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New Rides to the Moon

July 19, 2017

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Chair of the NSS Executive Committee

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New Rides to the Moon

- Review rockets under construction/development that are planned for the next ten years
- Look at rockets that might plausibly be part of a return to the Moon
- Provide a sense as to when they might fly and how successful they may be
- Focus on serious, well-funded projects from reputable organizations
- Don’t discuss vehicles like Delta IV Heavy that are targeted for replacement

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And the contenders are ….

- Long March 5
- Falcon Heavy
- SLS Block I
- Ariane 6
- New Glenn
- Vulcan
- SLS Block 1B
- Starship/Superheavy

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But first a little background …

- What is the "Sweet Spot" for commercial launch?
  - Geosynchronous comsats weighing under 9 metric tons
  - Ariane 5 ECA (on left) can launch
    - Two satellites totaling 9.1 MT to GTO
    - One 9.6 MT satellite to GTO
- Ariane 5 ECA (expendable) costs $150M
  - Could launch:
    - One 3 MT satellite to GTO AND
    - One 6 MT satellite to GTO
- Prior to SpaceX, Ariane 5 owned the commercial space market
  - "Build-a-rocket" architecture similar to Atlas V

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Falcon 9 rains on the Ariane 5 parade

- Customers did not like waiting for a “matchup” between a large and small satellite:
  - F9 only launches one satellite
- F9 (currently) can launch:
  - 8.3 MT to GTO expendable
  - 5.3 MT to GTO reusable
- And costs $62M for 5.5 MT to GTO
  - Block 5 values
- F9 has gained a significant market share on the lower end of the market with three modes:
  - Expendable
  - Sea landing for first stage
  - Return to launch site for first stage


CHN
中国航天

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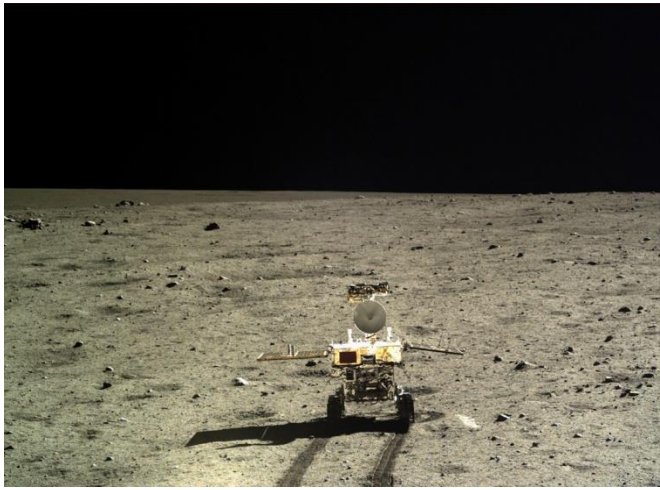
Long March 5: Basics

Similar to Delta IV Heavy



- **Builder:** China
- **Height:** 56.97 meters
- **Lift-off thrust:** 10.6 kN
- **Strap on boosters:** four (Lox/Kerosene)
- **First Stage:** Lox/LH
- **Second Stage:** Lox/LH
- **Third Stage:** None
- **Fairing size:** 5 meters diameter/12.5 meters long
- **Payload to LEO:** 25K kg/55K lb
- **Payload to GTO:** 15K kg
- **Payload to TLI:** 8.2K kg/18.1K lb
- **First flight:** November 3, 2016 (successful)
- **Reusability:** None
- **Current Status:** 2nd flight July 2, 2017 failed; no flights since then; July 2019 dubious
- **Planned payloads:** Lunar sample return, space station cores, interplanetary missions

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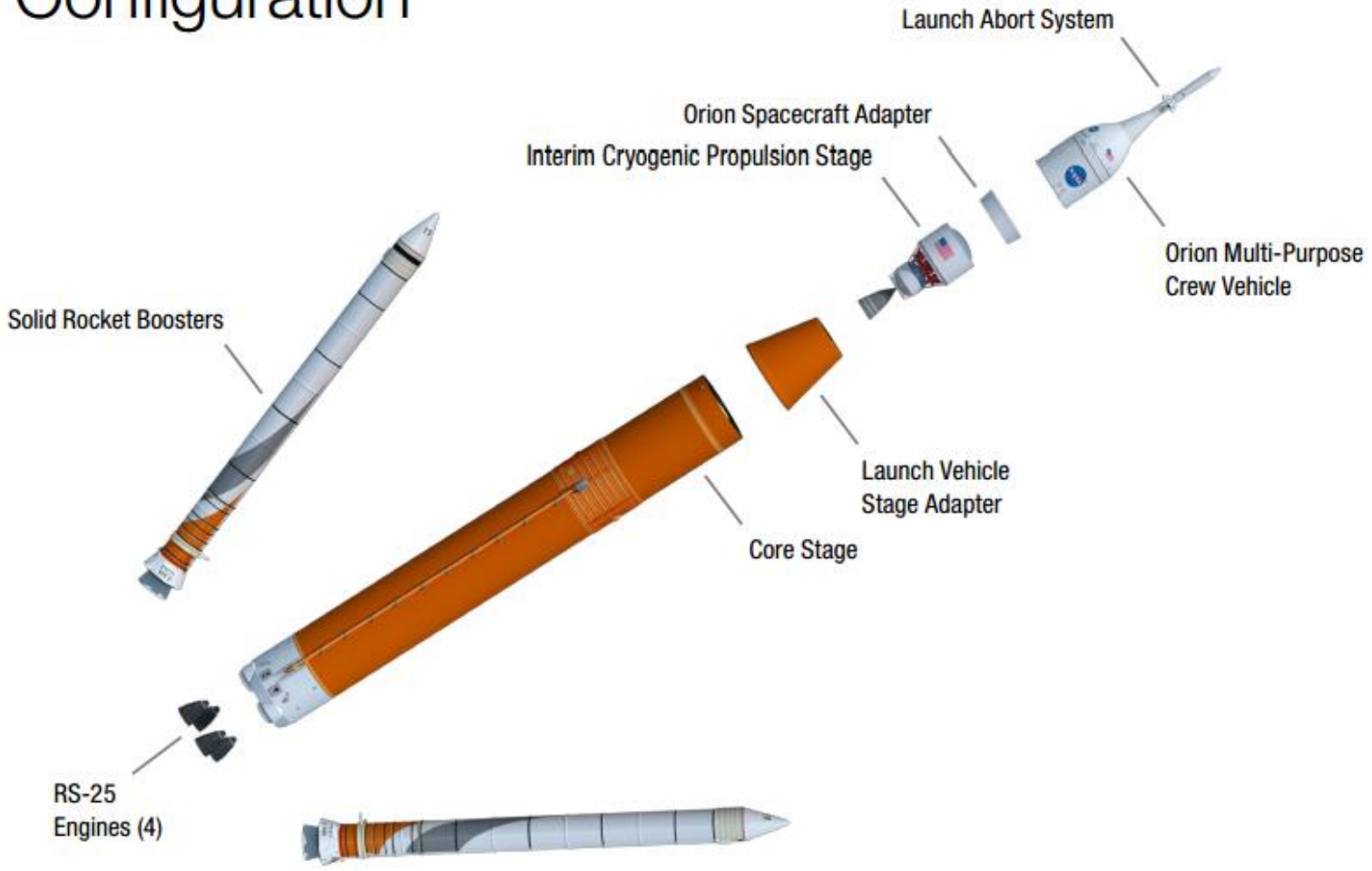
Falcon Heavy: Basics

About 2x capacity of Delta IV Heavy

- **Builder:** SpaceX/USA
- **Height:** 70 meters/229.6 ft
- **Lift-off thrust:** 22.8 kN
- **Side boosters**: two (Subcooled Lox/RP1)
- **First Stage**: Subcooled Lox/RP1
- **Second Stage**: Subcooled Lox/RP1
- **Third Stage**: None
- **Fairing size:** 5.2meters diameter/13.1 meters long
- **Payload to LEO**: 65K kg (expendable)/ 22.9K kg (reusable)
- **Payload to GTO**: 26.7K kg (expendable)/ 8K kg(reusable)
- **Payload to TLI:** 26.7K Kg < X < 16.8K kg (expendable)
- **Payload to TLI**: 8K kg < X < 4K kg (reusable)
- **First flight:** Feb. 6, 2018 Red Tesla Roadster to Mars
- **Reusability:** first stage and two side booster are reusable (2 RTLS; 1 on drone ship)
- **Current Status:** 3 successful fights so far, 4/11/19 Arabsat 6A, June 25, 2019 STP2
- **Current Reuse Status:** All 6 side boosters recovered; no center core recovery fully successful
- **Planned payloads:** AFSPC-44, Ovzon-3, AFSPC-52, ViaSat 3

8 MT to GTO
Reusable covers the Geosync sweet spot for $90M:
Ariane 5 is toast

SLS Block 1
Initial Configuration



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SLS Block 1: Basics

- **Builder:** NASA/USA (Boeing, Orbital/ATK, Aerojet Rocketdyne)
- **Height:** 98 meters/322 ft
- **Lift-off thrust:** 23.4K kN (8.8 Mlbf)
- **Side boosters:** two (Solid fuel)
- **First Stage:** Lox/LH
- **Second Stage:** Lox/LH (Identical to Delta IV Heavy Upper Stage)
- **Third Stage:** None
- **Fairing size:** 5.1 meters diameter/12.8 meters long
- **Payload to LEO:** 70K+ kg (expendable) [95K Kg if 2nd stage is counted as payload]
- **Payload to TLI:** 26K kg (expendable)
- **First flight:** Artemis-1 EOY 2020; slip to 2021 expected (no crew)
- **Reusability:** None
- **Current Status:** Under construction
- **Planned payloads:** Orion capsule; Lunar Gateway components, Artemis program
- **Cost:** Minimum $500M, $1B to $1.5B per flight depending on what you count


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Ariane 6: Basics for A64 Version

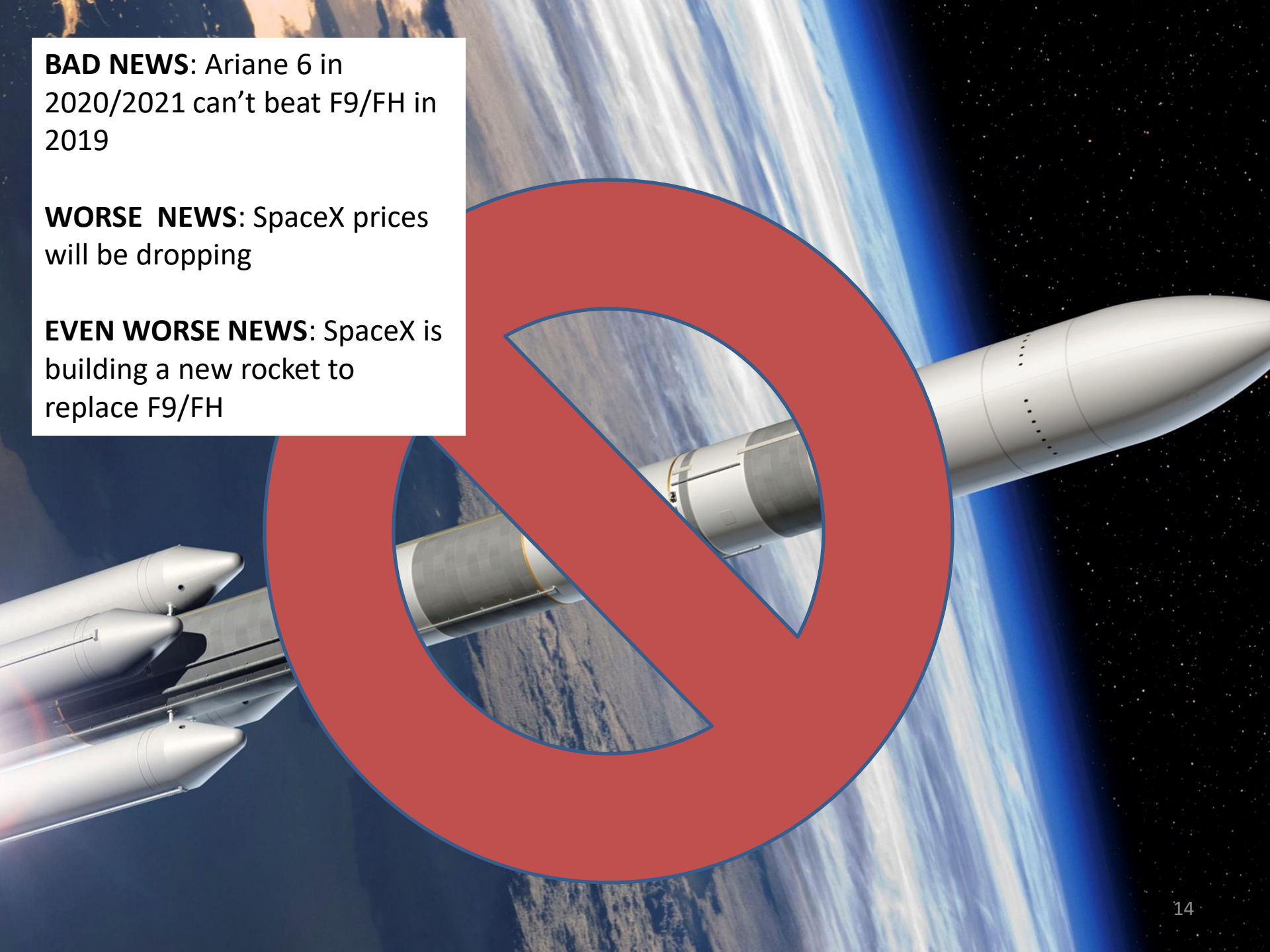
- **Builder:** ESA/Airbus Safran Launchers
- **Height:** 63 meters/207 ft
- **Lift-off thrust:** 15.4 kN
- **Side boosters**: four (solid fuel)
- **First Stage:** Lox/LH
- **Second Stage:** Lox/LH
- **Third Stage:** None
- **Fairing size:** 5.4 meters diameter/20 meters in length
- **Payload to LEO:** 22K kg/44k lbs(expendable)
- **Payload to GTO:** 12K kg /26K lbs (expendable)
- **Payload to TLI:** Less than 12K kg
- **First flight:** Second half 2020
- **Reusability:** None
- **Current Status:** First batch of 14 ordered January 2019; on schedule
- **Planned payloads:** ESA payloads, OneWeb, GeoSynch comsats; replaces Ariane 5

Compare to $62M for 5.5 K kg to GTO on F9 re-usable

Compare to $90M for 8 K kg to GTO on FH re-usable

12 MT to GTO
Covers the Geosync sweet spot and allows two 6 MT satellites to go up at once-

- With 4 boosters, costs 90M Euro for 12K kg to GTO (101M $US)
- With 2 boosters, costs 75M Euro for 5K kg to GTO (84.3M $US)



BAD NEWS: Ariane 6 in 2020/2021 can't beat F9/FH in 2019

WORSE NEWS: SpaceX prices will be dropping

EVEN WORSE NEWS: SpaceX is building a new rocket to replace F9/FH

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SOURCE: BRADY KENNISTON / NASASPACEFLIGHT.COM

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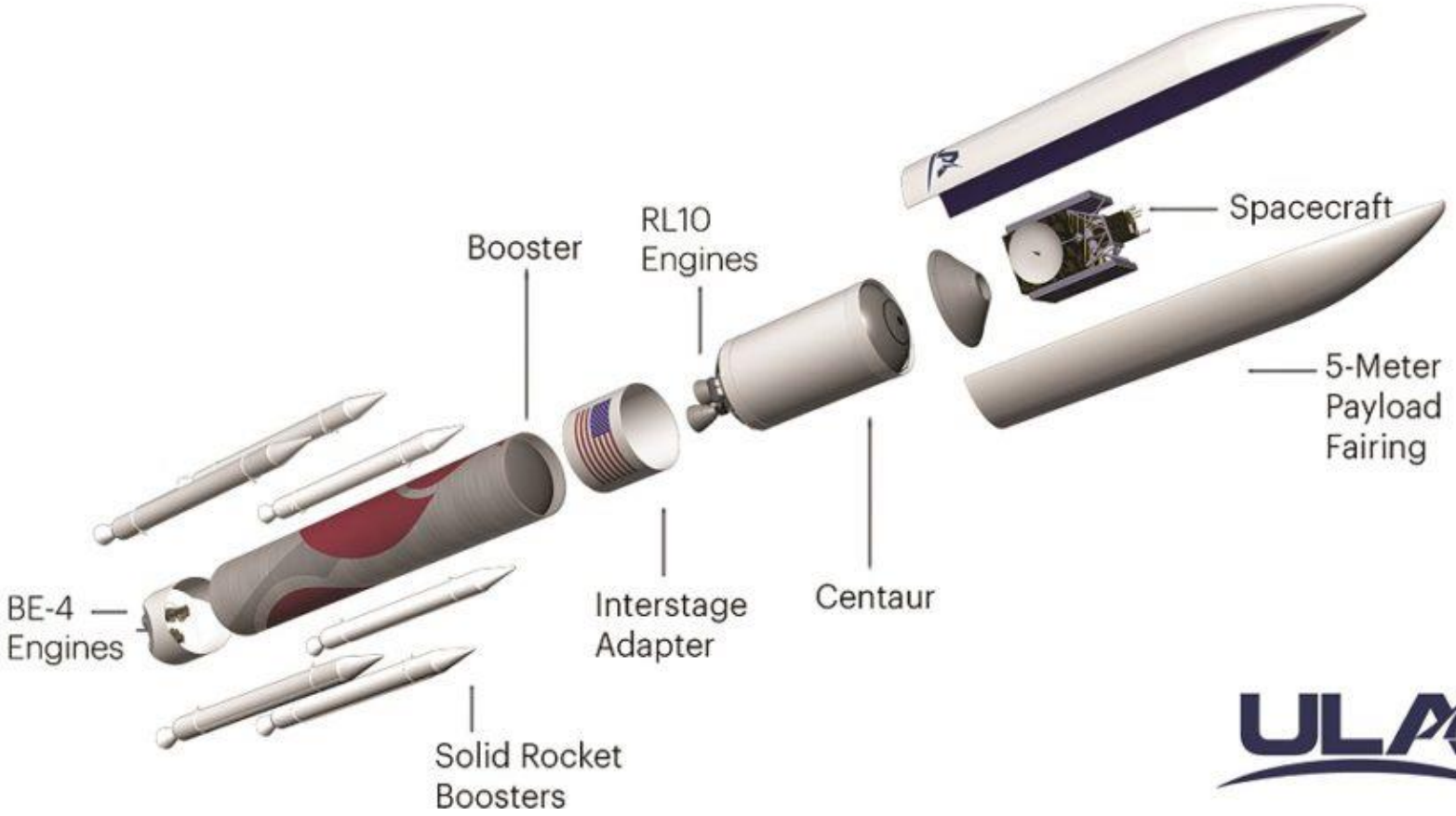
New Glenn: Basics

- **Builder:** Blue Origin/USA
- **Height:** 82 meters/270 ft
- **Lift-off thrust:** 17.1K kN (3.9M lbf)
- **Side boosters:** None
- **First Stage:** Lox/Methane [Seven BE-4 engines]
- **Second Stage**: Lox/Hydrogen [Two BE-3 engines]
- **Fairing size:** 7 meters diameter (23 ft)
- **Payload to LEO:** 45K kg/99k lbs(reusable first stage)
- **Payload to GTO:** 13K kg /29K lbs (reusable first stage)
- **Payload to TLI:** Less than 13 K kg
- **First flight:** June 2020
- **Reusability:** First stage only
- **Current Status:** In development
- **Planned payloads:** Five OneWeb, multiple Telesat, Eutelsat, mu Space Corp, and SKY Perfect JSAT, competing for U.S. military launches

13 MT to GTO Reusable covers the Geosync sweet spot and allows two 6 MT satellites to go up at once: expected to be very competitive with Falcon Heavy. Ariane 6 is toast.

Vulcan


Booster
RL10
Engines
Spacecraft
5-Meter
Payload
Fairing
BE-4
Engines
Interstage
Adapter
Centaur
Solid Rocket
Boosters

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Vulcan: Basics

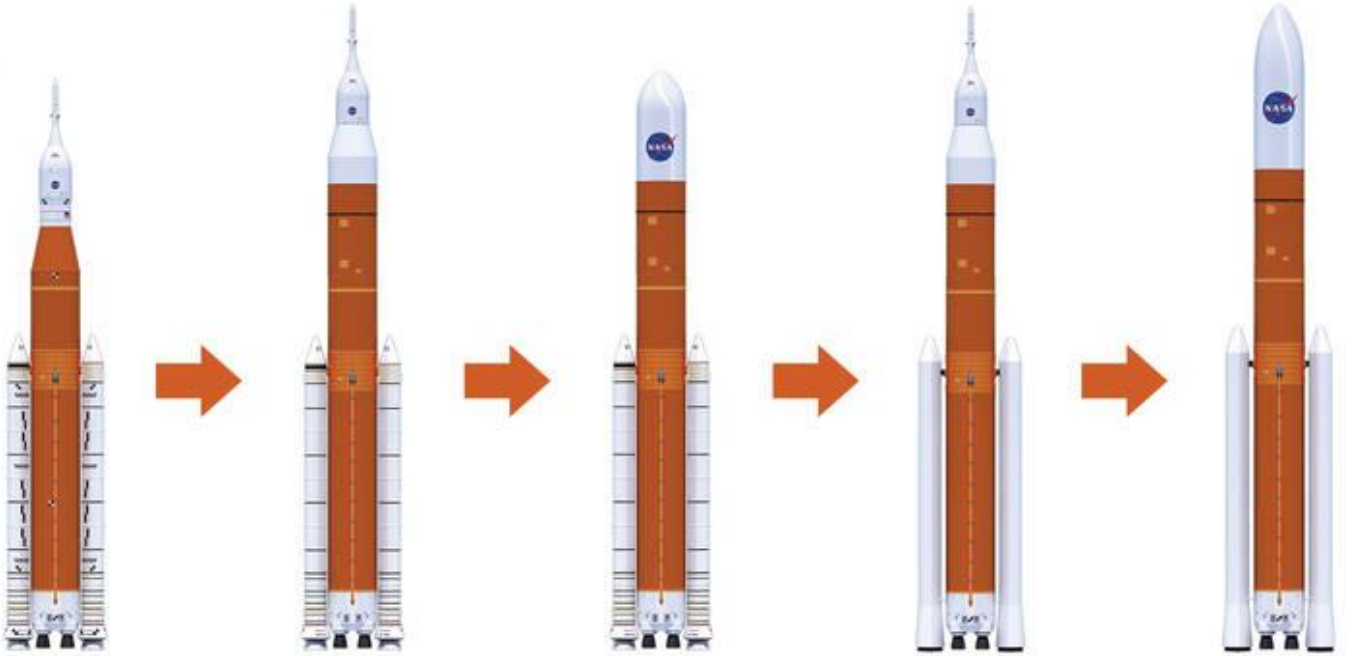
- **Builder:** ULA/USA
- **Height:** 58.3 meters
- **Lift-off thrust:** 4.9K kN plus solids [2.2K kN x 6 = 13.2K kN] = 18.1 K kN
- **Side boosters:** 0-6 solid rockets, with 6 exceeds both Atlas V and Delta IV Heavy
- **First Stage:** Lox/Methane
- **Second Stage**: Lox/LH, initially same Centaur stage used by Atlas V
- **Fairing size:** 5.4 meters diameter
- **Payload to LEO:** 35K kg (Vulcan Heavy with 6 SRBs)
- **Payload to GTO:** 16.3K kg (Vulcan Heavy with 6 SRBs)
- **Payload to TLI:** About 7 K kg (Vulcan Heavy)
- **First flight:** April 2021
- **Reusability:** 1st stage engines via air-drop; 2nd stage in-space reuse
- **Current Status:** In development; will use BE-4 engine from Blue Origin
- **Planned payloads:** Mostly U.S. government payloads
- **Cost:** $100M to $130M; divide by two if two satellites are launched

Vulcan 2021 is competitive with F8/FH in 2019. But SpaceX is not standing still.

SLS Evolution

Payload to TLI/Moon	> 26 t (57k lbs)	34-37 t (74k–81k lbs)	37-40 t (81k–88k lbs)	> 45 t (99k lbs)	> 45 t (99k lbs)
Payload Volume	N/A*	10,100 ft³ (286m³)*	18,970 ft³ (537 m³)	10,100 ft³ (286 m³)*	31,950 ft³ (905 m³)

* Not including Orion/ Service Module volume



	SLS Block 1	SLS Block 1B Crew	SLS Block 1B Cargo	SLS Block 2 Crew	SLS Block 2 Cargo
Maximum Thrust	8.8M lbs	8.8M lbs	8.8M lbs	11.9M lbs	11.9M lbs

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SLS Block 1B: Basics

(adds Exploration Upper Stage)

- **Builder:** NASA/USA (Boeing, Orbital/ATK, Aerojet Rocketdyne)
- **Height:** 110-111 meters
- **Lift-off thrust:** 23.4K kN (8.8M lbf)
- **Side boosters:** Two (Solid fuel)
- **First Stage:** Lox/LH
- **Second Stage:** Lox/LH (EUS – new stage)
- **Third Stage:** None
- **Fairing size:** 8.4 meters diameter/19.1 meters long
- **Payload to LEO:** 105K kg (expendable)
- **Payload to TLI:** 37-40K kg (expendable)
- **First flight:** **Artemis 3/June 2024 or Europa Clipper/2023**
- **Reusability:** None
- **Current Status:** Vehicle for Artemis 1 in assembly/test phase; EUS in development
- **Planned payloads:** Artemis missions 4-8, Europa Clipper

Lunar Comparison

- GEO/GTO: The clear winners are Falcon Heavy and New Glenn
  - Ariane 6, Vulcan are not in the same cost league
  - SLS is aimed at the Moon, and way more costly
  - Really hard to say whether FH or New Glenn will win
- Moon: Facially, SLS wins with 26MT to TLI
  - LM5 (18MT) [off-limits due to ITAR]
  - FH (<8MT)
  - Ariane 6(<12MT)
  - New Glenn (<13MT)
  - Vulcan (<7MT)
- But when cost is considered, FH or New Glenn are way ahead
- But the chunks launched are smaller, and you have to do in-space assembly to get to the Moon
- This is a battle of philosophy
  - The BIG ROCKET vs in-space assembly/re-fueling

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… But that isn't the whole story

- It's a bird, It's a plane, It's …..

Credit: Sam Taylor

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SpaceX is building a new rocket to replace Both F9 and FH

That rocket is called Starship/Superheavy

For some reason BFR wasn't working!

This is a bold play.

Elon is all in.

SpaceX is far ahead now, so they are scrapping their current product line and replacing it with something shiny and new

This is the stuff of legend.

But the really amazing thing is that it is being built out in the open so we can watch.

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July 18, 2018 Boca Chica Texas

StarHopper: credit Bocachicagal

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July 19, 2018 Boca Chica Texas

Starship Orbital Prototype: credit Bocachicagal

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July 14, Cocoa, Florida

Second Starship Orbital Prototype Rises: credit Omar Izquierdo and flying_briann

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Starship/Superheavy: Basics

- **Builder:** SpaceX/USA
- **Height:** 118 meters
- **Lift-off thrust:** 53K kN (11M lbf)
- **Side boosters:** None
- **First Stage:** Subcooled Lox/Methane
- **Second Stage:** Subcooled Lox/Methane
- **Third Stage:** None
- **Fairing size:** NO FAIRING – clamshell: 9 meters diameter, 1000 m^3 cargo area
- **Payload to LEO:** 100 MT (reusable)
- **Payload to Lunar Surface:** 100 MT (reusable) – with refueling in orbit
- **First flight:** Raptor engine testing well advanced; 2020 Starship orbital test flight; 2021 first commercial flight; 2023 fly around Moon
- **Reusability: 100%**
- **Current Status:** First hop by Starhopper done; Construction and testing underway
- **Planned payloads:** Replace F9/FH; everything ; everywhere, but lots of Starlink

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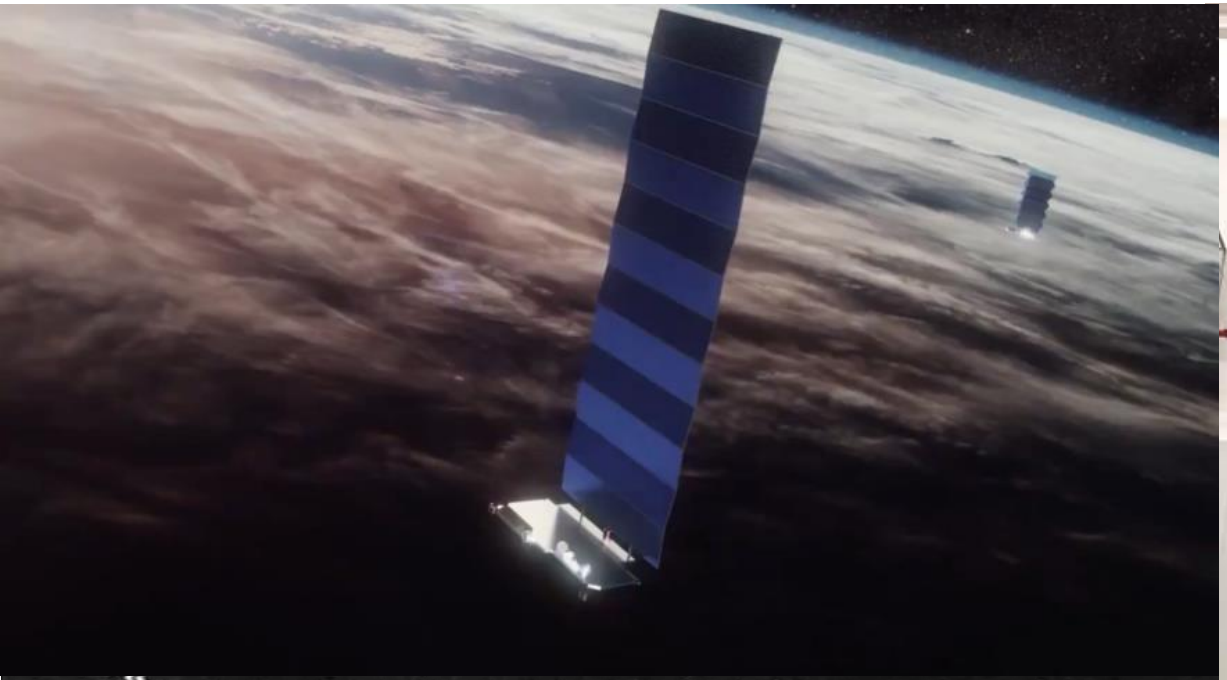
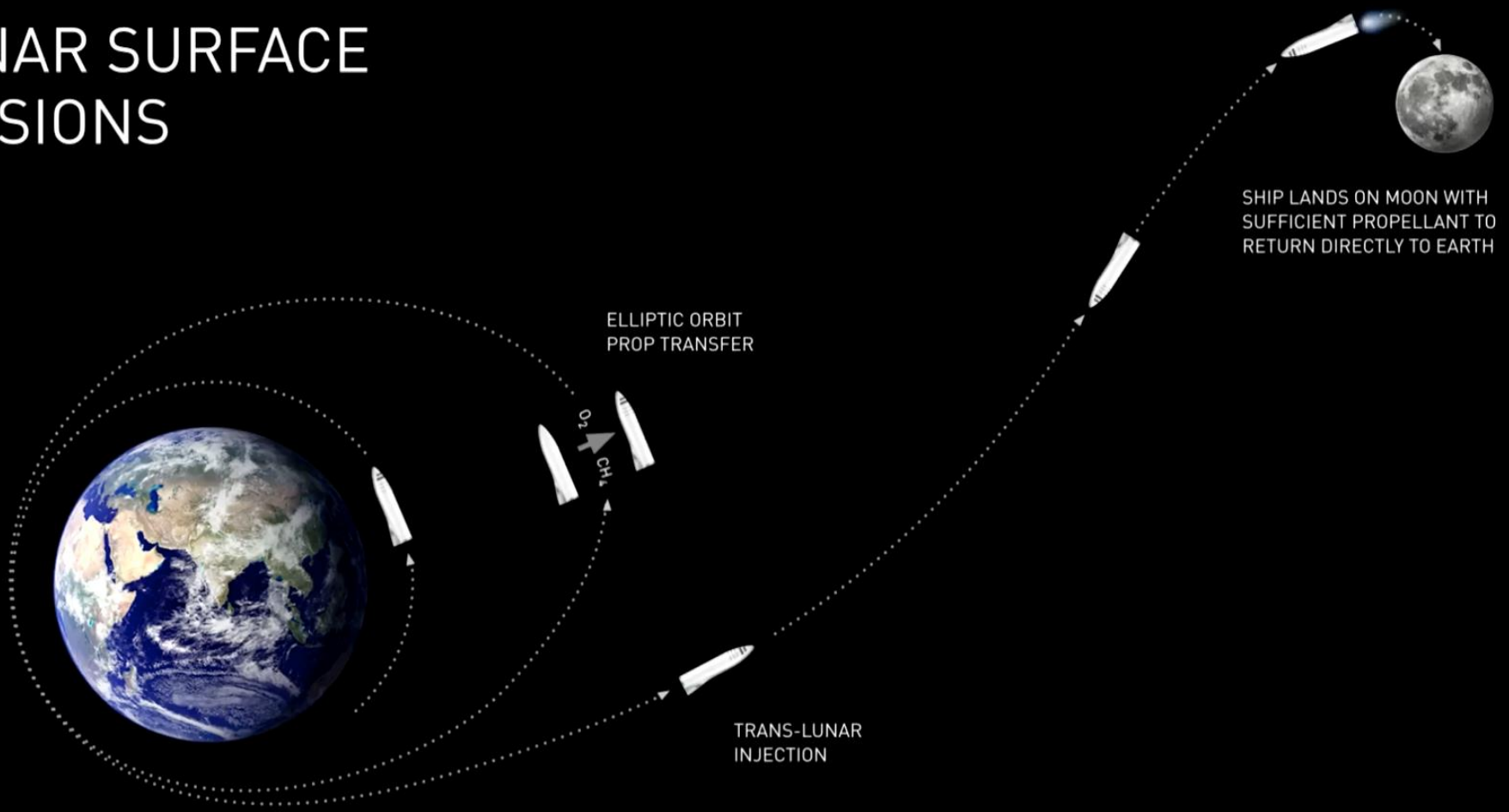
What is Starlink Anyway?



LUNAR SURFACE MISSIONS



A Thought Experiment

- Some dismiss Starship/Superheavy as being too risky to be successful
- Suppose the key innovative technologies fail:
  - The Starship heat shield doesn't work, and so it can't be re-used
  - In-Space re-fueling doesn't work
- Starship/Superheavy will still be extremely competitive with New Glenn, the only real threat to F9/FH
- If in-space re-fueling does work, an expendable version of Starship can put 100MT on Mars or the Moon
  - Nothing else comes close to being able to do this

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Conclusion: It's Complicated

- Russians are on a path to not being serious players
- Chinese are the tortoise to the hare, and in the real world the hare wins
- **Newsflash**: BFR/Starship-Superheavy has moved from never-never land to the visible horizon
- Ariane 6, New Glenn, and Vulcan targeted F9/FH
  - They will end up competing with Starship/Superheavy
  - Arianespace/Blue Origin/ULA need to re-think their strategy
- Musk is going "all in" with Starship/Superheavy
  - He will win everything or lose it all
  - If Starship/Superheavy flies, it is hard to imagine SLS making it to Block 2
- **Regardless of who wins out exactly, there is every prospect that these exciting choices will enable a new age of lunar exploration and development**

Questions?