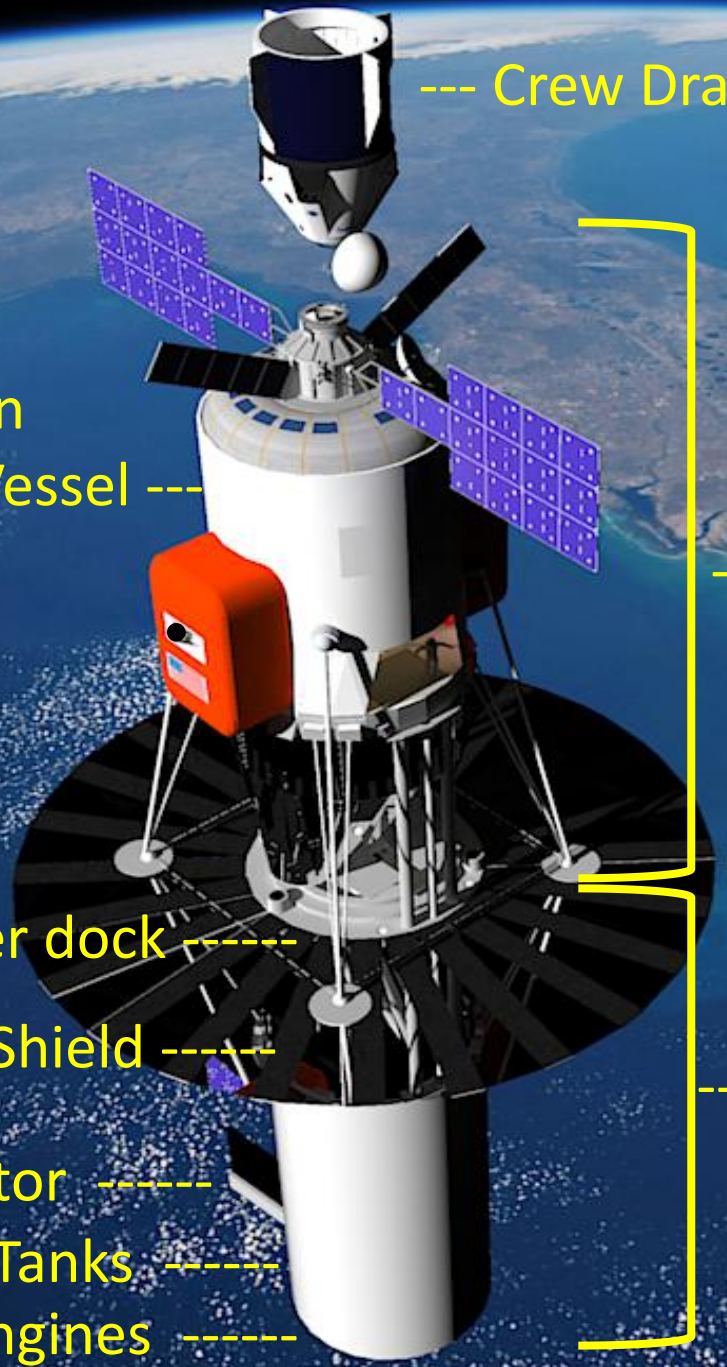


In LEO the OTV needs to be refueled and cargo and supplies transferred to Lander

The OTV needs to be filled with 1200 T of Liquid Methane and LOX using between 8 - 12 unmanned fuel Starships

The transfer of a Cargo Pod from an unmanned Fuel/Cargo Starship is depicted

In LEO:
New Crew Arrival



--- Crew Dragon, Starliner or Dream Chaser

A new crew arrives at the Lunar Lander. The new crew arrives in a Crew Dragon (up to 7 capacity)

Crew Cabin
Pressure Vessel ---

- Lunar Lander

OTV to Lander dock ------

OTV Solar Array & Reflective Sun Shield ------

-- Orbital Transfer Vehicle (OTV)

Radiator ------

Insulated Main Fuel Tanks ------

3 VacRaptor Engines ------

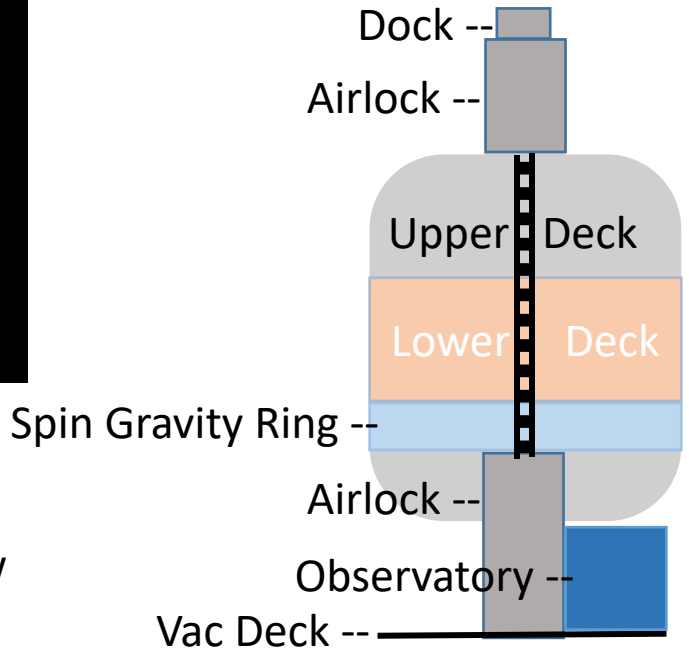
(8-12 Fuel Starship runs needed for complete fill)

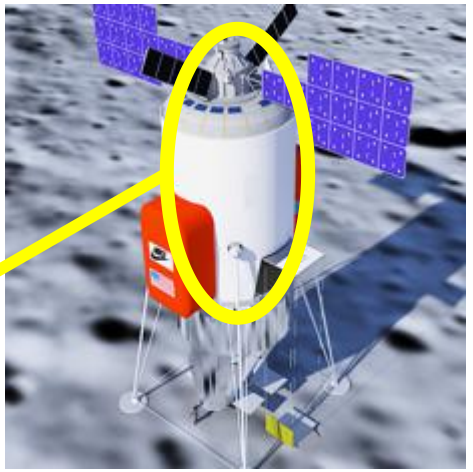
The Lunar Lander's Crew Cabin Carbon Composite Pressure Vessel (better anti-radiation performance than metal)

Built by SpaceX around 2017, this Carbon Composite pressure vessel is about 50% larger and heavier that the Vestal Lunar Lander concept imagines for it's crew cabin pressure vessel

Ref:https://www.reddit.com/r/space/comments/54souf/spacex_carbon_fiber_tank/

Side Schematic of Crew Cabin Pressure Vessel and Air Locks





Challenge:

How would you design the inside of the Crew Cabin?
What features?
What materials?
What technologies?

Low “Spin Gravity” Ring Option - A much more comfortable introduction to freefall

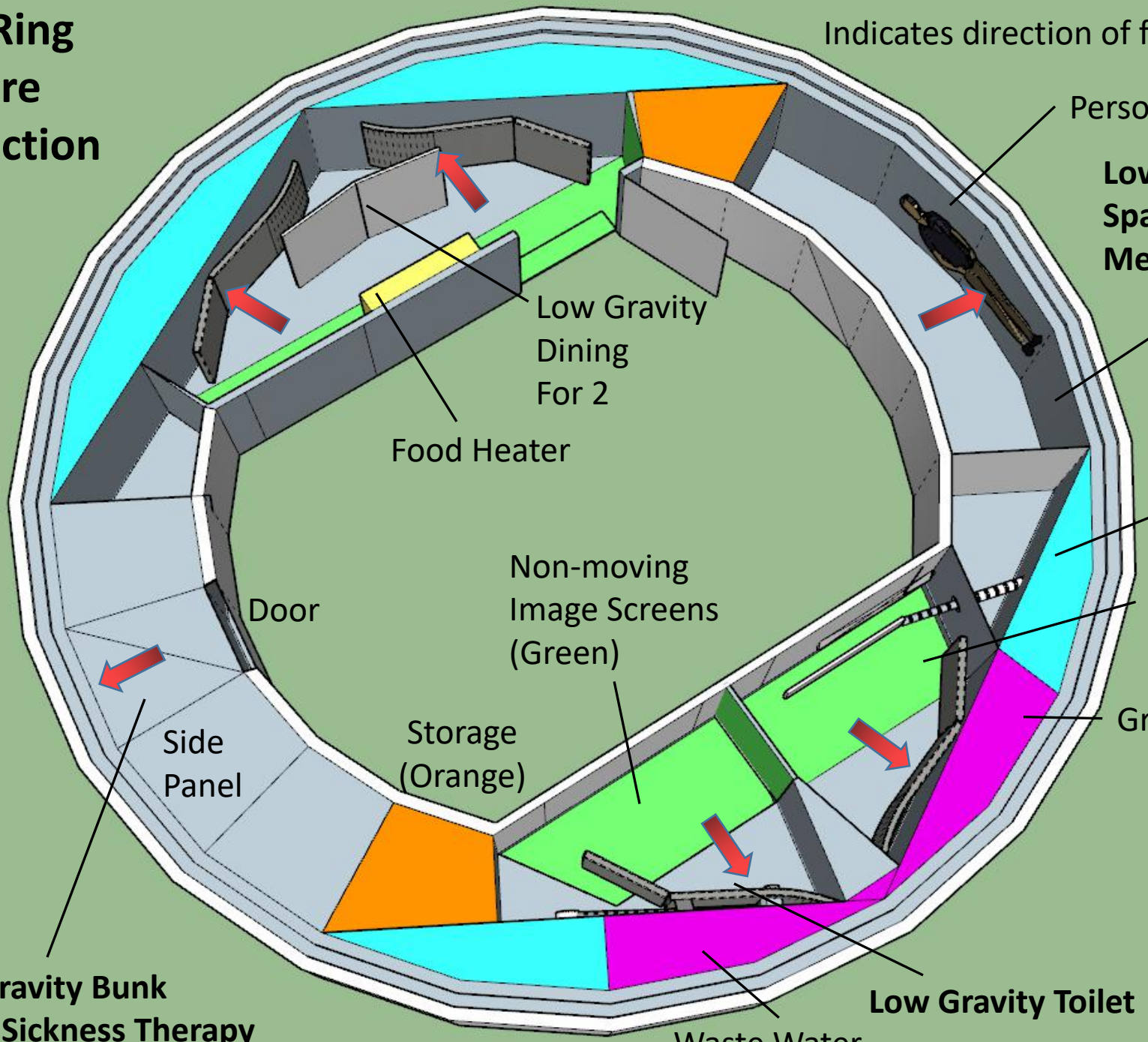
up to 1/8 g at seat height

used occasionally
spun up - then counter spun down

Seats reclined to minimize gravity force difference between feet and head

1.2 m thick
8.6 m outer diameter
2.5 tonnes (dry)

Most side panels not shown



Challenge:

What to you think about this concept, layout ....

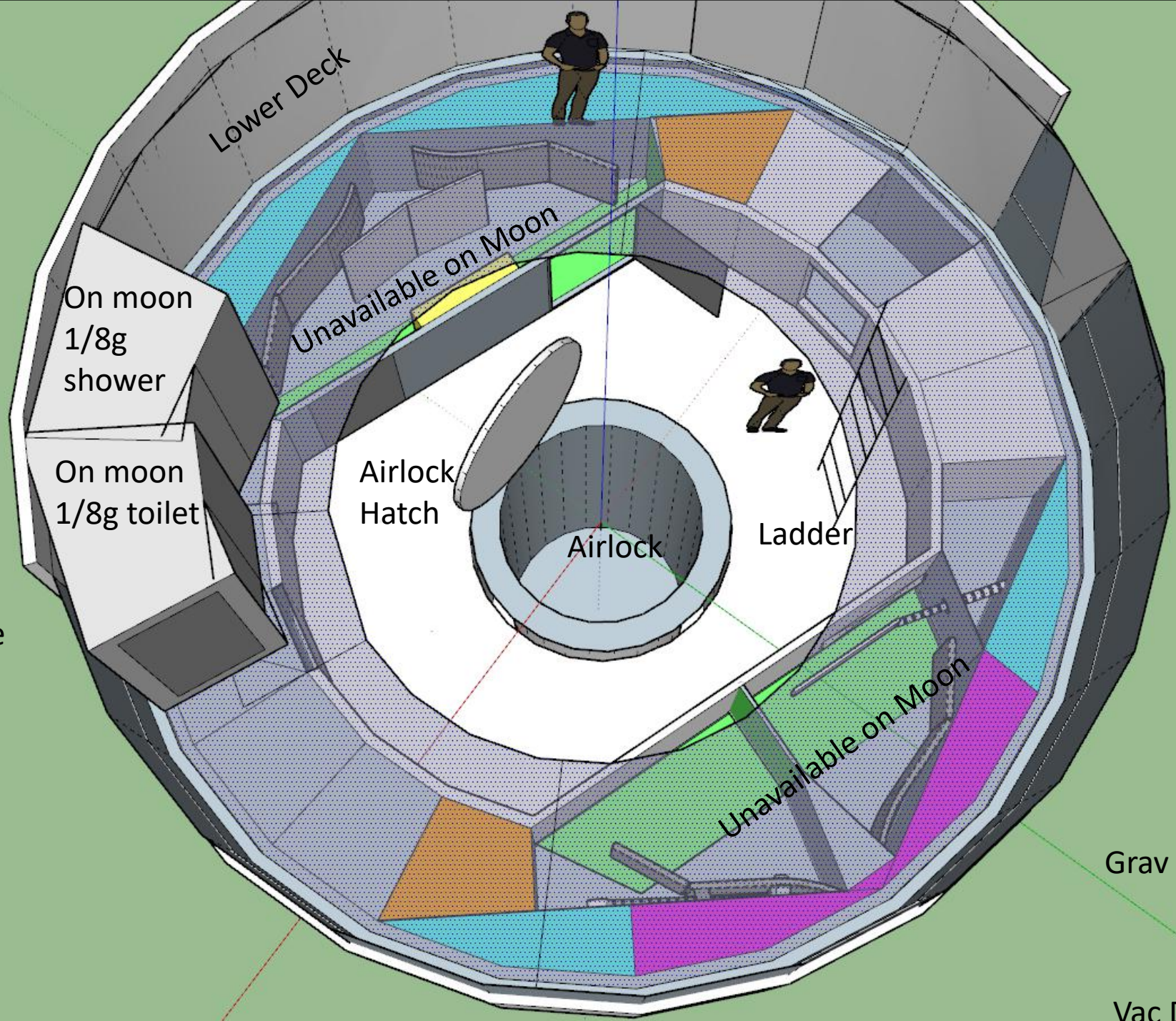
THE Low "Spin Gravity" Ring is placed at the bottom of the crew cabin pressure vessel.

This depiction shows the ring relative to the airlock that is at the center bottom of the crew cabin.

The translucent gray depicts the floor of the Lower Deck above the gravity ring

Challenge:

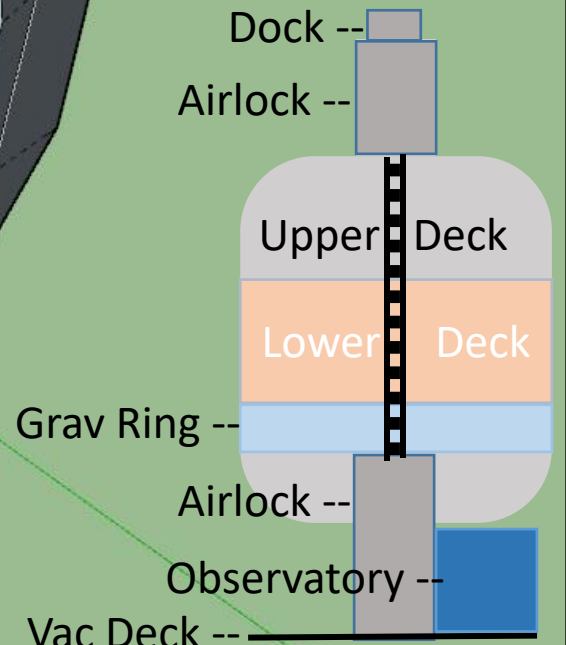
What to you think about this concept, layout ....



Challenge:

How would you build out the Crew Cabin? It is designed for 4-8 crew.

Side Schematic of Crew Cabin Pressure Vessel and Air Locks



In LEO: A week of training, fun in freefall, sightseeing

A week in LEO? Getting used to freefall, watching the world fly by ... a sunrise and sunset every 45 minutes ... a great opening to a great adventure.

It is also time for the Vestal Lunar crew to check out all the systems in preparation for departure to the moon

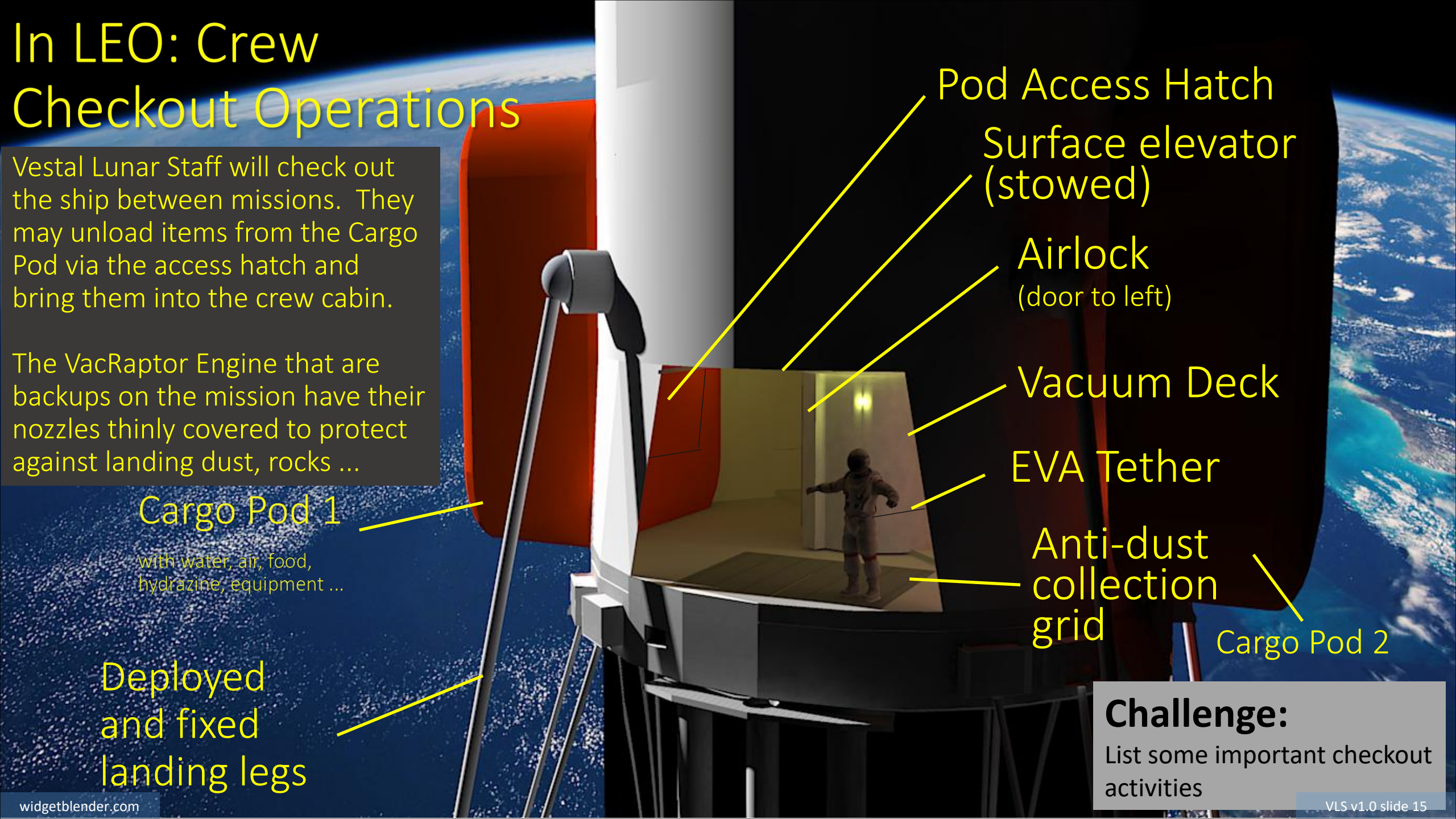
Pressurized observatory on back of vacuum deck, connected via the main air lock

Challenge:
What to you think about this concept, layout ....

In LEO: Crew Checkout Operations

Vestal Lunar Staff will check out the ship between missions. They may unload items from the Cargo Pod via the access hatch and bring them into the crew cabin.

The VacRaptor Engine that are backups on the mission have their nozzles thinly covered to protect against landing dust, rocks ...

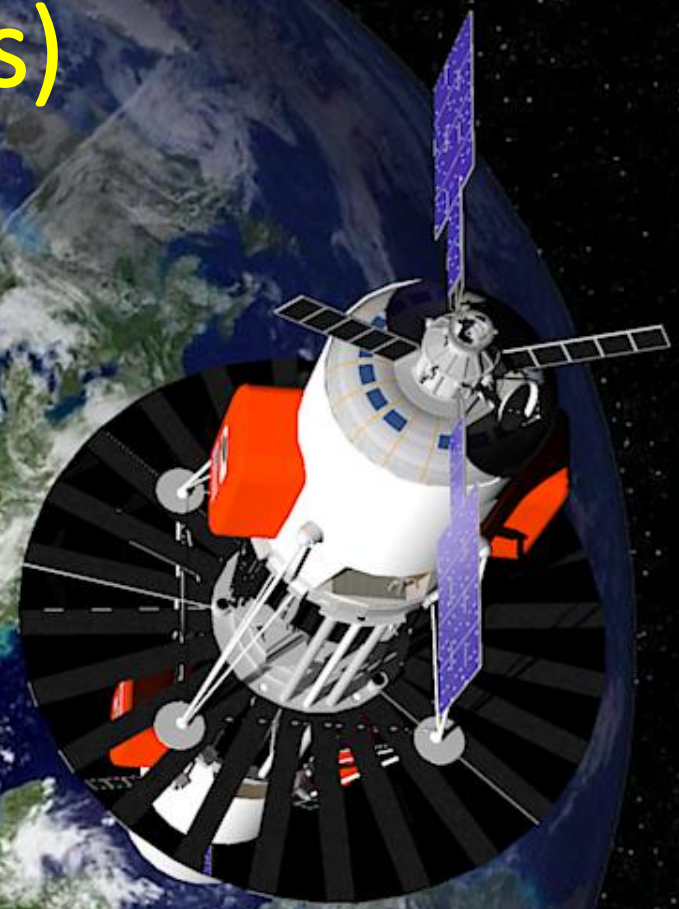


Challenge:

List some important checkout activities

Departure/transit to Lunar Orbit (3 days)

- An empty Crew Dragon un-docks from Lunar Lander (with the lander connected to the OTV). It will remain in a powered down state until the OTV-Lunar Lander return to LEO.
  - Note that Crew Dragon may need to be slightly upgraded to extend it's operational life in LEO from 3-4 free flying manned days to 20 unmanned free flying days
- The OTV fires its 3 VacRaptor Engines at high thrust for a short time to enter orbit that after an additional burn 3 days later will put into a type of lunar orbit called a Near Rectilinear Halo Orbit (NRHO) - a highly elliptical orbit around the moon.



DV needed = 3.65 km/s
Includes safety margins

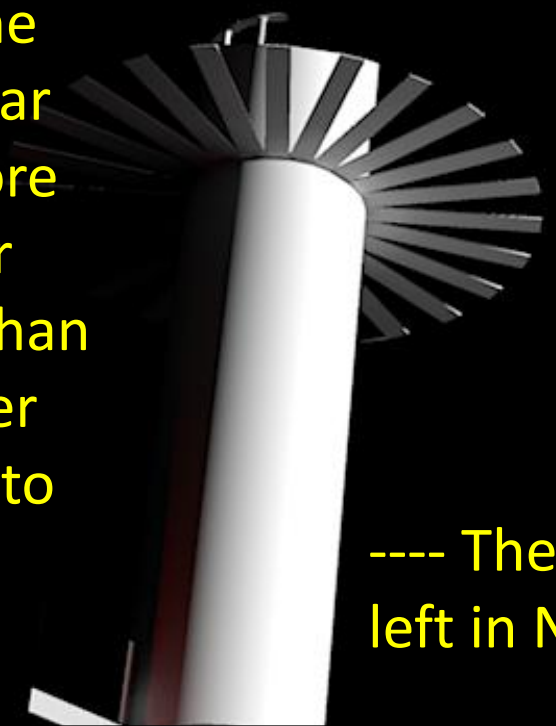
Challenge:

Do the DV calculations look OK? Activities for this phase? New radiation issues in this phase?

Separate OTV and Lunar Lander in Lunar Orbit (NRHO):

The 50 T dry mass lander (with crew and 8 T cargo = 59T total), full 183 T of fuel, undocks from Starship OTV, performs a burn to go a very low circular orbit over the moon surface

Apollo also left the return fuel in Lunar Orbit to allow more mass to the Lunar Lander. It more than doubles the lander mass if returning to LEO



---- The 75 T OTV (dry mass) is left in NRHO with 170 T of fuel

DV needed to surface = 2.75 km/s

Challenge:

Are there better orbits to use? What is the best timing to disconnect the Lander from the OTV

2 Day Lunar Surface Close Flyby

- Part of the tourist adventure is a very low flyover of many places on the lunar surface (like Tycho Crater) and witnessing many Sun and Earth rises and sets.
- They will fly over some historical sites like the Apollo landing locations.

View from inside the observatory

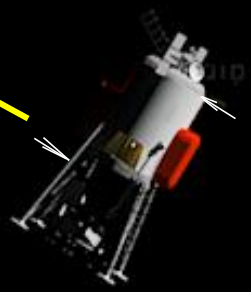
This part is in freefall as well

Challenge:
Can this work?
Suggest good sites to overfly.

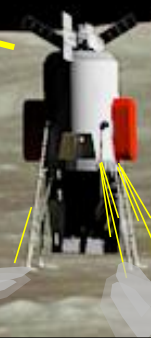
Landing sequence

- At about 200 m off the surface Raptors perform a significant DV horizontally to kill of horizontal velocity

- The lander performs a quick 90 deg roll with the Reaction Control System to create a legs down orientation



- The lander softly falls the 100 m (1/8 Earth gravity) with the SuperDracos firing and retaining vertical alignment



- The lander contact the surface at under 1 m/s, with the landing leg assembly absorbing the interface.

Challenge:
Can this work?

VLS: Designed around safety (as any tourist system need to be)

- The Lander has 3 Vacuum Raptor engines for redundancy as 1 engine could do the job. This adds 5 T for that sake of safety
  - You need to have 1 or 3 engines to maintain thrust symmetry around the center-of-mass, operating the center at up 100% thrust or the two sides at up to 50% thrust each.
  - For a given mission, the Vestal Lunar staff during checkout covers the nozzles of the unused engine(s) with a thin covering to protect from dust on rocks on landing. This cover will be blown off if the engines are needed if the other(s) fails.
- Carbon Composite Crew Cabin Pressure Vessel will create a minimal amount of secondary radiation that is common with metal pressure vessels. This can reduce dangerous radiation by over 50%, which is very important to Vestal Lunar crew that will be taking repeated trips. This is much more expensive than Stainless Steel or Aluminum, but affordable since the Vestal Lunar System is highly reusable.
- Solar Storm Storm Shelter: The Lander carries 4 T of water that can be quickly pumped into empty bags that can create an optimal shape in an optimal direction for absorbing the rare Solar Storm particles. Otherwise a lethal dose could occur.
- SuperDraco soft-landing engines protect the Lander from dust/rock kickback on landing.
- Abort to NASA Lunar Gateway ... this system can dock with Gateway if needed.
- 100% supply of critical extra supplies carried, enough time for a rescue mission

Challenge:

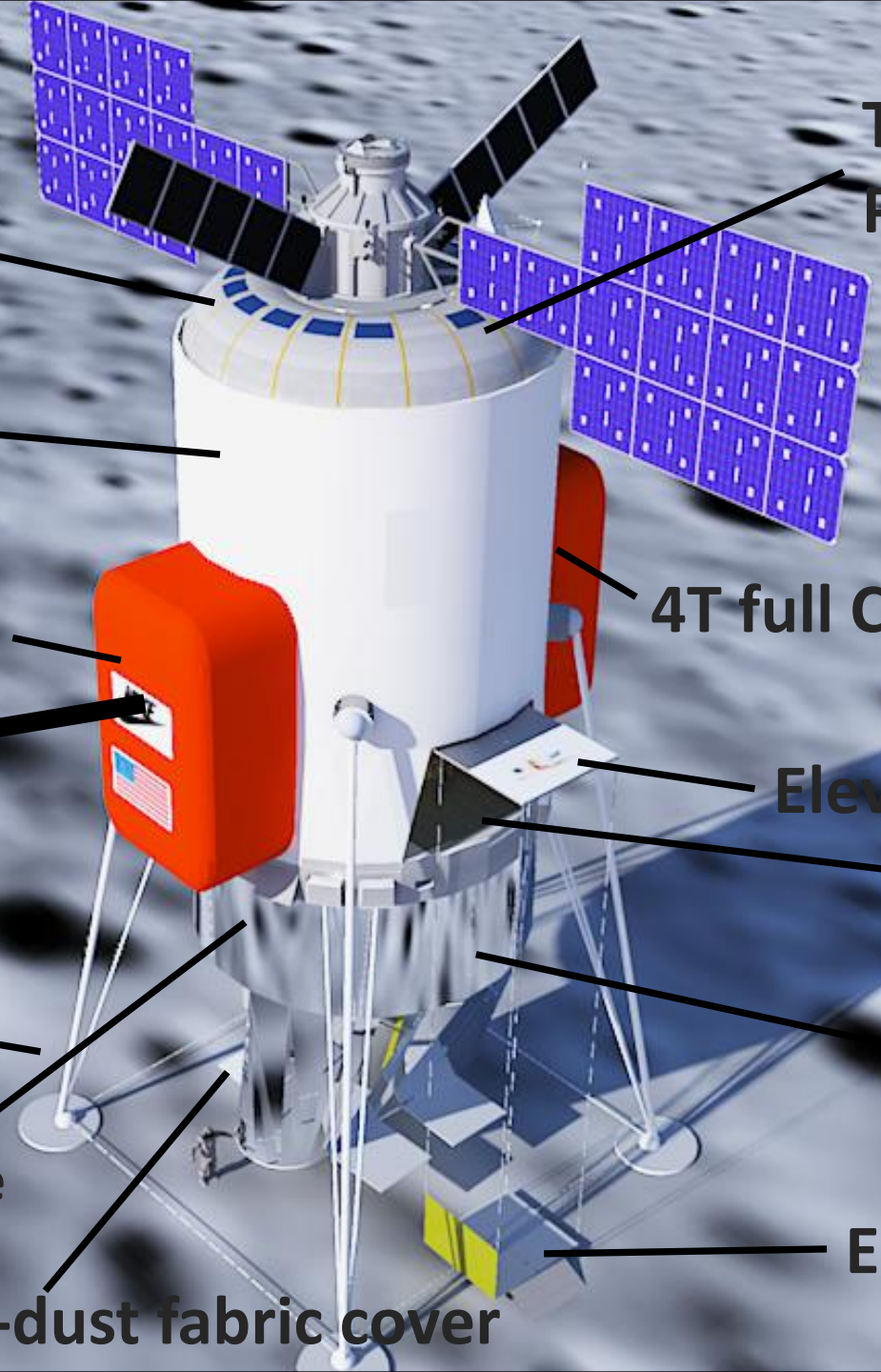
What other safety features can be included?

VLS Lunar Lander on Surface

50 T dry mass
10 T crew/cargo

3 Vac Raptor Lander

(RCS not shown)



Windows

Top of Crew Cabin Pressure Vessel

9 m high Crew Cabin Pressure Vessel

4T full Cargo Pod

4T full Cargo Pod

Sponsorship?

Elevator top slides out

Vac Deck

Shock absorbing Carbon Composite Tube Leg Assembly

56 T return fuel

SuperDraco Engine
(4-8 total)

Elevator

Mylar reflective anti-dust fabric cover

Challenge:
Comments on design

Lunar Surface Operations (DUST MANAGEMENT IS CRITICAL! It is like static charged pulverized glass!)

--- Airlock Hatch

- Vacuum Deck (shown here)
  - Connects outside to airlock
  - Vibrating grid floor (electrostatic?)
  - High intensity puffers
- Elevator
  - Grid floor (electrostatic?)
- Disposable Oversuits
  - Put the cheap oversuit over the expensive environmental suit

Challenge:

Any other dust management ideas?

Surface Activities (Crew + tourist for 2 3 hour excursions)

- Explore area on foot and in rover
  - Perhaps send the rover out first to scout locations
- Collect interesting surface rocks
  - You can bring up to 20 kg back per person, sell them if you wish
- Operate experiments to help pay for your tourist trip
  - You can bring up to 100 kg of cargo with you for any reason, these need to be left on the lunar surface
- Take pictures, make videos
  - You can use your media to sell to people for art, commercials ...

Challenge:

What other short surface activities would be good ones?

Ref: NASA Historic Image

Depart Lunar Surface using SuperDraco engines for 10 seconds Then 90 deg rotation and fire up of Raptor engine(s) … the reverse of the landing sequence

50 T of Ship
3 T of Crew and Cargo --
47 T of Fuel

Cargo Pods Remain --

Return to OTV still in lunar orbit

DV needed = 2.75 km/s

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)

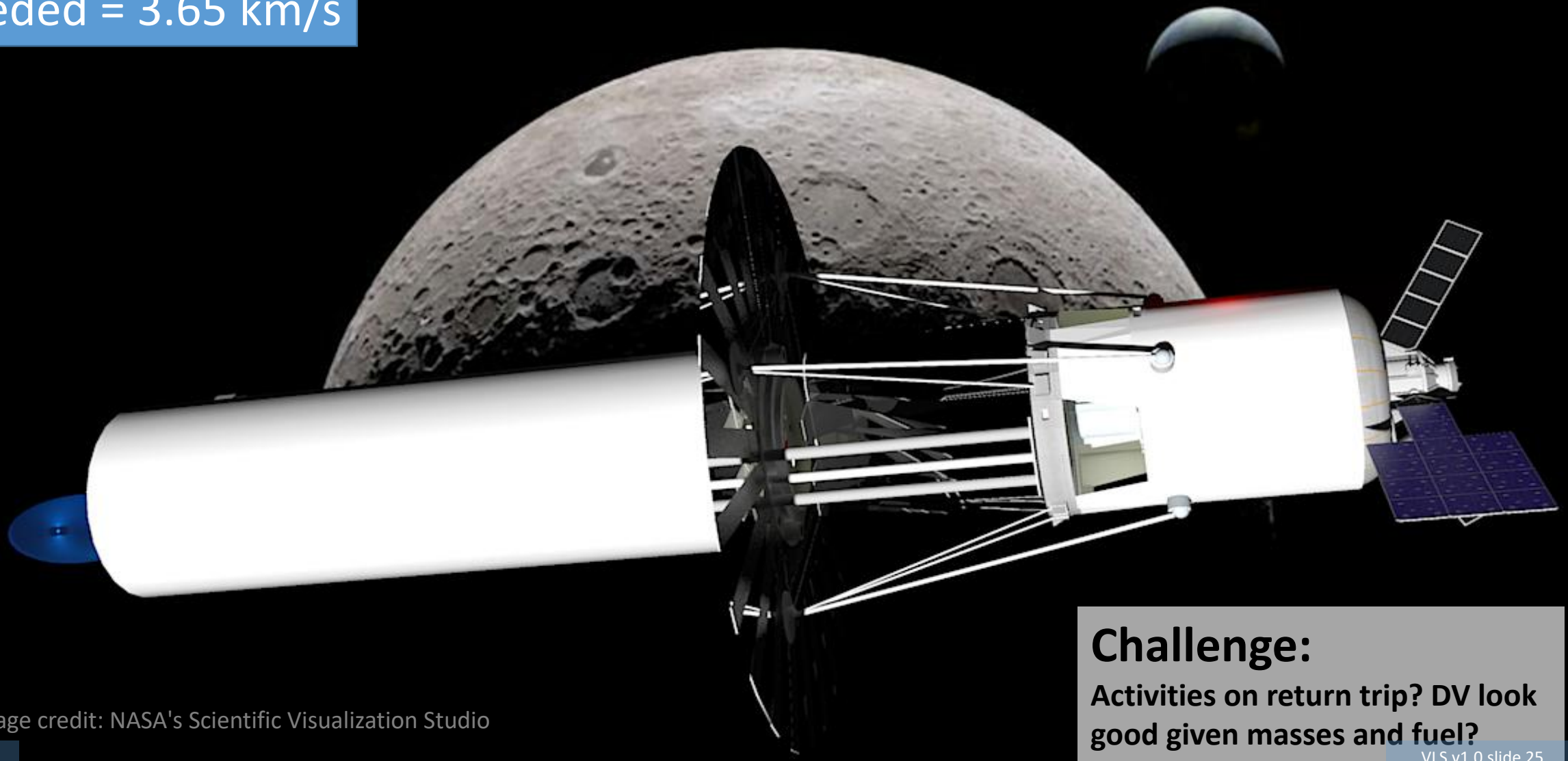
Thrust (sea-level): 71 kN (16,000 lbf), individually; 32,000 lbf, dual-engine cluster

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

Challenge:
Can this work?
4 or 8 engines?

Re-dock with OTV in Lunar Orbit. OTV fires engines to return to LEO

DV needed = 3.65 km/s



Background image credit: NASA's Scientific Visualization Studio

Challenge:

Activities on return trip? DV look good given masses and fuel?

Back in LEO: Return To Earth Surface

Once back in LEO the CD that the crew rode up to LEO in re-docks with the lander. The crew packs up to 20 kg of return cargo each and straps in for un-docking with the Lander.

It has been a great trip, but all good things must end. The last part of your journey might just be the most thrilling as you and crewmates pull multiple Gs (4+) as you re-enter the atmosphere before softly splashing down near Florida, USA.

Image credit: SpaceX