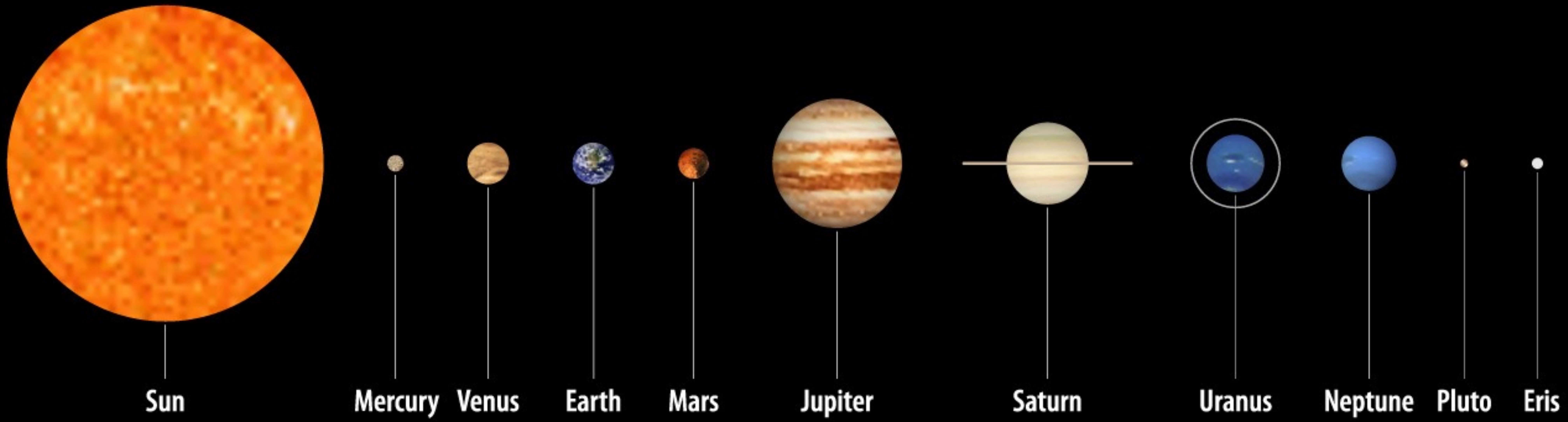
WHY GO ANYWHERE?

WHY MARS?

Credit: Roberto Ziche, NASA, planetpixelemporium.com, planetscapes.com


Sun
Mercury
Venus
Earth
Mars
Jupiter
Saturn
Uranus
Neptune
Pluto
Eris

	EARTH	MARS
DIAMETER	12,756 km / 7,926 mi	6,792 km / 4,220 mi
AVERAGE DISTANCE FROM SUN	150,000,000 km / 93,000,000 mi	229,000,000 km / 142,000,000 mi
TEMPERATURE RANGE	-88C TO 58C / -126F TO 138F	-140C TO 30C / -285F TO 88F
ATMOSPHERIC COMPOSITION	78% N_2, 21% O_2, 1% OTHER	96% CO_2, <2% Ar,<2% N_2, <1% Other
FORCE OF GRAVITY (WEIGHT)	100 LBS ON EARTH	38 lbs ON MARS (62.5% LESS GRAVITY)
DAY LENGTH	24 hrs	24 hrs 40 min
LAND MASS	148.9 MILLION km^2	144.8 MILLION km^2 (97% OF EARTH)
PEOPLE	7 BILLION	0


FROM EARLY EXPLORATION TO A
SELF-SUSTAINING CITY ON MARS

NOW

WANT TO GO

CAN AFFORD TO GO

COST OF TRIP TO MARS

=

INFINITE MONEY

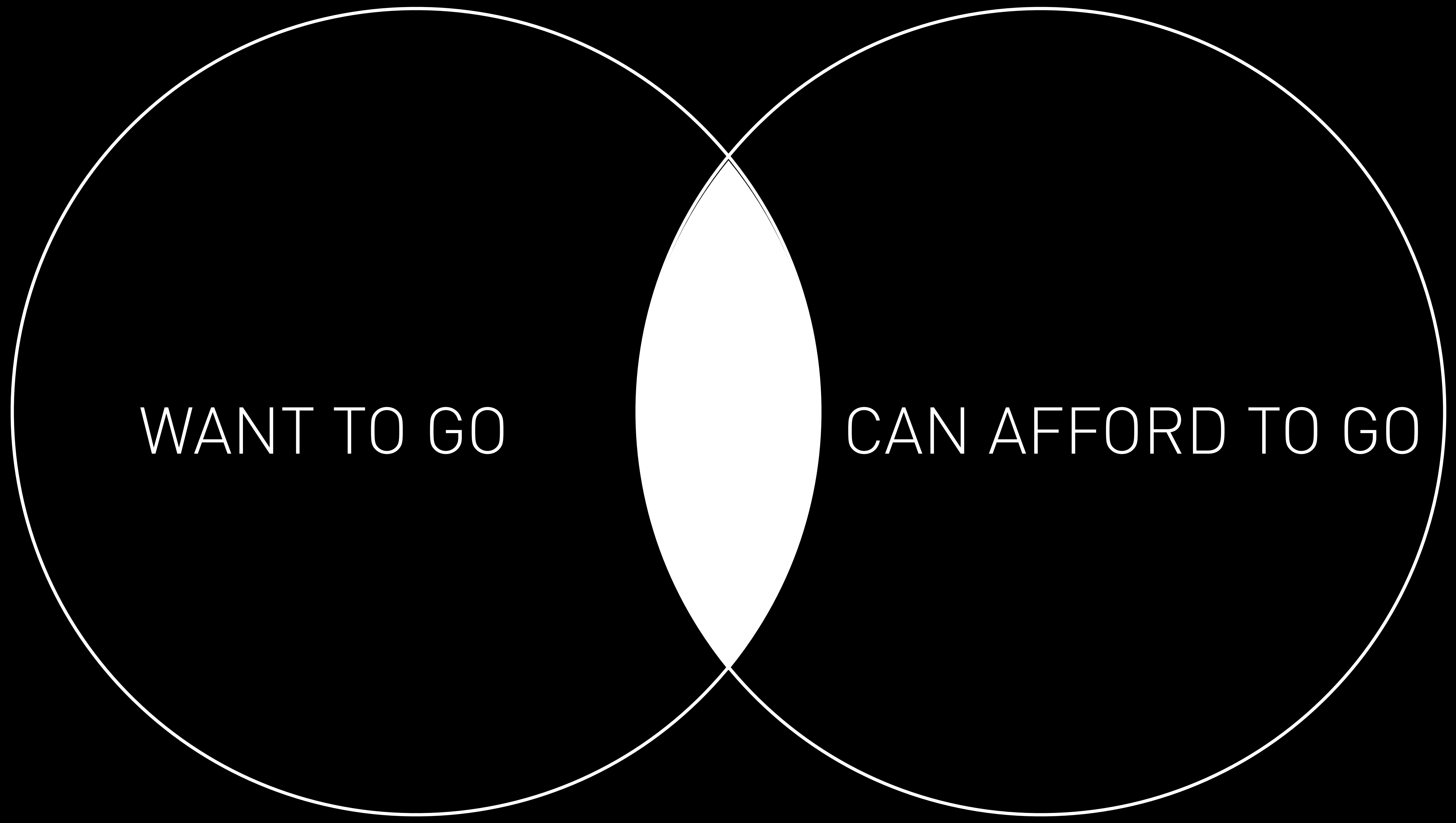
USING TRADITIONAL METHODS

COST OF TRIP TO MARS

=

$10 BILLION / PERSON

WHAT'S NEEDED



COST OF TRIP TO MARS

=

MEDIAN COST OF A HOUSE IN THE UNITED STATES

IMPROVING COST PER TON TO MARS BY FIVE MILLION PERCENT

FULL REUSABILITY

REFILLING IN ORBIT

PROPELLANT PRODUCTION ON MARS

RIGHT PROPELLANT

FULL REUSABILITY

To make Mars trips possible on a large-enough scale to create a self-sustaining city, full reusability is essential

Boeing 737

Price	$90M
Passenger Capability	180 people
Cost/Person - Single Use	$500,000
Cost/Person - Reusable	$43 (LA to Las Vegas)
Cost of Fuel / Person	$10

REFILLING IN ORBIT

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

PROPELLANT ON MARS

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

RIGHT PROPELLANT

	$C_{12}H_{22.4}/O_2$ 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

FULL REUSABILITY

REFILLING IN ORBIT

PROPELLANT PRODUCTION ON MARS

RIGHT PROPELLANT

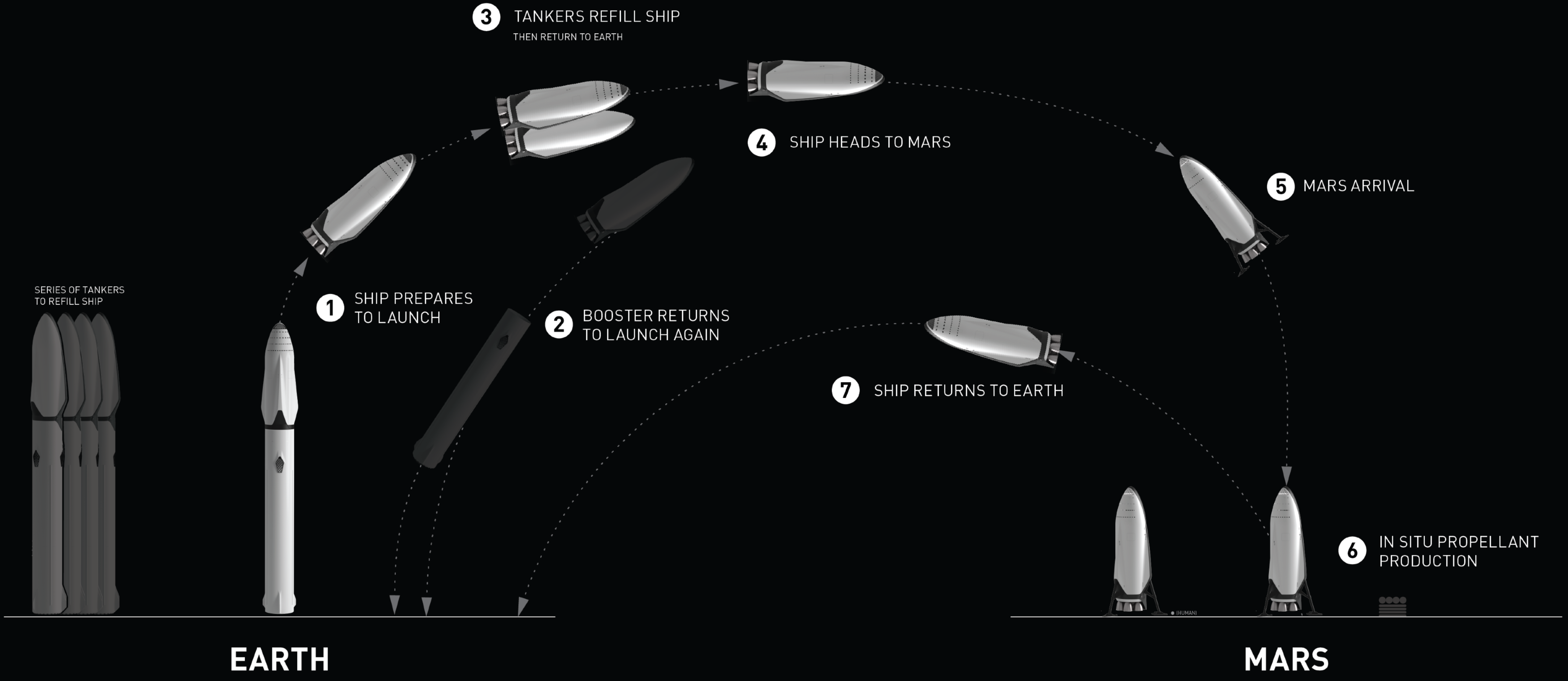
SYSTEM ARCHITECTURE

TARGETED REUSE PER VEHICLE

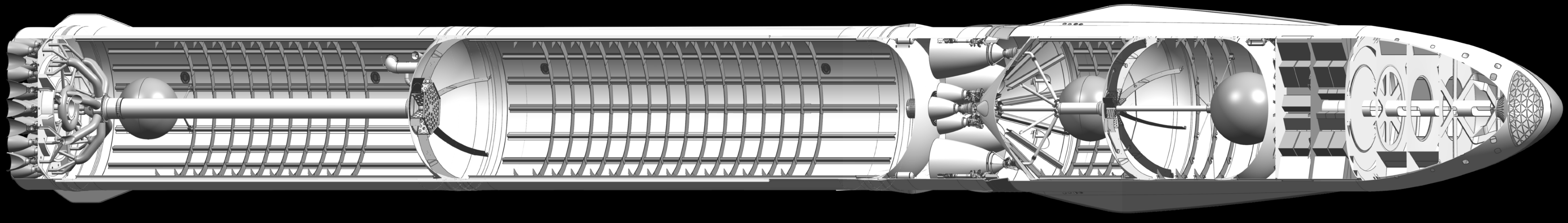
1,000 uses per booster

100 per tanker

12 uses per ship



VEHICLE DESIGN AND PERFORMANCE

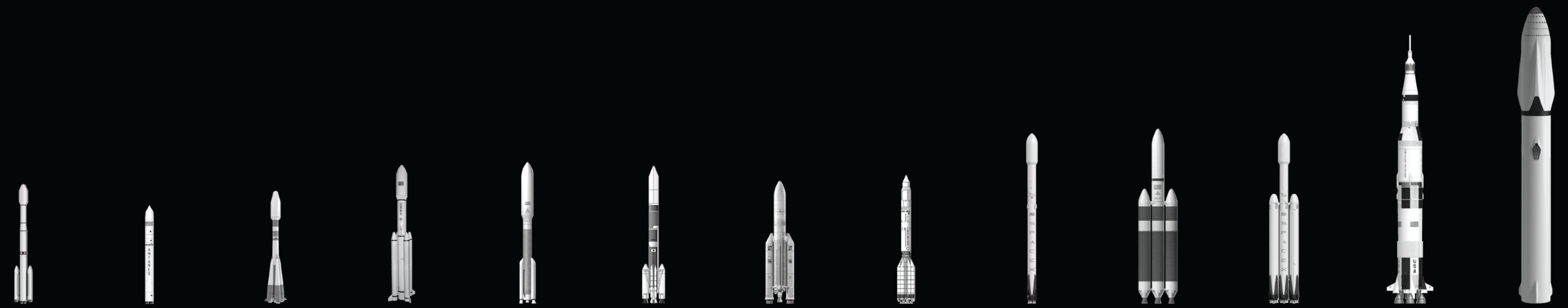


Carbon-fiber primary structure

Densified CH_4/O2 propellant

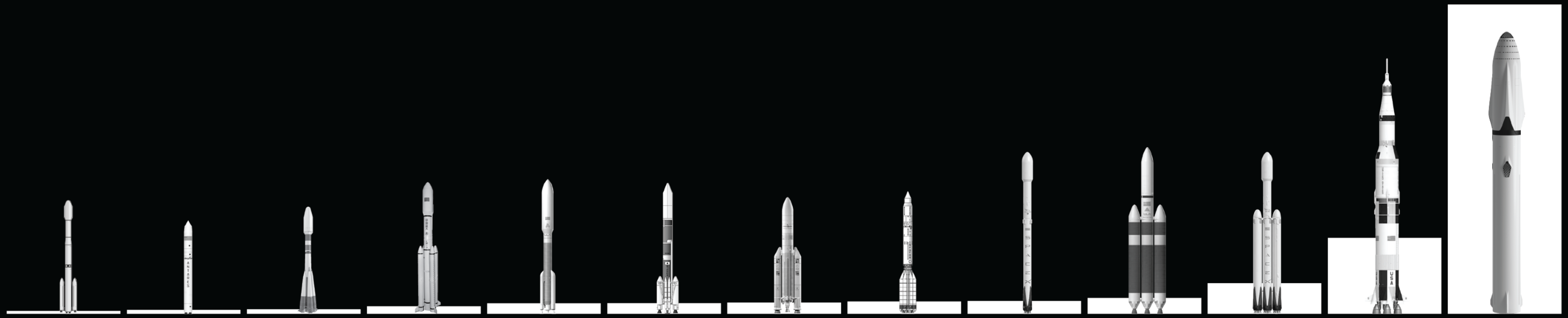
Autogenous pressurization

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

VEHICLES BY PERFORMANCE



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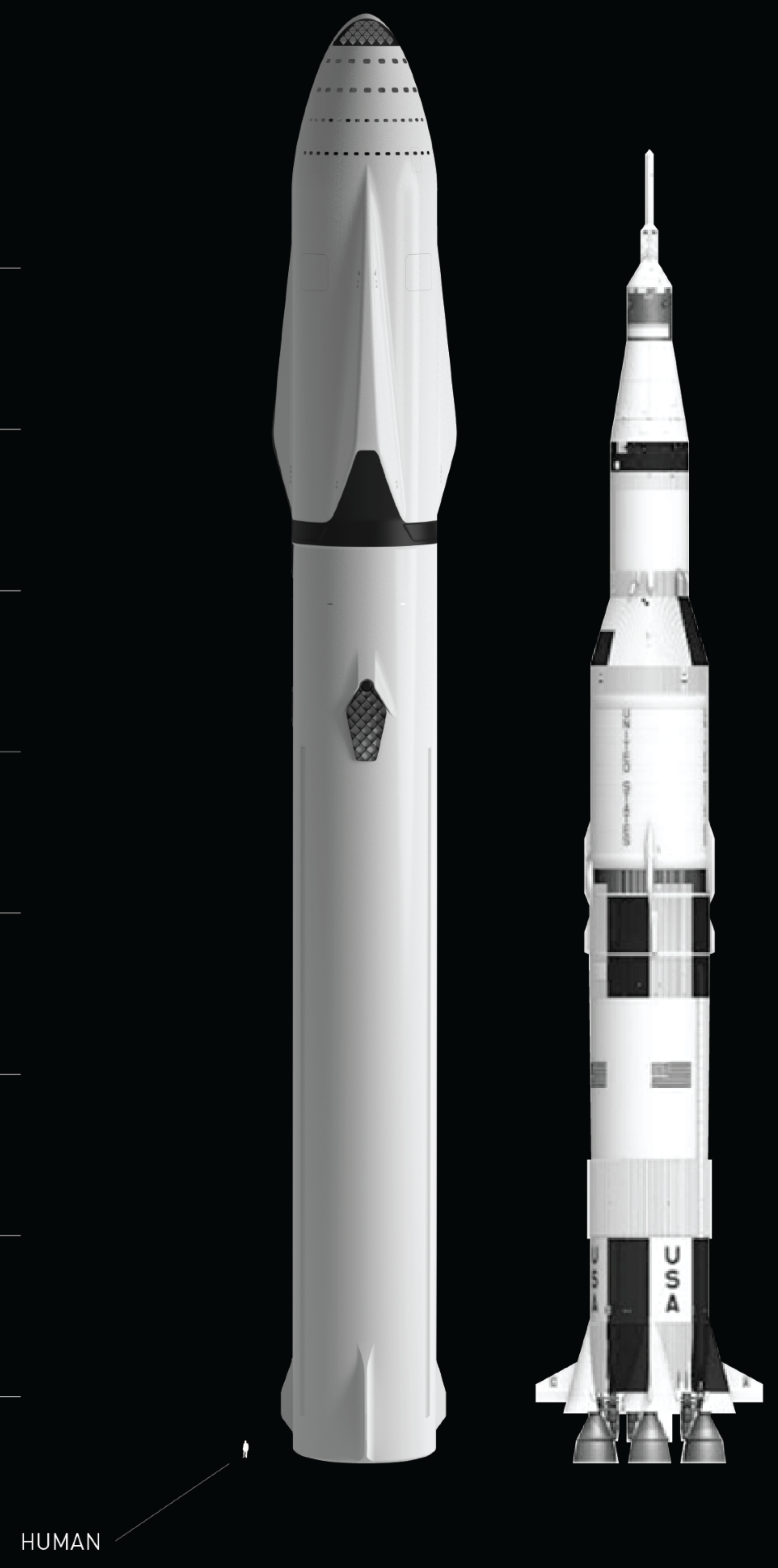
	MARS VEHICLE	SATURN V	RATIO
GROSS LIFT-OFF MASS (t)	10,500	3,039	3.5
LIFT-OFF THRUST (MN)	128	35	3.6
LIFT-OFF THRUST (t)	13,033	3,579	3.6
VEHICLE HEIGHT (m)	122	111	1.1
TANK DIAMETER (m)	12	10	1.2
EXPENDABLE LEO PAYLOAD (t)	550	135	4.1
FULLY REUSABLE LEO PAYLOAD (t)	300	–	–



RAPTOR ENGINE

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

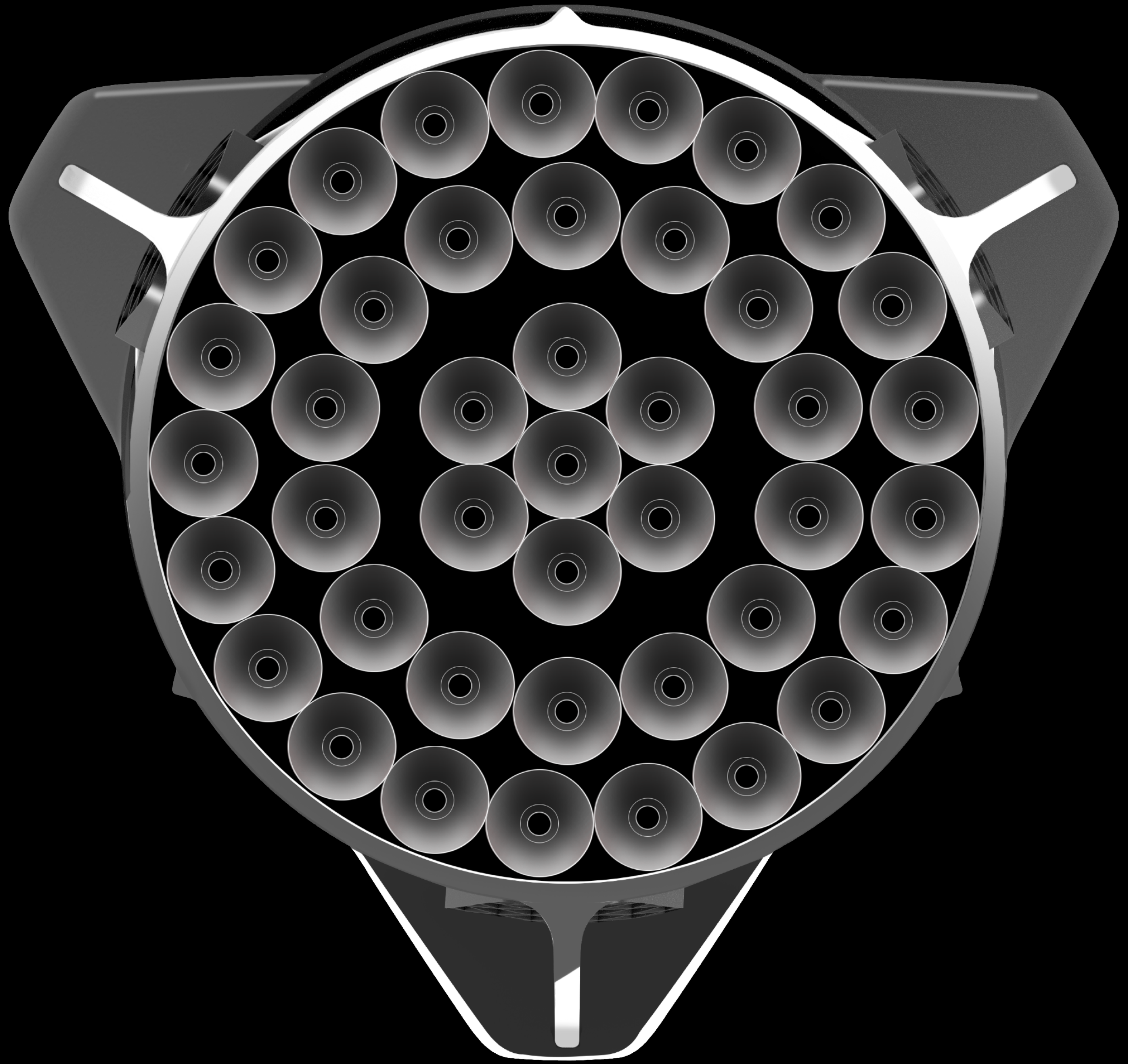
ROCKET BOOSTER

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

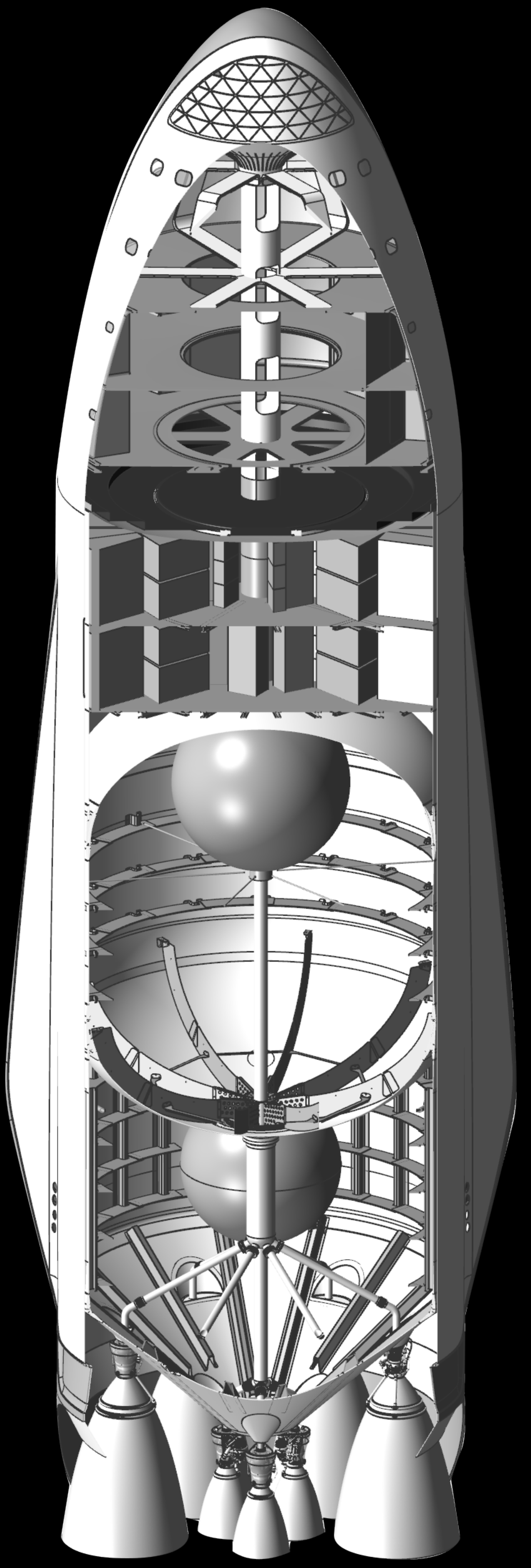
Inner ring: 14

Center cluster: 7

Outer engines fixed in place

Only center cluster gimbals

INTERPLANETARY SPACESHIP



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)

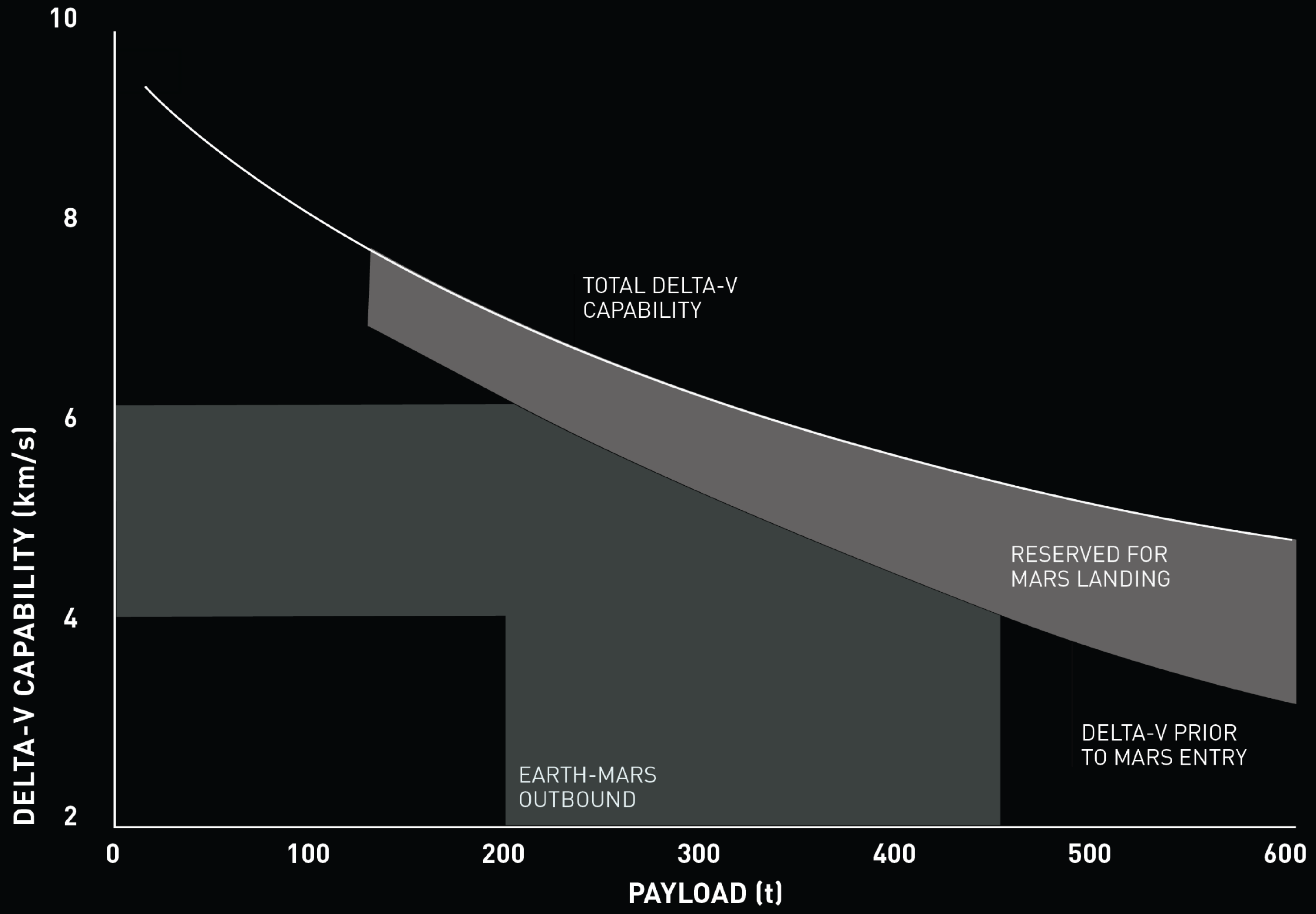
Long term goal of 100+ passengers/ship

SHIP CAPACITY WITH FULL TANKS

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

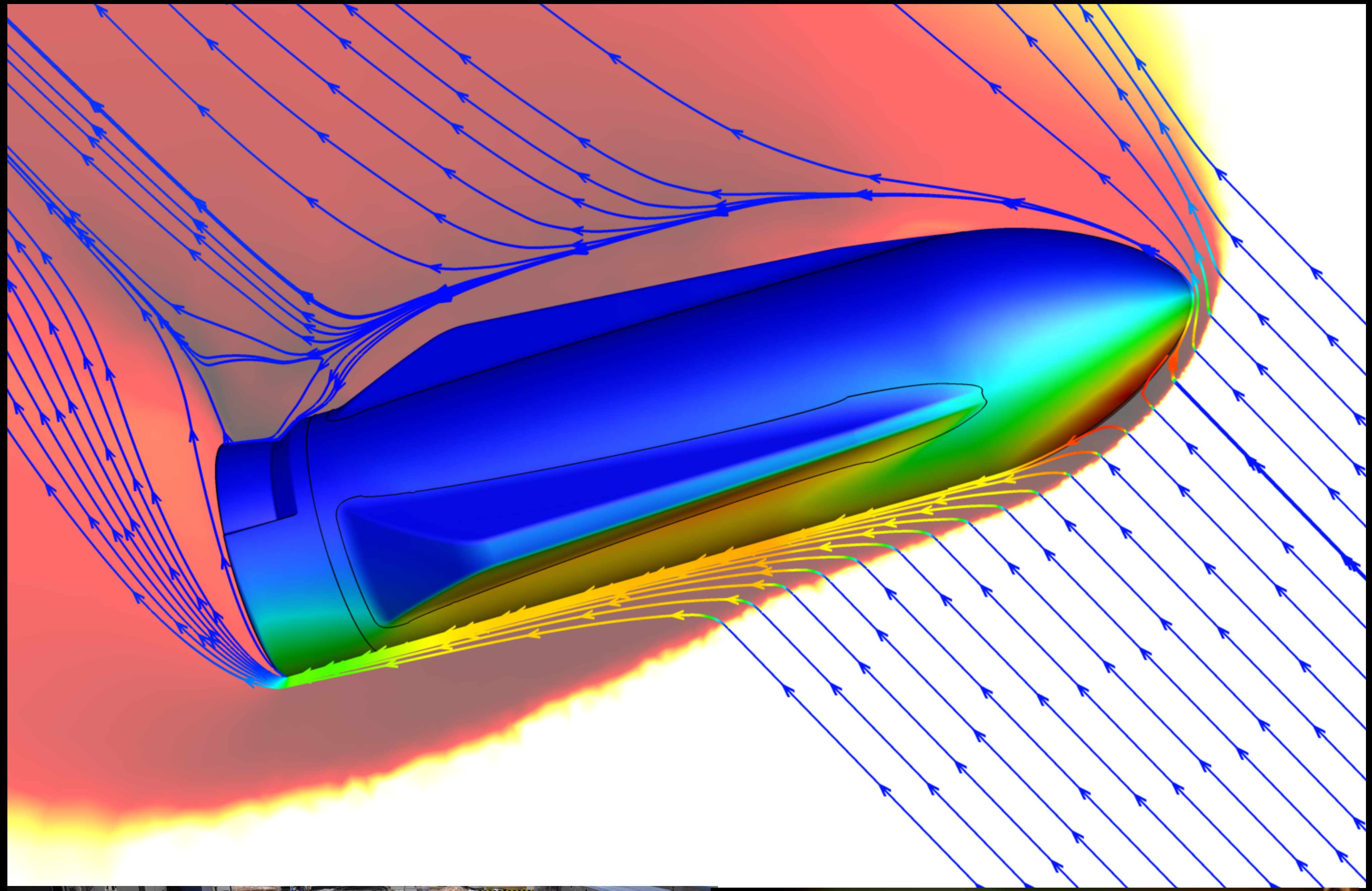
Aerodynamic forces provide the majority of the deceleration, then 3 center Raptor engines perform the final landing burn

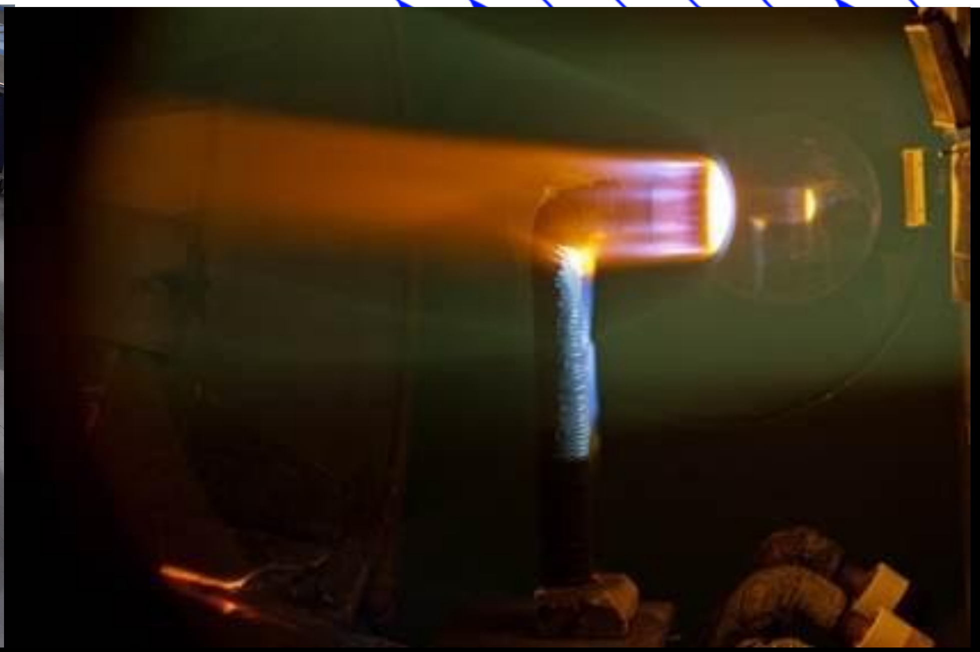
Using its aerodynamic lift capability and advanced heat shield materials, the ship can decelerate from entry velocities in excess of 8.5 km/s at Mars and 12.5 km/s at Earth

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

Heating is within the capabilities of the PICA-family of heat shield materials used on our Dragon spacecraft

PICA 3.0 advancements for Dragon 2 enhance our ability to use the heat shield many times with minimal maintenance



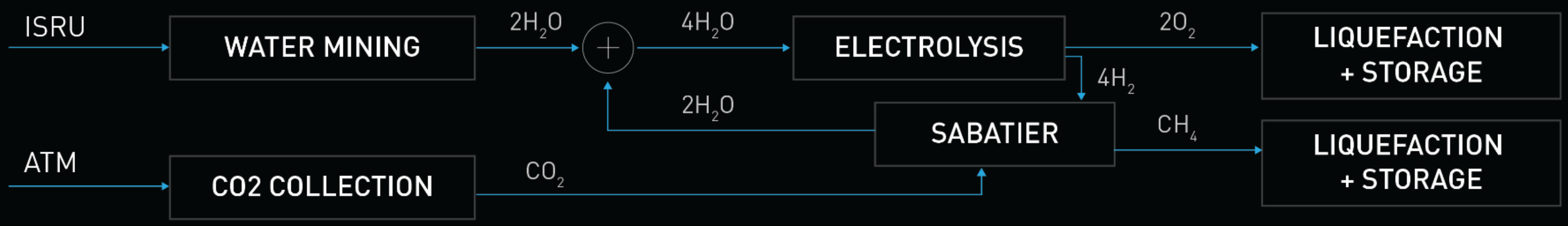


PROPELLANT PLANT

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

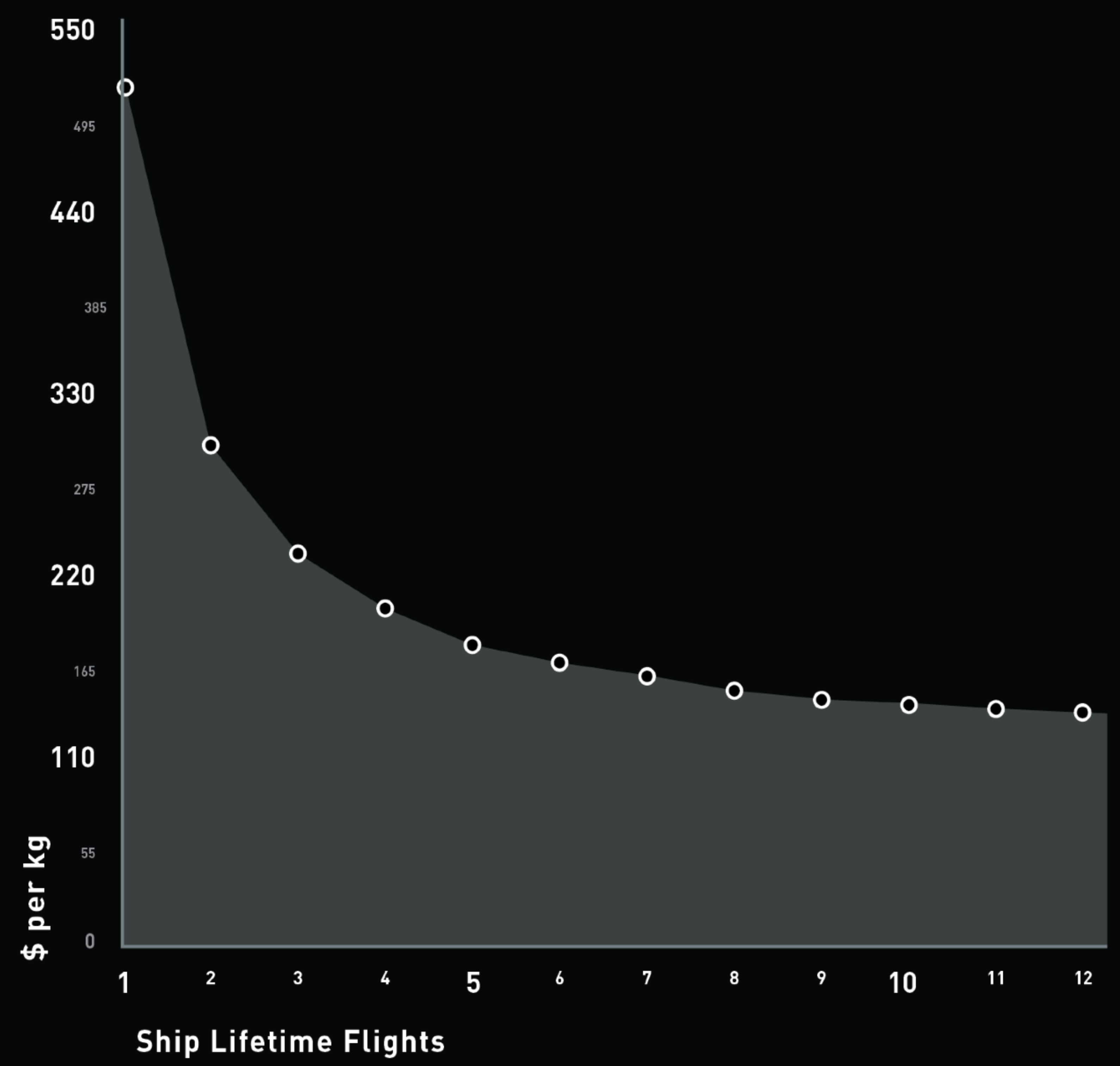
With full reuse, our overall architecture enables significant reduction in cost to Mars

	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

TIMELINES

2002

2006
First Flight attempt, NASA cargo transport partnership

2008
Falcon 1, 0.5 ton to Low Earth Orbit (LEO), fully expendable. First NASA cargo contract

2010
Falcon 9 v1.0, 10 tons to LEO, expendable. Dragon spacecraft to orbit and back

2012
Dragon spacecraft delivers and returns cargo from space station

2013
Grasshopper test rig demonstrates vertical take-off and landing

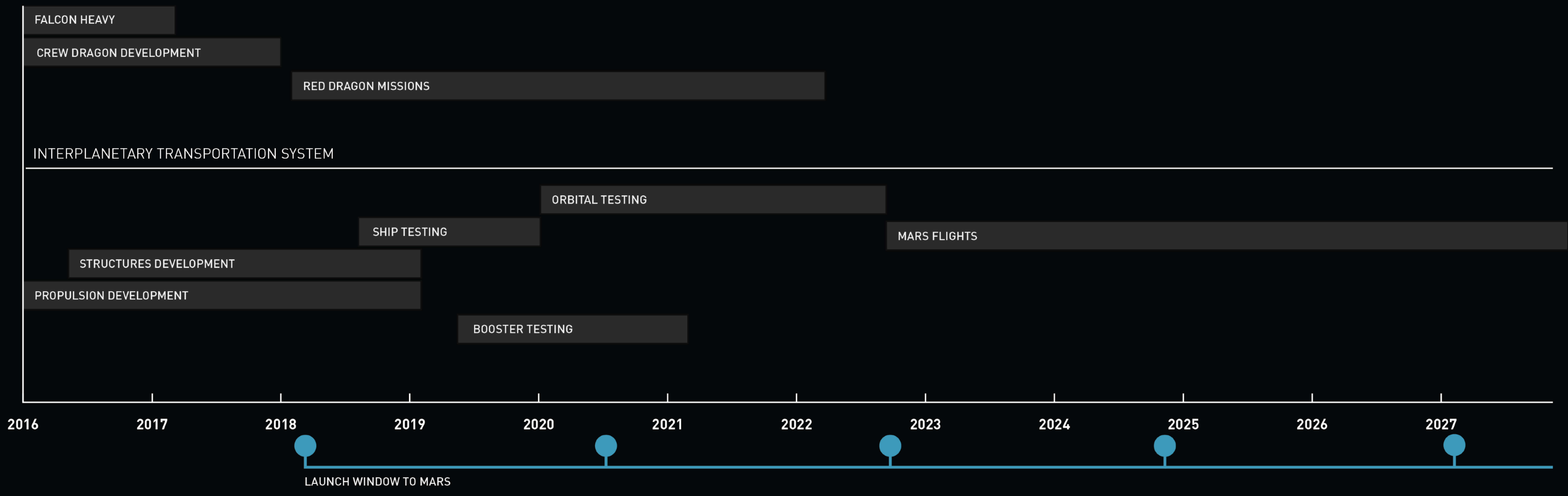
2014
First orbital booster to return from space for ocean landing. Falcon 9 v1.1, 13 tons to LEO, expendable

2015
First orbital booster to return from space and land on land. Upgraded Falcon 9, 22.8 tons to LEO, expendable

2016
First droneship landing for orbital boosters

FUTURE

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

RED DRAGON


Mission Objectives
Learn how to transport and land large payloads on Mars
Identify and characterize potential resources such as water
Characterize potential landing sites, including identifying surface hazards
Demonstrate key surface capabilities on Mars

RAPTOR FIRING

CARBON FIBER TANK


B1
C4


B1
C1

BEYOND MARS

JUPITER


ENCELADUS


EUROPA


SATURN