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*
**Updates**

**09/25/2017**

**Launches**
- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Atlas V September 23, 2017 ...NRO
- Global Commercial (slide 23) for launch of Proton September 11, 2017 ...Amazonas
- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Falcon 9 September 7, 2017 ...X-37
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 August 24, 2017 ...Formosat
- US Major Launches (slide 9), & US Launch Tempo (slide 24) for launch of Atlas V August 18, 2017 ...TDRS
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 August 14, 2017 ...CRS-12
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 July 5, 2017 ...Intelsat
- Launch Systems – Multiple Measures (slide 19), “Best” Total kg in a year by any Model, for Falcon 9 ->13 launches to date in 2017
- Global Commercial (slide 23) for launch of Ariane 5 May 4, 2017

**Other**
- Commercial Crew test flight dates (slide 6)

**06/26/2017**

**Launches**
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 June 25, 2017 ...Iridium
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 June 23, 2017 ...Bulgariasat
- Global Commercial (slide 23) for launch of Proton June 7, 2017
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 June 3, 2017 ...CRS-11
- Global Commercial (slide 23) for launch of Ariane 5 June 1, 2017
- Global Commercial (slide 23) for launch of Soyuz (Arianespace/French Guiana) May 18, 2017
- US Major Launches (slide 9), Global Commercial (slide 23) & US Launch Tempo (slide 24) for launch of Falcon 9 May 15, 2017 ...Inmarsat
- Global Commercial (slide 23) for launch of Ariane 5 May 4, 2017

**Other**
- Commercial Crew: Update to dates of 1st flights (slide 9)
- Budget: Updates for 2017 budget deal May 1, 2017 (slide 8), after the 2017 Continuing Resolution
- SLS: Corrected labeling of SLS data point (slide 10); point does include a % of ground systems
- Orion: Updates to Orion data text description (slide 20)
- Commercial crew/cargo: Clarification on crew/cargo data text description (slide 21)
Purpose

• Collects (only) **PUBLIC** space systems cost and related data – flight rate, payload mass, etc.
  • Compile **public** data - contract announcements, budget docs, etc.
  • Separate **non-recurring and recurring**
  • **Minimal data processing;** if adjustments, only for apples to apples
    • Inflation to current year dollars, to same orbit, same mass metric, etc.
  • **Provide context,** compare across systems, graph, visualize
  • Focus on US space systems **competitiveness** (it’s not all just costs)
  • **Keep fresh**
    • Update as new data is published, as launches occur, etc.
    • Focus on **recent data,** indicative of the near future
Purpose

Let's do the math
Caveats & Terminology

• The “price” to a customer is the procurement or contract “cost” to NASA, DoD, NRO, private sector, etc.
  • But total costs would include other internal program/project management costs – in a government agency, personnel and other costs
  • The data ahead are almost all flavors of this (NOT the “costs” inside a company or agency before this or that are added, etc.)
  • Among many other “asterisks”

• Uncertainties - inevitable; data refinement - continuous
  • Minimally processed data BUT-
    • Anecdotal evidence some launch pricing actually runs much higher in the end than publicly announced or advertised (Russia/Proton, etc.)
    • Some public data is processed more – due to different contract phases, multiple partners, not yet complete, age of the data, etc. (SLS, Orion, Commercial Crew, Apollo, etc.)
Source Data

• Source data for this report is available in the Life Cycle Cost (LCC) Model
• Data sheets are available upon request to NASA, government, government contractors or for peer/collaborative purposes
• Contact edgar.zapata-1@nasa.gov
**Source Data**

**Example Data Sheet**

- **Nominal or Inflated**
- **Document public source, pp., doc, etc.**
- **Document and justify adjustments (like “no EUS”)**

---

**Example Table:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Procurement $ ONLY</th>
<th>Sum Procurement</th>
<th>Sum</th>
<th>Nominal Budgets</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>839.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>714.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>1,747.9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>1,387.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>1,640.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Inflation Index:**

- 2006 = Base Year 1,000
- 2007 = 839.2
- 2008 = 1,747.9
- 2009 = 1,387.2
- 2010 = 1,640.0

**Notes:**
- **Actual** costs are documented in the budget data year, plus a year or more after, usually in the NASA budget documents.
- **Nominal** data is the sum of the budget through the data year, usually up to the current year, with the number also being the planned budget of the same documents.
- **Inflation** adjustments include separating out government program/project management, civil servants, etc., using the contract Inflation Indexes, to arrive at nominal costs from the original documents.

**Inflation adjustment to 2017 per NASA:**

- 2006 = 839.2
- 2007 = 714.5
- 2008 = 1,747.9
- 2009 = 1,387.2
- 2010 = 1,640.0

**NON-RECURRING COSTS**

- Sources: re. Notes Below

---

**Example Diagram:**

- **Legend:**
  - Document public source, pp., doc, etc.
  - Nominal or Inflated
  - Source Data
  - Document and justify adjustments (like “no EUS”)

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**Textual Excerpts:**

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**NON-RECURRING COSTS**

- Sources: re. Notes Below
The NASA Budget – Purchase Power Drop Since 2003 = 9%
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

1st Falcon Heavy Flight Demo TBD 2017

19 US Major Launches in 2017

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

SpaceX
13 Falcon 9 (8 commercial, 3 ISS cargo, 0 NASA, 2 DoD)
Landing Success / Attempts
% Sea / %Land / %Average
62% / 100% / 76%

Orbital ATK
0 Antares

+1 Minotaur (small, DoD)

NASA Mission Launches
(Fiscal Years 2014 – 2020)

US Commercial Crew dates
https://www.nasaspaceflight.com/2017/08/spacex-home-stretch-commercial-crew-readiness/

1st SLS Flight Demo 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/
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.

See Notes below
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 US Launch Price Data 2017$

$ Price per kg vs. Payload Capability

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 + Some In Development

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

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 LSP/Sci. and 8B. NASA ISS
9. Prices for private sector customers
9A. and 9B. Prices for private sector customers
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. Per ULA -> www.RocketBuilder.com

E. Zapata NASA 04/14/2017

Maximum Payload (kg) to Low Earth Orbit (200km, 28.5 circ.) - except as noted
Global Views

$ per Kg (2017$) Existing Capability

SPECIFIC COSTS $ PER KG
= $ PRICE / KG

$100,000

$10,000

$1,000

$100

100,000

10,000

1,000

100

1

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

$ per Kg (2017$) Existing Capability & Planned

SPECIFIC COSTS $ PER KG

$100,000

$10,000

$1,000

$100

1 10 100 1,000 10,000 100,000

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

Note: Proton-M and GSLV data point 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
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 (Cyggnus, 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)

<table>
<thead>
<tr>
<th>Spacecraft</th>
<th>Non-recurring NASA Development, Procurement Only, $M 2017$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSM-Apollo (crew to Cis-Lunar)</td>
<td>$26,700</td>
</tr>
<tr>
<td>CST-100 (crew to LEO)</td>
<td>$3,271</td>
</tr>
<tr>
<td>Cygnus (cargo to LEO)</td>
<td>$251</td>
</tr>
<tr>
<td>Dragon 1.0 (cargo to LEO)</td>
<td>$307</td>
</tr>
<tr>
<td>Dragon 2.0 (crew to LEO)</td>
<td>$2,201</td>
</tr>
<tr>
<td>LM-Apollo (crew to Lunar Surface)</td>
<td>$14,761</td>
</tr>
<tr>
<td>Orion (crew to Cis-Lunar)</td>
<td>$19,466</td>
</tr>
</tbody>
</table>

Average Shown; Uncertainty Lo $21B, Hi $32B

Total of Actuals to 2014, +Planned to complete

NASA Only Shown Private $ add $345M

NASA Only Shown Private $ add $352M

Total of Actuals to 2014, +Planned to complete

Average Shown; Uncertainty Lo $12B, Hi $17B

Total of Actuals to 2017, +Planned 2018-2021, +Estimates 2022-2023 to complete

Crew Commercial
Cargo Commercial
Cargo Commercial
Crew Commercial
Crew Cost+
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)

**Spacecraft Recurring Price to NASA per Unit, Procurement Only, $M 2017$**

**Alphabetical Order ->**

- **CSM-Apollo (crew to Cis-Lunar)**: $716
- **CST-100 (crew to LEO)**: $418
- **Cygnus (cargo to LEO)**: $174
- **Dragon 1.0 (cargo to LEO)**: $98
- **Dragon 2.0 (crew to LEO)**: $308
- **LM-Apollo (crew to Lunar Surface)**: $732
- **Orion (crew to Cis-Lunar)**: $980

**CCP: See caveat ahead**

- **Production Only.**
- **Average Shown:**
- **Uncertainty Lo $300M, Hi $1,100M**

- **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 $400M, Hi $1,000M**

**Manuf. $ Only**
- **Crew Commercial**
- **Cargo Commercial**
- **Cargo Commercial**
- **Crew Commercial**

**Manuf. $ Only**
- **Crew Commercial**
- **Cargo Commercial**
- **Cargo Commercial**
- **Crew Commercial**

**Manuf. $ Only**
- **Crew Commercial**
- **Cargo Commercial**
- **Cargo Commercial**
- **Crew Commercial**

**Cost+**
- **Crew Commercial**
- **Cargo Commercial**
- **Cargo Commercial**
- **Crew Commercial**

**Manuf. $ Only**
- **Crew Commercial**
- **Cargo Commercial**
- **Cargo Commercial**
- **Crew Commercial**

**Manuf. $ Only**
- **Crew Commercial**
- **Cargo Commercial**
- **Cargo Commercial**
- **Crew Commercial**

**CCP: See caveat ahead**

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.
Uncertainties, Programs Still in Development

• Future budgets in public documents are often “notional”
  • They may go UP or DOWN

• Example
  • Prior Commercial Crew Recurring Price (by 2020) is based heavily (with adjustments) on FY 16 notional public budget
  • The FY 18 notional public budgets are much LOWER by 2020 (operational)
    • [https://www.nasa.gov/sites/default/files/atoms/files/fy_2018_budget_estimates.pdf](https://www.nasa.gov/sites/default/files/atoms/files/fy_2018_budget_estimates.pdf)

• Other programs show INCREASES in 2018 notional public budget out to 2020 (development) vs. prior years

Cost data updates are a continuous process especially until programs complete development and regular operations begin
Competitiveness

2015 - 2017 data from assorted sources

Total Commercial 2017 = 21
Out of 57 Total Global Major Launches
(w. 5 failures --> SS-520, Electron, Long March 3B, Long March 5, PSLV)
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 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.

R² = 0.993

R² = 0.999

US Launch Systems Growth

- Delta II
- Atlas I+II+III
- Atlas V
- Delta IV
- Falcon 9
- Antares
Closing

• Space is hard
• Adding up space system costs, budgets, flights, payload capabilities, etc. – not hard, just tedious
  • Define competitiveness, compare systems, understand cost vs. productivity
  • Establish facts on the ground

• Value: situational awareness
  • Where are we?
  • Where might we go?

Questions?
Backup
Data Sources, Small Payload Launch Options, Small Launch in Development, Other (see slides 6-7)

- 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.”