Some Speculation on The Future...

- Where we are, where we're going (soon)
- Predicting the future (tl;dr - we're not good at it)
- Rockets are Wrong

The Vision

"Once you make it to low Earth orbit, you're halfway to anywhere!"

- Robert A. Heinlein

But First, Some Perspective…

- The first time I taught this particular lecture was in 2018. Let's start with some of those slides and see where we are today…

Today's News (in 2018)

2018 - Falcon Heavy First Flight ✓

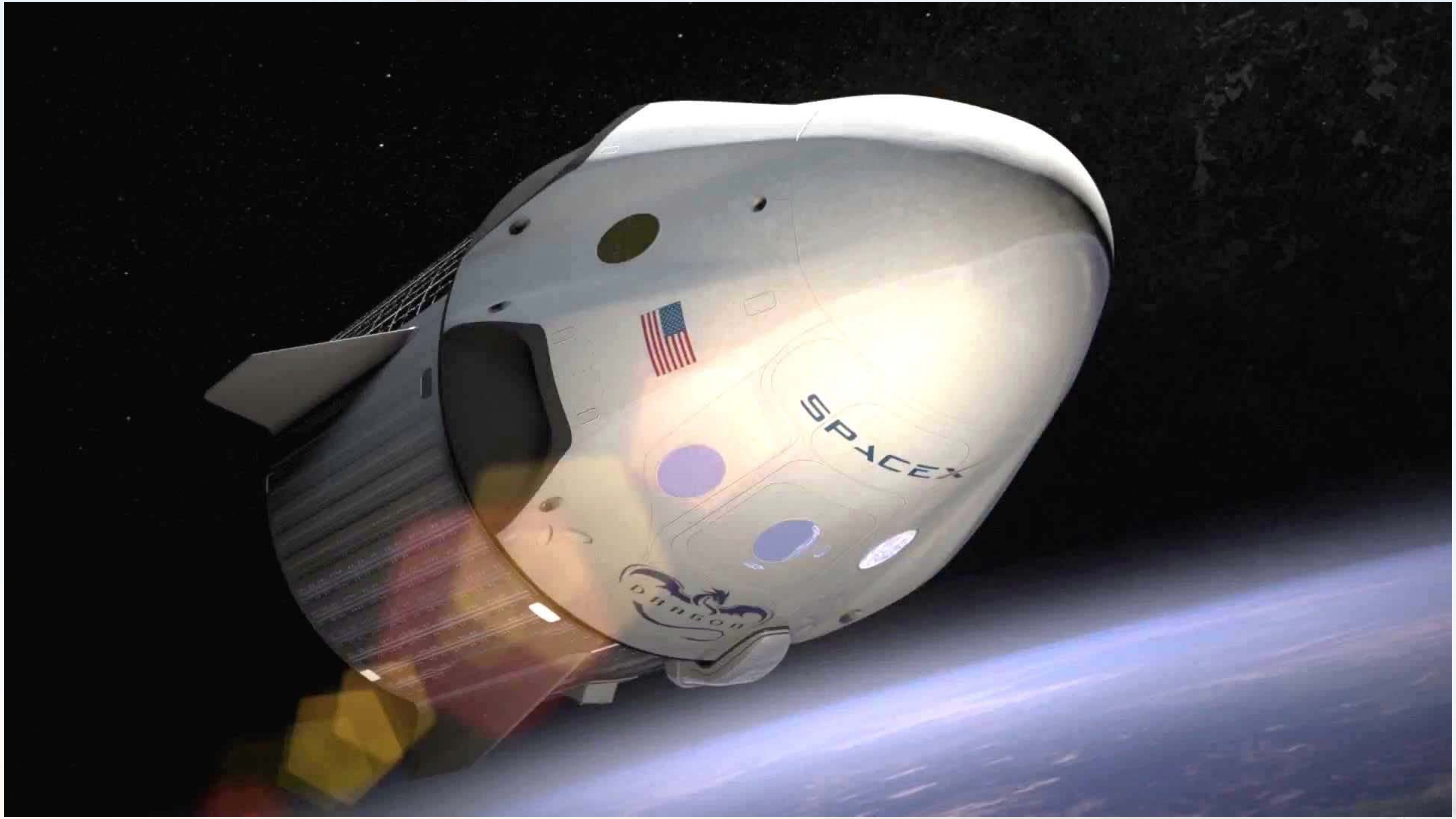
~~2019~~ 2021 - Virgin Galactic First Passengers

2018 - New Shepard First Passengers

2021

2019 - SpaceX Dragon 2 First Crew Flight

2020



2019 - Boeing CST-100 First Crew Flight

2023?

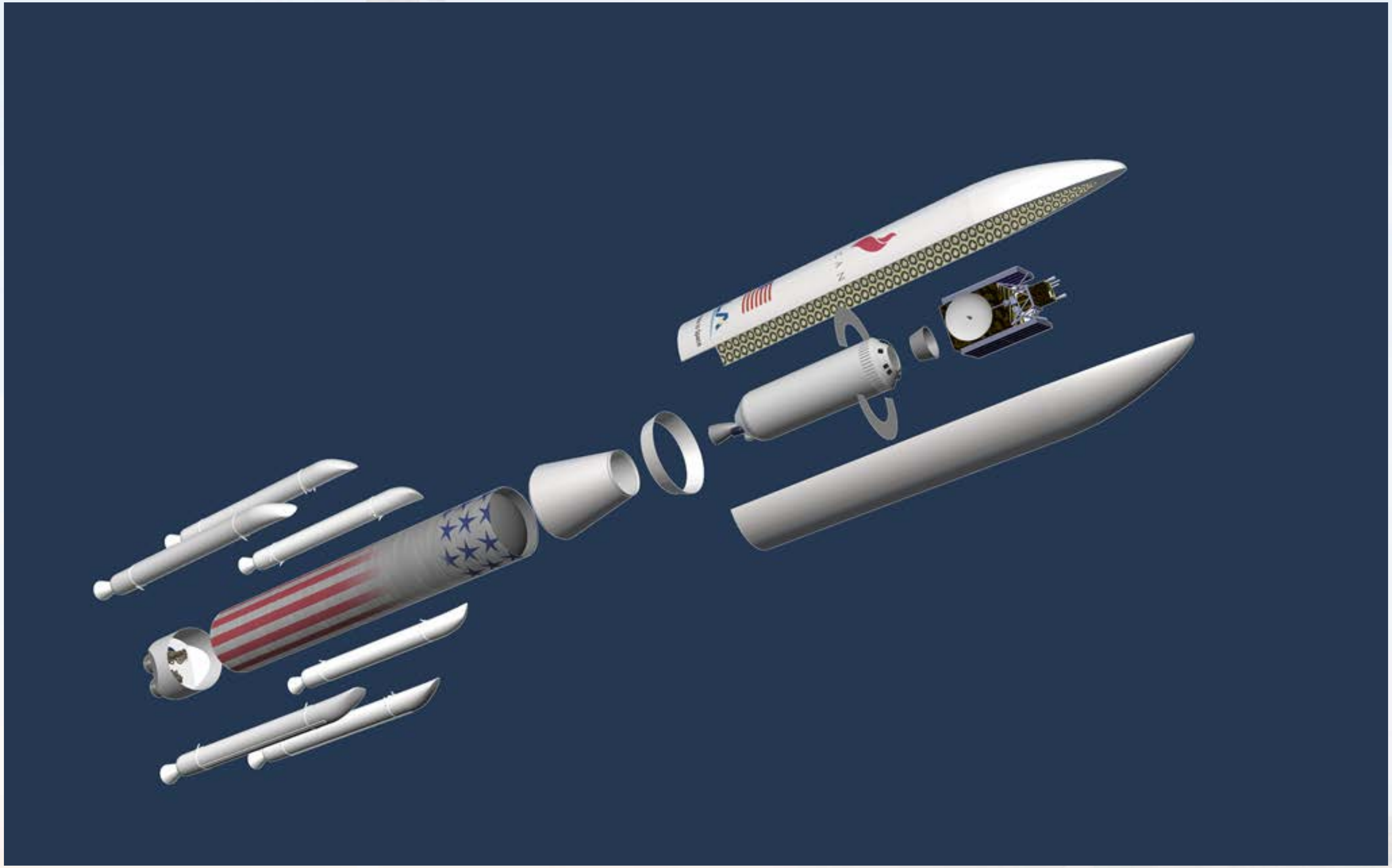
2024?

2020 - Space Launch System 1st Flight

2022

2021 - ULA Vulcan Launch Vehicle

2024



2021 - Blue Origin New Glenn Vehicle

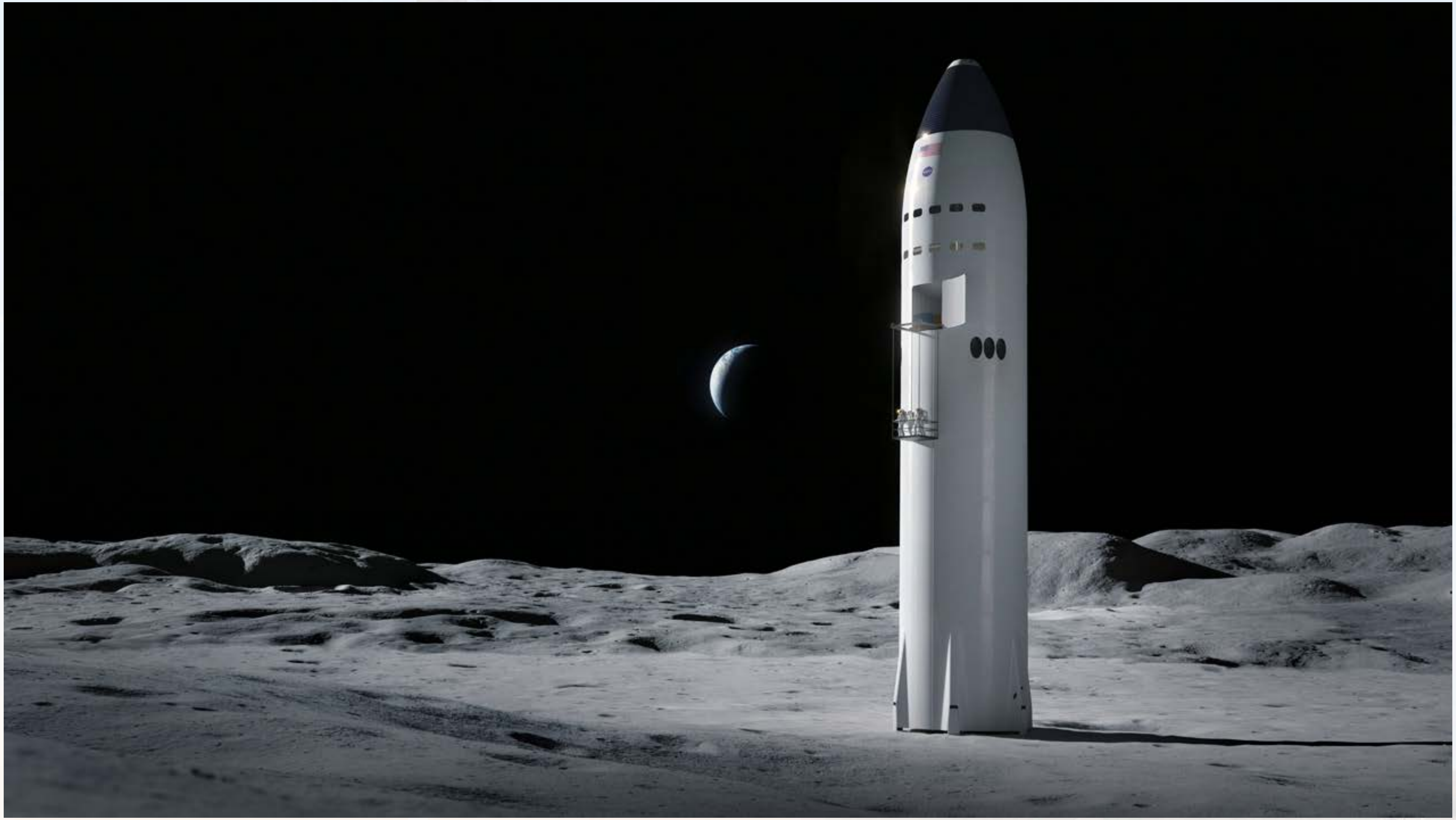
2024?

2023(?) – Artemis 2 Mission

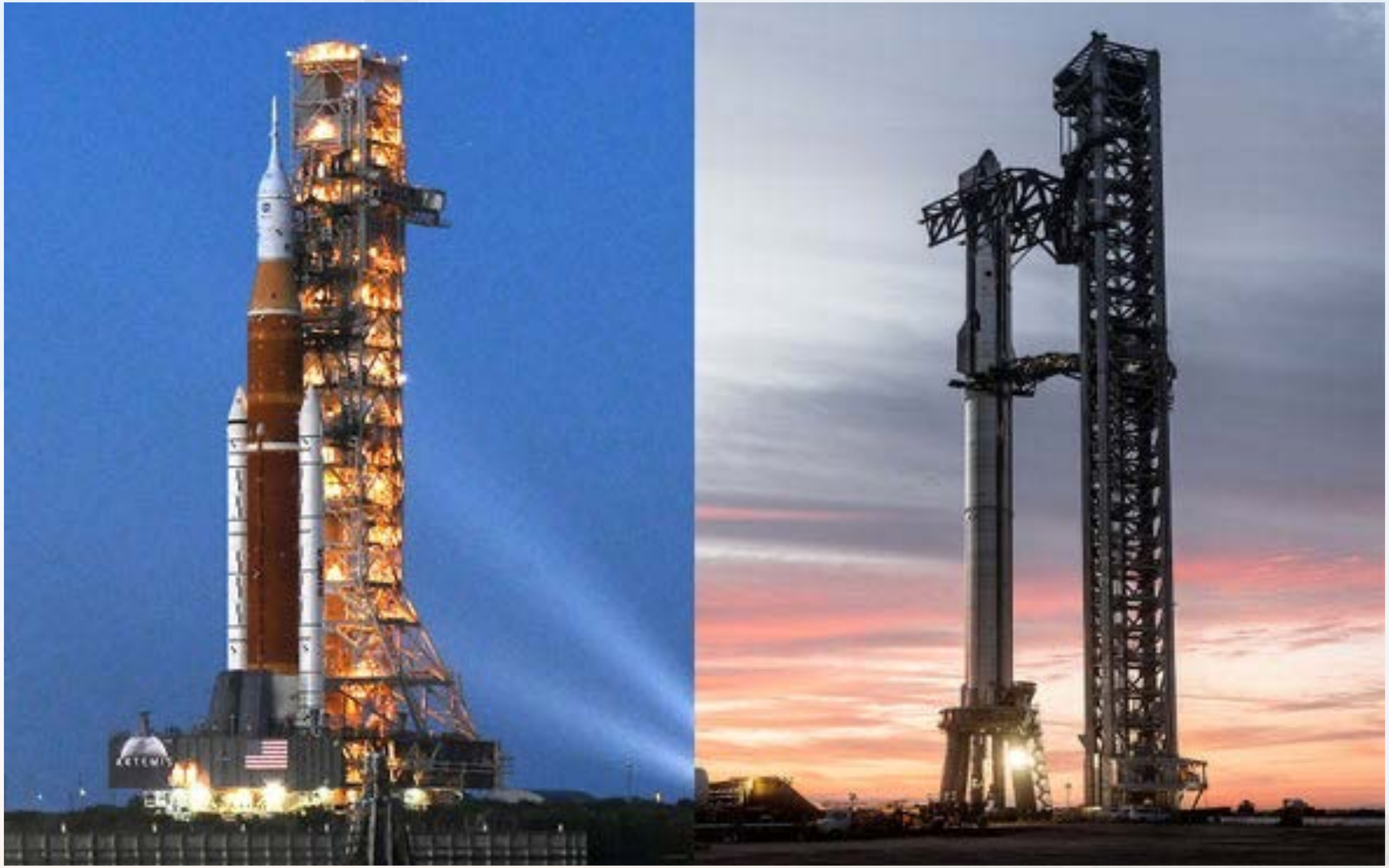
2025?

2024(?) – Artemis 3 Mission

2027?



The Race is On!!!



Suborbital Starship Testing

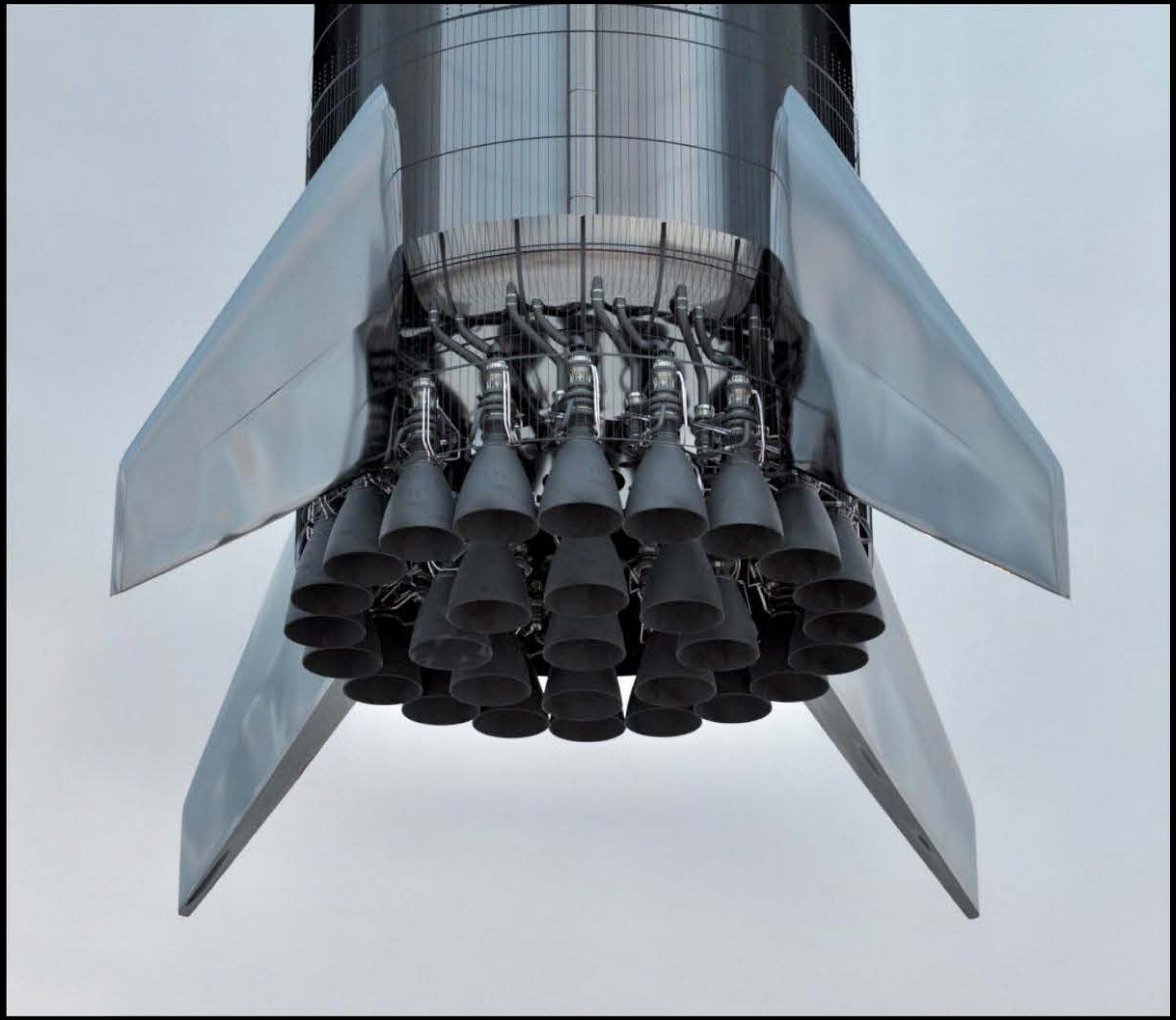
"The Flip"

Modern Launch Vehicle Engine Specifications

EVERYDAY ASTRONAUT

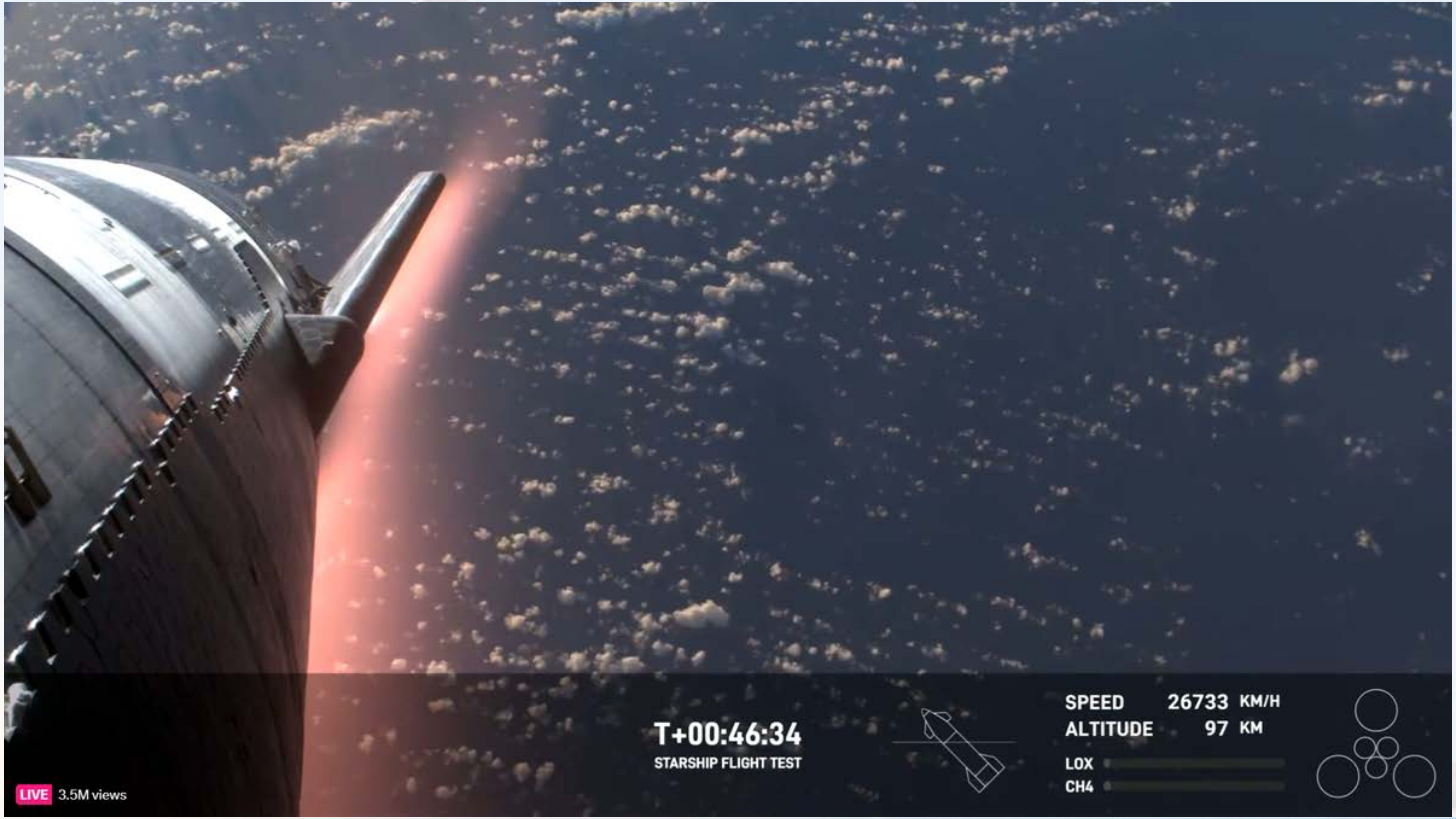
	Merlin	RD-180	F-1	Raptor	BE-4	RS-25
Cycle	Open	Closed (LOX rich)	Open	Closed (Full Flow)	Closed (LOX rich)	Closed (Fuel Rich)
Fuel Type	RP-1	RP-1	RP-1	Methane	Methane	Hydrogen
Total Thrust	0.84 MN	3.83 MN	**6.77 MN**	2.00 MN	~2.40 MN	1.86 MN
Thrust : Weight	**198 : 1**	78 : 1	94 : 1	107 : 1	~80 : 1	73 : 1
Specific Impulse *(ISP)*	282 sl 311 vac	311 sl 338 vac	263 sl 304 vac	330 sl ~350 vac	~310 sl ~340 vac	**366 sl** **452 vac**
Chamber Pressure	97 bar	257 bar	70 bar	**270 bar**	~135 bar	206 bar

Super Heavy Engine Configuration



Starship Integrated Flight Test 3

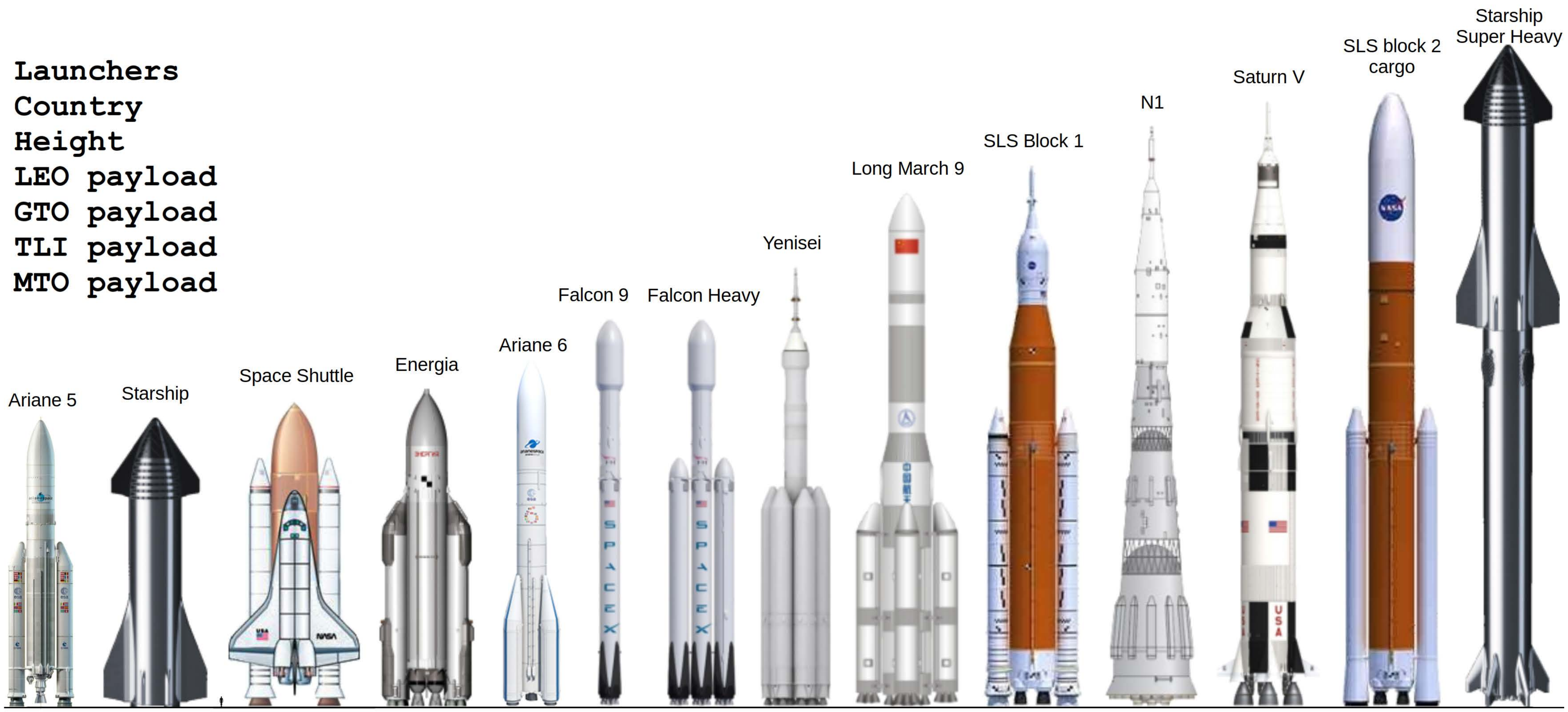
Starship IFT 3 Entry



Speculation on Interior Outfitting

Starship as Human Landing System

Launchers
Country
Height
LEO payload
GTO payload
TLI payload
MTO payload



Ariane 5
EU
48 m
20 t
10.6 t
8.9 t

Starship
USA
50 m
?? t
?? t

Space Shuttle
USA
56.1 m
27.5 t
10.9 t
9.2 t

Energia
USSR
57.5 m
100 t
38 t
32 t

Ariane 6
EU
63 m
21.7 t
11.5 t
9.7 t

Falcon 9
USA
70 m
22.8 t
8.3 t
7.0 t
4.0 t

Falcon Heavy
USA
70 m
63.8 t
26.7 t
22.4 t
16.8 t

Yenisei
Russia
~80 m
103 t

Long March 9
China
93 m
140 t
56 t
50 t
44 t

SLS Block 1
USA
98.1 m
95 t
55 t
42 t

N1
USSR
105 m
95 t
28.1 t
23.5 t

Saturn V
USA
110.6 m
140 t
57.8 t
48.6 t

SLS block 2 cargo
USA
111.3 m
130 t
55 t
46 t

Starship Super Heavy
USA
120 m
150 t

Soyuz-2
Russia/EU
46.3 m
8.2 t
3.3 t

Atlas V
USA
58.3 m
20.5 t
8.9 t

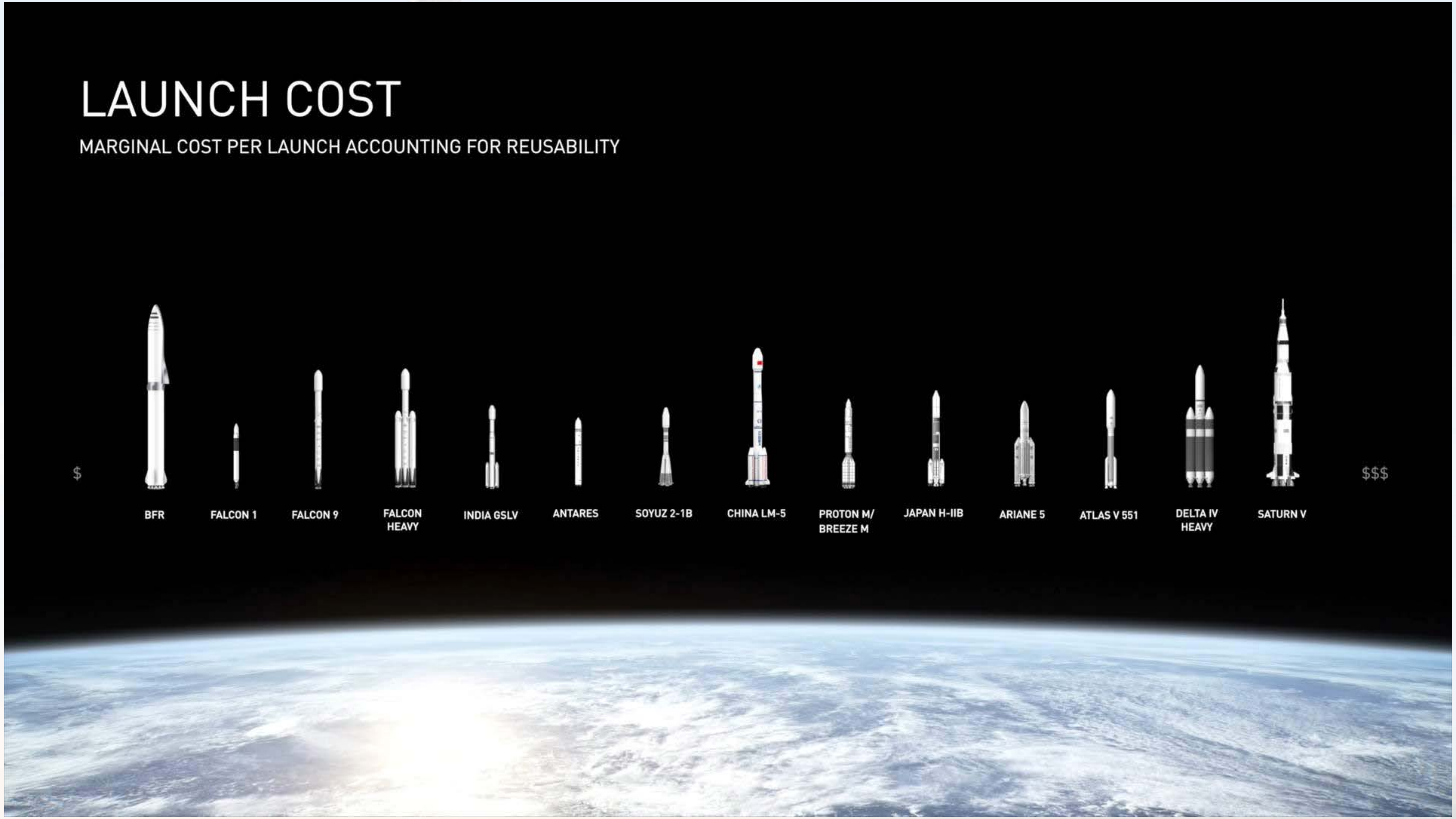
Titan IV
USA
62 m
21.7 t
5.7 t

Proton-M
Russia
58.2 m
23 t
6.9 t

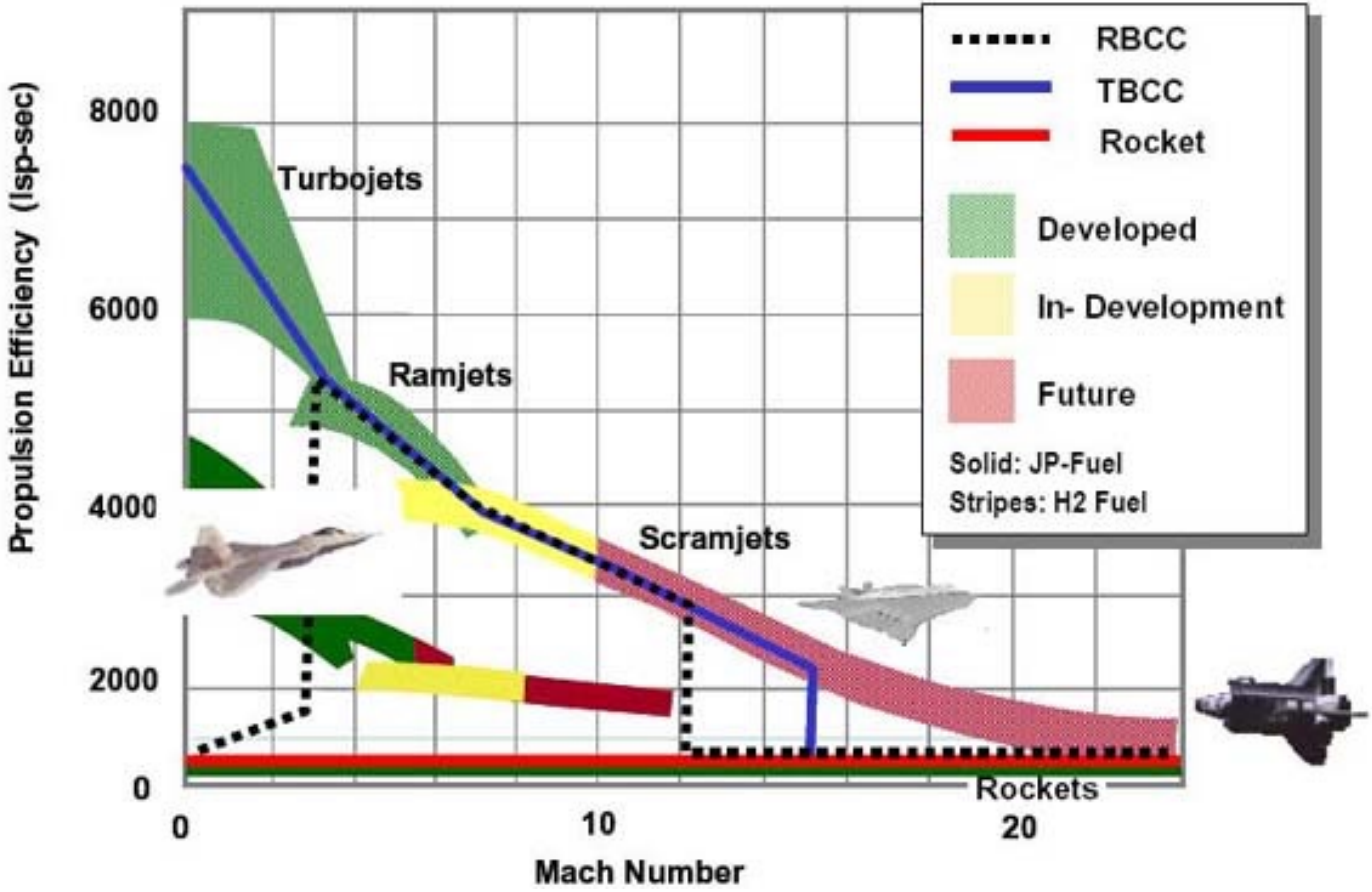
Vulcan Centaur
USA
61.6 m
27.2 t
14.4 t
12.1 t

Delta IV Heavy
USA
72 m
28.8 t
14.2 t

BFR Costs (per Elon Musk)



Sea Dragon ("For All Mankind")

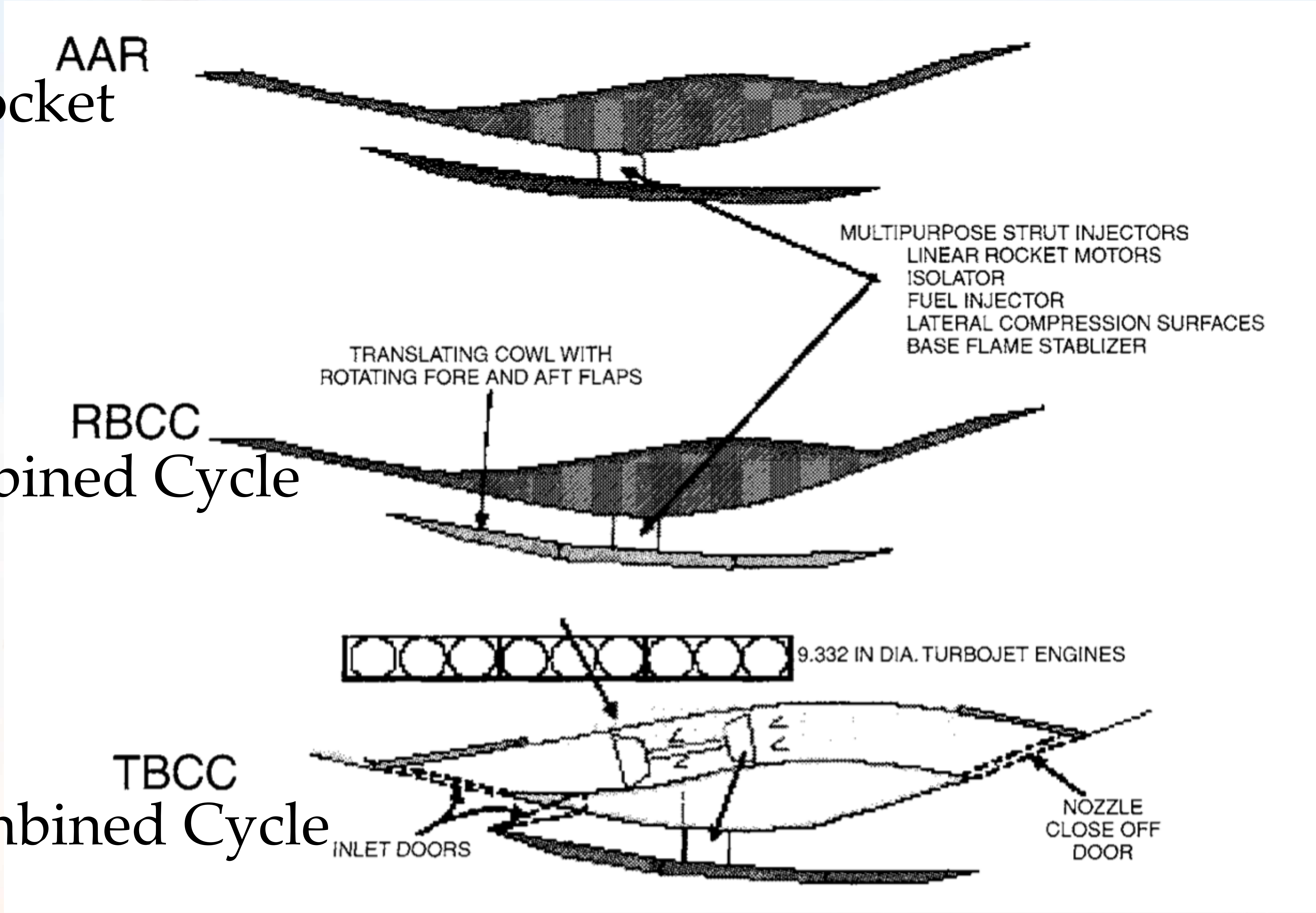

RBCC
TBCC
Rocket
Developed
In- Development
Future
Solid: JP-Fuel
Stripes: H2 Fuel
Propulsion Efficiency (Isp-sec)
8000
6000
4000
2000
0
Turbojets
Ramjets
Scramjets
Rockets
0
10
20
Mach Number

Approaches to Air-Breathing Propulsion

Air-Augmented Rocket

Rocket-Based Combined Cycle

Turbine-Based Combined Cycle



Combined Cycle Launch Vehicles RBCC and TBCC

Rocket Based Combined Cycle (RBCC)

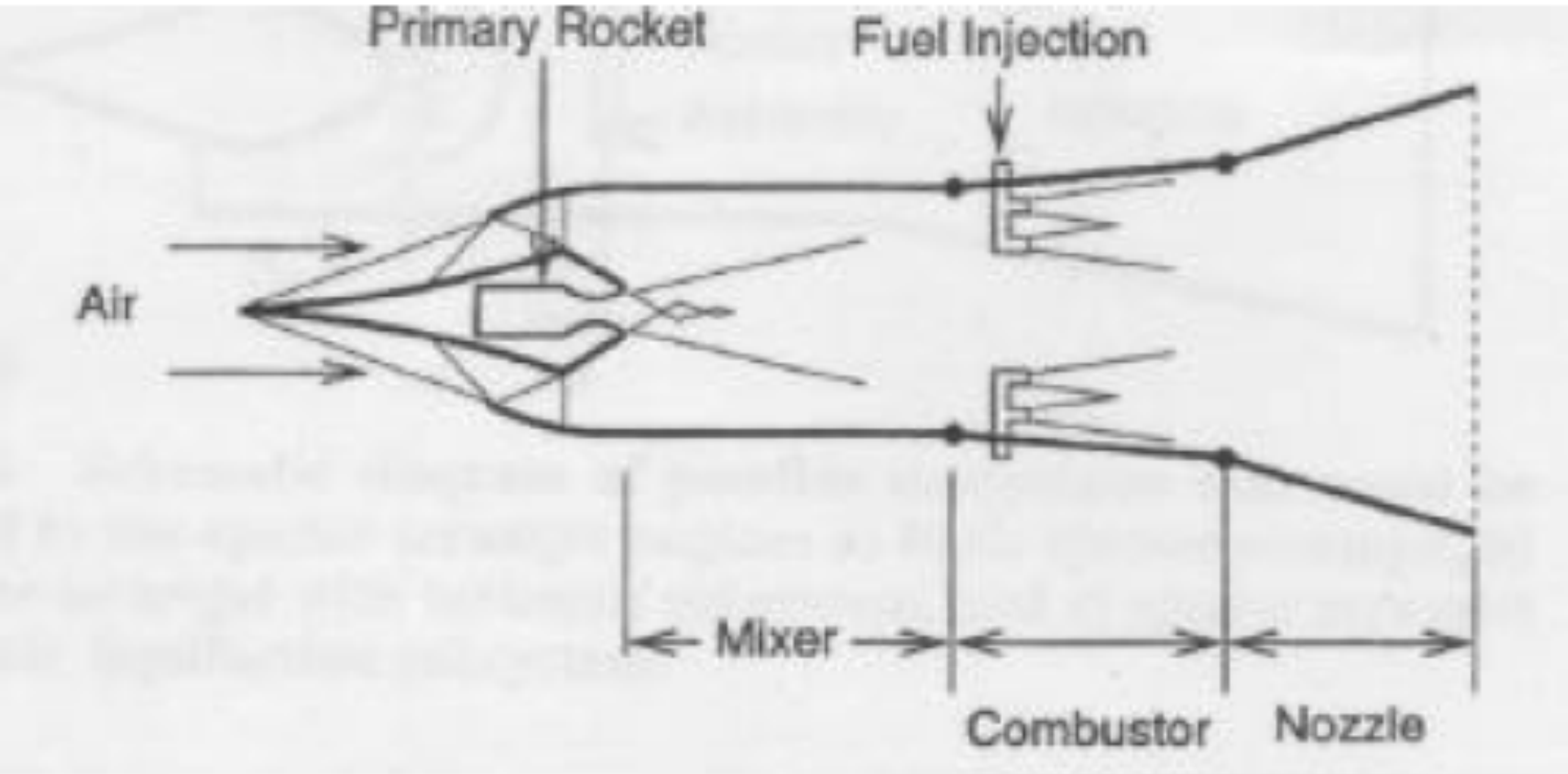
Rocket-ejector→Ramjet→Scramjet→Rocket

Turbine Based Combined Cycle (TBCC)

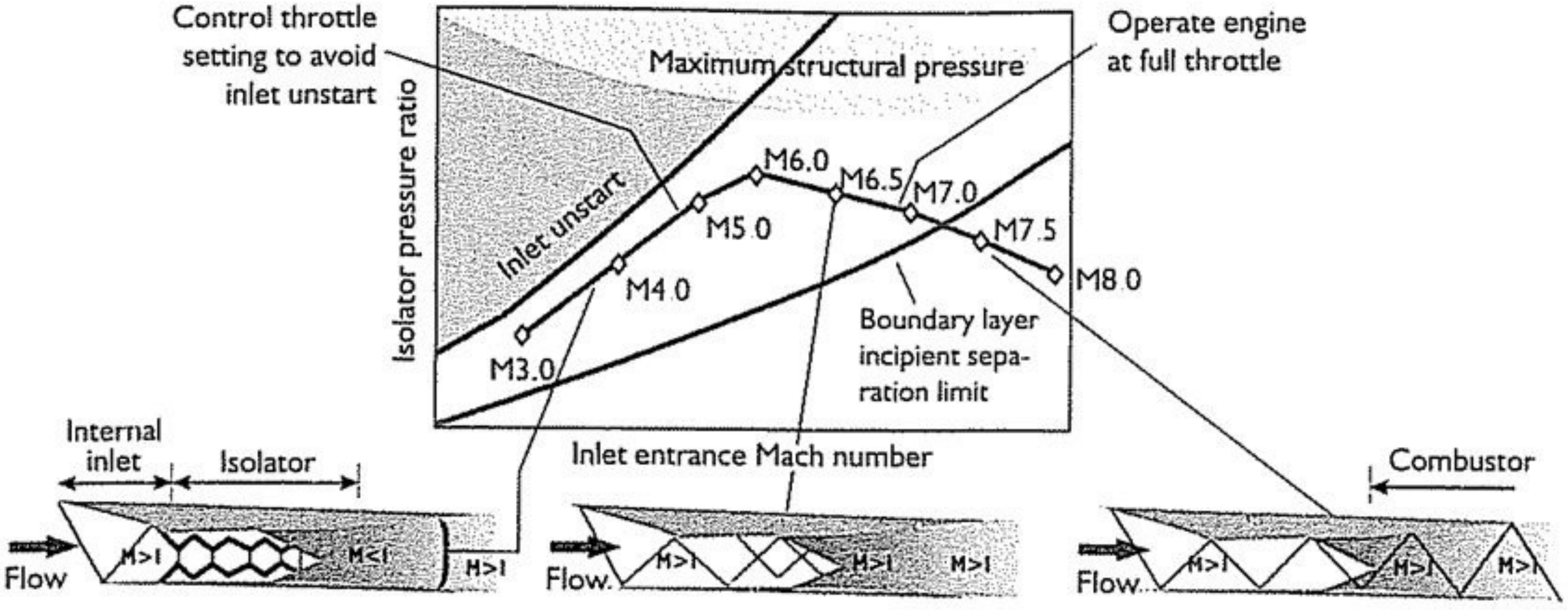
Turbojet→Ramjet→Scramjet→Rocket

- Both technologies are under development at the component/initial integration stages.
- Basic demonstration of scramjets has been shown, but survivable, reusable vehicles have not.
- Development will probably require decades, but may yield a revolutionary launch technology.
- Could be viable for both launch scenarios

Rocket-Based Combined Cycle (RBCC)



DUAL-MODE OPERATION



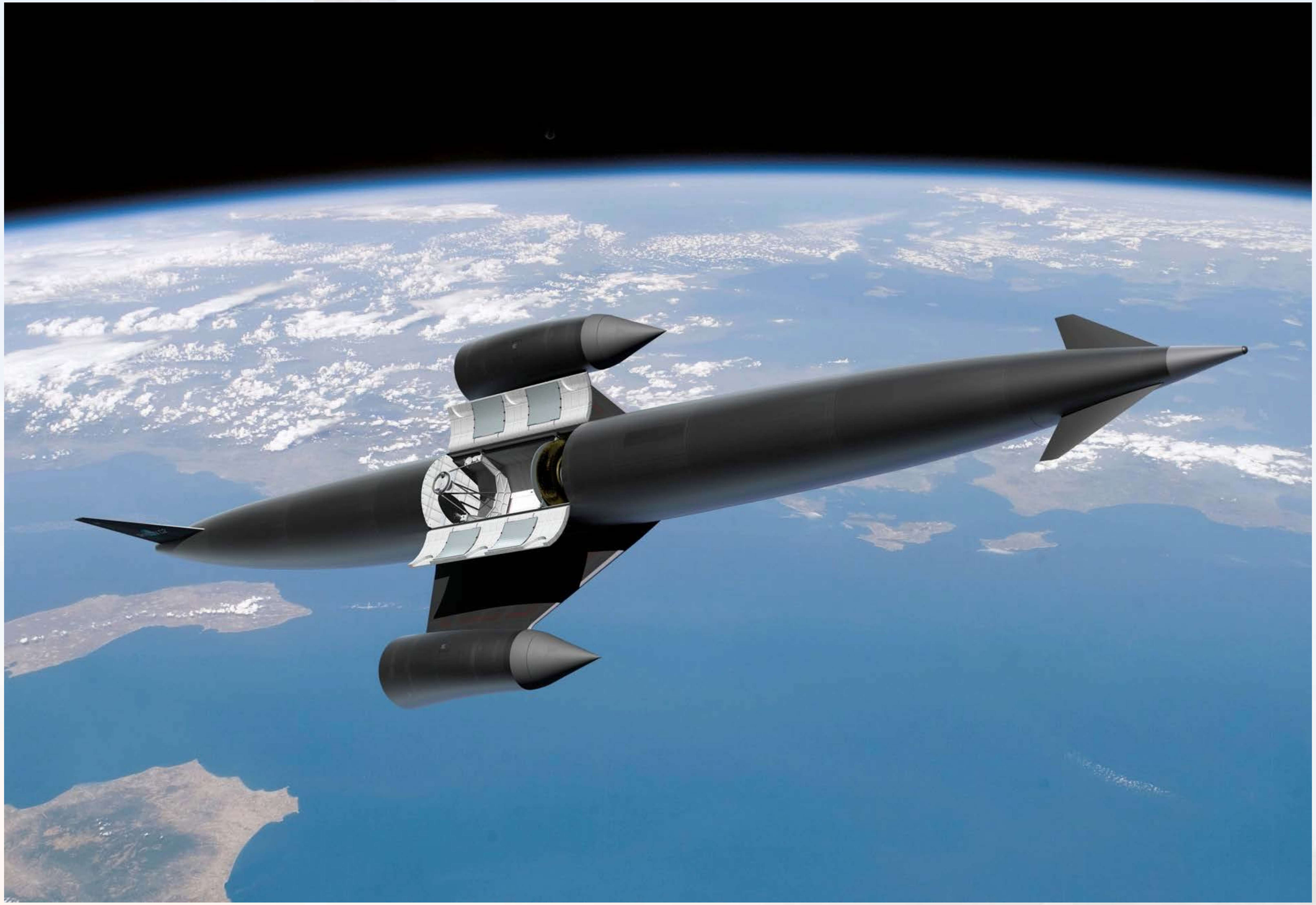
Dual-mode ramjet
- Precombustion shock train dominates isolator flowfield
- Shock train terminates in subsonic condition
- Boundary layer is separated
- Inlet close to critical

Dual-mode scramjet
- Precombustion shock train pulls back toward combustor entrance
- Shock train terminates in supersonic condition
- Boundary layer separation decreases

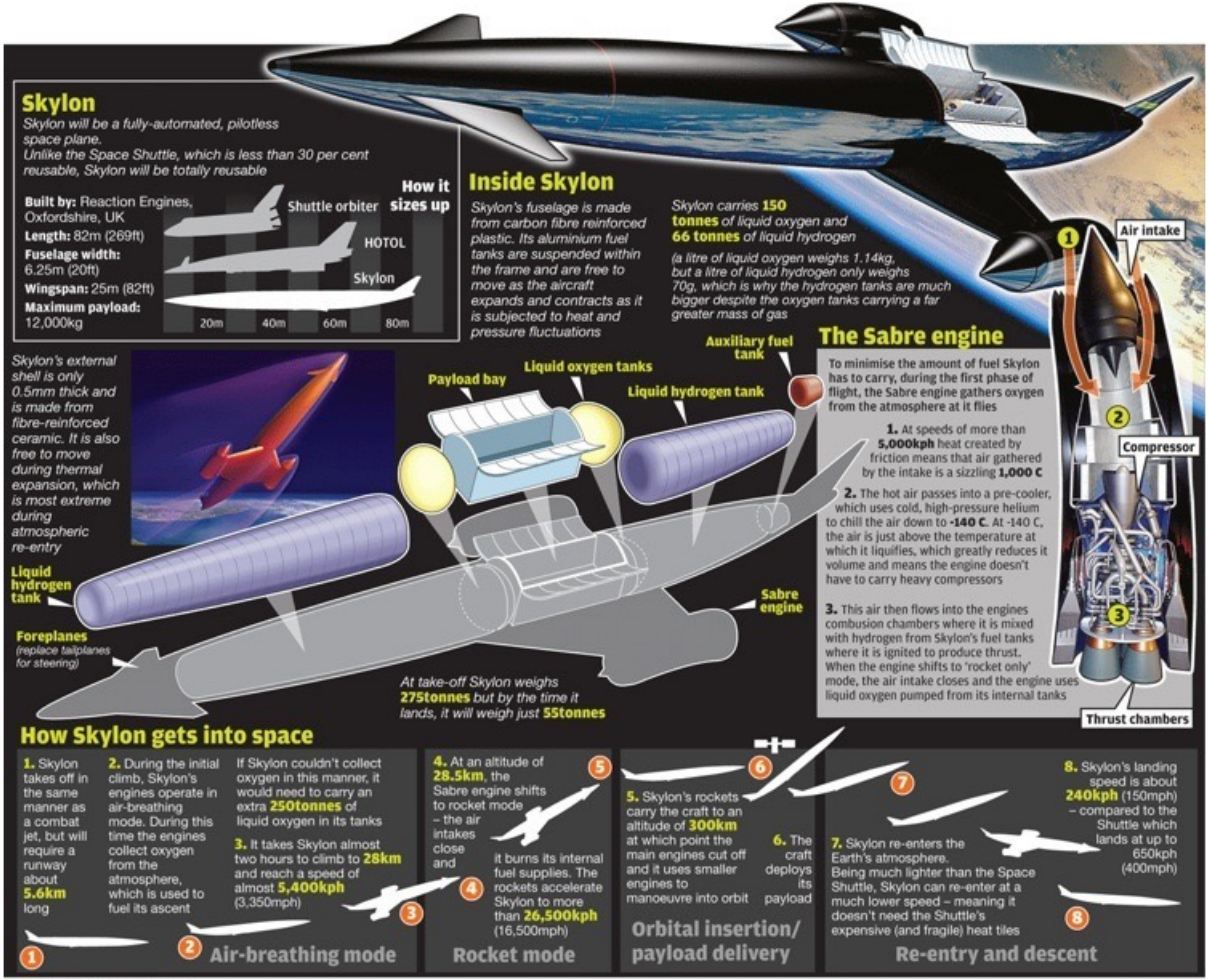
Scramjet mode
- Inlet shock continues through isolator/combustor
- Combustor supersonic throughout
- Boundary layer fully attached
- Precombustion shock-free isolator

Figure 3. As the vehicle speed increases from Mach 3 to Mach 8, the isolator pressure ratio passes through a peak at Mach 6. As the shock train and boundary layer retreat, the modes change from dual-mode ramjet to dual-mode scramjet to pure scramjet mode.

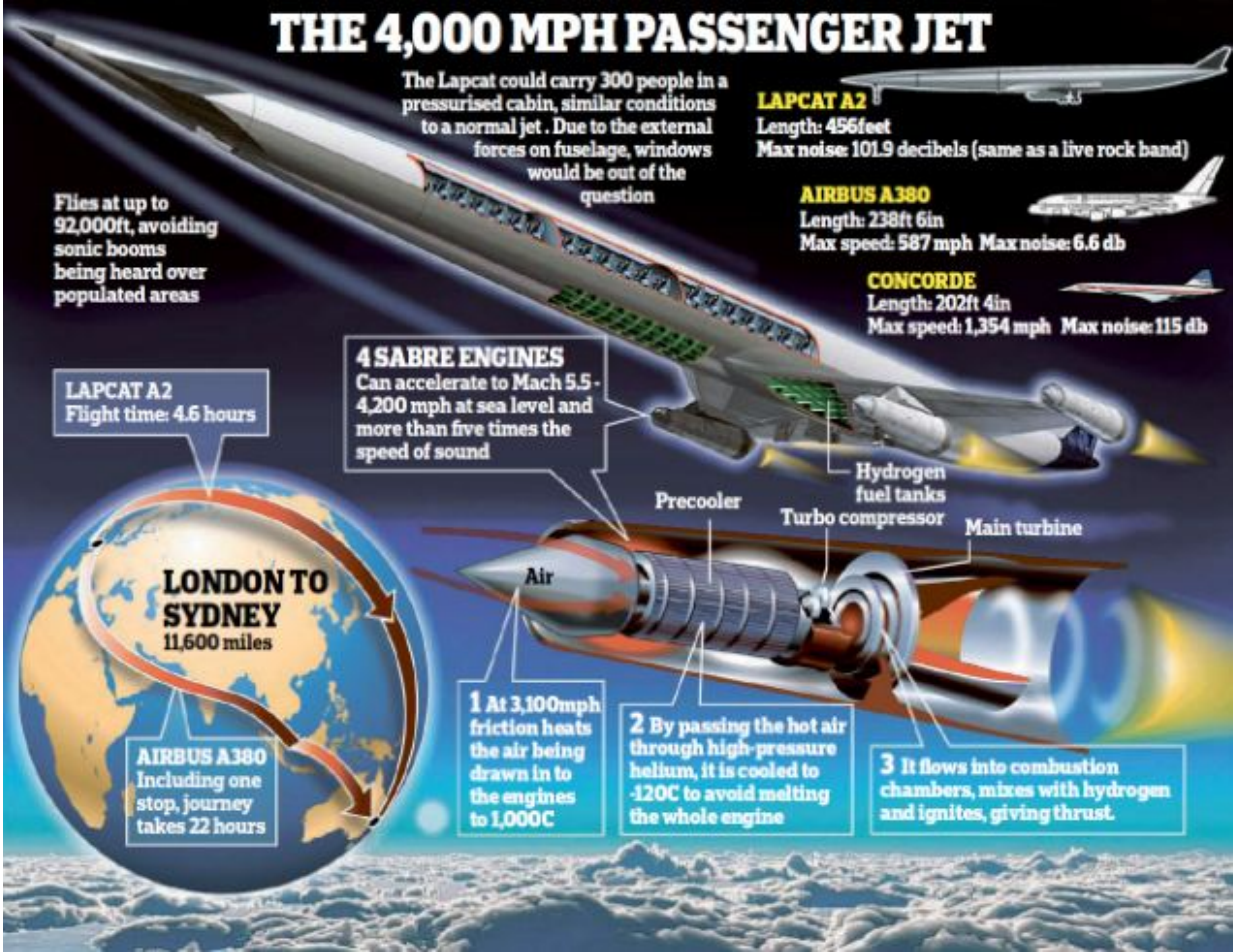
20?? - Skylon




SKYLON - THE FUTURE OF SPACE?

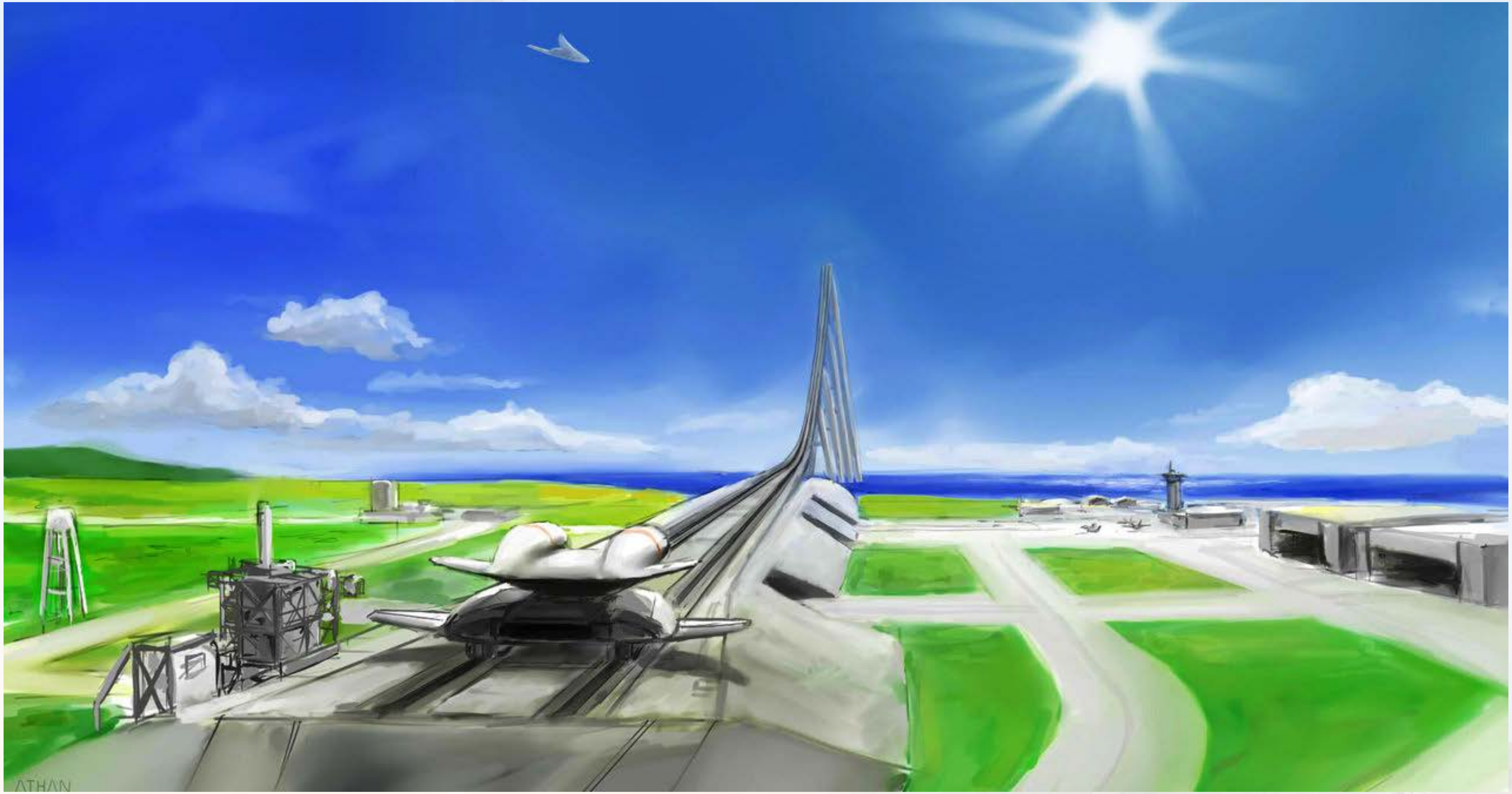


Graphic: Ben Gilliland

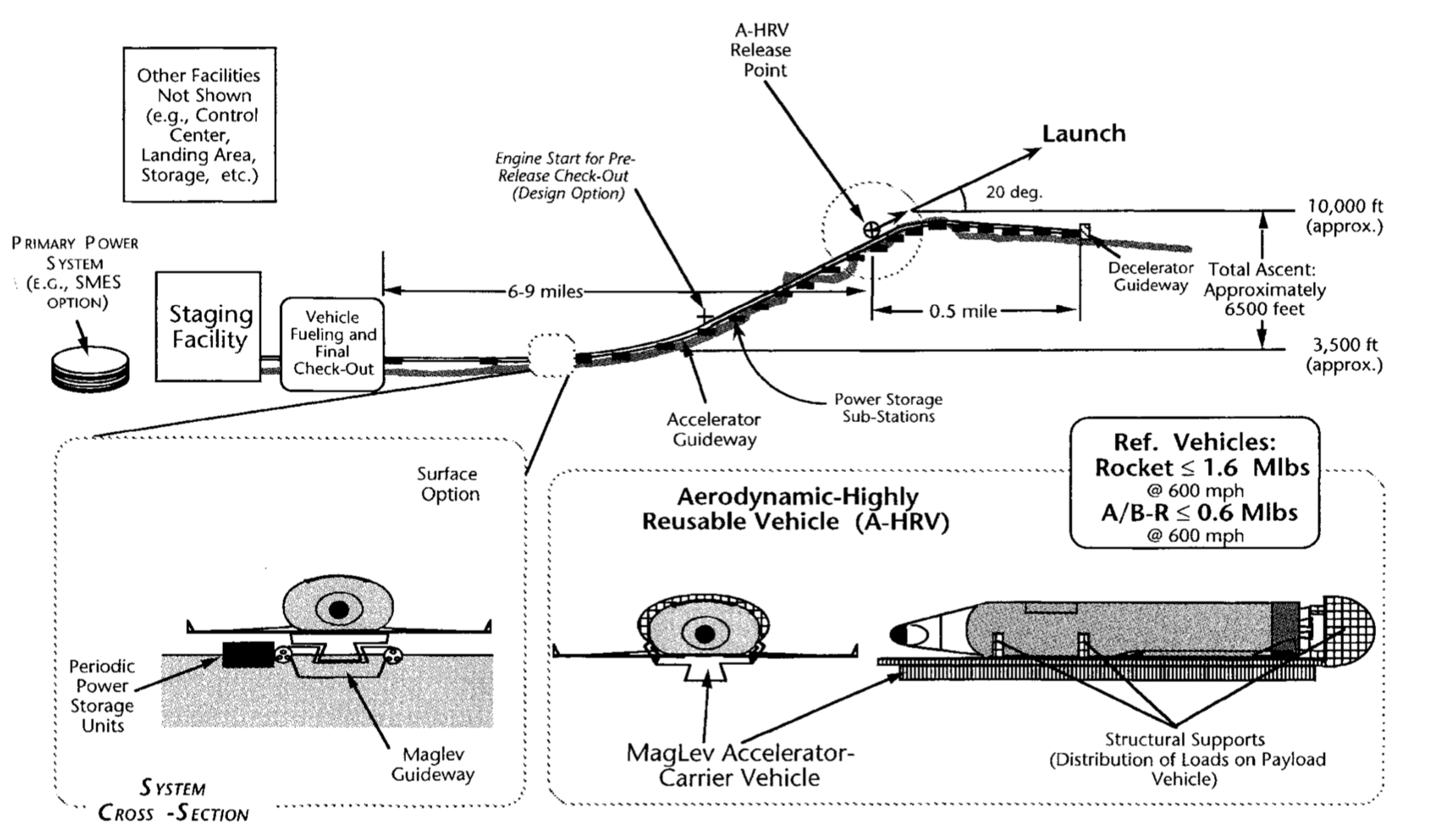


THE 4,000 MPH PASSENGER JET
The Lapcat could carry 300 people in a pressurised cabin, similar conditions to a normal jet . Due to the external forces on fuselage, windows would be out of the question
LAPCAT A2
Length: 456feet
Max noise: 101.9 decibels (same as a live rock band)
AIRBUS A380
Length: 238ft 6in
Max speed: 587 mph Max noise: 6.6 db
CONCORDE
Length: 202ft 4in
Max speed: 1,354 mph Max noise: 115 db
Flies at up to 92,000ft, avoiding sonic booms being heard over populated areas
4 SABRE ENGINES
Can accelerate to Mach 5.5 - 4,200 mph at sea level and more than five times the speed of sound
LAPCAT A2
Flight time: 4.6 hours
Hydrogen fuel tanks
Precooler
Turbo compressor
Main turbine
Air
LONDON TO SYDNEY
11,600 miles
AIRBUS A380
Including one stop, journey takes 22 hours
1 At 3,100mph friction heats the air being drawn in to the engines to 1,000C
2 By passing the hot air through high-pressure helium, it is cooled to -120C to avoid melting the whole engine
3 It flows into combustion chambers, mixes with hydrogen and ignites, giving thrust.

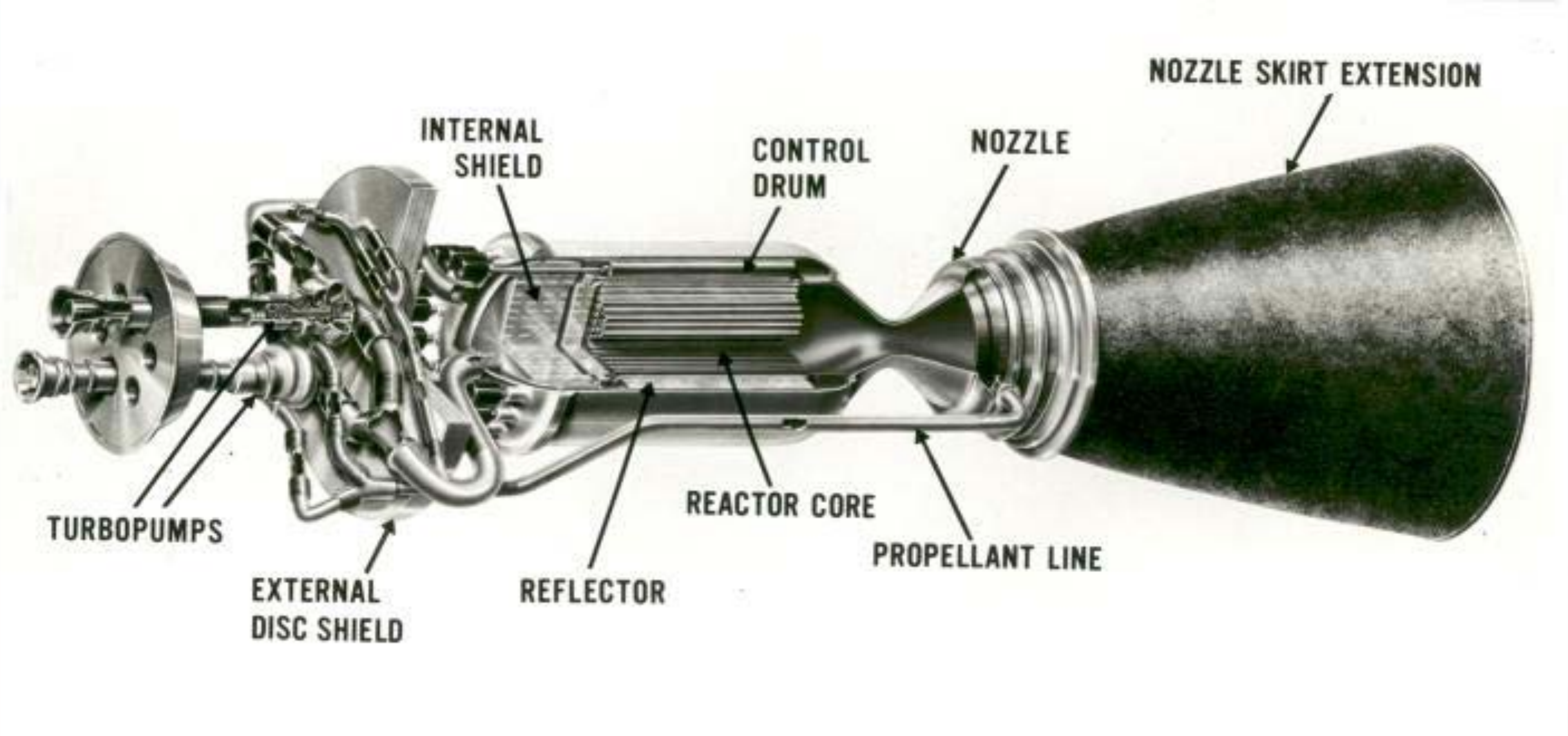
Catapult/Tracked Launch System



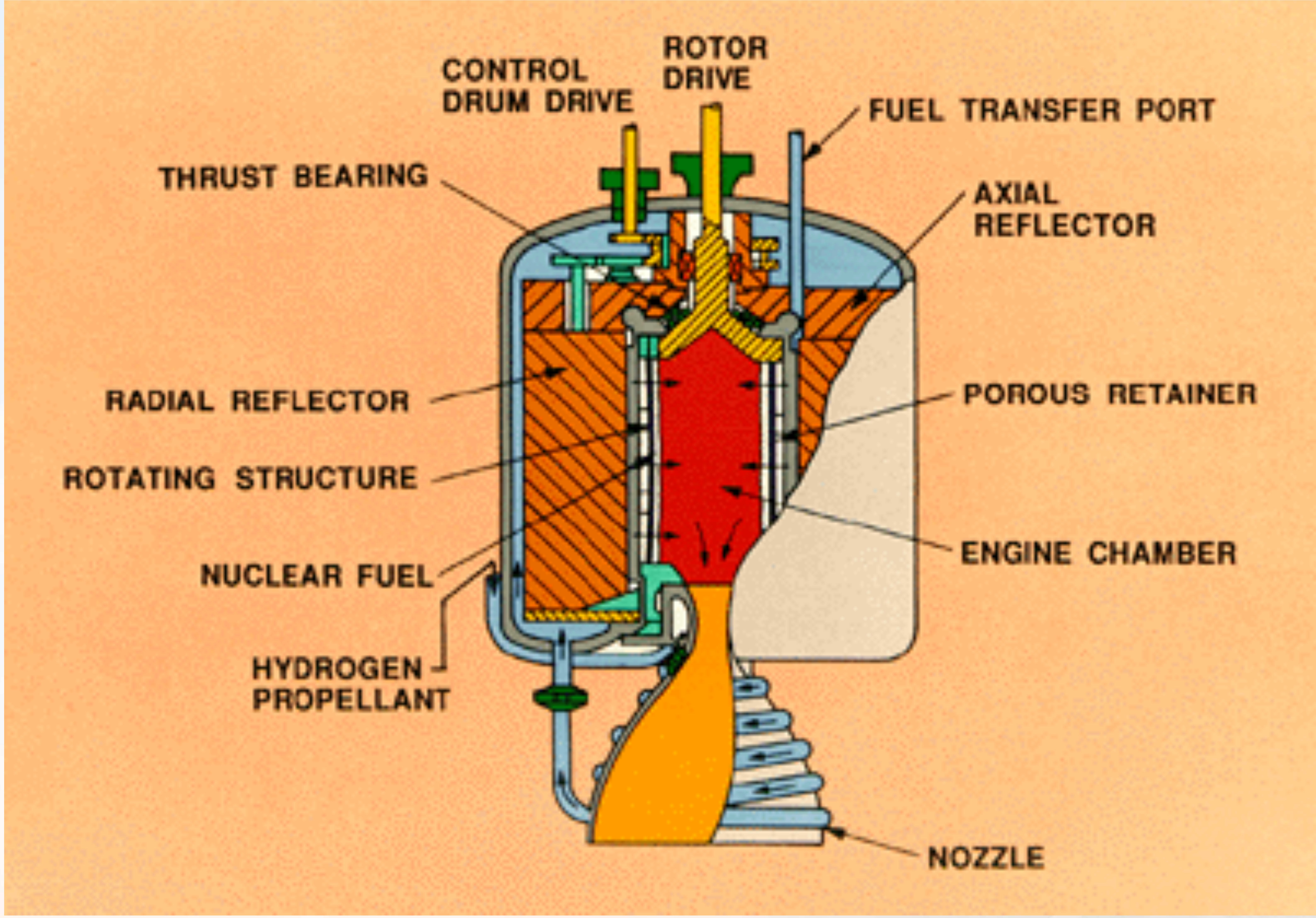
MagLifter Tracked Launch



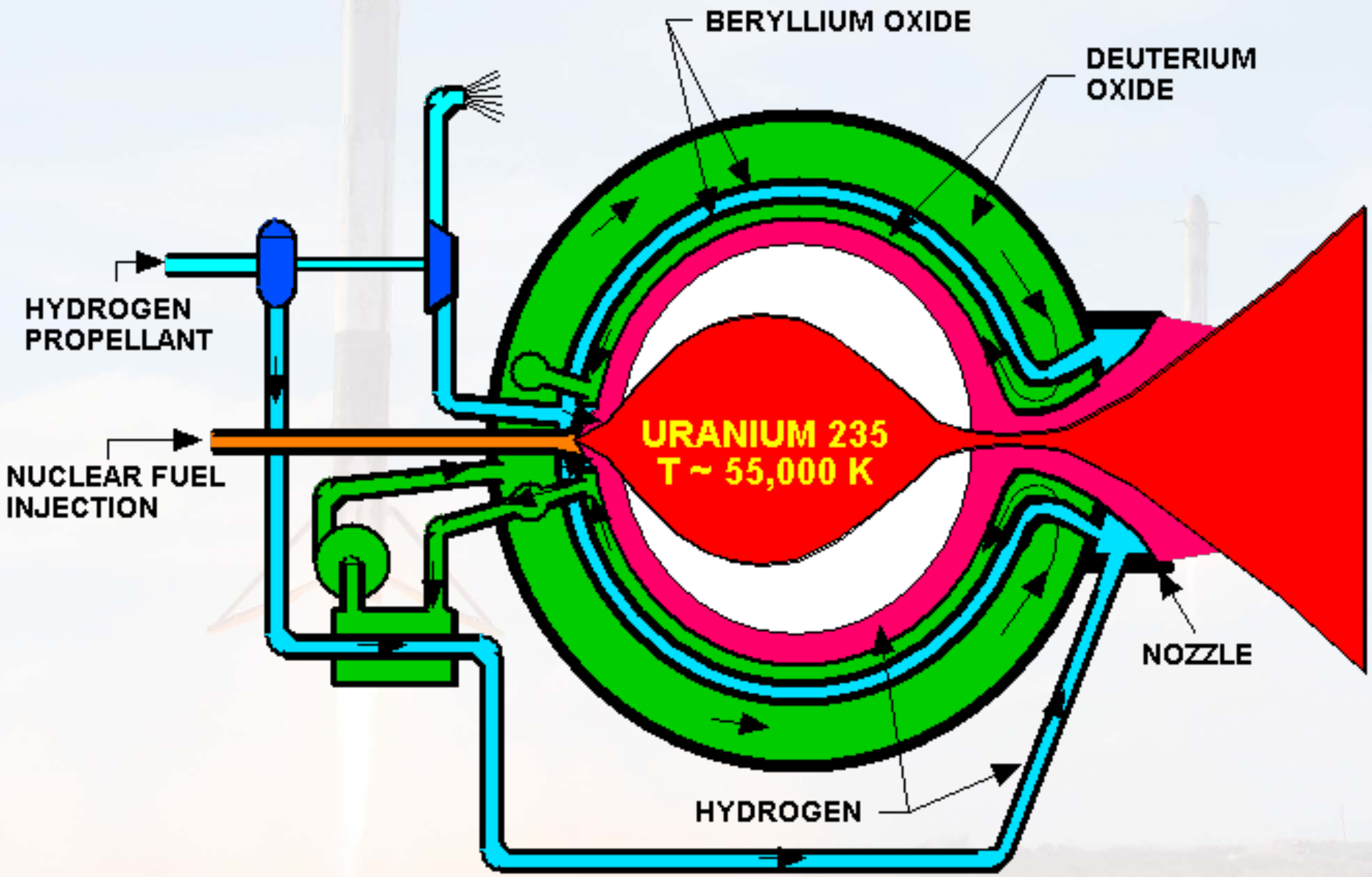
NERVA Nuclear Thermal Engine



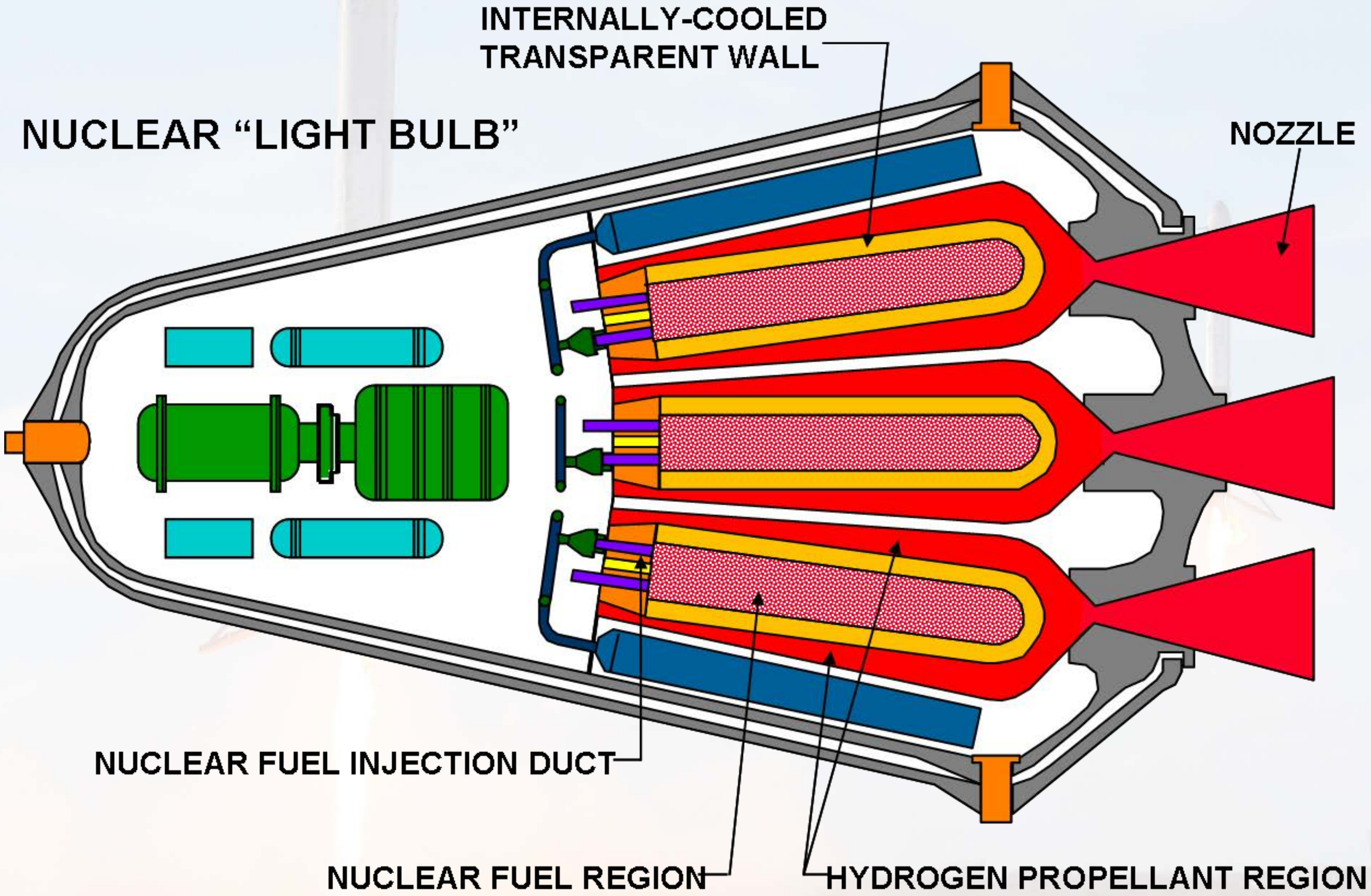
Liquid Core Nuclear Rocket



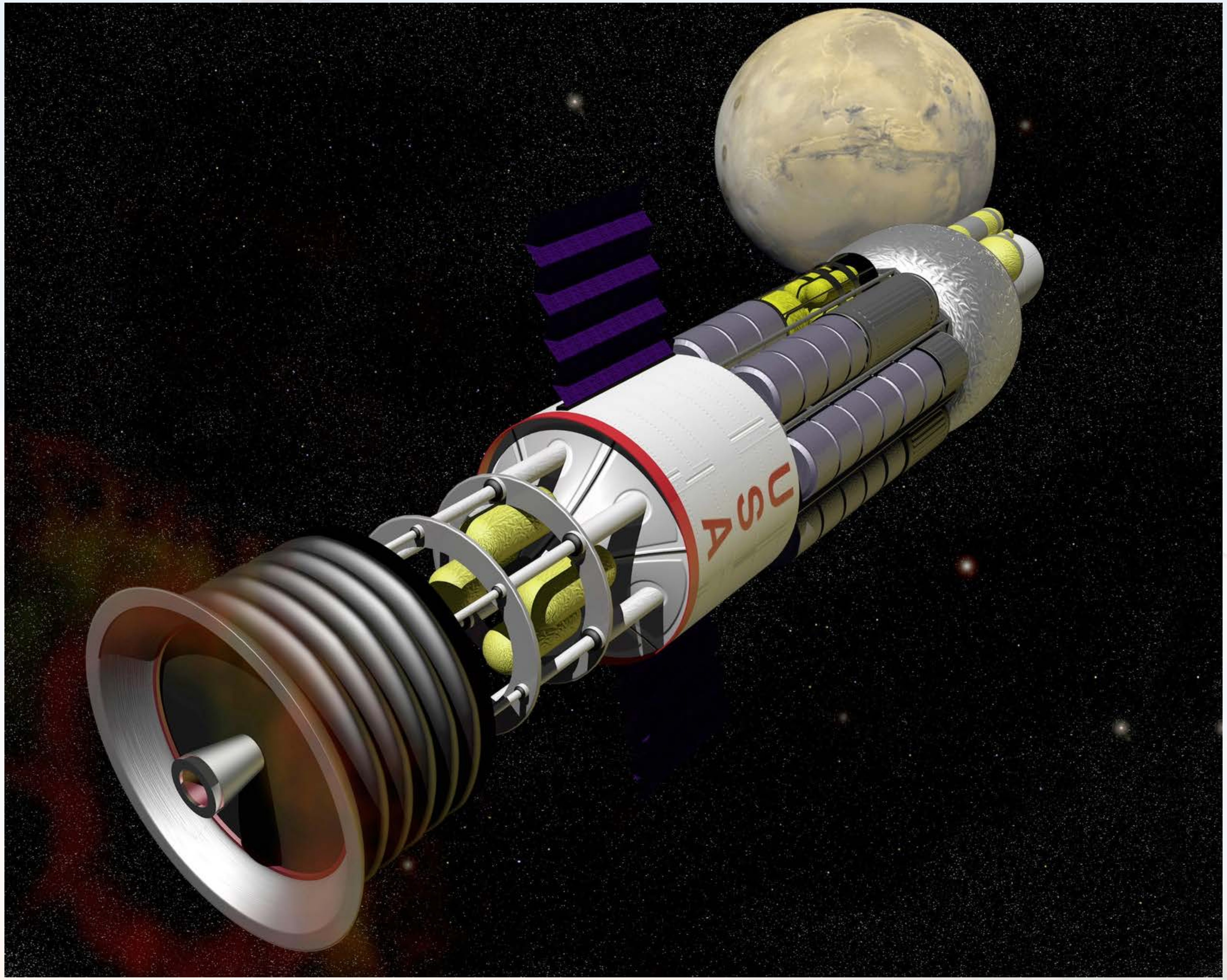
Gas-Core Nuclear Rocket Engine



Gas-Core Nuclear Rocket



Project Orion

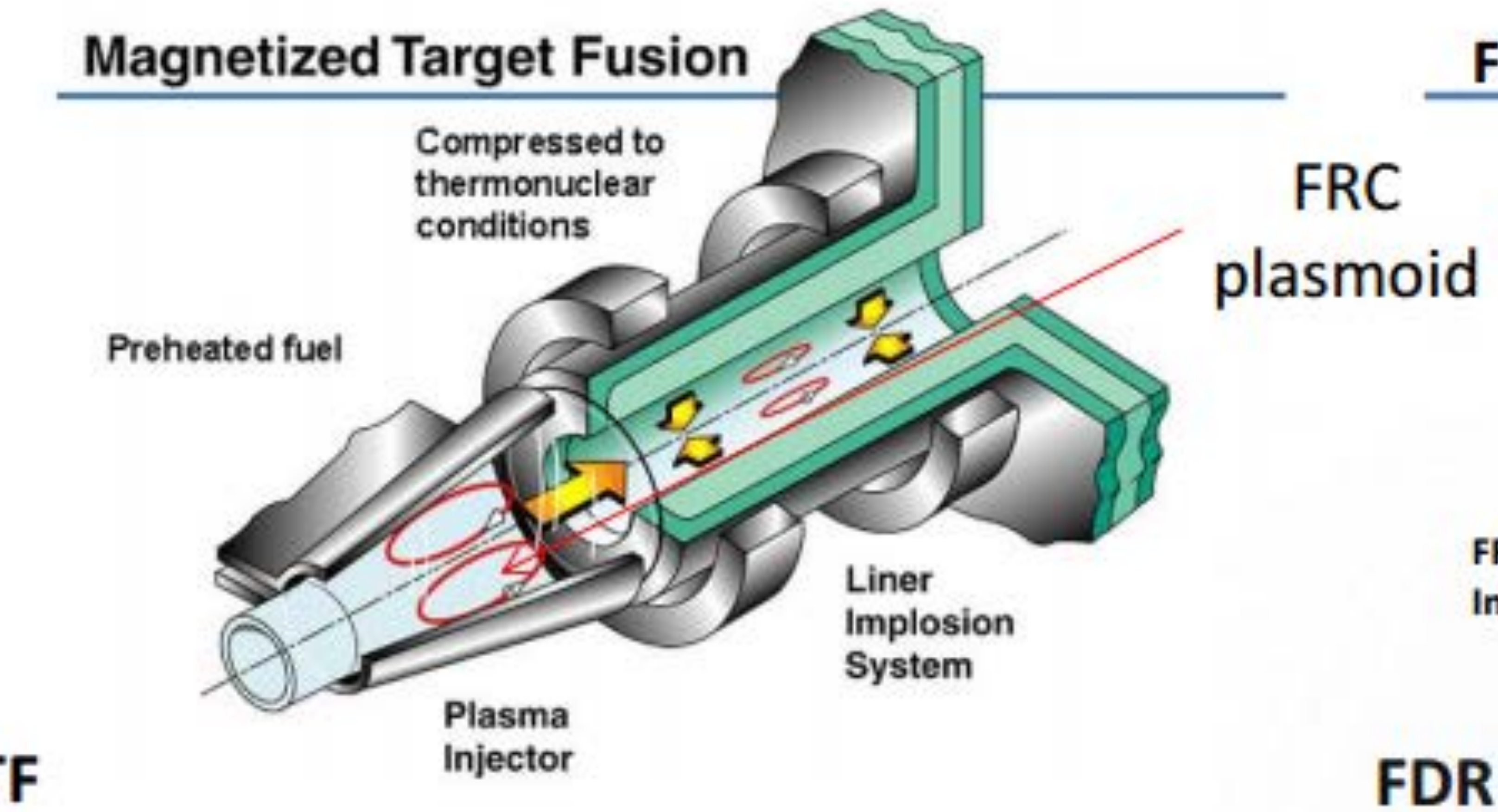


Nuclear Fusion Engine Approaches

Magneto-Inertial Fusion
Two Approaches

NIAC | MSNW

Shell (liner) implosion driven by B_θ from large axial currents in shell.

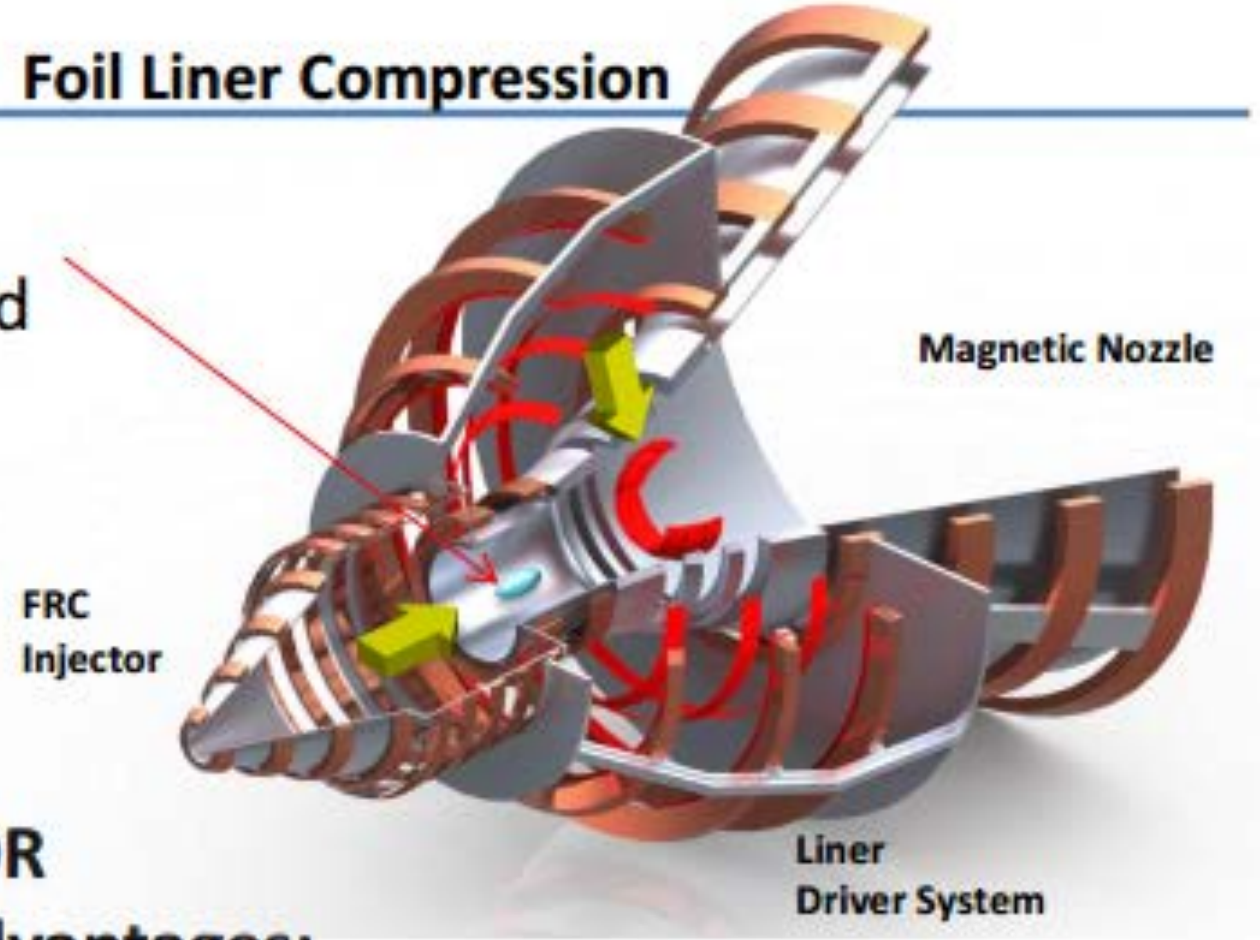


MTF

Issues:

- Extremely low inductance load difficult to drive (massively parallel HV caps and switches)
- Close proximity and electrical contact ⇒ major collateral damage with each pulse
- Small FRC must be formed close to implosion ⇒ marginal B for ignition w injector destruction
- Only inefficient 2D compression possible ⇒ requires much larger driver energy

Liner implosion from j x B force between external coil and induced liner currents



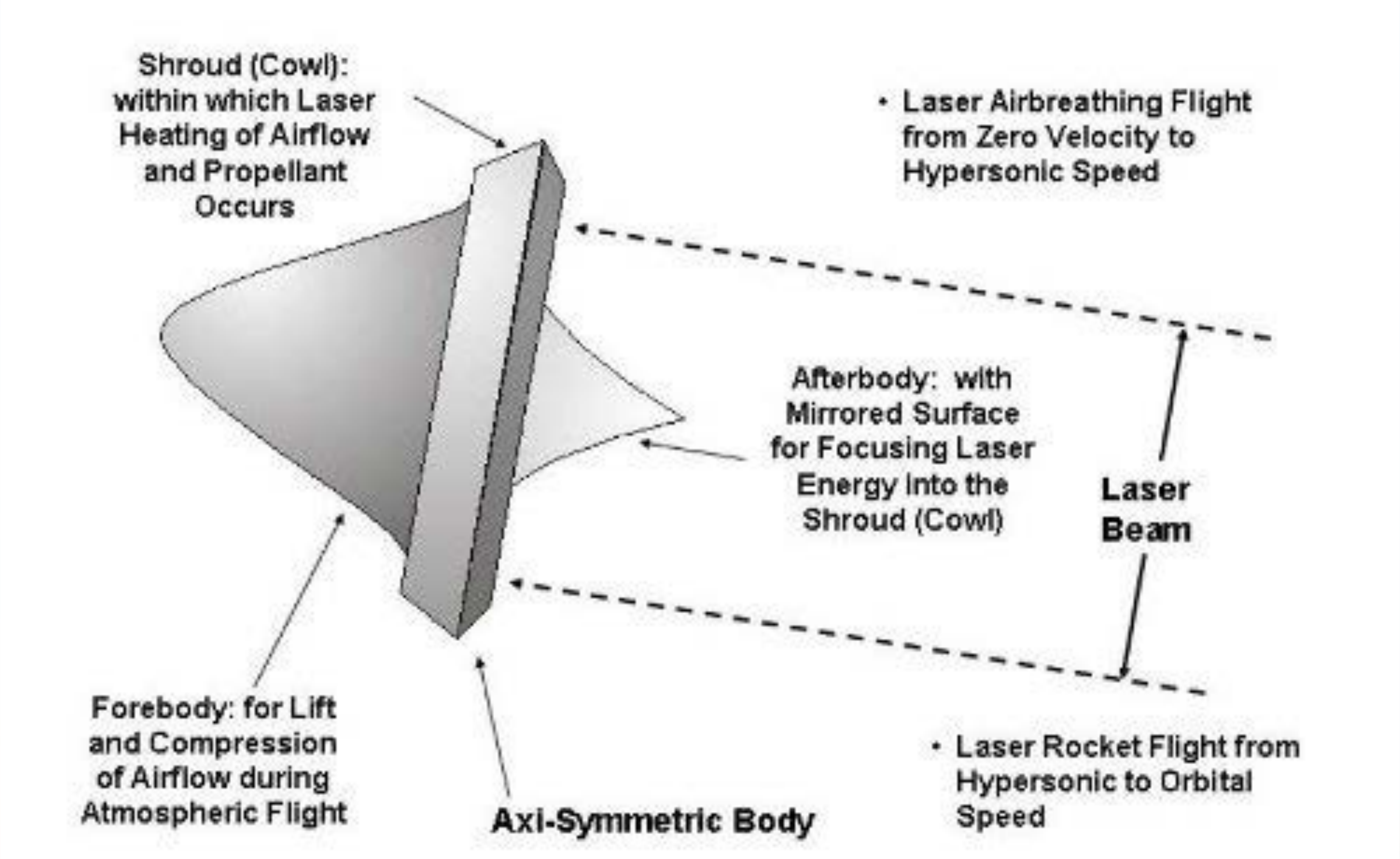
FDR

Advantages:

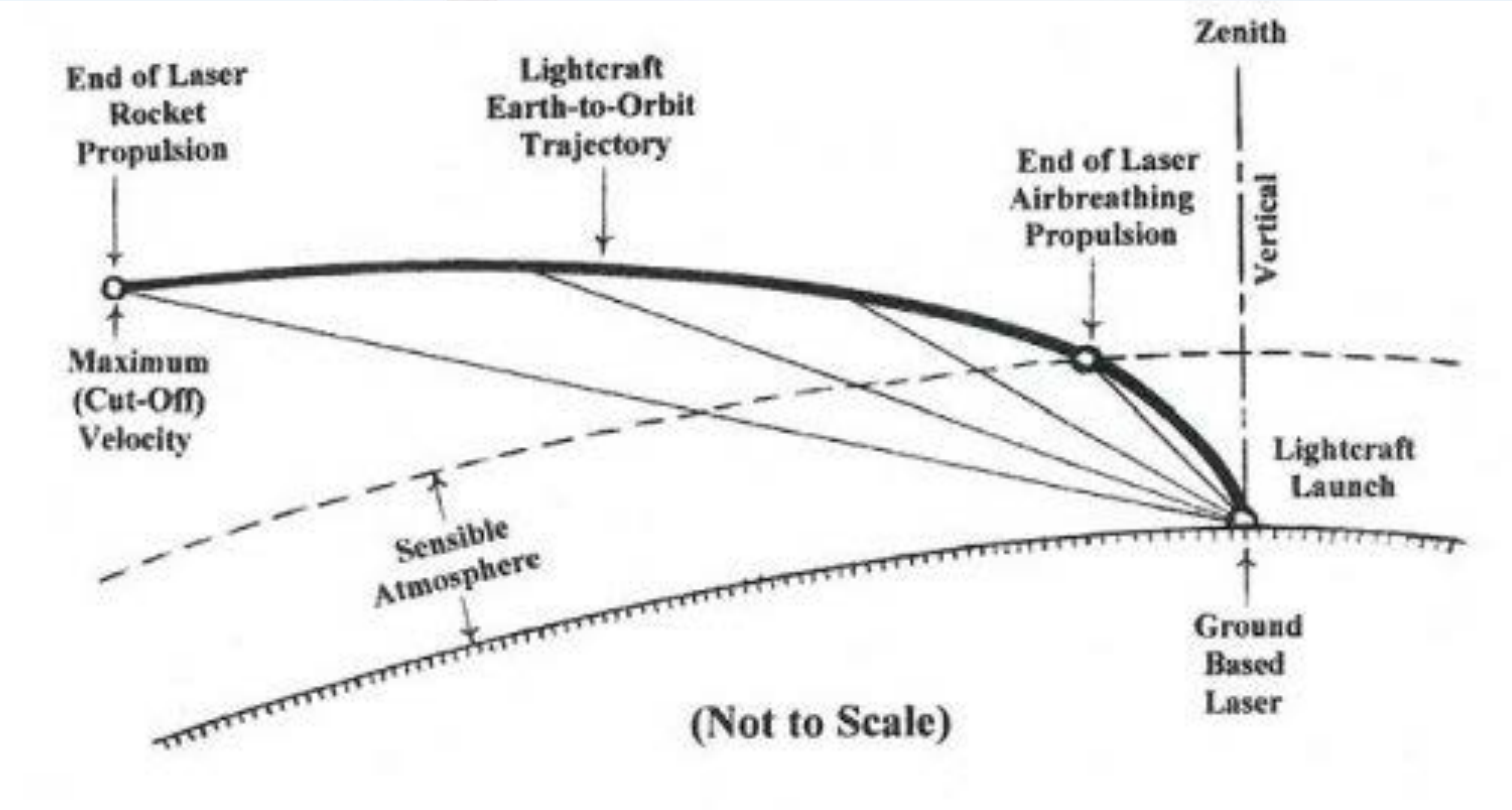
- Large driver coil easy to power with ample standoff
- Driver electrically isolated from liner and magnetically from fusion process
- Large FRC can be formed external to implosion with abundant B for ignition
- Full 3D compression can be realized for efficient compression and translation

Lightcraft Laser Launch System

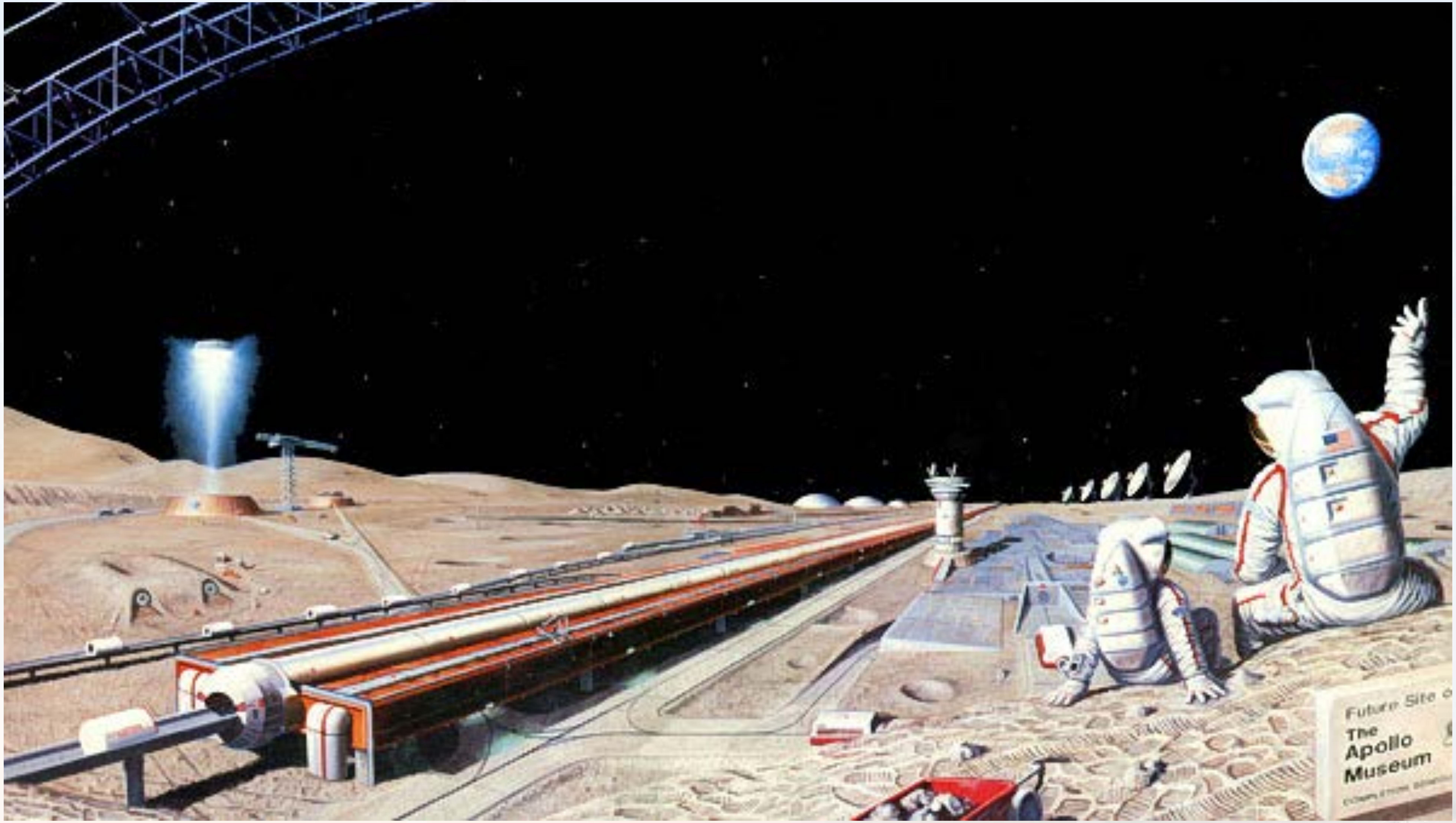
Lightcraft Operating Concept



Lightcraft Trajectory

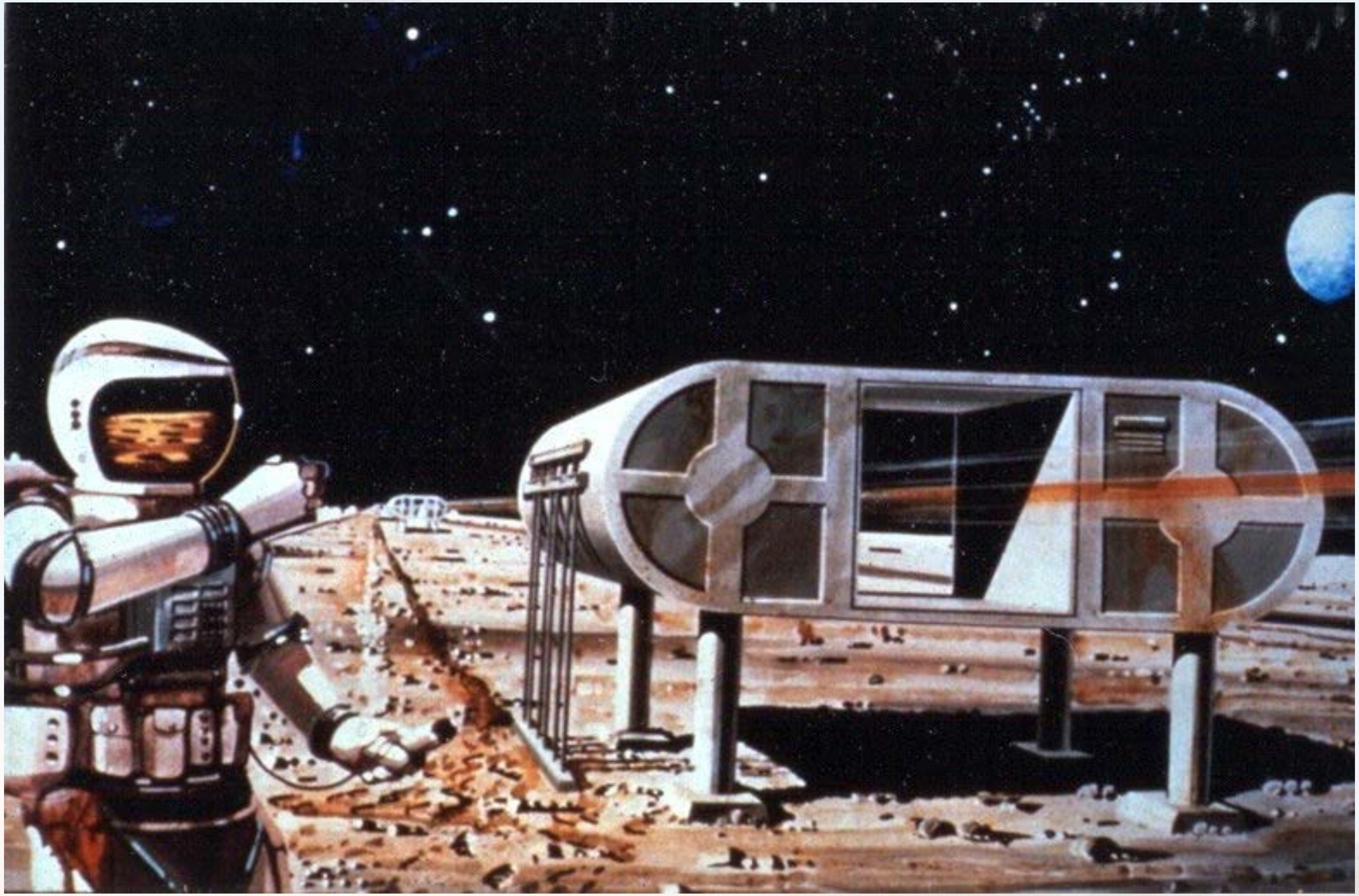


Lunar Surface Mass Driver



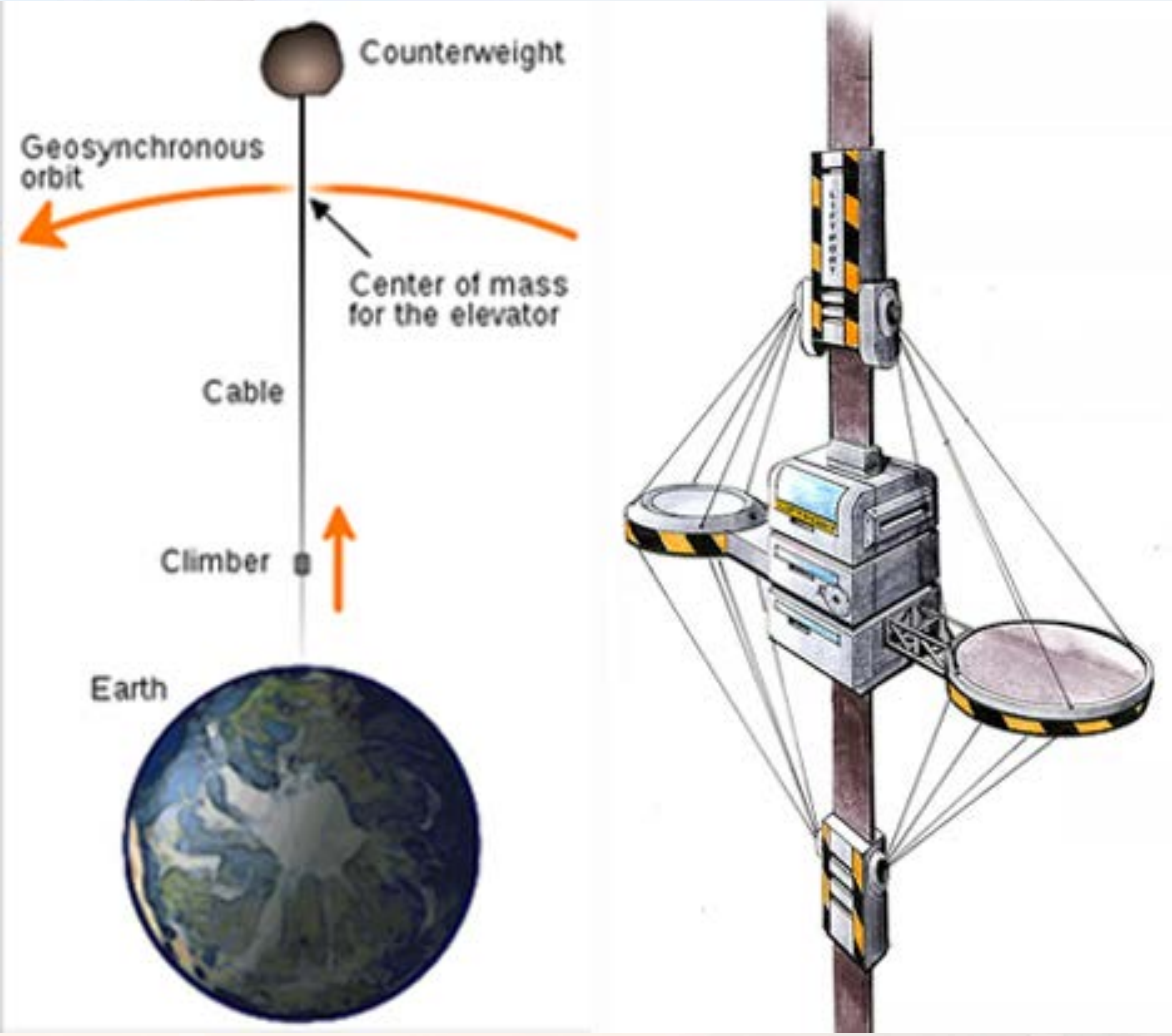
MIT Massdriver Prototype

Mass Driver Trajectory Adjustment

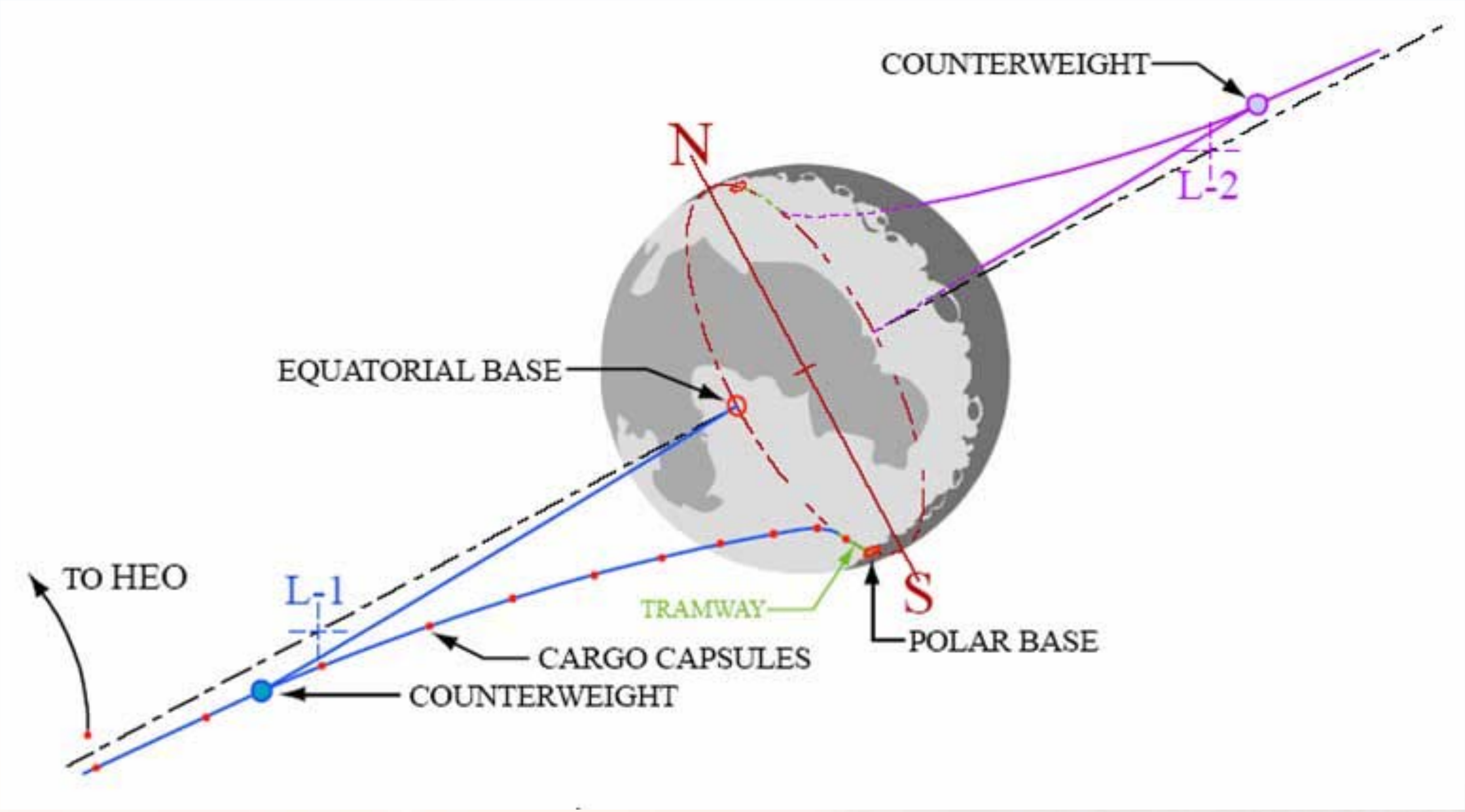


Space Elevator

Space Elevator Schematic



Lunar Space Elevator



Theoretical Cost to Orbit

- Convert to usual energy units

$$\frac{Total\ Energy}{kg\ in\ orbit} = 32 \times 10^6\ \frac{J}{kg} = 8.9\ \frac{kWhrs}{kg}$$

- Domestic energy costs are ~$0.09/kWhr

  - Theoretical cost to orbit <u>$0.99/kg</u>

Arthur C. Clarke’s Three Laws

1. When a distinguished but elderly scientist states that something is possible, they are almost certainly right. When they state that something is impossible, they are very probably wrong
2. The only way of discoing the limits of the possible is to venture a little way past them into the impossible
3. Any sufficiently advanced technology is indistinguishable from magic