The State of Play
US Space Systems Competitiveness

Prices, Productivity, and Other Measures of Launchers & Spacecraft

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Presentation to the Future In-Space Operations (FISO) Seminar
October 11, 2017
Purpose

• Collect space systems cost and related data (flight rate, payload, etc.) over time
  • Gathers only public data
  • Non-recurring and recurring
  • Minimal data processing
    • A few adjustments, mostly for apples to apples comparisons
      • Inflation to current year dollars
      • Same orbit, etc.
  • Graph, visualize, add context
  • Focus on US space systems competitiveness
  • Keep fresh – update as data arises, launches occur, etc.
  • Keep fresh – focus on recent data, indicative of the future
Caveats & Terminology

• The “price” to a customer is the “cost” to the customer (NASA, DoD, NRO, private sector, etc.)
  • Other government agency “costs” are personnel, government management, etc.
  • Occasional “asterisks”— included or not

• Uncertainties are inevitable
  • Anecdotal evidence some launch pricing actually higher than publicly announced (Russia/Proton, etc.)
  • Some public data is processed more – different contracts, phases, multiple partners, not yet final, age of the data, etc. (Apollo, Commercial Crew, SLS, Orion, etc.)
Source Data

Source data for this report is available in the NASA Life Cycle Cost (LCC) Model

Contact edgar.zapata-1@nasa.gov
As of 7/5/2017
14 US Major Launches in 2017

- ULA
  - 3 Atlas (2 DoD, 0 NASA, 1 ISS cargo, 0 commercial, 0 NOAA)
  - 1 Delta IV (1 DoD)
  - 0 Delta II (0 NASA)

- SpaceX
  - 10 Falcon 9 (7 commercial, 2 ISS cargo, 0 NASA, 1 DoD)
  - Landing Success / Attempts % Sea / %Land / %Average 62% / 100% / 72%

- Orbital Sciences
  - 0 Antares


10/17/16 Antares
12/06/2015 (Cyg/Atlas)

As of 7/5/2017

1st Falcon Heavy Flight Demo TBD

Mid 2017?

US Commercial Crew dates

1st SLS Demo Flight TBD. 2019

“The uncrewed Orion will travel into Distant Retrograde Orbit, breaking the distance record reached by the most remote Apollo spacecraft, and then 30,000 miles farther out (275,000 total miles). The mission will last 22 days and will test system readiness for future crewed operations.”

-as of 4/9/2016
http://www.nasa.gov/exploration/systems/
### The NASA Budget – Purchase Power Drop Since 2003 = 9%

#### Actual NASA Budget Increases = 1.95% per year average (compound) since 2003

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</table>

- **Decision: End Shuttle post-ISS**
- **Return To Flight**
- **2003 Columbia**
- **2004**
- **2005**
- **2006**
- **2007**
- **2008**
- **2009**
- **2010**
- **2011**
- **2012**
- **2013**
- **2014**
- **2015**
- **2016**
- **2017**

**Before 2003**
- Reusable Launch
- Hypersonics
- SLI, NGLT, etc.
- Technology

- a Shuttle Upgrades

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**E. Zapata NASA 05/02/2017**

**Purchase Power in 2003 $, per NASA Inf. Index**

**<-- US Commercial Crew ISS - Boeing & SpaceX Spacecraft**

**Rescissions (2012a/small)**

**<-- US Commercial Cargo ISS - Orbital ATK & SpaceX Launchers & Dragon & Cygnus Spacecraft**

**& ISS Crew Soyuz -->**
Recent Launch Prices as $/kg of Payload (2017$)
US Medium Launch + Scout, Shuttle, SLS, Falcon Heavy

- The line is a power curve fit ONLY to the points indicated with ->.
- For NASA and DoD, data are prices to the government, that is procurement costs only, excluding government management, personnel and related.
- For the Space Shuttle, to give a more consistent CARGO comparison, total recurring costs from life cycle cost data (1983-2013) were adjusted to remove crew at a Soyuz price rate, NASA management (civil service) and related were removed to leave procurement dollars only, and R&D years 1981-1982 were excluded as non-operational. Similarly, for SLS the NASA management (personnel) and related costs are also excluded, but unlike Shuttle, ground ops are excluded.
Recent Launch Prices as $/kg of Payload (2017$)
US Medium Launch - NO Scout, Shuttle, SLS

$ Price per kg vs. Payload Capability
Recent US Launch Price Data 2017$

Specific Costs = $ per kg

Payload Capability of Launcher
kg to LEO, 200km, 28.5 circ.
Recent Launch Prices as $/kg of Payload (2017$)

With Available US Small Launch / Services

NanoRacks as of 12/7/2015
SpaceFlight Services as of 12/7/2015
See Backup slides for data sources
Recent Launch Prices as $/kg of Payload (2017$)

With Available US Small Launch / Services + In Development

<table>
<thead>
<tr>
<th>Launch Vehicle</th>
<th>Source</th>
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<tbody>
<tr>
<td>Pegasus XL</td>
<td>NASA Sci.</td>
</tr>
<tr>
<td>Minotaur 1</td>
<td>NASA Sci.</td>
</tr>
<tr>
<td>Atlas V 401 DoD</td>
<td>NASA Sci.</td>
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<td>Falcon 9 DoD</td>
<td>SpaceX Private Sector</td>
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<tr>
<td>Falcon 9 LSP</td>
<td>SpaceX Private Sector</td>
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<tr>
<td>Delta IV Heavy</td>
<td>NRC+ELC</td>
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<tr>
<td>Antares NASA ISS Cargo</td>
<td>NanoRacks as of 12/7/2015</td>
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<tr>
<td>Atlas V 541 NASA Sci.</td>
<td>NanoRacks as of 12/7/2015</td>
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<td>Atlas V 551 DoD</td>
<td>NanoRacks as of 12/7/2015</td>
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<tr>
<td>Falcon Heavy</td>
<td>Private Sector Customer</td>
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<tr>
<td>Rocket Labs</td>
<td>Virgin Galactic Launcher One as of 9/14/2015</td>
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<tr>
<td>Generation Orbit</td>
<td>Rocket Labs as of 8/10/2015</td>
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<tr>
<td>NanoRacks 1U</td>
<td>NanoRacks as of 6/5/2015</td>
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<tr>
<td>SpaceX PPOD</td>
<td>NanoRacks as of 6/5/2015</td>
</tr>
</tbody>
</table>

See Backup slides for data sources
Recent Launch Prices vs. Payload Capability (2017$)

1. Pegasus XL 443 kg
2. Antares 4,900 kg
3. Atlas V 401 9,797 kg
4. DoD 2017 for a GPS launch
5. Minotaur 1 580 kg
6. Delta IV 28,790 kg $389.1M
7. Atlas V S417 17,443 kg
8. Falcon 9+ Dragon Spacecraft To High/ISS Orbit
9. Soyuz 2.1a $84M 8,200 kg
10. Falcon 9+ Dragon Spacecraft To High/ISS Orbit
11. Antares + Cygnus Spacecraft To High/ISS Orbit
12. Proton M $68M 22,000 kg
13. Ariane 5 $187M 21,000 kg
14. Soyuz 2.1a $84M 8,200 kg
15. Ariane 6 - Proposed $95M @~LEO Cap.
16. Delta IV 28,790 kg $389.1M
17. Atlas 541 & 551 Private Sector

E. Zapata NASA
04/14/2017

ULAs Avg. w. ELC
DoD Only

6. Delta IV
28,790 kg
Incl. ELC $389.1M

7. Atlas V S41
17,443 kg

Prices $ to NASA:

10. Falcon 9 + Dragon Spacecraft To High/ISS Orbit
11. Antares + Cygnus Spacecraft To High/ISS Orbit
9A. Falcon Heavy Private Sector Customer 63,800 kg
4. DoD 2017 for a GPS launch
8. NASA ISS

Prices $ to DoD:

6. Delta IV
28,790 kg
Incl. ELC $389.1M

6. Delta IV
28,790 kg
Incl. ELC $389.1M

Prices $ to Private Sector:

9B. Private Sector Customer

Prices $ to DoD:

6. Delta IV
28,790 kg
Incl. ELC $389.1M

6. Delta IV
28,790 kg
Incl. ELC $389.1M

Prices $ to Private Sector:

9B. Private Sector Customer

1. NASA price contracted for one 2017 launch (ICON)
2. NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Cygnus Spacecraft)
3. NASA price contracted in 2010, launched in 2013 (MAVEN)
4. DoD price contracted in 2017 for a GPS launch
5. DoD Price contracted, launched in 2013
6. Price to DoD of the launch service including the amortized EELV Launch Capabilities (ELC) contract, the yearly ELC contract amount divided evenly over the DoD only launches, for NRO
7. NASA Price contracted in 2012, each, with two launches procured together, launched in 2016 + TBD 2017
8A. and 8B. NASA Sci. price (8A) contracted in 2012, launched in 2016 (JASON), and (8B) NASA price contracted for block of launches as a service (ISS cargo, derived price, minus Dragon Spacecraft)
9A. Red = NASA
9B. Blue = DoD
10. Price to NASA; higher orbit, plus includes providing the Dragon spacecraft for carrying / placing the customers cargo (pressurized, unpressurized, return, etc.)
11. Price to NASA; higher orbit, plus includes providing the Cygnus spacecraft for carrying / placing the customers cargo (pressurized, disposal, etc.)
12. 13. and 14. Prices to customers from 2015 launches in the 2016 FAA launch compendium
15. NASA price contracted in 2015 for one 2018 launch. See backup slide.
Global Views
Global Views

$ per Kg (2017$) Existing Capability & Planned

Note: Proton-M and GSLV data points uncertainty high. Minotaur I data point is old, 2013. Pegasus has no announced customers after NASA in 2017. "Planned" data points are from specific company statements, but StratoLaunch, ULA/Vulcan, and Angara A5 data points are derived from less specific company statements. Falcon Heavy Gov't is estimated based on Falcon 9 Gov’t price percentages above private sector price.
Global Views

Launch Prices Existing Capabilities (2017 $)

LAUNCH PRICE $:

$0 $50,000,000 $100,000,000 $150,000,000 $200,000,000 $250,000,000 $300,000,000 $350,000,000 $400,000,000

KG TO LEO PAYLOAD CAPABILITY OF LAUNCHER
200 KM @ 28.5 CIRC.
Global Views

SLS (procurement $ only, no upper stage, + a percent of ground ops $, no flight ops $, IF 2 flights per year)
70,000kg->LEO
$1,094,000,000 per Launch
(Add EUS upper stage costs for more capability to ~105t)

Falcon Heavy
63,800 kg->LEO
$90,000,000 Price to Private Customer
Trying to estimate a launch price, the cost of a launch for NASA or DoD? Ask the following, then see which data point above is most similar.

1. **Who is procuring the launch?**
   - The NASA Launch Services Program?
   - The NASA ISS Transportation Office (Cargo)?
   - The NASA ISS Commercial Crew Office?
   - The DoD / Air Force?
   - The DoD / Air Force for the National Reconnaissance Office (NRO)?
   - A private sector customer?

2. **How is the launch procured?** As a block of launches, or as a single award unrelated to others? As a service (like cargo to the ISS)?

3. **With what other items is the launcher being procured alongside, such as a spacecraft (Cygnus, Dragon)?**

4. **What is being launched?** Is the launch for simpler cargo, repetitive and similar, or more complex, irreplaceable, unique? Or is it for crew?
Spacecraft Costs – Development
(Costs = Price to NASA)

- Spacecraft Non-recurring NASA Development, Procurement Only, $M 2017$

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Cost, $M 2017</th>
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<tr>
<td>CSM-Apollo (crew to Cis-Lunar)</td>
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<tr>
<td>CST-100 (crew to LEO)</td>
<td>$3,271</td>
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<td>Cygnus (cargo to LEO)</td>
<td>$251</td>
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<td>Dragon 1.0 (cargo to LEO)</td>
<td>$307</td>
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<td>$2,201</td>
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<tr>
<td>LM-Apollo (crew to Lunar Surface)</td>
<td>$14,761</td>
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<tr>
<td>Orion (crew to Cis-Lunar)</td>
<td>$19,466</td>
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Alphabetical Order ->

Non-recurring $M

- $26,700
- $3,271
- $251
- $307
- $2,201
- $14,761
- $19,466

Total of Actuals to 2014, +Planned to complete

NASA Only Shown Private $ add $345M

Total of Actuals to 2014, +Planned to complete

NASA Only Shown Private $ add $352M

Amount Shown; Uncertainty Lo $21B, Hi $32B
Spacecraft Costs – Per Unit – $ Thru Delivery Point as Indicated
(Costs = Price to NASA)

- CSM-Apollo (crew to Cis-Lunar)
- CST-100 (crew to LEO)
- Cygnus (cargo to LEO)
- Dragon 1.0 (cargo to LEO)
- Dragon 2.0 (crew to LEO)
- LM-Apollo (crew to Lunar Surface)
- Orion (crew to Cis-Lunar)

Recurring $M

- Production Only. An estimate @1 unit a year. If @2 flights year, $654M/unit. Scenario if Orion less than 1 Flts/year thru 2046 = $1,672M/unit.
- ALL - Element Production and it’s related Ops included (as a service), BUT the launcher and it’s costs are excluded. For CST-100 & Dragon 2.0, estimates / planned.
- Production Only. Average Shown; Uncertainty Lo $300M, Hi $1,100M
- Production Only. Average Shown; Uncertainty Lo $400M, Hi $1,000M
Competitiveness

2015-2017 data from assorted sources

Out of 44 Total Global Major Launches
(w. 4 failures → SS-520, Electron, Long March 3B, Long March 5)
1. The failures in the Delta II line for 8/27/98, 5/5/99 and 8/23/00 were a variant, the Delta III, which was then retired.

2. For the near overlapping Atlas V and Delta IV partial failure points, the first partial failure is a Delta IV launch on 12/21/2004; the second partial failure is an Atlas V on 6/15/2007.

= Partial Failure
= Failure
Backup
As of 12/07/2015 - NanoRacks - “Commercial payloads start at $60,000 per 1U” + volume discounts, to 50kg as advertised @ http://nanoracks.com/resources/faq/
  • 3U $295,000, 6U $545,000, 12U $995,000, 50kg $1,750,000, 100kg $3,950,000, 200kg $5,950,000, 300kg $7,950,000 as advertised @ http://www.spaceflightindustries.com/schedule-pricing/
• SpaceX - secondary payload “PPOD” to LEO $200,000-$325,000 (=67,000-$108,000/kg; from Aug. 2012, 26th Annual AIAA USU, Conference on Small Satellites)
• SpaceX – secondary payload, ESPA-class satellite weighing up to 180 kilograms would cost $4–5 million for LEO; from August 2012, 26th Annual AIAA USU, Conference on Small Satellites (=22,000 to $28,000/kg)

As of 09/14/2015 – Virgin / Launcher One - In development - 400kg to LEO for $10M (=25,000/kg) per http://www.parabolicarc.com/2015/09/14/virgin-galactic-announces-capable-launcherone/

As of 08/10/2015 - Rocket Lab - In development - 100kg to LEO for $4.9M (=49,000/kg) per http://www.geekwire.com/2015/reserve-a-launch-for-your-satellite-online-rocket-lab-can-make-it-so/ albeit to a 310 mile high orbit, implying performance to LEO 200nm is more, so the “

As of 06/05/2015 - Generation Orbit - In development – 40kg to LEO for $2.5M (=62,500/kg) per http://www.satellitetoday.com/launch/2015/06/05/generation-orbit-gains-golauncher2-commitments-plans-golauncher-3/

As of 07/08/2016 – Stratolaunch / Vulcan Aerospace – In development – No public price statements by the company. Some early payload performance statements (6,100kg to LEO) that have since been overtaken by events. https://en.wikipedia.org/wiki/Stratolaunch_Systems
Ariane 6 in the news:

July 2, 2014

Airbus Defends Springing Last-minute Ariane 6 Design on ESA

“PARIS — The head of Airbus’ space division on July 1 said his company was forced to come up with an Ariane 6 rocket design that competed with the version approved by the European and French space agencies because the agency version ultimately would have decimated Europe’s rocket industry.

Testifying before the French Senate Committee on Foreign Affairs, Defense and Armed Forces, Francois Auque said the solid-fuel-dominated Ariane 6 design that the European Space Agency and the French space agency, CNES, approved in July 2013 would have attracted mainly European government customers — a market whose size would mean reducing Europe’s rocket design and production industry by two-thirds.

To avoid being decimated, he said, European rocket builders needed to be sure that the commercial market, which accounts for 90 percent of the launches of Europe’s current heavy-lift Ariane 5 vehicle, would support the new vehicle.”

http://www.spacenews.com/article/launch-report/41117airbus-defends-springing-last-minute-ariane-6-design-on-esa
Delta IV Cost (Price) to NASA:

March 18, 2015

Delta 4-Heavy Selected for Launch of Solar Probe

“As expected, NASA announced its selection of the United Launch Alliance Delta 4-Heavy rocket to dispatch the Solar Probe Plus mission from Earth. Liftoff from Cape Canaveral is set for July 31, 2018, at the opening of a 20-day launch window, NASA said in a press release.

... 

The launch contract’s value is $389.1 million, according to NASA.”

http://spaceflightnow.com/2015/03/18/delta-4-heavy-selected-for-launch-of-solar-probe/
Falcon 9 Cost (Price) to NASA:
November 22, 2016

NASA Selects Launch Services for Global Surface Water Survey Mission

“NASA has selected Space Exploration Technologies (SpaceX) of Hawthorne, California, to provide launch services for the agency’s Surface Water and Ocean Topography (SWOT) mission. Launch is targeted for April 2021 on a SpaceX Falcon 9 rocket from Space Launch Complex 4E at Vandenberg Air Force Base in California.

The total cost for NASA to launch SWOT is approximately $112 million.”