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

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Presented at

The American Institute of Aeronautics & Astronautics Space 2017 Forum

Session: Space Cost and Economics

Orlando FL, September 12-14, 2017

Context

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

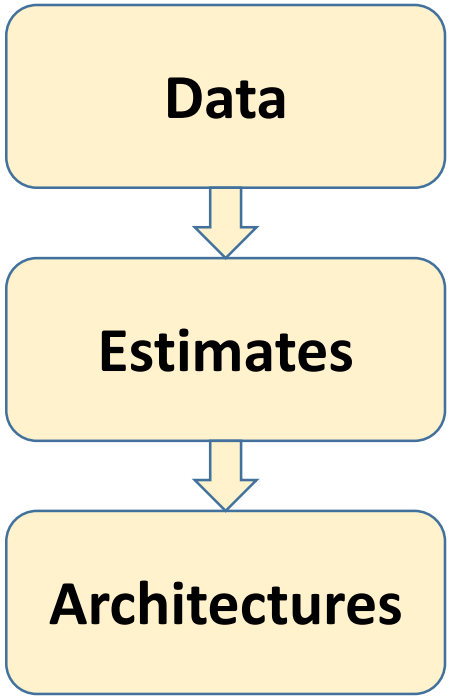
   "An Assessment of Cost Improvements in the NASA COTS/CRS Program and Implications for Future NASA Missions"

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

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

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

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



Purpose

- NASA Commercial cargo & crew programs life cycle cost data
  - Organize
  - Quantify
  - Compare
  - Document

Is that a rhetorical point, or would you like to do the math?

I'd like to do the math. –Sheldon Cooper

A Little History First

- 2004 Bush / Vision for Space Exploration (post-Columbia)

End Shuttle after ISS construction finished, and -

*"**Separate** to the maximum practical extent **crew from cargo** transportation to the International Space Station and for launching exploration missions beyond low Earth orbit"*

*"Pursue **commercial** opportunities for providing transportation and other services supporting the International Space Station and exploration missions beyond low Earth orbit"*

Fast Forward to 2010

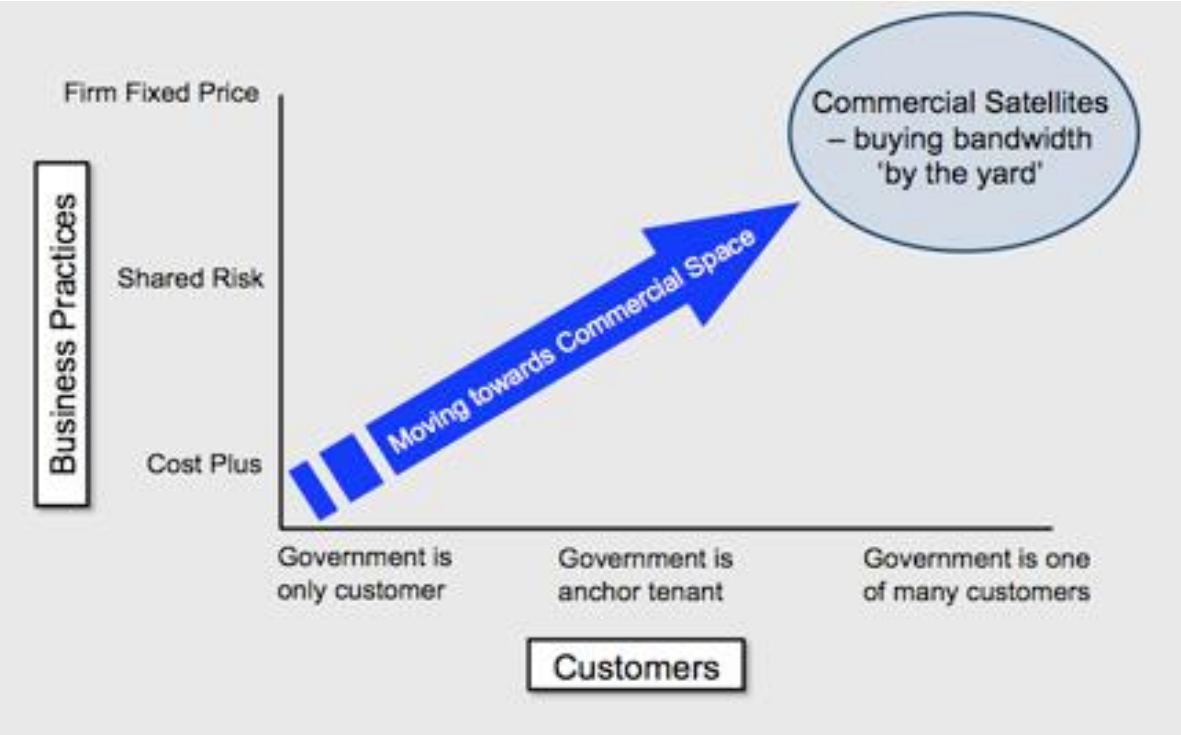
- NASA Commercial Market Assessment of Crew & Cargo Systems
  - NASA Cost Model (NAFCOM) predicted $1.7 – 4.0 billion for Falcon 9 development
  - SpaceX indicated Falcon 9 launch vehicle development was approximately $300 million.

"It is difficult to determine exactly why the actual cost was so dramatically lower than the NAFCOM predictions."

To date? More reports, debate and discussion!

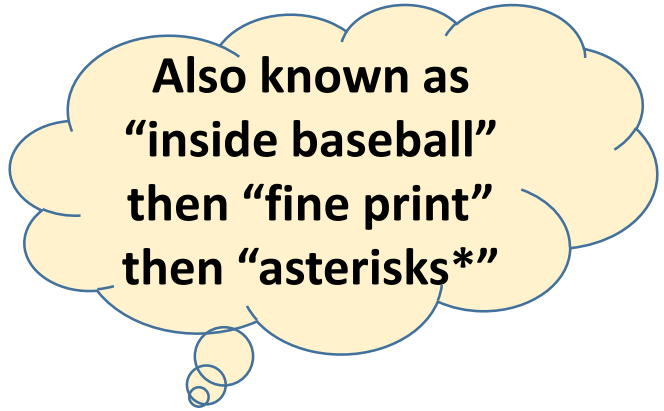
History

- Much of the debate and discussion – what is commercial?



Office of the Chief Technologist, NASA
https://www.nasa.gov/offices/oct/partnership/comm_space/

Method



- **Public primary sources** – NASA budgets, GAO, IG, etc.
- **Clarity** – lets itemize the bills, set terminology
  - **What** (launcher vs. spacecraft, 4 total), **when** (non-recurring development vs. recurring manufacture & operations), **who** (NASA payments to a company / procurement dollars, NASA management / personnel and other costs, other fund Sources / State of Virginia, private investment by each partner), **how** (Other Transaction Authority / Firm Fixed Price/Commercial/Service vs. traditional/cost-plus),
  inflation (in what year dollars), process costs (partners not carried forward in the process),
  failure costs (destruction of cargo, partial payments, loss of a docking ring, private sector losses/cube-sats, etc.), Soyuz purchases awaiting US crew,
  *….it can all sound pedantic, sorry, but it pays off in the end!
- **Quantify benefits too – “why”**
  - *If you find cost estimating difficult, you’re going to love estimating benefits*

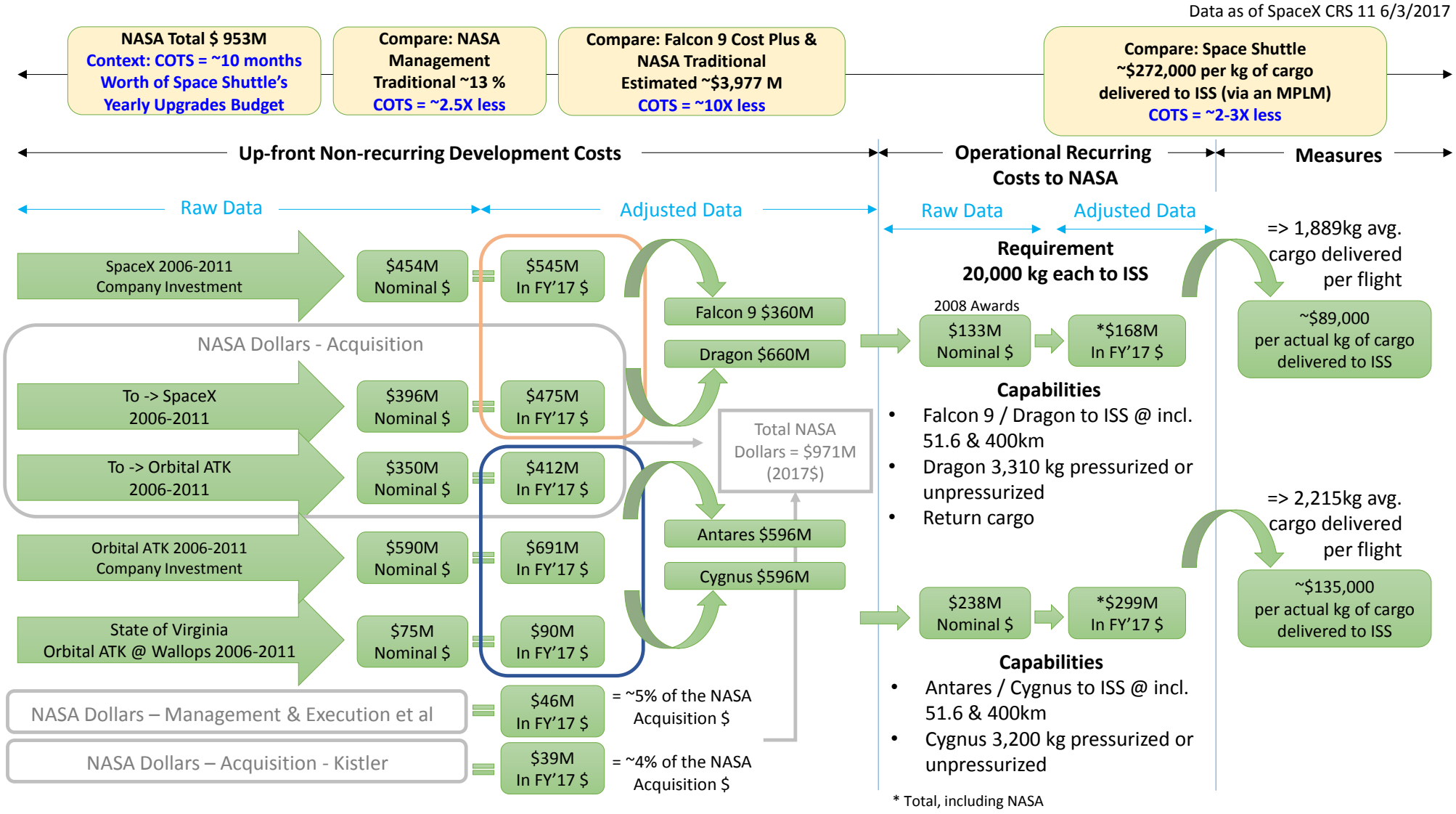
Method

- Once we have all these numbers, how do we know if we are doing better or worse?
  - Estimated Shuttle costs – “what-if” still flying in 2017?

- Issues ahead – difficulties in the comparison – but worth a try
  - Esp. comparisons for the same requirements


Cargo spacecraft. Left to right, the Orbital ATK Cygnus cargo spacecraft at the ISS, the SpaceX Dragon cargo spacecraft approaching the ISS, and the Space Shuttle delivering cargo to the ISS via the MPLM cargo carrier inside the Space Shuttle Discovery. Images NASA.

Data – Commercial Cargo Only



Data – Commercial Cargo Only – Summary

- ISS Commercial Cargo Recurring Cost (as of SpaceX CRS-11, 6/3/2017) =

  actual payments / actual cargo mass

  $89,000/kg (SpaceX) to $135,000/kg (Orbital ATK) (2017$)

- Failures counted as zero mass delivered but NASA costs incurred

- Shuttle “what-if” 2017 if 2 flights a year and a 20,000kg cargo requirement
  - Costs of 2 Shuttle flights per year = apx. 80% of historical yearly costs
  - MPLM average historical cargo delivery = 13,841kg per flight

  Shuttle “what-if” 2017 = $272,000/kg

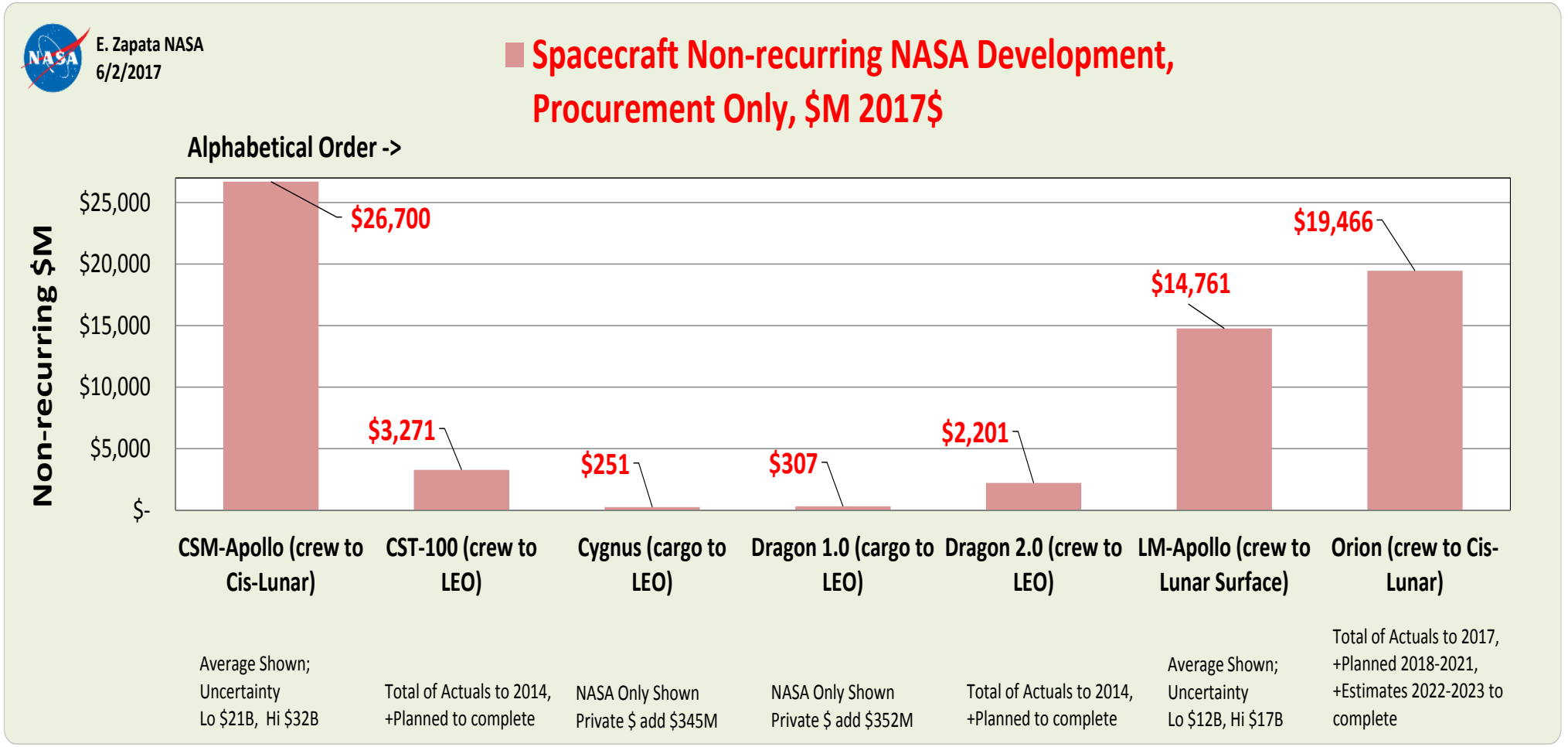
Data – Commercial Cargo Only – FAQs

- Why not load the 2nd Shuttle MPLM to it's average?
  - Shuttle $197,000/kg
  - Commercial = 50-70% of the Shuttle "what-if"
- Why not load everything (Dragon, Cygnus, MPLM) to their "maximums"?
  - Similar results as "actuals" = Similar volume limitations?
- Why not compare to a Shuttle flying 5X a year?
  - Shuttle $96,000/kg
  - Slightly higher than SpaceX @ $89,000/kg, less than Orbital ATK @$135,000/kg
  - Issue: Why fly the other 3 Shuttle flights? What is the real requirement?
- What about including (amortizing) development costs in total costs per kg?
  - Similar results.
  - Be clear on year-dollars of any comparison. Shuttle's $16B development cost is $64B (100% NASA dollars) in 2017 to amortize over all flights (and possibly a declining flight rate, again, what would have been the requirement?)

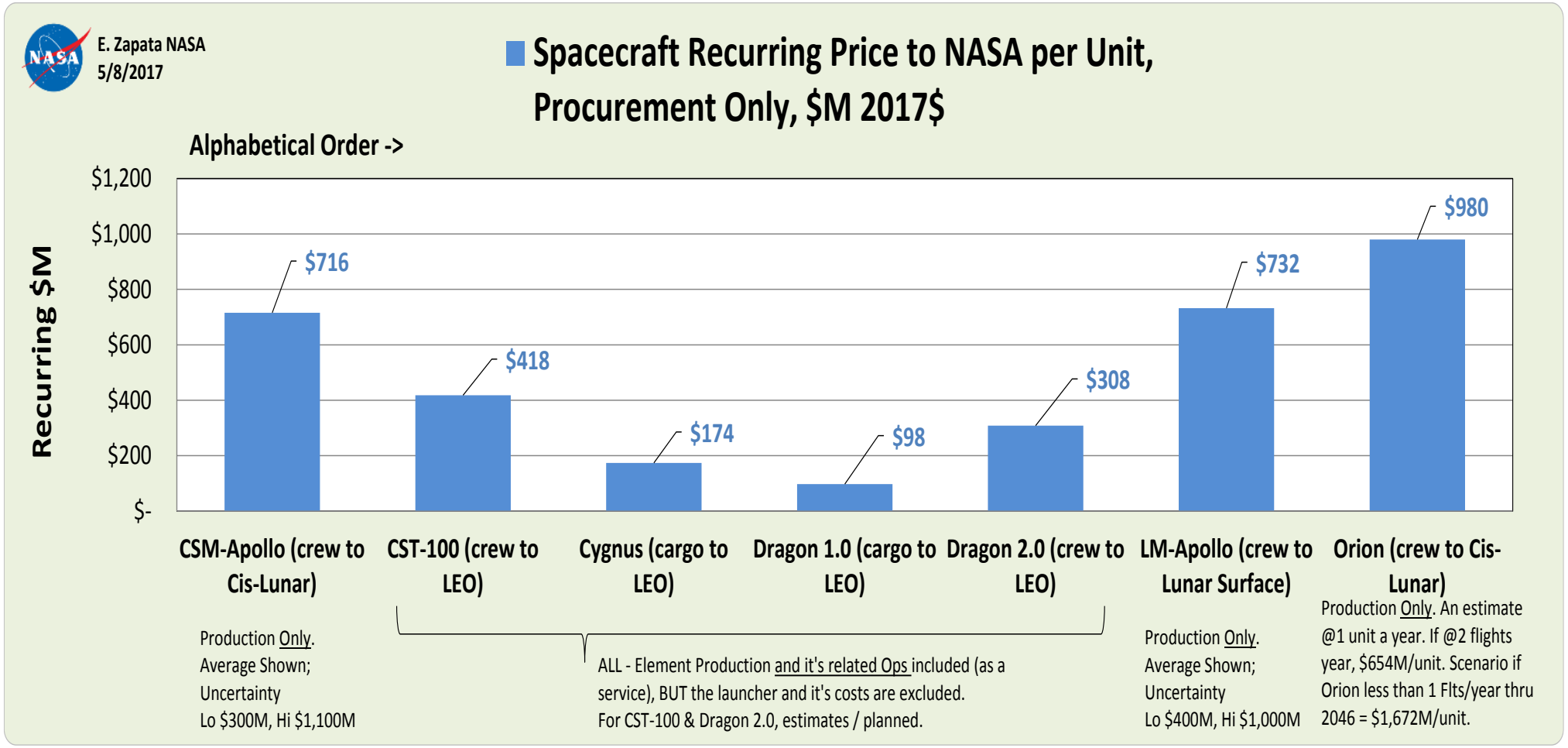
..and the big FAQ…

- What about crew?
- The Shuttle also took up crew.
- Both commercial programs go together, cargo and crew.

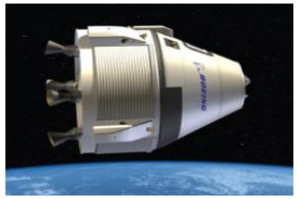
Data – Cargo & Crew, Non-Recurring Costs (Excludes Launcher)



Data – Cargo & Crew, Recurring Costs (Excludes Launcher)



Data – Commercial Crew



Measure	SpaceX Crew Dragon (2017$)	Boeing CST-100 Starliner (2017$)
Up-front Cost to NASA, SpaceX & Boeing only	$2,201M (estimate to completion)	$3,271M (estimate to completion)
Up-front Costs to NASA, other partners not chosen for later services, Blue Origin, Sierra Nevada, ULA, Paragon	$440M (historical data)	
Operational cost per crew rotation, SpaceX & Boeing (includes everything - launcher, spacecraft, ground operations and launch and mission operations up to the ISS)	$405M (estimated)	$654M (estimated)

Summary of measurable cost data to date, with estimates for forward years, commercial crew to ISS. The up-front development of the Commercial Crew capability is not yet complete, but the nature of these contracts places most cost risk with the commercial partner. This means delays may occur but this should not cause the up-front costs to NASA to rise. Operational costs to NASA per crew rotation derive from public budget documents, contract awards and requirements documentation.

See: Commercial Spaceflight and ISS Crew and Cargo Transportation, BUD-5
https://www.nasa.gov/sites/default/files/files/NASA_FY_2016_Budget_Estimates.pdf
See: CCtCap awards
https://www.nasa.gov/content/commercial-crew-program-the-essentials/
Images NASA.

Sorry…more "inside baseball"

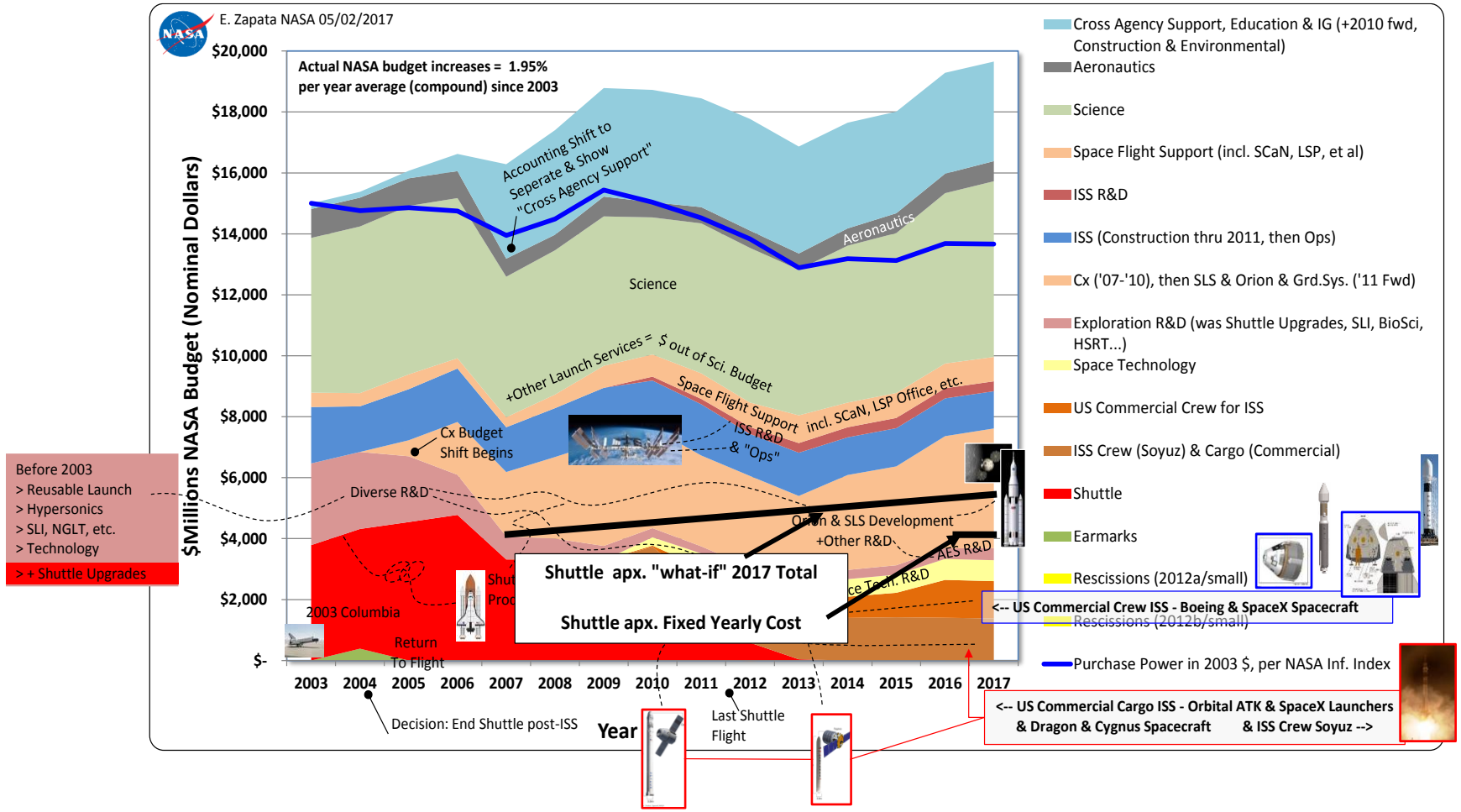
Data – Commercial Cargo AND Crew

Requirement	US Commercial Cargo & US Commercial Crew Costs per Year (2017$)	If cargo repeats the 2016 experience = 11,218kg total delivered over 4 flights		Space Shuttle Costs per Year (2017$)	If cargo repeats the Shuttle/MPLM experience = 13,841kg delivered each flight
Cargo 2 Flights	$335M	$62,597/kg SpaceX Dragon 1.0 & Falcon 9		All cargo flies with crew ↓	
Cargo 2 Flights	$597M	$101,913/kg Orbital ATK Cygnus & Antares / Atlas			
Crew Rotation 1	$654M	Boeing CST-100 & Atlas	1st Shuttle Flight per Year	$5,046M	$364,582/kg
Crew Rotation 2	$405M	SpaceX Dragon 2.0 & Falcon 9	2nd Shuttle Flight per Year	$5,445M	$196,682/kg
	$1,991M →			Yearly $ = 37 to 39% of Shuttle	

A holistic view of NASA's requirement for cargo and crew to the ISS. The apples-to-apples comparison of commercial services versus the Space Shuttle, though curious, starts to break down around here. Most of this is a desirable breakdown, stemming from NASA's move to separate cargo from crew. Cargo data for 2016 only, the most recent complete year of data.

Data – Commercial Cargo AND Crew

- Stepping back – confirms the prior, but a little low (~Soyuz effect)



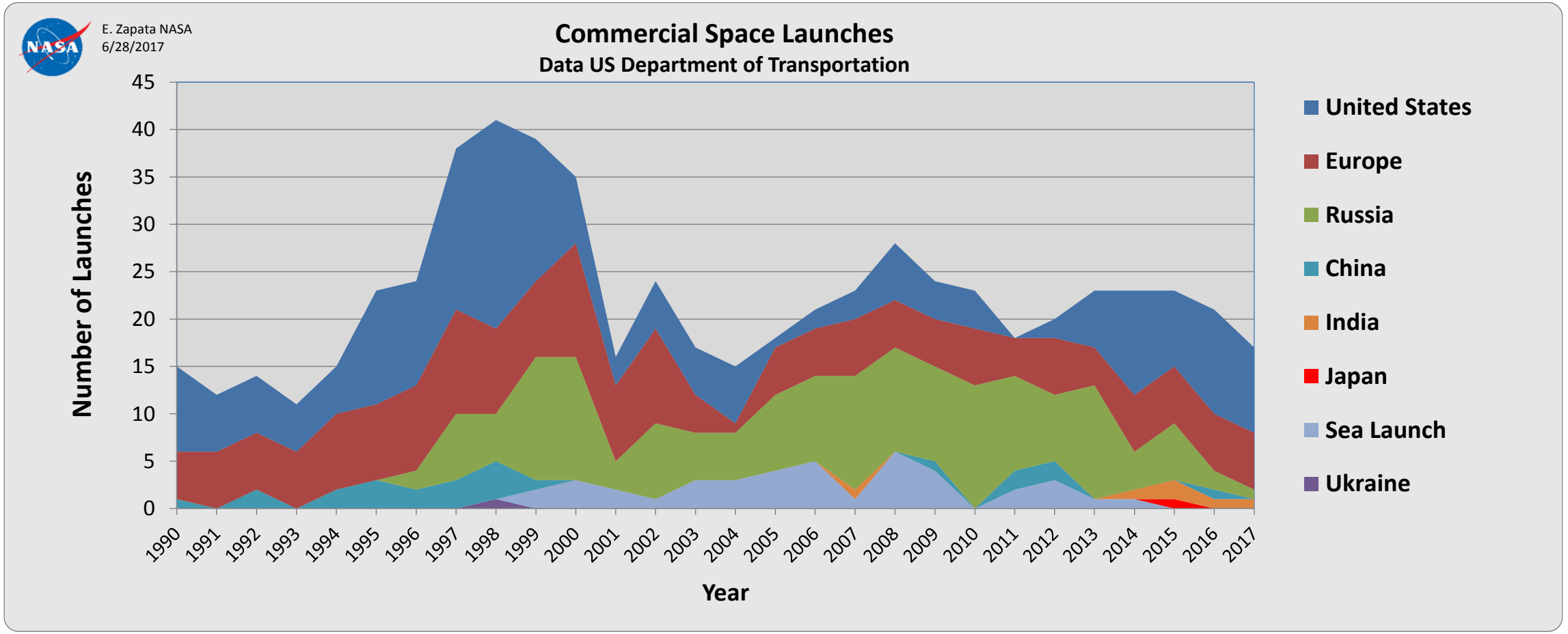
Benefits of NASA Commercial Cargo/Crew – Direct

- Most over-looked benefit – the ability to “buy by the yard” - rather than having to “buy the whole bolt of cloth”
  - Also called down-side supply chain flexibility, the ability to reduce costs significantly if the requirement is also reduced significantly
- Redundancy, multiple partners
- Reduced cost risk to NASA – Firm Fixed Price service contracts
- Simplified NASA (civil servants) program & project offices
  - COTS was 5% of funds under management compared to ~13% traditionally
- Learning, potential for reliability growth & further cost improvements
  - Higher flight rate from use of systems by non-government customers

Benefits of NASA Commercial Cargo/Crew – Indirect

- Amortizing costs over government and non-government customers
  - Falcon 9 only; other elements TBD (Dragon, Antares, Cygnus)
- Private capital, a second set of books, leverage
  - NASA's commercial cargo program *leveraged 1.4 other dollars to every 1 NASA dollar*
- US Economic Benefit
  - As of May 15, 2017, SpaceX has launched 20 payloads for non-US government customers
  - ~ $1.2 billion in other US economic activity that might (likely) otherwise have gone abroad
  - Perspective: NASA invested only about $140M in the Falcon 9 portion of the COTS program (excludes Antares, Dragon, Cygnus)

Benefits of NASA Commercial Cargo/Crew – Indirect



Number of commercial space launches by year. Data through 2014 is from the US Department of Transportation. Data for 2014-2017 through 6/28/2017 comes from tracking individual launches.

Benefits of NASA Commercial Cargo/Crew – Indirect

- Alignment of incentives, true competition

"…builds in an automatic incentive for companies to complete the effort on or under cost and as soon as possible so they can be reimbursed and move forward to the next milestone. COTS companies are also highly incentivized to hold cost and schedule because of our strategy to invest in multiple companies. This engages the engine of competition where companies strive to offer the best value and capture a share of existing markets or create new markets as soon as possible."

-Commercial Orbital Transportation Services, A New Era in Spaceflight," NASA, 2014

The Sierra Nevada Dream Chaser spacecraft. The vehicle will deliver cargo only under the NASA CRS II contract award. Image NASA.

Issues

- Partner financial health
  - *Commercial* space is especially hard
- Stakeholder expectations, intangibles
  - A satellite captured by astronauts
  - A reusable first stage returning to the launch site

Loud cheers are hard to quantify!

“questions about the vision boil down to whether we want to incorporate the Solar System in our economic sphere, or not.”

–John Marburger

How NASA’s investments say yes to this vision will be their ultimate measure.

Space Shuttle STS-49 Endeavour Intelsat VI Repair. Astronauts Thuot, Hieb and Akers take manual hold of the satellite as commander Brandenstein delicately maneuvered the orbiter to within a few feet of the 4,215kg communications satellite. **Image NASA.**

Opportunities

- One word - Plastic!
- No really –
  - *Commercial* future deep space systems?
    - Habitation?
    - Landers?
    - More?
- Yesterday – two related works
  - Session - Reinventing Space II: “The **Opportunity** in Commercial Approaches for Future NASA Deep Space Exploration Elements”
  - Session - Space Exploration: “NASA Human Spaceflight **Scenarios**, Do All Our Models Still Say ‘No’?”

Conclusions

- Rigorous, comprehensive review of NASA commercial cargo and crew cost data, including benefits and issues

"By isolated measures or by the most holistic measures, the ISS cargo partnerships are a significant advance in affordability and the ISS commercial crew partnerships appear just as promising."

Acknowledgements

The author gratefully acknowledges the assistance and review of Alan Lindenmoyer, Commercial Orbital Transportation Services (COTS) program manager, Allison Zuniga in the NASA Emerging Space Office, and the encouragement and ideas of participants across many NASA centers in NASA Emerging Space Office discussions.

Questions?

Backup

Summary Data Table

CARGO	Data	Total Actual Cargo to Date	Average Actual Cargo to Date		Total Recurring Cost to NASA, Cargo to ISS, incl. Gov't Costs	Specific Costs to NASA, Cargo to ISS
		kg	kg		$M 2017$	$/kg
Recurring						
Launcher / Cargo Carrier				**Flights per Year**		
Antares / Cygnus	6 successes, 1 failure	15,505	2,215		$ 299	$ 134,833
Falcon 9 / cargo-Dragon	10 successes, 1 failure	20,774	1,889	n/a, each flight same cost	$ 168	$ 88,781
Shuttle / Orbiter / MPLM	11 flights w. MPLM	152,255	13,841	1	$ 5,046	$ 364,582
				2	$ 5,445	$ 196,682
				3	$ 5,843	$ 140,716
				4	$ 6,241	$ 112,733
				5	$ 6,640	$ 95,943
Sierra Nevada	Data pending					
Non-recurring	**NASA Investment, Incl. Gov't Costs**	**Add Amortization per Flight to Date**	**Additional Amortized Specific Cargo Costs**			
Launcher / Cargo Carrier	**$M 2017$**	**$M 2017$**	**$/kg**			
Antares / Cygnus	$ 437	$ 62	$ 28,213			
Falcon 9 / Dragon	$ 495	$ 45	$ 23,850			
Shuttle / Orbiter / MPLM	$ 64,134	$ 475	$ 34,322			
CREW	**Data**				**Estimated Recurring Cost to NASA, Crew to ISS, incl. Gov't Costs**	**Estimated Non-recurring Cost to NASA, Crew to ISS, Procurement Costs Only (Excludes Gov't)**
Recurring					**$ per Crew Rotation Flight**	**$M 2017$**
Launcher / Crew Carrier						
Atlas / CST-100	NASA public budget docs				$ 654	
Falcon 9 / crew-Dragon					$ 405	
Non-recurring						
Atlas / CST-100						$ 3,271
Falcon 9 / crew-Dragon						$ 2,201