The Opportunity in Commercial Approaches for Future NASA Deep Space Exploration Elements

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The American Institute of Aeronautics & Astronautics Space 2017 Forum

Session: Reinventing Space II

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Context

1. Commercial & Cost Data
   Tomorrow – Sept. 13, Space Cost and Economics, 10am-12:30pm

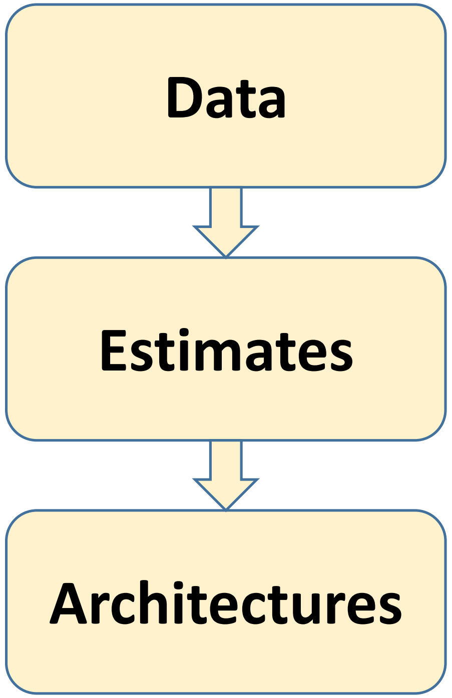
   "An Assessment of Cost Improvements in the NASA COTS/CRS Program and Implications for Future NASA Missions"

2. Estimating Costs for New Elements from Data
   Here – Sept. 12, Reinventing Space II, 3:30-6:30pm

   "The Opportunity in Commercial Approaches for Future NASA Deep Space Exploration Elements"

3. Exploration Scenarios
   Later – Sept. 12, Space Exploration, 7:30-9pm

   "NASA Human Spaceflight Scenarios Do All Our Models Still Say 'No'?"



Purpose

- Explore the potential for commercial partnerships, modeled on recent programs, to reduce the cost to NASA for "…other required deep space exploration capabilities…"

Background

- Increased affordability and other improvements in partnerships for cargo and crew to ISS
  - Tomorrow – Sept. 13, Space Cost and Economics, 10am-12:30pm
  - Location: Celebration 2

  "An Assessment of Cost Improvements in the NASA COTS/CRS Program and Implications for Future NASA Missions"

- 2016 NASA request for information stated it must "maximize the efficiency and sustainability of the Exploration Systems development programs", as "critical to free resources for re-investment…such as ***other required deep space exploration capabilities***."

Background

- Cancellation of Constellation program can be seen simply, as not **adding** a lunar lander to NASA's budget, potentially **another** billion+ dollars a year

- Multiple deep space exploration elements are like multiple's of the kind of programs NASA has usually been approved for – **one or two at a time**

…when exploration approaches depend on adding ever more layers of cost to NASA's budget, even adding money just delays re-entering the same trap…

…then "*you are right back where you started, the budget crashes, you can't afford to build the new thing without cancelling the old thing*."

Jeff Greason, "A Settlement Strategy for NASA, NSS Keynote Address," 2011

Background

- There are a **dozen+ items** like landers in deep space exploration
  - Probes
  - Communications
  - Stages
  - Landers
  - Habitation in-space
  - Habitation at the surface destination
  - And much more…spacesuits, rovers, other unique spacecraft, ISRU, surface power, depots, refillable stages, tankers, etc.

Background

We know we must reduce the costs of deep space systems significantly or no NASA space exploration plans ever add up (budget / costs, time, and other "-ilities")

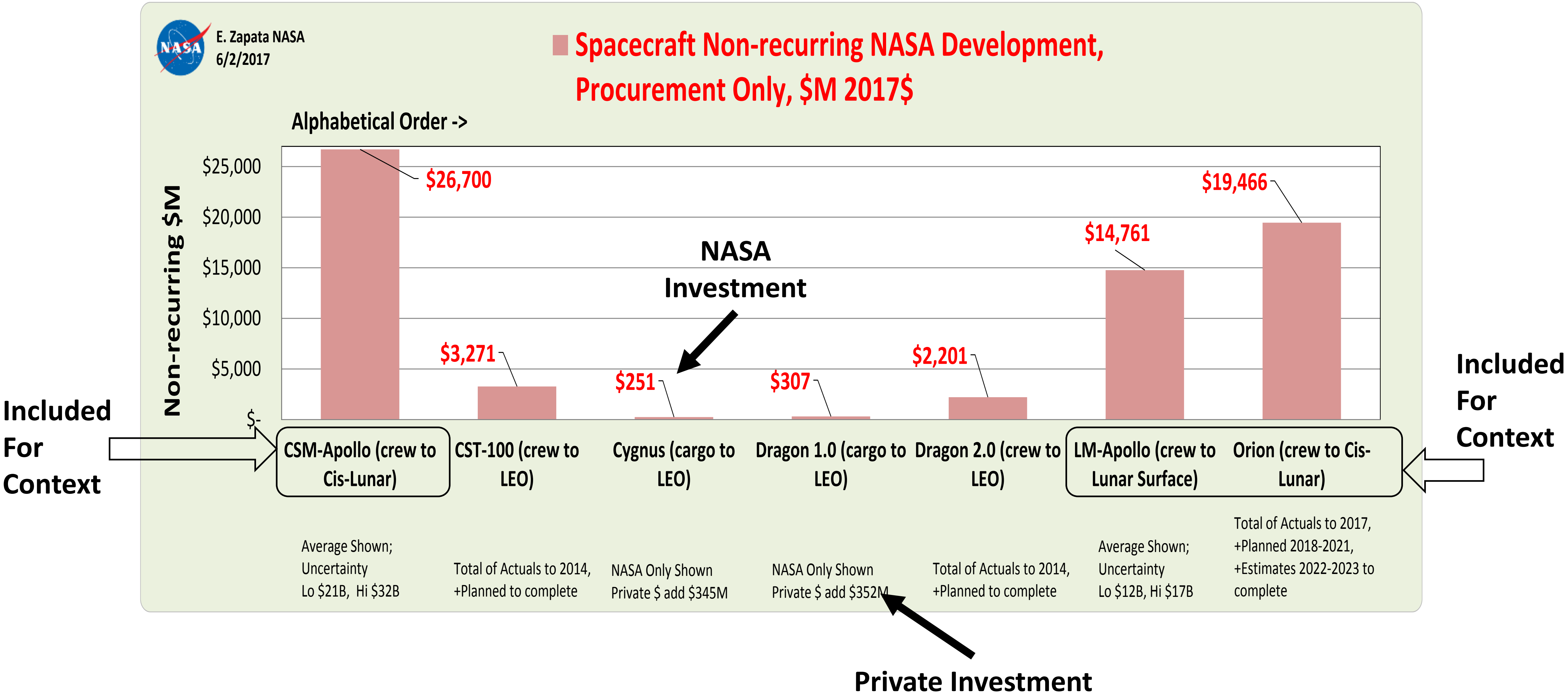
- Tonight – Sept. 12, Space Exploration, 7:30-9pm
- Location: Exposition Hall

"NASA Human Spaceflight Scenarios, Do All Our Models Still Say 'No'?"

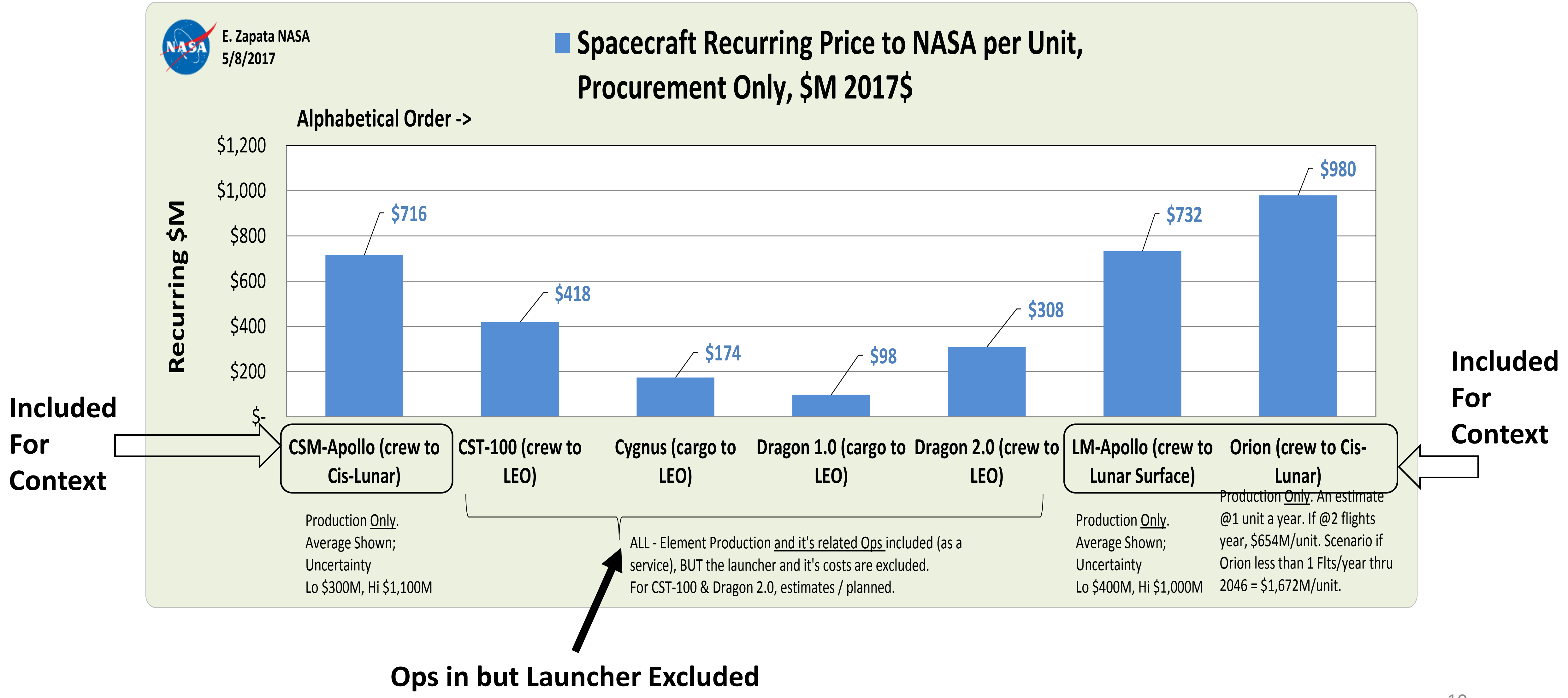
Commercial – Beyond…

- Beyond LEO
  - Schier, J., “Concept for a Lunar Power and Communications Utility,” 2015
  - Zuniga, A., Turner, M., Rasky, D., Pittmann, R., Zapata, E., “Kickstarting a New Era of Lunar Industrialization via Campaigns of Lunar COTS Missions,” , 2016
- Beyond NASA
  - Non-NASA customers preferable, but not a litmus test
  - Many aspects to what’s “commercial” to NASA – NASA “investor” mindset, “cost risk” posture, risk buy-down process, # of partners, “services”, more…
- Beyond Biases
  - Quantify before making decisions
  - Can’t afford not to consider all options!

Cost Data – Non-Recurring Costs (Excludes Launcher)



Cost Data – Recurring Costs (Excludes Launcher)

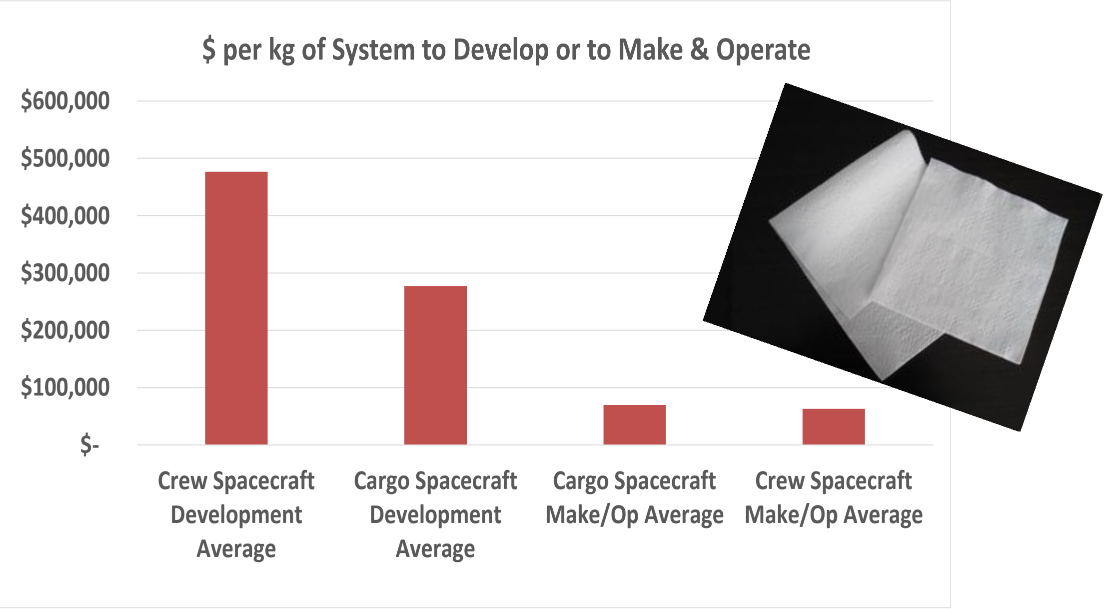


What's Our Back of our Napkin Look Like?

- ? Umm…say a deep space spacecraft could be about 10,000 kg dry mass
  - ~$5B to develop
  - ~$700M per unit, to make/op

- ?Umm…say a small Apollo scale lunar lander is just over 4,000 kg dry mass
  - ~$2B to develop
  - ~$300M per unit, to make/op…

(Here's where Spock says "Fascinating")



Of course, we know this is all wrong! But it hints at something that might be on target.

What's Our Back of our Napkin Look Like?

- Deep space spacecraft are much more complex right?

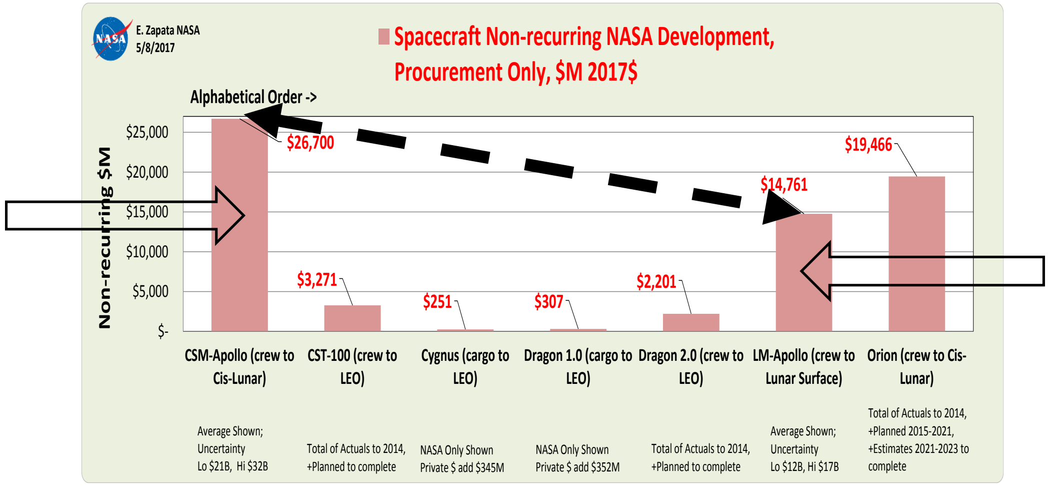
- Landers are much more complex right?

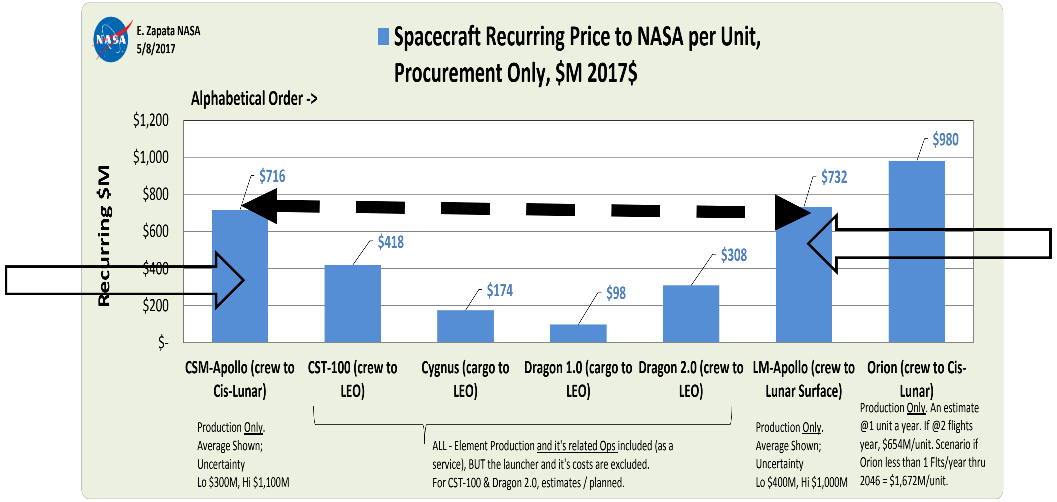
…maybe not.

Method – Forget Commercial Data a Moment – Look to Apollo

- Assumption: If complexity tells us about costs, then costs tells us about complexity

Apollo cost data indirectly tells us the Apollo lander was LESS complex or ABOUT AS as complex as it's sister spacecraft





Method

- **Scale** relationships bounded by dry mass
- **Complexity** relationships bounded by actual Apollo experience

+ many dusty and dry equations

Gather Historical Data

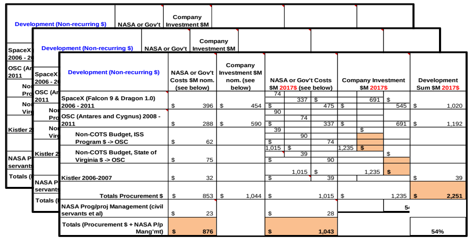
Review, Parse, Organize

- item type, scale, type of cost, acquisition approach, acquisition process costs, etc.
- multiple sources
  - consistency?
  - credibility?
  - completeness?
- inflation adjustment

Historical Item $

Up-front vs. Operational $

Procurement vs. Government $



- data sheets
  - sources
  - traceable
  - transparent

Cost Estimating Relationships

Analogs
Ratios
Scaling
Uncertainties & Bounds
(CER 1 vs. CER 2)

- landers
- in-space stages
- more…

Extrapolate

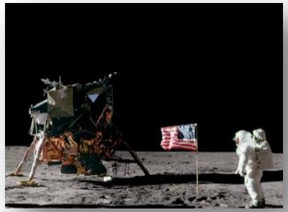
New Item $

"Cost Baseball Cards"

- sanity check
  - estimate a known quantity, compare
- sanity check
  - stepping back
- strengths and weaknesses
- rack and stack

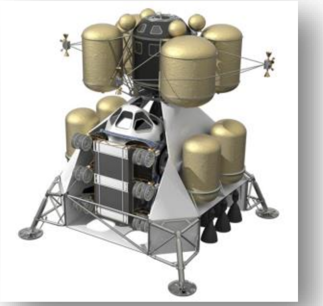
Introduction to a "Costed" Baseball Card – Landers Example

Lunar & Mars Landers - Development



Lunar Apollo LM

Lunar Constellation Altair



Mars Lander Concept

Lander Scale & Acquisition Approach	Apollo Scale Lunar Lander $B Development	Altair Lunar Lander (does not do LOI) $B Development	Altair Lunar Lander (does LOI) $B Development	Mars Lander (ver. 40t Payload, incl. MAV) $B Development
No Prop. Mass (kg)	4,214	8,392	12,829	19,881
Mass at Liftoff (kg)	15,065	30,000	45,864	W. MAV LOX 71,076
Commercial / PPP - Low	LO $2.4	$3.4	$4.3	$6
Commercial / PPP - High	$4.3	$6.0	$7.7	$10
Cost-Plus, Sole Source	$15.1	$20.8	HI $26.9	$36

NASA LCC Model 5/8/2017

Description of Basis of Estimate:

Cost estimating relationships combine older (Apollo) and recent (Commercial Crew, Orion) historical data according to the acquisition approach indicated (cost-plus or commercial, public private partnership / PPP).

If the acquisition approach is a commercial, public private partnership, the lander cost estimate departs from the experience with either the CST-100 or the Dragon crew spacecraft.

If the acquisition approach is cost-plus, sole-source, the lander cost estimate departs from the experience with the Orion crew spacecraft.

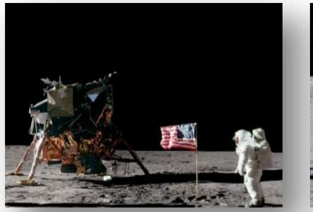
Notes:

1. These are procurement dollars ONLY, in **2017 $.** Estimates do NOT include government program & project management.
2. All estimates are for 1 provider. Generally, for partnerships with multiple partners use 2X the average of lo/hi plus process costs (other early partner investments).
3. Development includes flight test.
4. **Ground Ops & Launch, Flight Ops**: IF a commercial / PPP basis, ground ops & launch and flight ops development are within the development estimate, and ground ops & launch are within the per unit estimate. IF cost-plus / sole-source, ground ops & launch and flight ops are NOT included in any estimates.
5. **Mission Ops**: For all estimates, additional costs must be estimated for especially unique in-space operations (rendezvous, mate, transfer of propellant, etc. as apply.)

2

Introduction to a “Costed” Baseball Card – Landers Example

Lunar & Mars Landers - Manufacture



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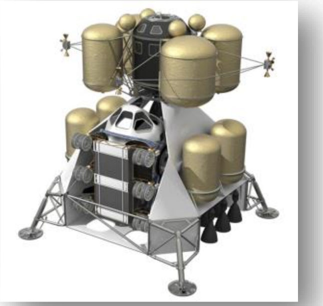

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Mass at Liftoff (kg)	15,065	30,000	45,864	W. MAV LOX 71,076
Commercial / PPP - Low	LO $0.6	$0.8	$1.0	$1.4
Commercial / PPP - High	$0.9	$1.3	$1.7	$2.3
Cost-Plus, Sole Source	$1.3	$1.8	HI $2.3	$3.1

NASA LCC Model 5/8/2017

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3

Sanity Checking

- Reference checks of cost-plus Altair scale lunar lander development \$8-12B vs. \$21-27B
  - LOW – but we know these references severely underestimated other related elements
  - Accounting issues (NAFCOM-ish estimates often place significant element life cycle costs in other budget lines like program integration, etc.)

- JPL Mars lander estimate in the \$44B range (cost-plus? lander \$ thru 1st long stay)
  - Roughly consistent with the \$36B (cost-plus) here
  - What's-in / what's out issues, etc.

- Commercial / Cost-plus relationships the same; what varies are the points of departure

- Lander Costed Baseball Cards
  ☑ Sane (so far) ☐ Insane

Pros, Cons, Uncertainty

- Pros
  - “Quantifying” and “**justifying**” factors applied to historical costs
  - Extensive notes / justifications with all adjustments, calculations, deviations from historical data
  - “Justifying” factors – see “Independent Cost Assessment of the Commercial Crew Program”, Booz-Allen Hamilton
- Cons
  - Identified where estimates likely low/high and why
- Uncertainty
  - Esp. complexity – the leap from what we know to what we want

Data sheets available for collaboration upon request

Summary & Forward Work

- ☑ Relationships
  - ☑ Scaling
  - ☑ Complexity
  - ☑ Commercial, cost-plus
- ☑ Landers
  - ☑ Lunar
  - ☑ Mars
- ☑ Propulsive & Propellant Elements
  - ☑ Stages
  - ☑ Tankers
  - ☑ Depots
- ❑ Habitation - next
- ❑ More?

Conclusions & Recommendations

- **Significant cost reductions from the norm of cost-plus contracting are possible** for new space system elements in NASA's exploration scenarios. We analyzed landers and stages across scales and types for life cycle costs, development, and manufacturing (some with operations), if these were acquired using commercial / public private partnerships. There is no basis to conclude that public private partnerships end at low Earth orbit, prohibited or incapable of going beyond that point to deep space, the moon or Mars.
- **Data sheets and cost estimation sheets are available upon request** to assure the broadest dissemination of knowledge, further peer review, and continuous improvement of these life cycle cost estimates to date.
- Including these commercial options in NASA space exploration architectures, that assembly of many space systems for specific missions, could **significantly improve two factors** where NASA exploration programs face difficulties. Deep space systems as public private partnerships could significantly reduce the **cumulative cost of deep space exploration elements** while addressing the **risk of irrelevance**, as reduced costs equal outcomes that are sooner rather than forever a matter for another generation.
- **Lastly, it's recommended that NASA acquisition processes avoid prematurely favoring one contracting approach over another**, avoiding the preconception very advanced systems must fall under traditional cost-plus like contracting. Partnerships are investments before they might ever be acquisitions. Investment & Acquisition processes should formally place all options on the table and assess NASA needs vs. industry capabilities in a traceable process that creates successful outcomes for NASA while growing the space sector.

Acknowledgements

The author gratefully acknowledges the extensive collaborative work while supporting life cycle cost analysis in multiple studies under the leadership of Charles Miller, leading to the methodology and many of the results refined here repeatedly in costed baseball cards. Particularly, the 2011 Propellant Depot study (inside NASA), the 2015 Evolvable Lunar Architecture (ELA) study under a grant for NASA, and the 2016 Ultra-Low Cost Access to Space (ULCATS) study supporting the US Air Force. The author also gratefully acknowledges the collaboration and support of Alan Wilhite and Dave Chato, specifically on items such as propellant tankers / stages, propellant depots and technical / performance requirements.

Questions?