

Commercial Space Flight

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Lecture organized by HAW Hamburg
Hamburg Aerospace Lecture Series
(DGLR, RAeS, VDI, ZAL, HAW Hamburg)

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Commercial Space Flight

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Lecture followed by discussion
No registration required!
Entry free!

Date: Thursday, 06.06.2019, 18:00
Location: HAW Hamburg
Berliner Tor 5
Hörsaal 01.13

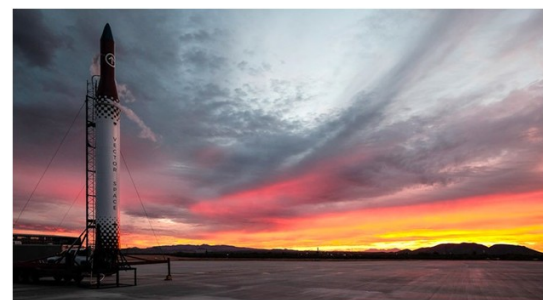
In little more than a decade, **SpaceX**, **Blue Origin**, and a host of other upstart companies have changed the conversation about commercial space. While the plans and dreams of these pioneers were initially dismissed by nation states and major corporate launch providers, they have emerged as disruptors for the global launch market.

On March 13th, commercial launch was further legitimized by NASA Administrator Jim Bridenstine's announcement that NASA's new flagship rocket, the Space Launch System (SLS), would not be ready in 2020 for its first mission. Bridenstine suggested that Orion's flight around the Moon, the cornerstone mission for the SLS, could be performed by the commercial launch providers. "We have amazing capability that exists right now that we can use off the shelf in order to accomplish this objective," he said.

This talk will chronicle the evolution of the disruptive commercial industry. Whether it is the billionaires, Bezos and Musk, or small bootstrap providers like **Rocket Lab**, **Sierra Nevada**, or **Vector Space**, these disruptors are rapidly reducing the cost of delivering satellites to orbit. How did we get here and where are we going are just two of the questions that will be examined by this lecture?



Falcon Heavy, SpaceX (picture: Artis)



Vector-R rocket Vector Space Systems (picture: Artis)

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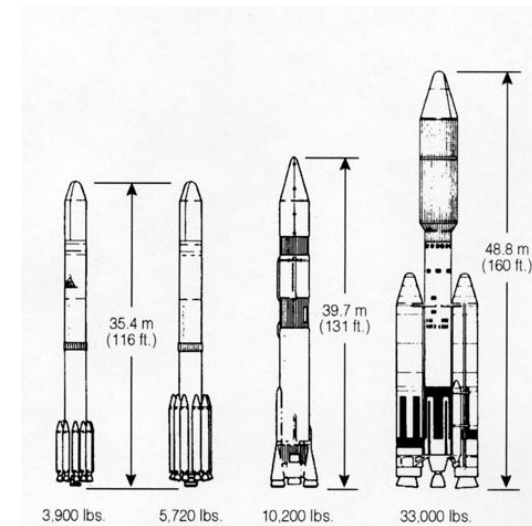


A Brief History

- Where did the shuttle come from?
- How did Ariane, Chinese, and Russian commercial space boosters become viable?
- How was the United Launch Alliance formed?
- What about the SLS?
- What is the future of commercial space?
- What about the Billionaires: Musk & Bezos?
- What about the small players: Vector Space Systems & Rocket Labs?
- What is next?
- What will it take to succeed?

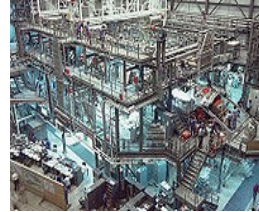
The 1970s

- During the 1970s, three primary systems were employed by the US for NASA, DOD, and commercial launches:
 - Delta II, McDonald Douglas
 - Atlas Centaur, General Dynamics
 - Titan 3C, Martin Marietta
- These boosters were evolved from the Thor IRBM and the Atlas and Titan ICBMs
- The US owned the international launch business
- In 1969, President Nixon decided to proceed with the Space Shuttle development instead of manned flights to Mars
- NASA was tasked with developing an economic case for the ongoing operation of the Space Transportation System



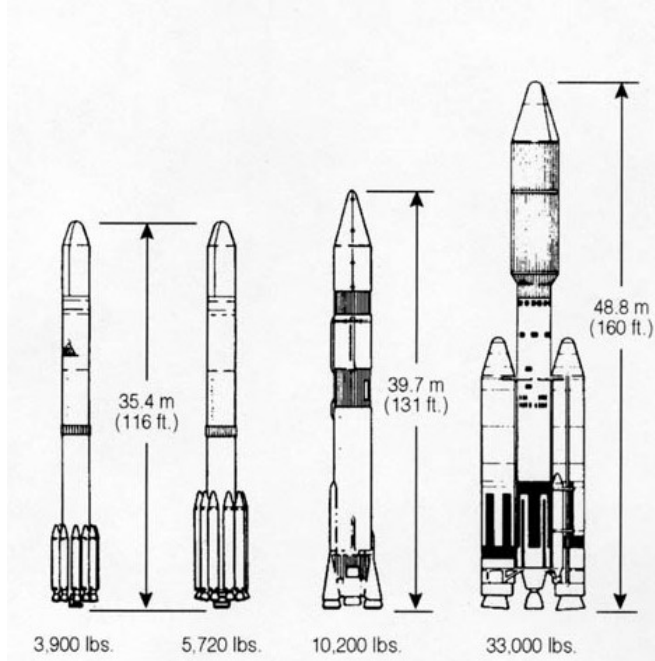
Operational Cost Justification

- NASA chose the name “Space Transportation System” since it envisioned the shuttle as the space truck that could carry all NASA, DOD, and US commercial satellites to orbit
- NASA projected 50 to 60 missions per year with airliner like turn arounds
- NASA projected at \$500/lb cost to LEO
- US commercial and research payloads would be carried at marginal cost with the government subsidizing each launch
- When the decision was made on the main shuttle contractors in 1972, work was spread among companies to make the program more attractive to Congress, such as the contract for the SRBs to Morton Thiokol

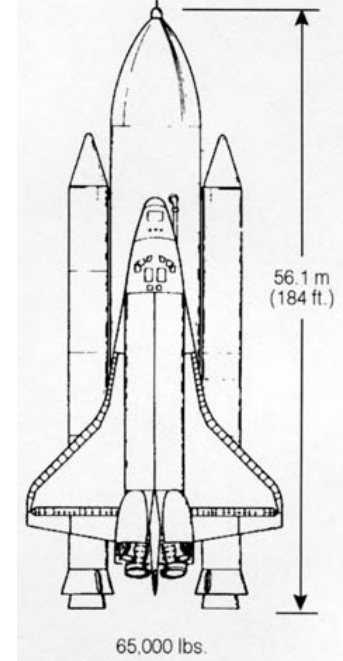


https://en.wikipedia.org/wiki/Criticism_of_the_Space_Shuttle_program
https://en.wikipedia.org/wiki/Space_Shuttle

Making the Dollars Work



Expendable Launchers



Space Shuttle



The Solution to Everyone's Problem

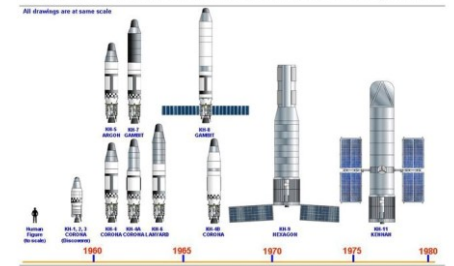




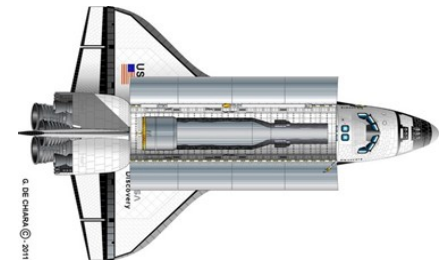
The Driving Requirement

- The DOD required polar orbits for its Key Hole (KH-xx) spy satellites launched from Vandenberg
- The Enterprise was taken to Vandenburg and stacked at the SLC-6 complex to demonstrate the capability and infrastructure
- So the size of the shuttle bay and the mass to orbit for polar operations were defined by the DOD before they would sign on to the cost savings deal
- Over the life of the shuttle, five classified missions were flown from KSC with unspecified payloads

Evolution of American Reconnaissance Systems



Giuseppe De Chirco © 2011



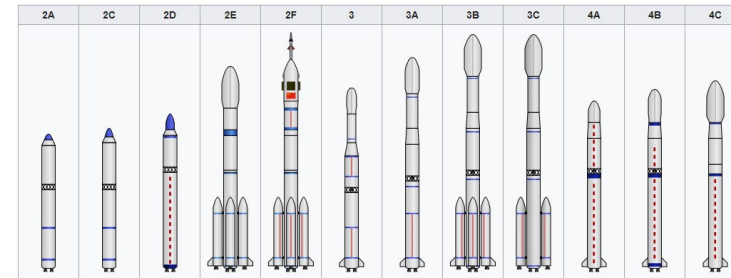
Shuttle Deployments

- The shuttle deployed:
 - DOD DSP satellite
 - Tracking and data relay satellite (TRDS)
 - Syncom IV-2 Navy communications satellite, the frisbee launch
 - Magellan space probe stacked on a Centaur upper stage
 - And a host of other birds
- Each Shuttle flight could carry multiple satellites
- Compared to expendable boosters, the launches were a lot cheaper for the satellite owners. But it was ***government math***



Seeing Opportunity

- Ariane Space rapidly moved from the European to the world market for commercial launch services
- China began to offer commercial services using the Long March
- After the fall of the Soviet Union, Russia became a fierce cost competitor sweeping big programs like DirecTV, O3b, and One Web. Russia teamed with Ariane to exploit the French Guiana equatorial launch facility



Vehicle	Rocket	Dnepr	Soyuz 2	Proton M	Ariane 5 ECA	Soyuz 2	Vega
Country/Region	Russia	Russia	Russia	Russia	Europe	Europe	Europe
2014 Total Launches	2	2	9	8	5	4	1
LEO kg (lbs)	2,150 (4,740)	3,700 (8,157)	4,850 (10,692)	23,000 (50,706)	21,000 (46,297)	4,850 (10,692)	2,300 (5,071)
GTO kg (lbs)	—	—	1,700 (3,800)	6,920 (15,256)	9,500 (20,944)	3,250 (7,165)	—

Reality

- While the shuttle costs had far been higher than estimated and launch rates had never exceeded 9 per year (1985) and there was not an alternative
- Then, the Challenger disaster in 1986 made everyone face reality
- Plans to launch from Vandenberg were scrapped
- The DOD started a panicked search to find other alternatives
- The shuttle would stop carrying commercial payloads and focus on space station assembly and operations
- After the Columbia disaster in 2003, NASA had to prepare two shuttles for every flight





EELV Program

- After a brief return to Delta II, Atlas Centaur, and the Titan III-x boosters, the DOD considered how to replace the lift capacity that had been planned for the shuttle
- The DOD estimated the cost at **\$1B** for developing evolved vehicles based on **existing engines** and **\$5B** for a blank sheet design **with new engines** in a 1994 study, hence the future was the Evolved Expendable Launch Vehicle (EELV) program which would also be able to serve the needs of commercial users
- The DOD stated that access to space was critical to:
 - place critical United States Government assets and capabilities into space
 - augment space-based capabilities in a timely manner in the event of increased operational needs or minimize disruptions due to on-orbit satellite failures, launch failures, or deliberate actions against U.S. space assets
 - support government and commercial human space flight
- A blank check was about to be written in the name of national security

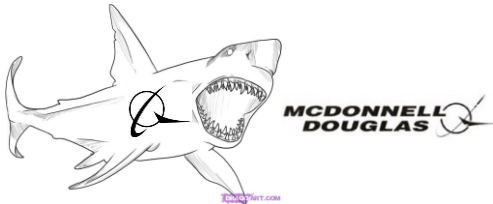
The Bidders



And the winners were:



And then, a funny thing happened:

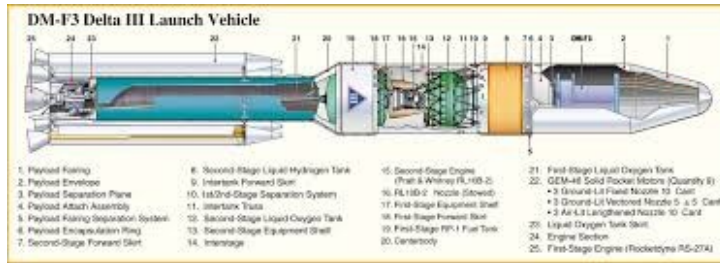


The DOD wanted two boosters to guarantee access to space even if one is grounded due to a failure

Two Program for the Future

Boeing Delta III

Lockheed Martin Titan IV



Launch vehicles built on time proven Delta II and Titan III-x technology were soon ready to meet the DOD's requirements.....



1998-99: Two Bad Years

- Titan IV Failure August 20, 1998 – 1.3 billion
- Delta III's first launch August 26, 1998. It exploded 10 seconds after launch
- Delta III's second launch May 4, 1999. Second stage failed and delivered the payload to a useless orbit. After a 3rd launch failure of a dummy payload, Boeing declared the program a success and began development of the Delta IV
- Boeing and Lockheed Martin delivered a 2-year series of failures costing the DOD \$3.5B. A lot of knowledge had been lost over 15 years
- ***"I think this is probably one of the worst times in the launch history of the country,"*** said retired Air Force Gen. Howell M. Estes III, former head of the U.S. Space Command. ***"Even the old rockets aren't working, and some of the newer rockets aren't working. That's the concern, and it comes at the very time we most need to get the launch costs down and assure access to space"***



The United Launch Alliance

- In 2002, the new EELV Delta IV and Atlas V vehicles flew for the first time. By 2004, they had 6 successful flights. Unfortunately, they were too expensive for the commercial market leaving the full cost to the DOD
- In 2003, Boeing was found to be in possession of proprietary documents from Lockheed Martin
- The DOD has expressed concerns that with only a few rocket launches each year, one of the two companies could fail leaving them dependent on a single booster
- To end the litigation and uncertainty, unable to compete in the commercial market, uncertain of future contracts, both companies agreed to form the United Launch Alliance joint venture. Each company has a 50% stake in ULA
- Loath to be dependent on one type of booster, the DOD directed the ULA maintain both boosters to guarantee the DOD's access to space



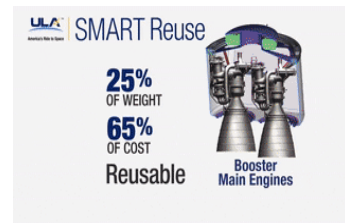
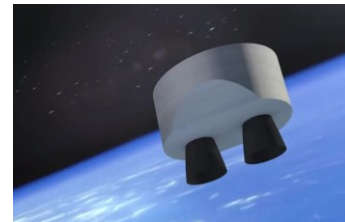
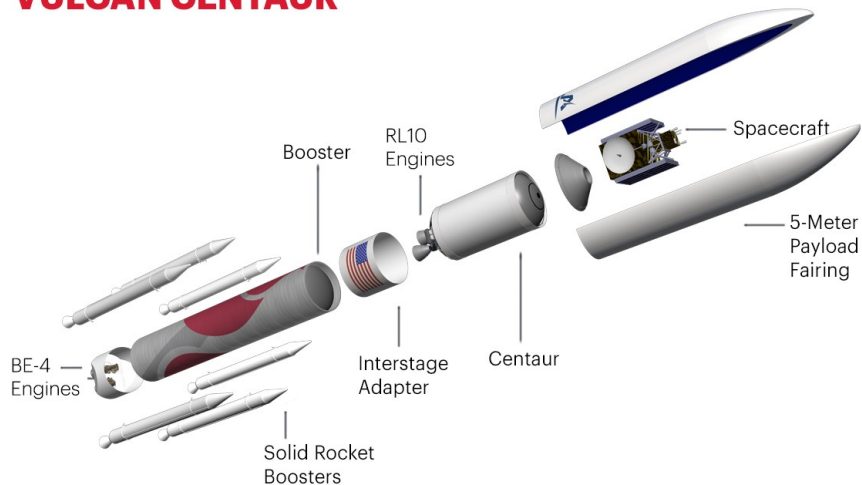
The United Launch Alliance

- On Wednesday October 4th, 2006, U.S. antitrust authorities yesterday approved a plan by Lockheed Martin and Boeing to merge their government rocket businesses, creating a monopoly in a multibillion-dollar market that the Federal Trade Commission acknowledged will probably lead to higher prices and lower quality
- The failure to attract commercial users would add \$8B to the cost of the EELV program for the government. The expected cost overage was \$13B, more than 70%. This triggered a legal trip wire designed to stop out of control programs. Secretary of Defense Donald Rumsfeld certified to congress that the program was vital to the national security of the United States
- The United Launch Alliance had *ascended to cost plus heaven* at **\$400M** per launch vehicle plus payments for other expenses. Having a perfect launch record is not cheap
- In 2015, congress set a deadline of 2022 for the replacement of the Atlas V due to national security concerns related to the Russian RD-180 engine
- The ULA replacement for the Atlas V is called the Vulcan



ULA Vulcan

VULCAN CENTAUR



The Vulcan will use the Blue Origin BE-4 engine for the first stage and the proven RL-10 engine for the second – the choice of **developing new vs buying down risk**

The ULA projects that the Vulcan will be able to reduce cost by a factor of two

The first flight of the Vulcan is planned for April of 2021

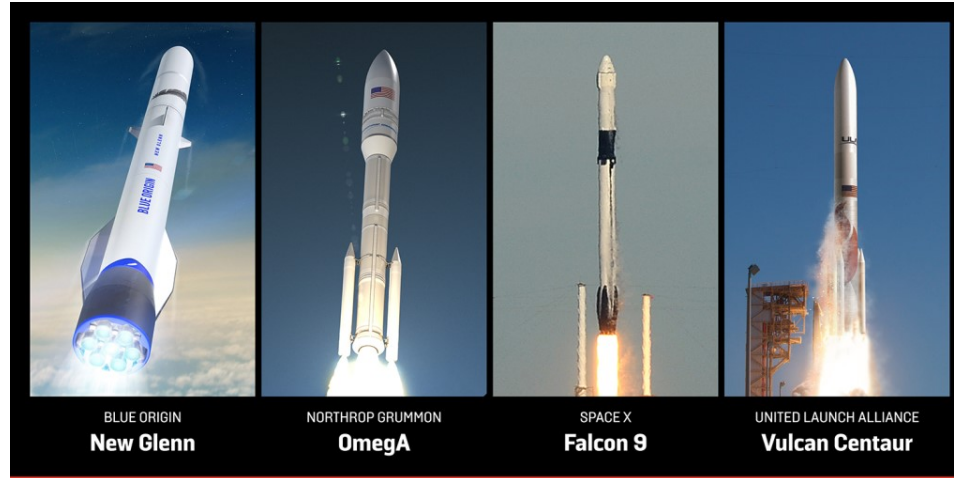
Once SpaceX Falcon 9 family became available, the DOD did not need to pay for the ULA to maintain two independent launch systems to guarantee their access to space

Northrup Grumman Omega

- Based on the heritage of Pegasus and Minotaur, Orbital ATK developed the Antares which now delivers cargo the ISS using the Cygnus supply ship
- Orbital ATK received DOD funding in 2016 to design a new booster to eliminate our dependence on Russian RD-180. The first launch of the Omega is scheduled in 2021
- Northrup Grumman acquired Orbital ATK in June of 2018 to enter the space launch market place
- First stage is based on shuttle SRBs with Castor strap-on boosters and the third stage is based on the RL-10 engine. The design is similar to the Ares I crew vehicle booster for which NASA funded development and then cancelled



For all the Marbles



- Bids are due by August 1st, 2019 for a 2020 contract award which will be made to two winners for 25 launches worth an estimated \$3.8 billion
- After that award, the government will terminate development payments to the competitors. Should they lose, it will be difficult for Northrop Grumman and/or the United Launch Alliance to compete for private launches
- Even US national security has a limited budget

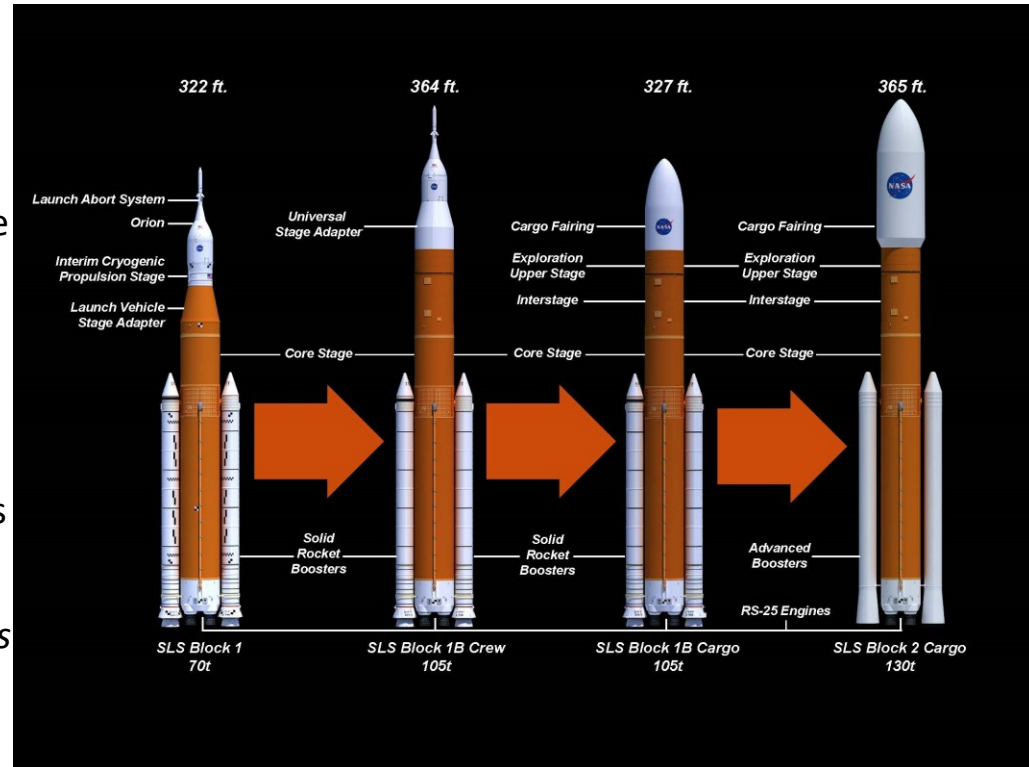
Space Launch System

- After the cancellation of the Constellation Program to replace the Space Shuttle in 2010, the Space Launch System was proposed by NASA to provide future human access to space by exploiting shuttle hardware
- The program was projected to have development costs of \$18B through 2017. \$10B for the SLS rocket, \$6B for the Orion, and \$2B for launch infrastructure at the Cape
- After massive cost overruns, NASA announced on November 8th, 2017 that the earliest possible flight for the SLS would occur in December of 2019. The launch date has been revised to mid 2021
- When it was a national priority, we went to the moon in 8 years
- Based on current estimates, a single SLS launch will cost **\$500M**. Since this is not a commercial enterprise, the \$20B+ of development costs do not need to be recovered. Until the first flight occurs, that cost estimate is likely to continue to grow
- ***In America, NASA programs are rarely cancelled. Rather, they are deprioritized and left in place to maintain jobs while they languish with little hope of ever being successful***



A Troubled Future

- On March 13th, NASA Administrator Jim Bridenstine's announced that NASA's new flagship rocket, the Space Launch System (SLS), would not be ready in 2020 for its first mission
- Should the SLS fly in 2021. The earliest date for a manned flight would be 2022
- *"We have amazing capability that exists right now that we can use off the shelf in order to accomplish this objective,"* said Brindenstine
- Only two SLS Block 1 boosters have been funded and work on the SLS derivatives has been suspended
- Including the development expenses, the two SLS Block 1 boosters are *bespoke works of art* with a true cost of more than \$10B per copy



Changing Objectives and Inconsistent Funding

- **1989: Space Exploration Initiative.** On the 20th anniversary of the moon landing, G.H.W. Bush proposed a mission to the moon and then onto Mars. It was cancelled by Clinton
- **2004: Vision for Space Exploration/Constellation.** After the Columbia, G.W. Bush proposed a sustained and affordable exploration program starting with manned missions to the moon in 2020. NASA began the development of the Crew Exploration Vehicle and the Ares rocket
- **2013: Asteroid Redirect Mission.** Obama proposed missions to asteroids using the Orion Capsule (CEV) and a new booster called the SLS
- **2017: Deep Space Gateway.** The asteroid mission was dropped by NASA and the Orion and SLS were repurposed for the lunar orbiting gateway
- **2018: Manned Lunar Landing in 2024.** The Trump administration proposed a manned return to the moon by 2024 and followed by a push to Mars
- ***Unlike NASA's 1960 focus on the moon, each new administration redefines the mission and does not provide NASA adequate funding to achieve the objective within their tenure!***

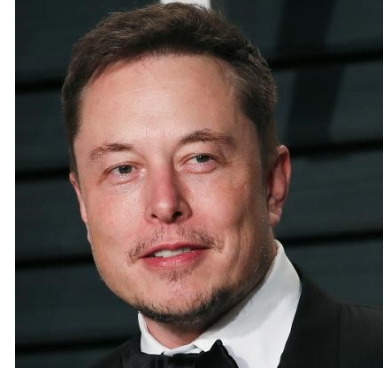
The Space Billionaires

- While countless small companies attempted to enter the space business between 1995 and 2005, none of them could attract venture capital
- Paul Allen backed Rutan's Scaled Composites for the X-Prize. Richard Branson immediately stepped in to create Virgin Galactic. Tourist flights will probably take place prior to the end of 2021
- Jeff Bezos quietly started Blue Origin and developed the New Shepard for space tourism. Elon Musk, was well ----- ***"Elon Musk"***
- While many people scoff at space tourism, it was the Barnstormers of the 1920s and 1930s that led people to accept commercial aviation



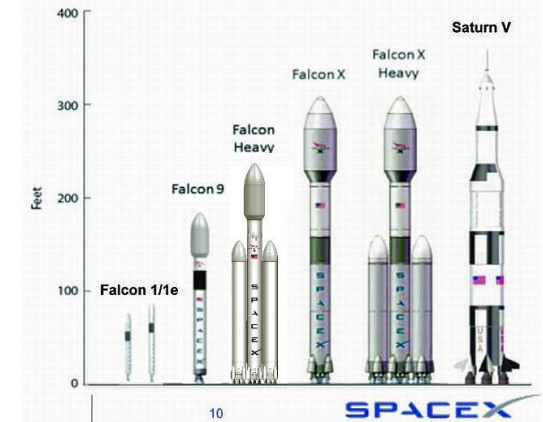
The Billionaire Boys

- Elon Musk has parlayed his fortune (\$2B) from PayPal along with space station supply and DOD contract money to create SpaceX, Tesla, Solar City, and the Boring Company
- Jeff Bezos has quietly invested countless billions into Blue Origin. On a scale of wealth, Musk is only *fringe rich* compared to Bezos
- Bezos has agreed to sell his BE-4 methane methane-LOX engine to the ULA
- They have the money available in the form of internal, venture, or government capital to complete their visions without going to the public capital markets



SpaceX

- After the initial flights of the Falcon 1, they moved on to the Falcon 9 abandoning the small launch market. The Falcon 1 was what software people call a *minimally viable product*. DARPA loved the design for “on-demand” launch of military payloads
- Rather than mass producing a single vehicle, they are continually evolving with every flight adding new capabilities to their vehicles
- After several failures, SpaceX has been able to recover and reuse the first stages of **\$39M** Falcon 9 launch vehicle
- On February 6th of 2018, SpaceX launched the first **\$100M** Falcon Heavy. The second launch occurred in April of 2019
- *“I don’t know how to build a \$400M rocket”* ,Gwynne Shotwell



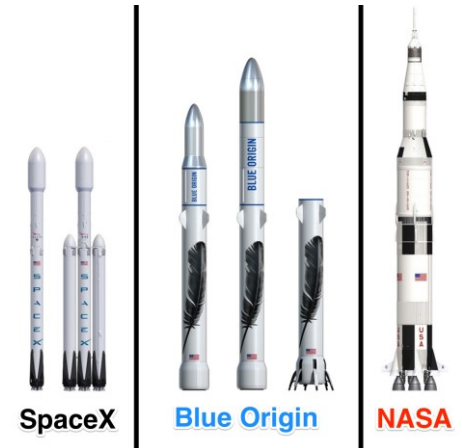
SpaceX

- SpaceX has generated significant revenues through its space station resupply contract
- The Dragon capsule has been used for resupply missions and is poised for a manned flight later in 2019 after the completing and unmanned flight earlier this year
- While there are exaggerated claims and missteps, SpaceX continues to make progress
- Contrary to the DOD, NASA, and ULA wisdom, Musk developed the Merlin, Kestrel, and Raptor engines
- Initially referred to as the BFR, SpaceX has begun testing the landing system for the Starship booster



Blue Origin

- While the New Shepard continues development for space tourism, the real focus is the New Glenn
- The New Glenn is a Saturn V class booster with a reusable first stage
- Like Musk, Bezos has a vision of making humanity a multi-planet species
- Bezos plans to fly the New Glenn in 2021
- Contrary to the DOD, NASA, and ULA wisdom, Bezos elected to create the new BE-4 engine





Blue Moon



Announced on May 10th, projected to be capable of meeting NASA's 2024 return to the moon mission



New Shepard Flight



It is a beautiful cabin, but what happens if one of your fellow travelers experiences motion sickness

Jeopardy

- At \$400M and \$500M per launch, neither the ULA Vulcan or NASA SLS can compete with the proven costs of SpaceX or the projected costs of Blue Origin. The ULA has already conceded the commercial market
- The 2020 national security contract award could end the ULA's and/or Northrup Grumman's programs
- The recent ground test may result in SpaceX's first manned crew flight being delayed into 2020
- While the CST-100 capsule is reusable, the Atlas V is not. How can the Boeing CST-100/ULA Atlas V system compete with a lower cost fully reusable system?
- NASA recently invited SpaceX, Blue Origin, and the traditional contractors to respond its Moon 2024 solicitation

Jeopardy

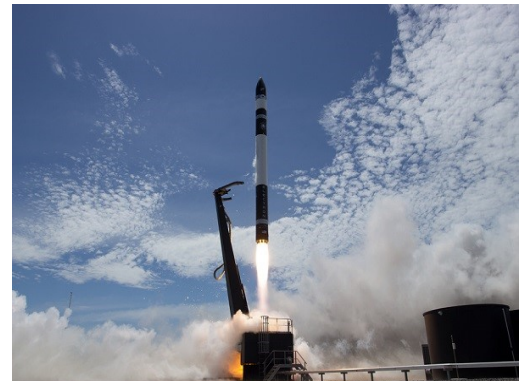
- The last shuttle flights were used to pre-position large a spare ammonia cooling unit along with other large spares for the space station
- What will happen to the space station if a major component fails for which there is no on-orbit spare without the shuttle to deliver it to orbit?
- Unoccupied, the space station would rapidly fall into disrepair
- Commercial alternatives are appearing for both NASA's and the ULA's primary missions
- Eventually, ***someone will say that the emperor has no clothes***





The Small Players

- Vector Space Systems: Jim Cantrell's \$1.5M launch vehicle capable of taking 50 kg to LEO. Their first orbital flight is scheduled for 2019
- Rocket Lab's first flight occurred in January of 2018. Beck's Electron is designed to deliver 150 kg to a sun synchronous orbit at \$5-6M per launch
- Both of these companies are highly attractive to time sensitive users who don't want to wait to hitch hike on a big booster
- Like Musk and Bezos, Cantrell and Beck denied conventional wisdom and developed their own engines





So What is Next?

- The space business is going to be very exciting
- While it is difficult to see how high cost suppliers can survive, the ULA has deep support in congress
- The EELV has now been renamed the National Security Space Launch System
- Launching payloads into space is becoming a commodity business
- Welcome to the **Wild West! *Your generation will be real space cowboys!***



What Will it Take to Succeed?

- The market requires at least two providers for each launch payload capacity to guarantee cost effective access to space
- Dedication to a clearly articulated vision
- Sustained funding and a viable business case to recover sunk development costs
- Mass production and/or reusability of launch vehicles
- Ruthless quality and cost control