DEFENSE DAILY

Briefing Slides From
Elon Musk
Mars Presentation
At 2016 IAC in Mexico

Not refilling in orbit would require a
3-stage vehicle at 5-10x the size and cost

Spreading the required lift capacity across
multiple launches substantially reduces
development costs and compresses schedule

Combined with reusability, refilling makes
performance shortfalls an incremental rather
than exponential cost increase

Allows reusability of the ship and
enables people to return to Earth easily

Leverages resources readily available on Mars

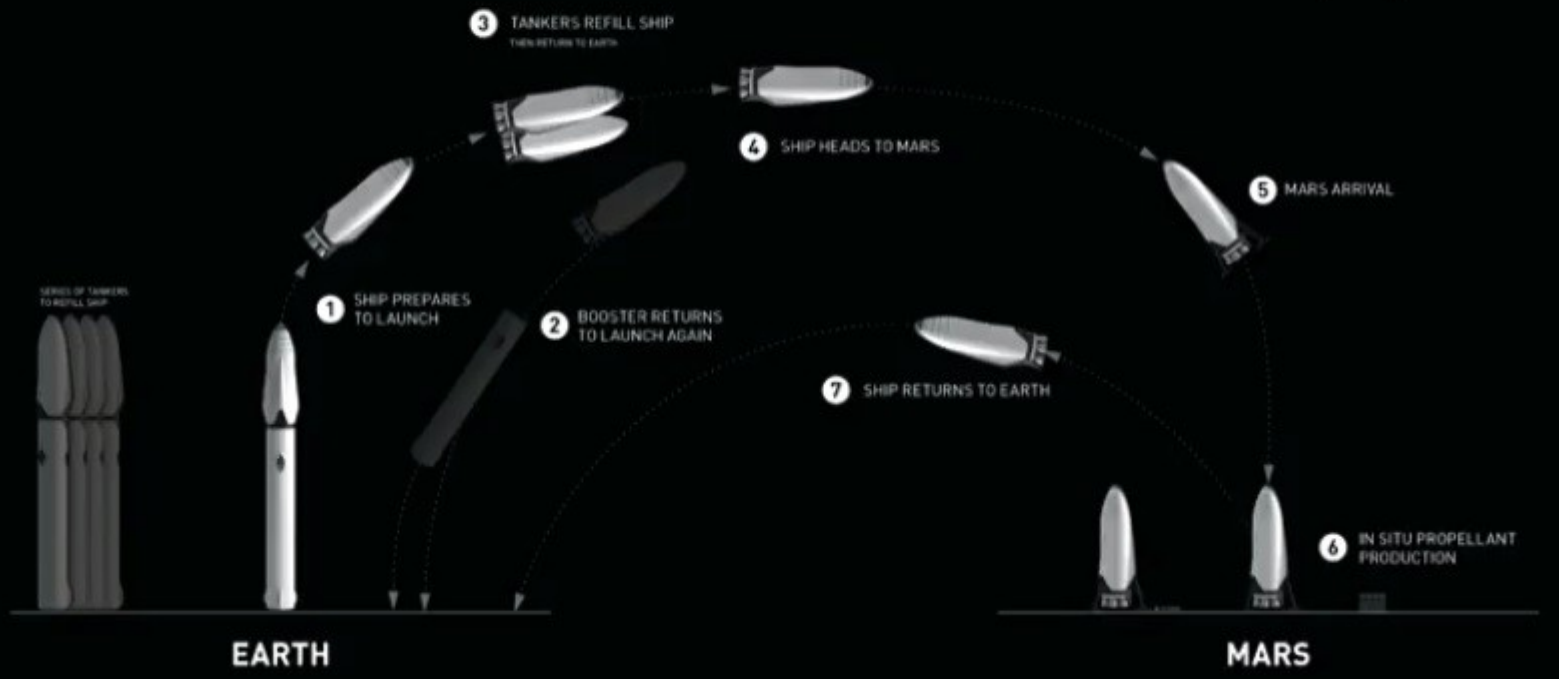
Bringing return propellant requires approximately
5 times as much mass departing Earth

	$C_{12}H_{22.4}/O_2$ KEROSENE	H_2/O_2 HYDROGEN/OXYGEN	CH_4/O_2 DEEP-CRYO METHALOX
VEHICLE SIZE	●	●	●
COST OF PROP	●	●	●
REUSABILITY	●	●	●
MARS PROPELLANT PRODUCTION	✕	●	●
PROPELLANT TRANSFER	●	●	●

● GOOD
● OK
● BAD
✕ VERY BAD

SYSTEM ARCHITECTURE

TARGETED REUSE PER VEHICLE
1,000 uses per booster
100 per tanker
12 uses per ship



Carbon-fiber primary structure

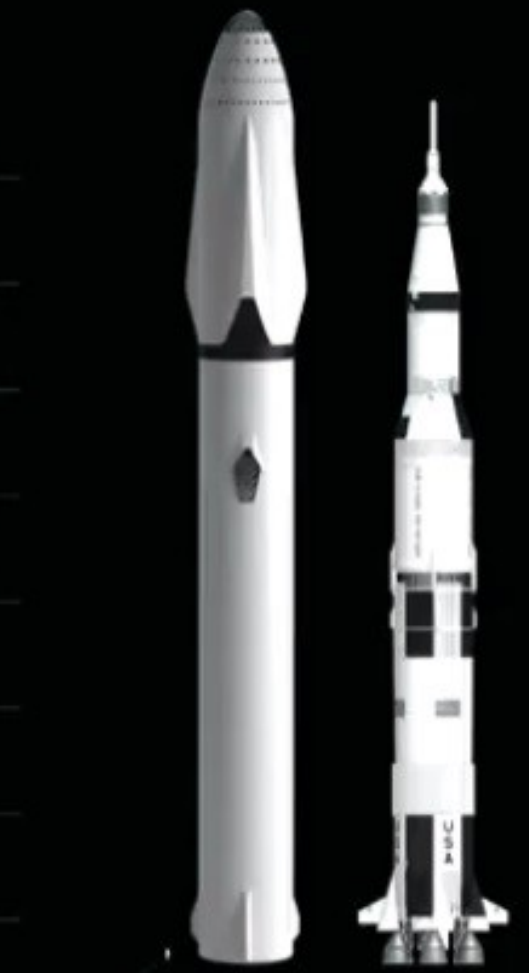
Densified CH_4/O2 propellant

Autogenous pressurization

VEHICLES BY PERFORMANCE

VEHICLE NAME	INDIA GSLV	ANTARES	SOYUZ 2-1B	CHINA LM7	ATLAS V 551	JAPAN H-IIB	ARIANE 5	PROTON M / BREEZE M	FALCON 9	DELTA IV HEAVY	FALCON HEAVY	SATURN V	MARS VEHICLE
PAYLOAD TO LEO (KG)	5,000	7,000	8,200	13,500	18,850	19,000	20,000	22,000	22,800	28,300	54,400	135,000	550,000

	MARS VEHICLE	SATURN V	RATIO
GROSS LIFT-OFF MASS (t)	10,500	3,039	3.5
LIFT-OFF THRUST (MN)	128	35	3.6
LIFT-OFF THRUST (t)	13,033	3,579	3.6
VEHICLE HEIGHT (m)	122	111	1.1
TANK DIAMETER (m)	12	10	1.2
EXPENDABLE LEO PAYLOAD (t)	550	135	4.1
FULLY REUSABLE LEO PAYLOAD (t)	300	–	–



Cycle	Full-flow staged combustion
Oxidizer	Subcooled liquid oxygen
Fuel	Subcooled liquid methane
Chamber Pressure	300 bar
Throttle Capability	20% to 100% thrust

Sea-Level Nozzle

- Expansion Ratio: 40
- Thrust (SL): 3,050 kN
- Isp (SL): 334 s

Vacuum Nozzle

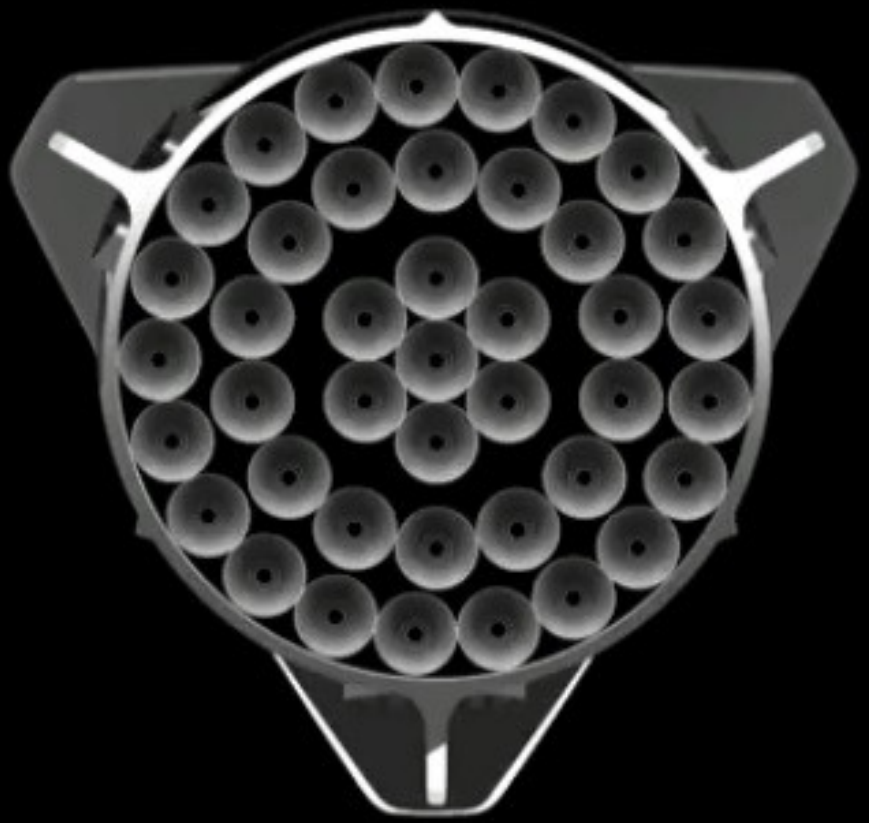
- Expansion Ratio: 200
- Thrust: 3,500 kN
- Isp: 382 s

Length	77.5 m
Diameter	12 m
Dry Mass	275 t
Propellant Mass	6,700 t
Raptor Engines	42
Sea Level Thrust	128 MN
Vacuum Thrust	138 MN

Booster accelerates ship to staging velocity, traveling 8,650 km/h (5,375 mph) at separation

Booster returns to landing site, using 7% of total booster prop load for boostback burn and landing

Grid fins guide rocket back through atmosphere to precision landing

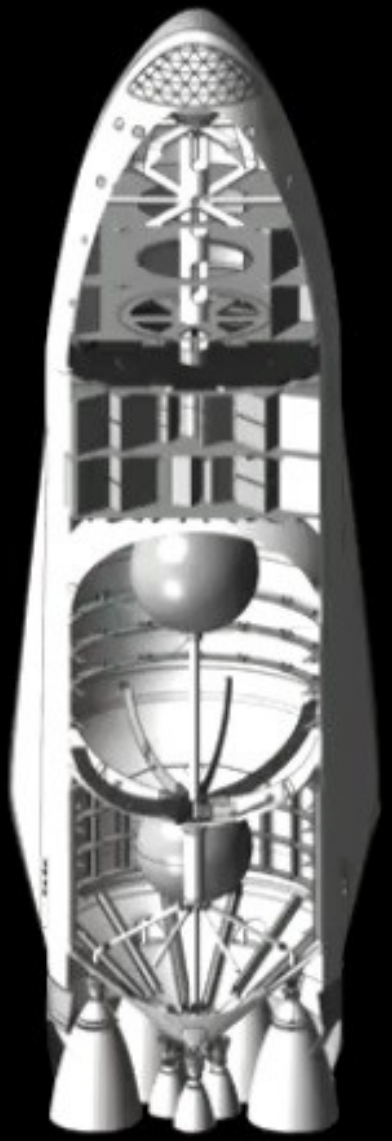


Engine configuration

- Outer ring: 21
- Inner ring: 14
- Center cluster: 7

Outer engines fixed in place

Only center cluster gimbals



Length	49.5 m
Max Diameter	17 m
Raptor Engines	3 Sea-Level - 361s Isp
	6 Vacuum - 382s Isp
Vacuum Thrust	31 MN
Propellant Mass	Ship: 1,950 t
	Tanker: 2,500 t
Dry Mass	Ship: 150 t
	Tanker: 90 t
Cargo/Prop to LEO	Ship: 300 t
	Tanker: 380 t
Cargo to Mars	450 t (with transfer on orbit)

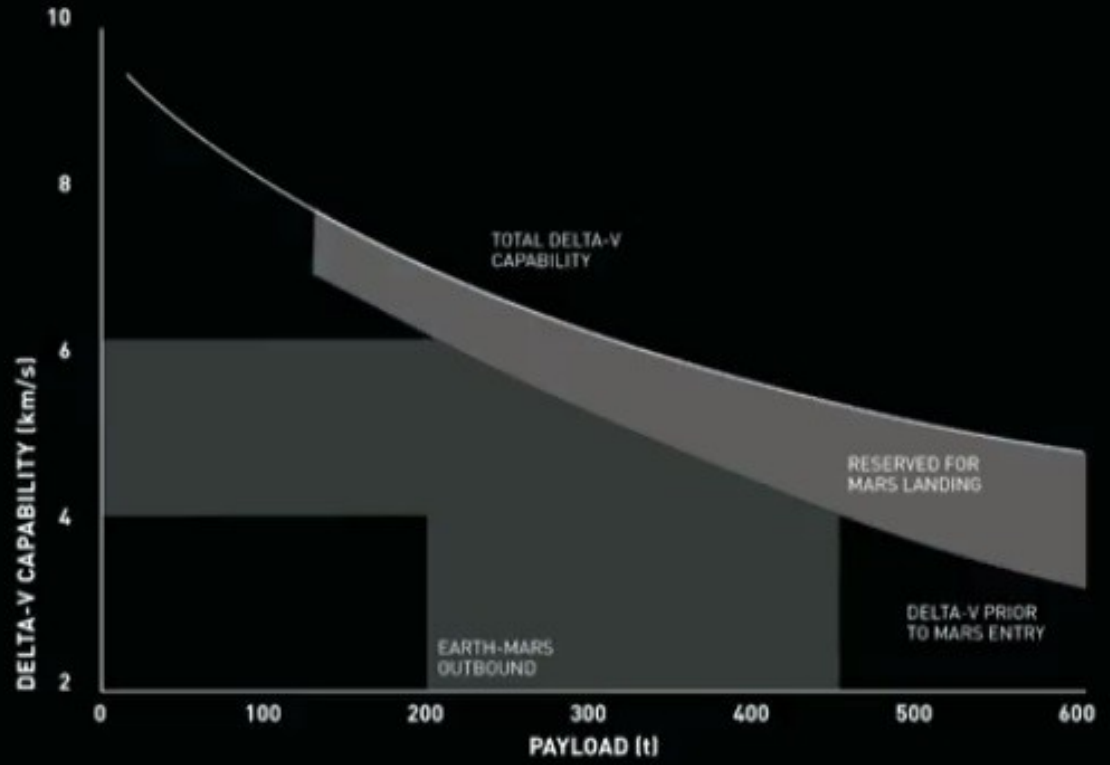
Long term goal of 100+ passengers/ship

SHIP CAPACITY

EARTH-MARS TRANSIT TIME (DAYS)
BY MISSION OPPORTUNITY

YEAR	TRIP TIME (d)
2020	90
2022	120
2024	140
2027	150
2029	140
2031	110
2033	90
2035	80
2037	100
AVERAGE	**115**

TMI DELTA V: 6 km/s
Mars Entry Velocity: 8.5 km/s

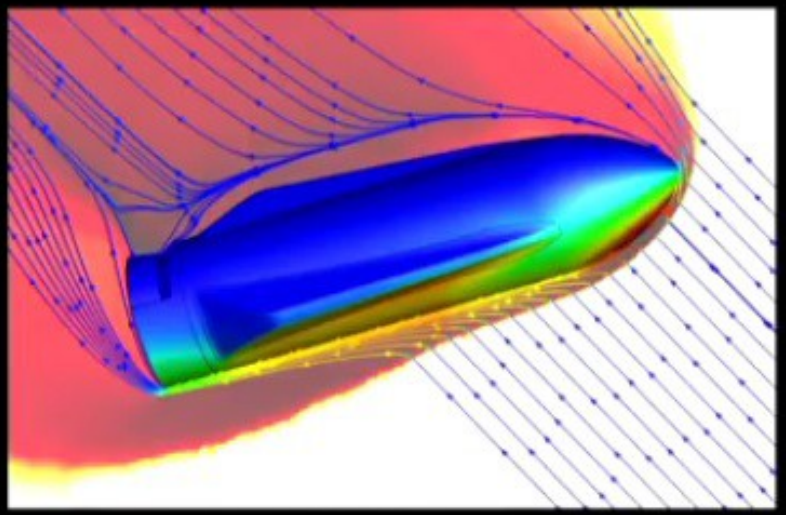


ARRIVAL

From interplanetary space, the ship enters the atmosphere, either capturing into orbit or proceeding directly to landing

Using its aerodynamic lift capability and advanced heat shield materials, the ship can decelerate from entry velocities in excess of 8.5 km/s at Mars and 12.5 km/s at Earth

G-forces (Earth-referenced) during entry are approximately 4-6 g's at Mars and 2-3 g's at Earth



First ship will have small propellant plant, which will be expanded over time

Effectively unlimited supplies of carbon dioxide and water on Mars

- 5 million cubic km ice
- 25 trillion metric tons CO2

$$2H_2O + CO_2 \longrightarrow 2O_2 + CH_4$$

COSTS

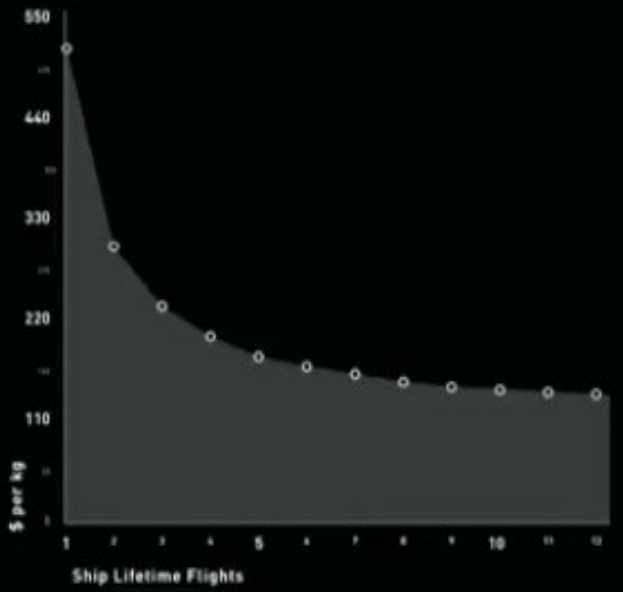
With full reuse, our overall architecture enables significant reduction in cost to Mars

	BOOSTER	TANKER	SHIP
FABRICATION COST	$230M	$130M	$200M
LIFETIME LAUNCHES	1,000	100	12
LAUNCHES PER MARS TRIP	6	5	1
AVERAGE MAINTENANCE COST PER USE	$0.2M	$0.5M	$10M
TOTAL COST PER ONE MARS TRIP (Amortization, Propellant, Maintenance)	$11M	$8M	$43

Cost Of Propellant: $168/t
Launch Site Costs: $200,000/launch
Discount Rate: 5%

Sum Of Costs: $62 M
Cargo Delivered: 450 T

Cost/ton to Mars: <$140,000



FUNDING

Steal Underpants
Launch Satellites
Send Cargo and Astronauts to ISS
Kickstarter
Profit

NEXT STEPS


FALCON HEAVY
CREW DRAGON DEVELOPMENT
RED DRAGON MISSIONS
INTERPLANETARY TRANSPORTATION SYSTEM
ORBITAL TESTING
SHIP TESTING
MARS FLIGHTS
STRUCTURES DEVELOPMENT
PROPULSION DEVELOPMENT
BOOSTER TESTING
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
LAUNCH WINDOW TO MARS