Mare Tranquilitatis Hole
- a habitable place for a first lunar settlement

Building a Lunar Habitat at the bottom of Mare Tranquilitatis Hole for 250 persons

a conceptual study

by

Werner Grandl

April 2024
EGU24-10730

Lunar Holes, discovered in 2009 by the Japanese lunar orbiter SELENE (Selenological and Engineering Explorer), (J. Haruyama et al. 2012)

a Marius Hills Hole (MHH)

59 x 50 m, 48 m deep

b Mare Tranquilitatis Hole (MTH)

98 x 84 m, 107 m deep

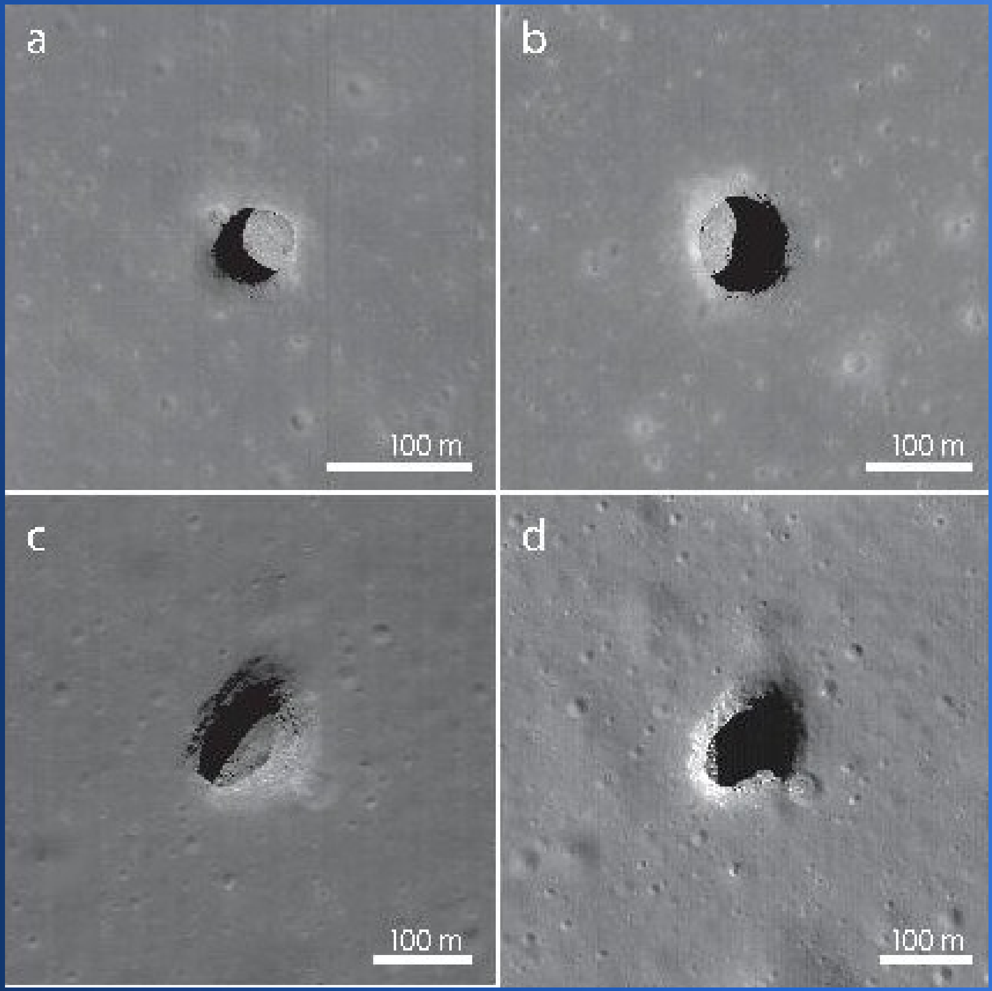
c,d Mare Ingenii Hole (MIH)

118 x 68 m, 45 m deep

At the bottom of the holes

temperatures range from

- 20 °C to + 30 °C (Haruyama et al.)

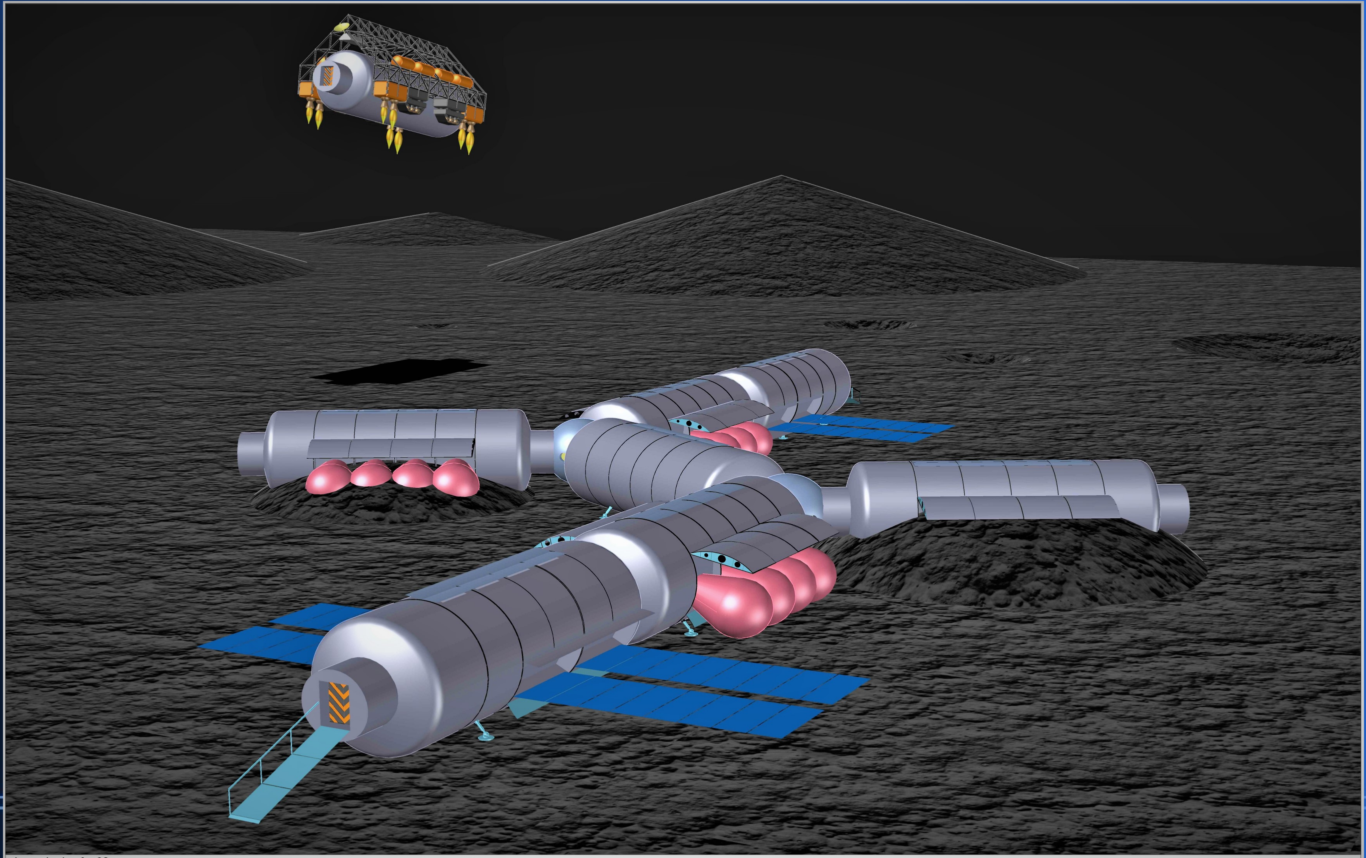


- Lunar holes are supposed to be the entrance to subselene lava tubes.

FIRST STEP: An initial modular lunar base on the lunar surface near MTH for 32 astronauts to prepare the construction site (W.Grandl & C.Böck 2020)

The initial lunar base is built of cylindrical modules and spherical nodes.

It is extended by inflatable elements and finally covered with regolith.

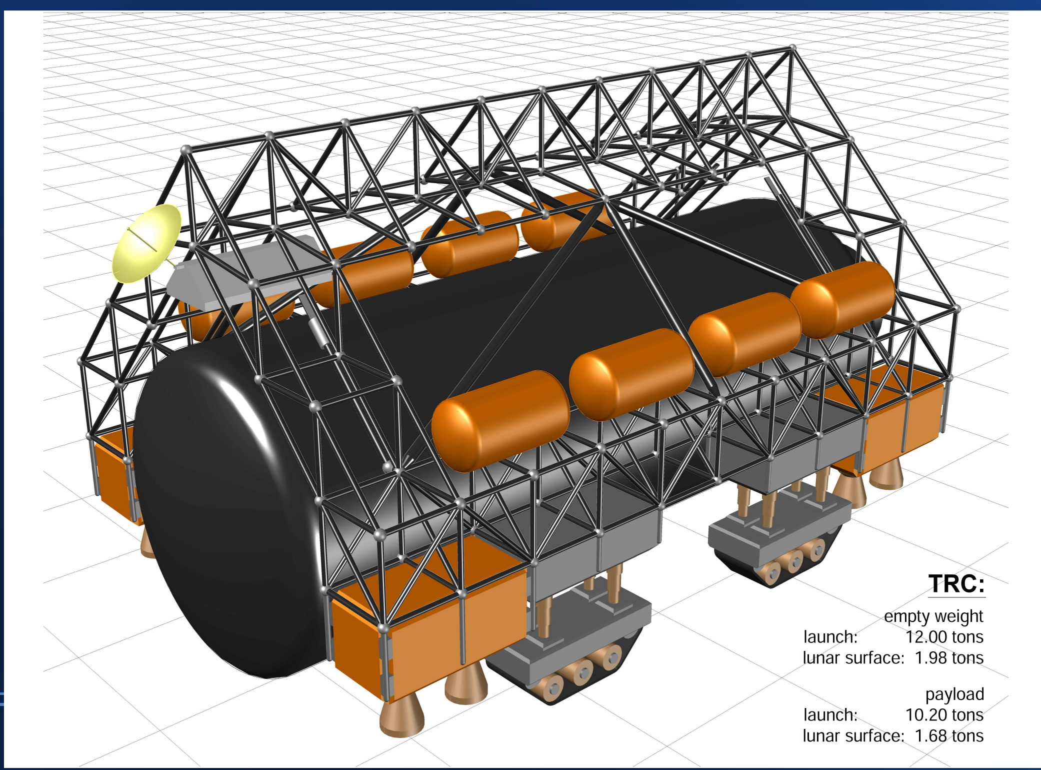


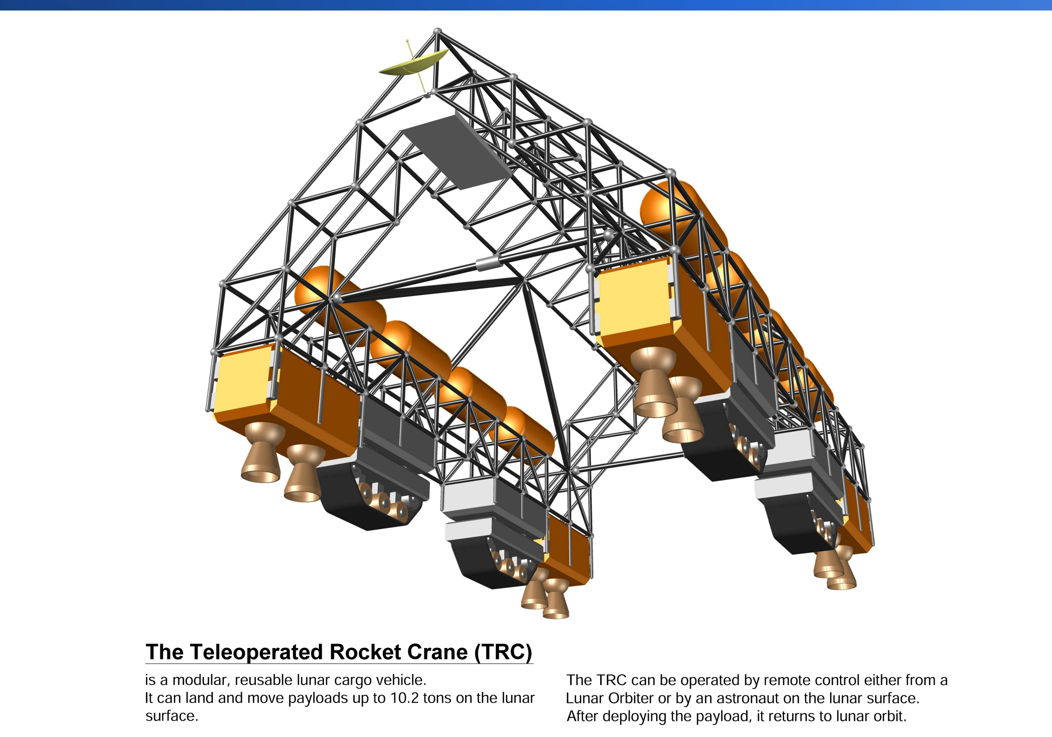
Lunar Lodge for 32 persons

For assembling of the initial base a Teleoperated Rocket Crane is used. It is assembled in lunar orbit and can land and move payloads up to 12 t (W. Grandl 2012).

The TRC can move with crawlers on the lunar surface.

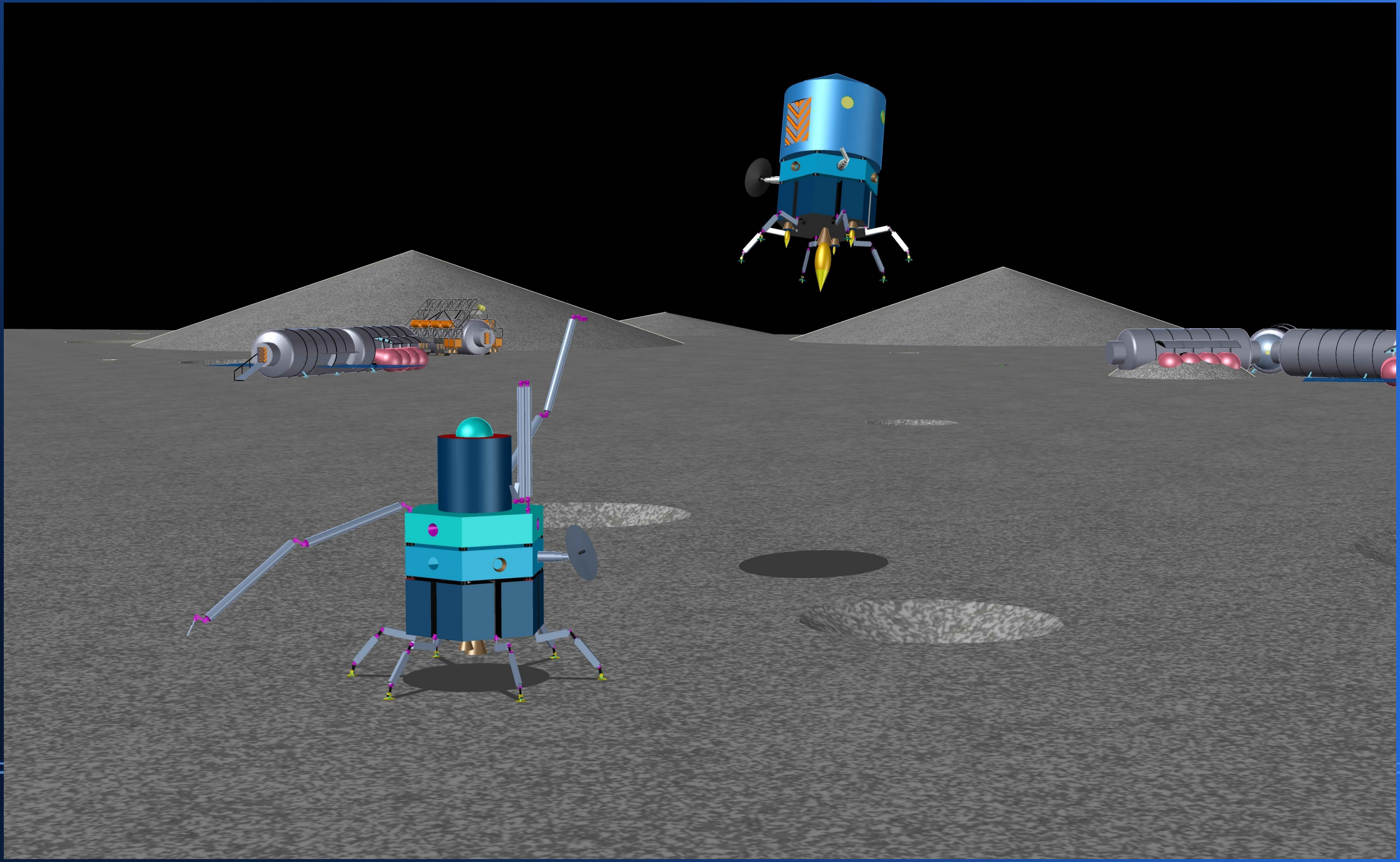
It is operated by remote control from a lunar orbital station or from astronauts on the lunar surface.





For transport of humans between lunar orbit and lunar surface as well as transport between 2 different locations on the Moon we have designed the SPIDER lander (W.Grandl & C.Böck 2020).

SPIDER robotic explorer and SPIDER lander; both vehicles can walk or „hop“ on the Moon. They have 6 „legs“, a main engine and lateral maneuvre thrusters.



For transport of the modules to lunar orbit we propose to use the FALCON HEAVY (FH) launcher of SpaceX with partial reuse

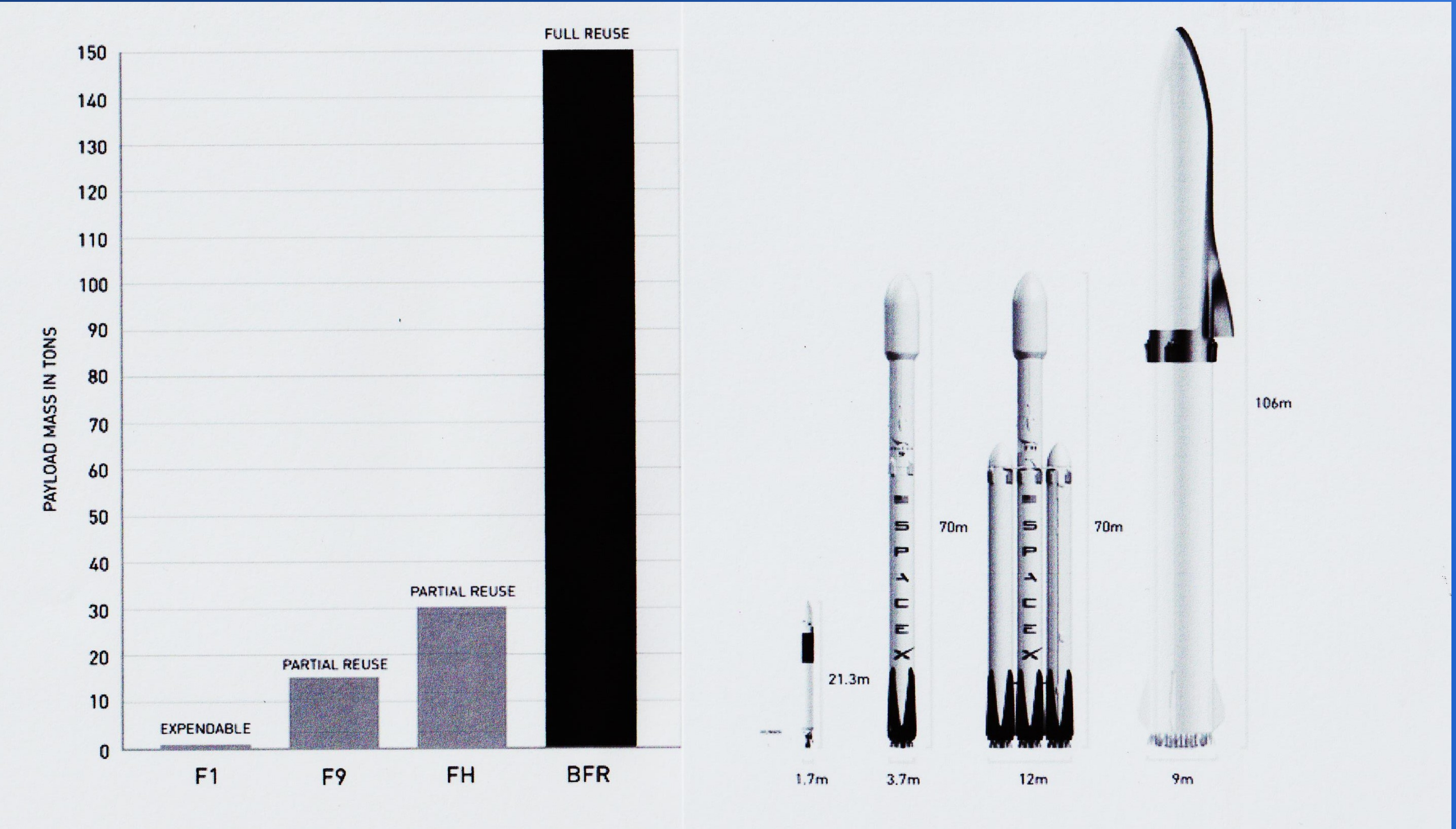


Fig. 5. Vehicle payload comparison in tons.

Fig. 4. Vehicle overview: Falcon 1, Falcon 9, Falcon Heavy and BFR.

Credit: Elon Musk, The Starship Users Guide, SpaceX 2020

For transport of heavy cargo with smaller shape we propose to use the SpaceX STARSHIP , which is fully reusable if refueled in Earth orbit.

After vertical landing on the Moon, an elevator is needed to put the payloads down on the lunar surface. Thus the size of payloads is limited to the capacity of the elevator.

PERFORMANCE

The Starship and Super Heavy system offers substantial mass-to-orbit capabilities. At the baseline reusable design, Starship can deliver over 100 metric tons to LEO. Utilizing parking orbit refueling, Starship is able to deliver unprecedented payload mass to a variety of Earth, cislunar, and interplanetary trajectories. A summary of available Starship capabilities is provided in Table 3 below. The single launch mass-to-orbit assumes no orbital refueling of Starship. The maximum mass-to-orbit assumes parking orbit propellant transfer, allowing for a substantial increase in payload mass. These performance numbers assume full Starship reuse, including Super Heavy return to launch site. For performance estimates to a specific orbit, please contact sales@spacex.com.

Orbit	Mass-to-Orbit Single Launch	Mass-to-Orbit Prop Transfer (t)
LEO[1]	100+	100+
GTO[2]	21	100+
Lunar Surface	N/A	100+
Mars Surface	N/A	100+

[1]Up to 500-km circular orbit at up to 98.9-deg inclination

[2]Assumes 185 x 35,786 km orbit at 27-deg inclination with 1800 m/s ΔV to go

CARGO CONFIGURATION

Starship was designed from the onset to be able to carry more than 100 tons of cargo to Mars and the Moon. The cargo version can also be used for rapid point-to-point Earth transport. Various payload bay configurations are available and allow for fully autonomous deployment of cargo to Earth, Lunar, or Martian surfaces with one example shown in Figure 7.

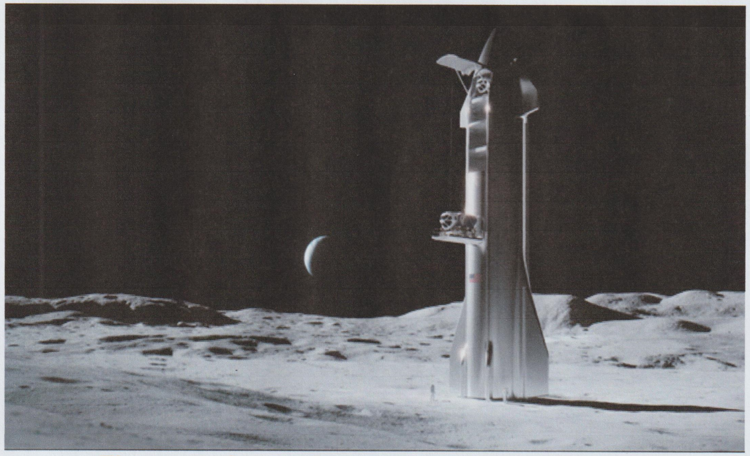
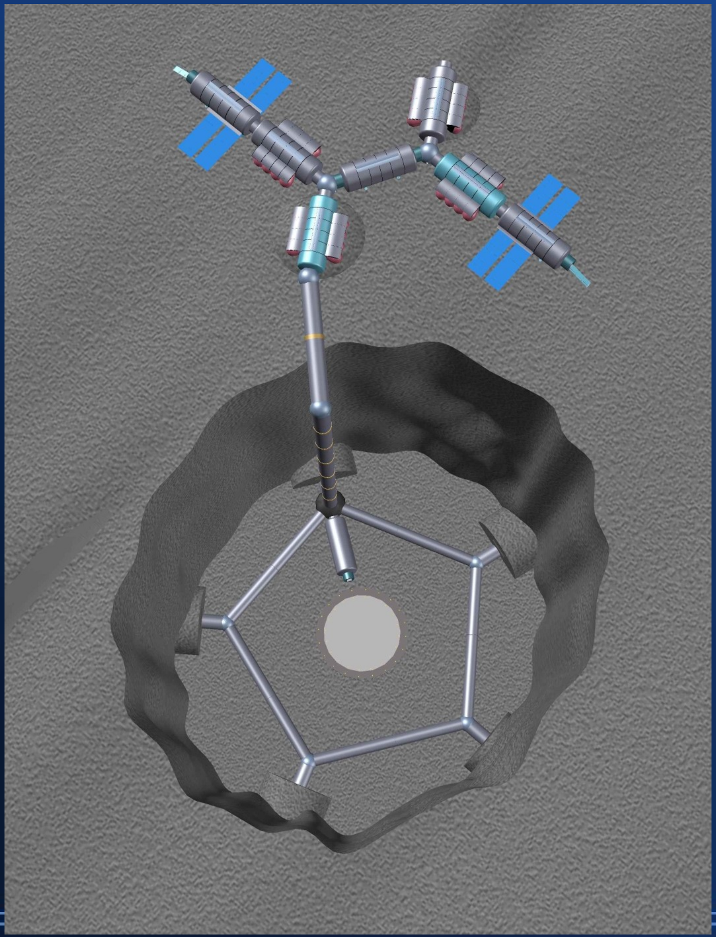


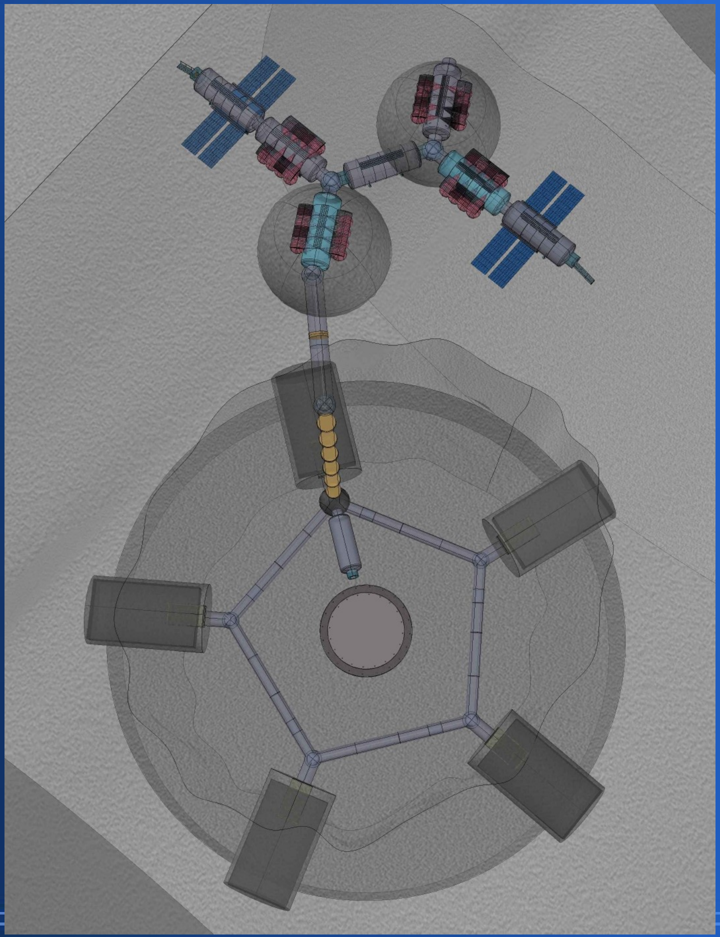
Figure 7: Cargo Starship on Lunar Surface

Credit: Elon Musk, The Starship Users Guide, SpaceX 2020

SECOND STEP: At the bottom of Mare Tranquilitatis Hole 5 caves are excavated (if possible by enlarging existing lava tubes). The walls of the caves are sintered with laser-devices and prepared for inflatable hulls. The excavated material is filled into bags to build shieldings against cosmic rays after finishing the construction.

The caves are connected by aluminium tubes and nodes. A vertical tube with an elevator connects the subselene structure with the modular base on the surface.

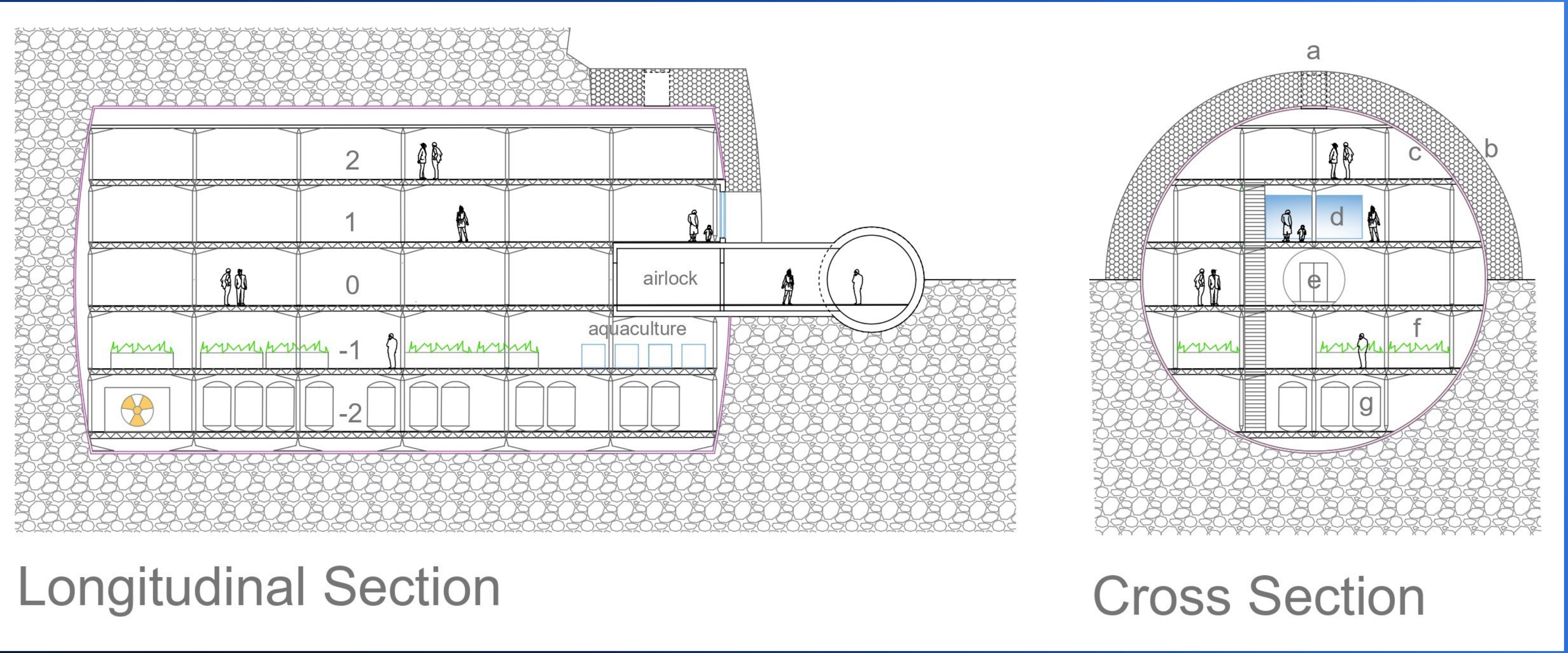




In the centre of the structure a landing platform is built by sintering regolith.

Subselene habitat structure for 50 inhabitants (one of five), made of an inflated hull and interior aluminium lightweight trusses, colums and floor elements

Cave structure on the bottom of MTH: diameter 16 m, overall lenght 30 m,
volume 6030 m³ , total floor area 2100 m²



a emergency exit b regolith containment bags
c inflated hull d window to MTH
e airlock f,g life support system

For construction of the interior colums, trusses and floors an Automated Beam Builder is used (NASA & Grumman Aerospace 1978).

1 fabricated aluminium beam

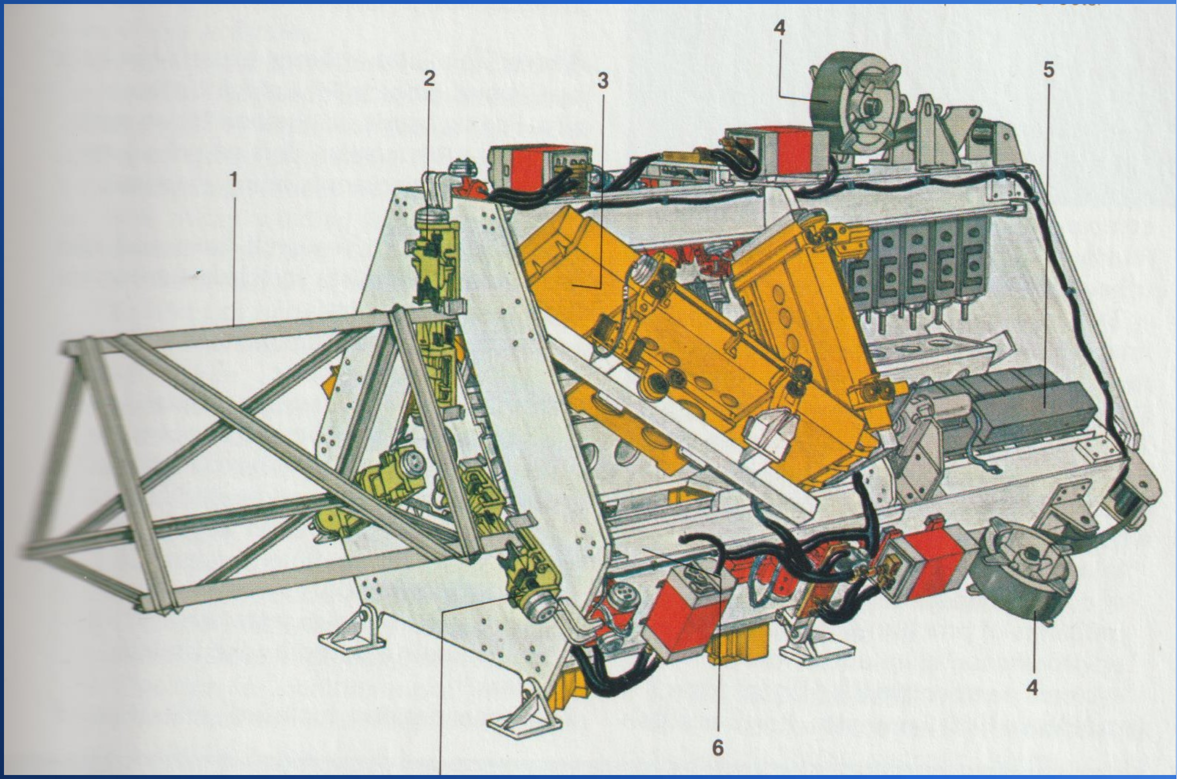
2 cutting device

3 spot welding unit

4 storage rolls (aluminium tape)

5 roll forming unit

6 track



- The aluminium tapes are about 50 x 1 mm (mass: 0.135 kg / m)
- The mass of the trusses is about 0.81 kg / m
- The mass of the entire aluminium structure (trusses, colums and floors) for each cave is about 35 t.

Estimation of costs :
We assume the reduction of launching costs by reusable SpaceX launchers from about € 20,000 / kg to approx. € 7,000 / kg payload.

FIRST STEP Lunar surface base	mass in tons t	number of launches / Type of launcher	Estimated costs € / ton	Total cost estimation €
modules, machinery rocket crane, lander	144 t (12 t / launch)	12 Falcon Heavy	8,000,000 / t (8,000 / kg)	1,152,000,000
SECOND STEP Subselene habitat				
beam builder,aluminium digging machinery	195 t	2 SpaceX Starship	7,000,000 / t (7,000 / kg)	1,365,000,000
inflating structure material (9.5 kg/m2)	90 t	1 SpaceX Starship	7,000,000 / t (7,000 / kg)	630,000,000
connecting tubes, elevator, airlocks, etc	100 t	1 SpaceX Starship	7,000,000 / t (7,000 / kg)	700,000,000
equipment	200 t	2 SpaceX Starship	7,000,000 / t	1,400,000,000
ENGINEERING and PRODUCTION COSTS				1,450,000,000
Human transport	250 Persons	3 SpaceX Starship	3,600,000 / pers.	900,000,000
Total costs				**7.597 billions**

An optimistic TIME SCHEDULE

	2022	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Engineering Design phase		X	X	X	X	X	X	X	X	X									
Prototypes for MODULES						X	X												
Prototypes machinery						X	X												
Human flight preparations					X	X	X	X	X	X	X	X							
Construction 1st Lunar Base								X	X										
Digging the caves in MTH										X									
Build habitats in the caves											X	X							
Completing eqipment												X	X						
Transport of inhabitants												Ω	Ω	Ω					

Thank You for Watching! „Ad Astra!“