Emerging US Space Launch Trends and Space Solar Power

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Purpose

• Provide an overview of emerging US space launch and space systems trends that are critical to the future of new space business cases – like space solar power

• But first...some background, some visions, and some needs.
Background – The (Slightly) Bigger Picture

- The Entire NASA Budget since 2003 – and Purchasing Power

Actual NASA budget increases = 1.535% per year average (compound) since 2003

Shuttle

2003 Columbia

2005 Budget Shifts Begin...

2005

2006

2007

2008

2009

2010

2011

2012

2013

2014

2015

2016

2017

2018

2019

2020

2021

2022

2023

2024

2025

2026

2027

2028

2029

2030

2031

2032

2033

2034

2035

2036

2037

2038

2015 Human Exploration & Operations Budget = $8,185M

NASA Scenario Model

2015

You are Here!

100%? 50%? None?

For?

Decision: End Shuttle post-ISS

Last Shuttle Flight

Shift to Separate Cross-Agency Support

Science Launchers

Shuttle Production & Ops

Orion & SLS >
Background – The HEO Picture

- The Human Exploration & Operations (only) part of the NASA Budget

Life Cycle Cost Bars = All Procurement (Industry) and Government Costs as Modeled in Real Year $M

2015 Human Exploration & Operations Budget = $8,185M

2015 Human Exploration & Operations Budget = $8,185M

100%? 50%? None?
For?

2015
You are Here!
Visions of Mars

- ISS, SLS, Orion
- Then Deep Space Habitat
- Then Transit Habitat (& Propulsion/Power)
- Then – not shown:
  - In-Space Stage(s), Assorted
  - Mars Landers
    - Descent
    - Ascent/Return
  - Cargo/Crew
  - Mars (Surface) Habitats
  - Taxis
  - Rovers
  - Power Plants
  - In-situ Resource Plants
  - Equipment

Visions of Mars – or not?

• National Research Council 2014

“Human Spaceflight Budget Projections. With current flat or even inflation-adjusted budget projections for human spaceflight, there are no viable pathways to Mars.

Potential Cost Reductions. The decadal timescales reflected above are based on traditional NASA acquisition. Acceleration might be possible with substantial cost reductions resulting from

a. More extensive use of broadly applicable commercial products and practices

b. Robust international cost sharing (that is, cost sharing that greatly exceeds the level of cost sharing with the ISS)

c. Unforeseen significant technological advances in the high-priority capabilities.”
Visions of Mars – or maybe?

• Jet Propulsion Laboratory 2015 – Price, Baker, Naderi

“This was the motivation for this study of a “minimal architecture” based on a high technology readiness level and the concept of staggered mission campaigns, in order to stay close to the current HSF annual budget adjusted for inflation.

This work was aimed at showing an example (an existence proof) that journeys to Mars could be doable using technologies that NASA is currently pursuing and on a time horizon of interest to stakeholders -- without large spikes in NASA budget.”

http://spirit.as.utexas.edu/%7Efiso/telecon/Price_5-20-15/Price_5-20-15.pdf
Visions of Mars – the Scope of the Challenge

- SLS with Larger Upper Stage (~100+t>LEO)
- 2 SLS/Year, 1 w. Orion as Payload. Other Payload TBD (No $ available)

![Graph showing life cycle cost bars for NASA Scenario Model with various cost categories and years from 2015 to 2038. The graph indicates the total human exploration and operations budget of $8,185M for 2015.](image-url)

- Upper Stage “challenge” No $ - Exceeds Usual Budget Growth
- Replace SRB/SRM, “Advanced Booster” by 2030 for SLS ~130t>LEO No $ - at Current Budget Growth/Inflation
Visions of Mars – the Scope of the Challenge

- Or alternate futures? Other stakeholders.
Needs

• Option 1: Getting More **Money**?

> “Meaningful human exploration is possible under a less-constrained budget, ramping up to approximately $3 billion per year in real purchasing power above the FY 2010 guidance in total resources.”

  - Seeking a Human Spaceflight Program Worthy of a Great Nation, by The Review of US Human Spaceflight Plans Committee

• Also NRC 2014, et al

• Option 2: Getting More **Time**? (& **Money**, & **Doing Less**)

  • JPL 2015 et al
  • Mars landing by 2039
  • Assumption of infinite patience – if neglecting certain stakeholders

There’s a reason stakeholders are called “stake” holders
Needs

• Option 3: Adapting? – like Smith Corona?
  • For a time, saw threat as typewriters manufactured abroad
    • Response: Plants moved abroad
  • For a time, created “personal word processors” – advanced for their time
    • Why use someone else’s software?
    • Why use someone else’s electronics?
    • Why use someone else’s floppies?
    • Numerous advantages over those “PCs”
  • Bankruptcy 1995

Adapting - right to the end
Visions of Launch Affordability

...Once upon a time...the Reusable Launch Vehicle program, NASA, late 1990’s

$1000/lb = $2,222/kg
Affordability – How are we doing?

- What do the numbers tell us?
Emerging Space

Spacecraft Cost Data - Development

(Cost as Price to NASA)

- Holistic view, recent/old, cargo/crew, commercial/cost-plus

![Diagram showing spacecraft cost data](image_url)

- **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)
- **LEM-Apollo** (crew/to Lunar Surface)
- **Orion** (crew/to Cis-Lunar)

**NASA Non-recurring Investment / Development, Procurement $ Only, $M FY 2015**

- **Average Shown; Uncertainty Lo $20B, Hi $31B**
- **Total of Actuals to 2014, Planned to complete**
- **NASA Only Shown Private $ add $148M**
- **NASA Only Shown Private $ add $124M**
- **Total of Actuals to 2014, Planned to complete**
- **Average Shown; Uncertainty Lo $12B, Hi $16B**
- **Total of Actuals to 2014, Planned 2015-2020, Estimates 2021-2022 to complete**
Emerging Space
Spacecraft Cost Data – Manufacturing - “Thru Delivery”
(Cost as Price to NASA)

- Holistic view, recent/old, cargo/crew, commercial/cost-plus

**Spacecraft Recurring Price to NASA per Unit, Procurement $ Only, $M FY 2015**

<table>
<thead>
<tr>
<th>Make</th>
<th>Only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Shown;</td>
<td></td>
</tr>
<tr>
<td>Uncertainty</td>
<td></td>
</tr>
<tr>
<td>Lo $300M, Hi $1,000M</td>
<td></td>
</tr>
</tbody>
</table>

Make Only.
Average Shown; Uncertainty Lo $300M, Hi $1,000M

Make Only. An estimate @1 unit/year. If @2 flights year, $566M/unit. Scenario if Orion less than 1 fits/year = $1,560M/unit.

Manuf. $ Only

Manuf. and Ops/Launch $
Emerging Space Competitiveness

2015 = 19 Commercial Launches out of 68 Total Global Major Launches

- The US is regaining commercial launch market share
- Customers appear glad to return – for the right price

2015 data from assorted launch records
### Emerging Space

#### US Launch Prices (Costs to the Customers)

<table>
<thead>
<tr>
<th>Price per kg</th>
<th>Cost per kg Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>$4,600/kg</td>
<td>$4,600/kg</td>
</tr>
<tr>
<td>$2,000/kg?</td>
<td>$2,000/kg</td>
</tr>
</tbody>
</table>

**Notes:**
- **Cost of Entry = Price of the Specific Launcher for that Customer / Application in $ Millions**
- **Maximum Payload Capability of Launcher, kg to LEO, 200km/28.5 circ. (regardless of actual kg used by customer)**
- **$ per kg**
- **Best Recent Yearly "System" (All Atlas's, All Delta's, All Falcon 9's, etc.) Capability Demonstrated, Total kg to LEO in a Year**

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**Recent Cost Data 2012-2017**

In Order of Cost of Entry >

- **E. Zapata NASA**
  - 10/14/2015

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**Emerging Space**

**Cost of Entry**

<table>
<thead>
<tr>
<th>Launcher</th>
<th>Minimum Cost of Entry $ M</th>
<th>Cost of Entry per $ per kg Basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minotaur I, DoD/ORD</td>
<td>$58,000</td>
<td>$48,276</td>
</tr>
<tr>
<td>Pegasus XL, NASA LSP, Sci, Class-D</td>
<td>$55,000</td>
<td>$44,300</td>
</tr>
<tr>
<td>Falcon 9, Commercial</td>
<td>$46,000</td>
<td>$38,400</td>
</tr>
<tr>
<td>Falcon 9, NASA LSP, Cargo, Black-buy, Bundle</td>
<td>$4,600</td>
<td>$580</td>
</tr>
<tr>
<td>Falcon 9, NASA LSP, Sci, Class-C</td>
<td>$4,600</td>
<td>$580</td>
</tr>
<tr>
<td>Falcon Heavy, Commercial</td>
<td>$4,600</td>
<td>$580</td>
</tr>
<tr>
<td>Falcon 9, DoD (w. NASA &amp; NOAA)</td>
<td>$4,600</td>
<td>$580</td>
</tr>
<tr>
<td>Antares, NASA LSP, Delta IV Heavy, NRO Service ONLY, No ELC</td>
<td>$109,000</td>
<td>$28,740</td>
</tr>
<tr>
<td>Atlas V 401, NASA LSP, Sci, Class A/B</td>
<td>$109,000</td>
<td>$28,740</td>
</tr>
<tr>
<td>Atlas V 541, NASA LSP, Sci, Class A/B</td>
<td>$109,000</td>
<td>$28,740</td>
</tr>
<tr>
<td>ULA (Atlas/Delta Avg, All Customers)</td>
<td>$128,790</td>
<td>$38,710</td>
</tr>
<tr>
<td>ULA (Atlas/Delta Avg, DoD Only, Service + ELC)</td>
<td>$128,790</td>
<td>$38,710</td>
</tr>
<tr>
<td>Delta IV Heavy (Service only)</td>
<td>$109,000</td>
<td>$28,740</td>
</tr>
<tr>
<td>NRO Space Shuttle [ref. crew excluded from calculation; see notes]</td>
<td>$775,000</td>
<td>$123,750</td>
</tr>
<tr>
<td>Atlas best total kg/year 2014 (6 flights)</td>
<td>$195,200</td>
<td>$50,000</td>
</tr>
<tr>
<td>Delta best total kg/year 2014 (9 flights)</td>
<td>$24,370</td>
<td>$50,000</td>
</tr>
<tr>
<td>Delta best total kg/year 2012 (4 flights)</td>
<td>$24,370</td>
<td>$50,000</td>
</tr>
<tr>
<td>SLS (+grd ops, no upper stage, no Orion, 2 flts/year)</td>
<td>$24,370</td>
<td>$50,000</td>
</tr>
<tr>
<td>SLS (+grd ops, no upper stage, no Orion, 1 flt/year)</td>
<td>$24,370</td>
<td>$50,000</td>
</tr>
</tbody>
</table>

**Best Recent Yearly "System" Capability Demonstrated, Total kg to LEO in a Year**

- **Minotaur I, DoD/ORD**
  - Not yet operational (2016)
- **Pegasus XL, NASA LSP, Sci, Class-D**
  - Not yet operational (2018)
- **Falcon 9, Commercial**
  - Not yet operational (2016)
- **Falcon 9, NASA LSP, Cargo, Black-buy, Bundle**
  - Not yet operational (2018)
- **Falcon Heavy, Commercial**
  - Not yet operational (2016)
- **Falcon 9, DoD (w. NASA & NOAA)**
  - Not yet operational (2016)
- **Antares, NASA LSP, Delta IV Heavy, NRO Service ONLY, No ELC**
  - Not yet operational (2018)
- **Atlas V 401, NASA LSP, Sci, Class A/B**
  - Not yet operational (2018)
- **ULA (Atlas/Delta Avg, All Customers)**
  - Not yet operational (2018)
- **ULA (Atlas/Delta Avg, DoD Only, Service + ELC)**
  - Not yet operational (2018)
- **Delta IV Heavy (Service only)**
  - Not yet operational (2018)
- **NRO Space Shuttle [ref. crew excluded from calculation; see notes]**
  - Not yet operational (2018)
- **Atlas best total kg/year 2014 (6 flights)**
  - Not yet operational (2018)
- **Delta best total kg/year 2014 (9 flights)**
  - Not yet operational (2018)
- **Delta best total kg/year 2012 (4 flights)**
  - Not yet operational (2018)
- **SLS (+grd ops, no upper stage, no Orion, 2 flts/year)**
  - Not yet operational (2018)
- **SLS (+grd ops, no upper stage, no Orion, 1 flt/year)**
  - Not yet operational (2018)

**But if NASA - Not $184M Rather $389.1M**
This is Not New – and it’s not limited to launch systems

- SpaceHab was 1/10th the cost as commercial (as defined then) versus business-as-usual
  - One of a handful of historical data points with a Business-as-Usual ~ analog (SpaceLab)
  - Dependent on Shuttle; very much an ECLSS system extension shielded within the Orbiter payload bay

SpaceHab double-research module, STS-107 Columbia, NASA
In the Pipe

- Reusability – Falcon 1st Stage(s)?
- ULA Vulcan launcher – price drops?
- Constellations of Sat’s – Round 2? OneWeb, Google/SpaceX, etc.
- Small Launch – business plans around the business plans of ever more Small Sat capabilities
Visions of Space Solar Power

“Integrated Symmetrical Concentrator” (ISC) Solar Power Satellite, late 1990s, NASA

http://science.ksc.nasa.gov/shuttle/nexgen/Nexgen_Images/solar_power_satellite_concept.jpg (Public Domain)


By permission, John C. Mankins
Relevance to Space Solar Power

*Are the barriers to Mars and Space Solar Power the same?*

- Both need more affordable space transportation
- Both need more affordable space systems
- Will both always be 20 years away?
Relevance to Space Solar Power – A New Option

1. Get Money
2. Get Time
3. Adapt
4. NASA as Investor – transforming to become “one of many customers”

NASA, [http://www.nasa.gov/offices/oct/partnership/comm_space/](http://www.nasa.gov/offices/oct/partnership/comm_space/)
Relevance to Space Solar Power – A New Option – Make, Buy, Partner

Major characteristics of a NASA COTS/CRS “like” partnership include:

- Significantly improved alignment of incentives – both short and long term - partnering decision considers potential non-government market/business cases (seen more in SpaceX getting commercial launches, but OSC not; not seen in either side yet for their spacecraft)
  - Private sector market pressures akin/aligned with the gov’t “ops” long term POV
  - Other potential future work; e.g., cargo business can lead to crew business
- Investor mindset, government as “investor” (beyond “engineering management” or “contractor management” or “smart buyer”)
- Early commitment to buy future services in block contracts; addresses/reduces long term business case (investment) risk
- OTA/SAA with fixed payments for achieving development milestones (not cost plus); more risk to the private sector partner, less risk to the government
- Small gov’t office for acquisition & management (e.g., ~3% of total program cost)
- Maturation/risk buy down with numerous early partners; delay down-selecting prematurely
- Two providers selected, not just one (competition built in throughout, even in the operational phases)
- “Bundling” the acquisition; e.g., service requires a vehicle and a spacecraft

COTS/CRS - another existence proof of the potential for NASA to FIRST invest, to FIRST enable a healthier market, THEN to procure - at much less cost.

Example-$4.0B to $1.7B Falcon 9 investment predicted if traditional ways of doing business vs. ~$300M* actual

Relevance to Space Solar Power

- **NASA as Investor / Partner**
  - Smaller amounts of $ to justify
  - NASA (and partner contributions) $ leveraged into large effects
    - Business case maturation
    - Strategic technology maturation / demonstration
      - Modularity
      - Assembly
      - Transmission
  - Encourage non-government investors
    - “NASA on board” (credibility of NASA)
    - “Virtuous cycle” – more investors ease the case for more NASA partnering (credibility of the business)

“As was mentioned previously, a number of technology and systems level demonstrations can be accomplished without new space transportation”

- *The Case for Space Solar Power, J. Mankins*
Closing

- Space sector supply AND demand can, will and must grow together
- Large scale programs – like Space Solar Power – face similar challenges

  Money
  Time
  Adapt
  Transform

- An increased emphasis on public-private partnerships offers the most viable path forward

...when you have eliminated the impossible, whatever remains, however improbable, must be the truth? -Sherlock Holmes in The Sign of the Four

You can always count on Americans to do the right thing - after they've tried everything else. –Winston Churchill
Backup
# Comparison of NASA Space Exploration Architecture Level Assessments

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<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>2014 NRC Committee on Human Spaceflight</td>
<td>..increases faster than *inflation (pp.41)</td>
<td>†Unaddressed</td>
<td>Yes – Phobos early 2040s, Mars surface 2050s</td>
<td>Yes</td>
<td>Ends 2028</td>
<td>~No?</td>
<td>Unaddressed</td>
</tr>
<tr>
<td>2015 JPL H2M Minimal Architecture</td>
<td>...increases at rate of *inflation</td>
<td>†Unaddressed</td>
<td>Yes – surface by 2039</td>
<td>Yes</td>
<td>Ends 2028</td>
<td>~No?</td>
<td>Unaddressed</td>
</tr>
<tr>
<td>2015 Planetary Society Humans Orbiting Mars</td>
<td>Segues off of JPL H2M Minimal Architecture</td>
<td>All NASA areas increase at same rate as HEO</td>
<td>Lunar 1st, Mars as follow-up study</td>
<td>**No</td>
<td>n/a-&gt;</td>
<td>Possible - Budget set aside –ample fund split possible</td>
<td>n/a</td>
</tr>
<tr>
<td>Evolvable Lunar Architecture w. PPP</td>
<td>...increase at historical budget growth...</td>
<td>All NASA areas increase at same rate as HEO</td>
<td>**No</td>
<td>n/a-&gt;</td>
<td>Possible - Budget set aside –ample fund split possible</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Evolvable Mars Campaign</td>
<td>TBD</td>
<td>All NASA areas increase at same rate as HEO</td>
<td>Lunar 1st, Mars as follow-up study</td>
<td>**No</td>
<td>n/a-&gt;</td>
<td>Possible - Budget set aside –ample fund split possible</td>
<td>n/a</td>
</tr>
</tbody>
</table>

* aerospace, space systems specific inflation per se ill-defined
** moves funds from X to Y
† if flat, this shifts the whole NASA portfolio split

What about the 1991 Space Exploration Initiative (SEI)? Budget growth by *multiples of then current*. Rest ~ n/a.