



**Integrating Efficiency of Industry Processes and Practices
alongside Technology Effectiveness in Space Transportation
Cost Modeling and Analysis**

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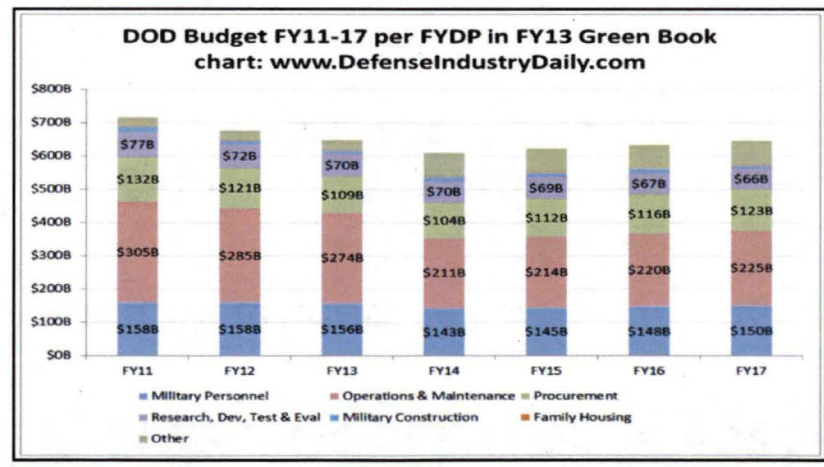
Situational Awareness

- “Budgetary pressure will increase in coming decades as more members of the baby-boom generation retire and become eligible for federal health programs.” (GAO¹)
- NASA budget outlook always uncertain; currently projected as flat².

	2012	2013	2014	2015	2016	2017	2018
Construction of Facilities	373.3	441.2	552.8	359.5	362.9	360.0	360.0
Environmental Compliance and Restoration	59.6	44.8	66.4	90.9	87.5	90.4	90.4
Inspector General	36.3	38.3	37.0	37.0	37.0	37.0	37.0
NASA FY 2013	18,448.0	17,770.0	17,711.4	17,711.4	17,711.4	17,711.4	17,711.4

Notes:
- FY 2011-2012 are consistent with submitted operating plans however, for comparability purposes, values for Space Technology in those years reflect the

- DoD overseas ops, war costs wind down³.



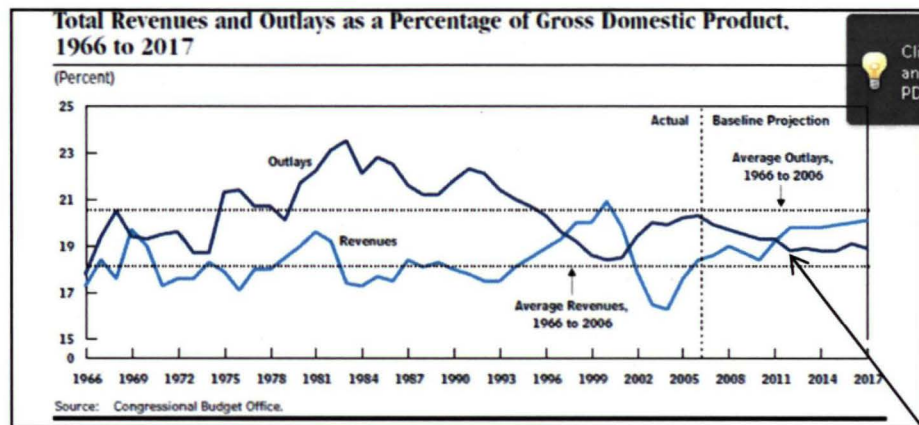
FY 2013 Budget Request

Budget Authority (\$M) by Account, by Theme	Actual FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017
Science	4,916.2	4,873.4	4,912.2	4,914.4	4,914.4	4,914.4	4,914.4
Earth Science	1,721.9	1,760.5	1,784.8	1,775.6	1,835.5	1,836.2	1,772.8
Pioneering Science	1,450.8	1,501.4	1,523.3	1,337.7	1,522.0	1,519.4	1,398.8
Astrobiology	426.1	472.7	466.4	703.0	693.7	728.9	712.0
James Webb Space Telescope	476.8	518.6	423.6	658.1	648.8	621.6	571.1
Heliophysics	436.2	420.5	447.8	643.0	636.7	638.3	667.4
Aeronautics	933.6	948.4	945.5	951.1	951.5	951.5	948.8
Space Technology	466.3	474.7	488.8	499.9	499.9	499.9	499.9
Exploration	3,871.9	3,792.8	3,828.8	4,174.4	4,876.3	4,876.4	4,876.4
Exploration Systems and Development	2,882.1	3,007.1	2,788.4	2,777.4	2,913.1	2,913.1	2,913.1
Commercial Spaceflight	606.8	406.0	429.7	428.1	429.7	429.7	429.7
Exploration Research and Development	232.3	299.7	333.7	333.7	333.7	333.7	333.7
Space Operations	5,566.3	4,897.8	4,893.2	4,836.1	4,836.1	4,836.1	4,836.1
Space Shuttle	1,392.9	556.2	72.9	0.0	0.0	0.0	0.0
International Space Station	2,713.6	2,829.9	3,007.8	3,177.6	3,177.6	3,212.9	3,234.9
Space and Flight Support (SFS)	459.8	400.9	435.0	407.5	404.4	422.3	420.0
Education	1,461.4	1,361.1	1,368.8	1,364.9	1,364.9	1,364.9	1,364.9
Cross-Agency Support	2,586.4	2,883.8	2,847.5	2,847.5	2,847.5	2,847.5	2,847.5
Center Management and Operations	2,189.3	2,204.1	2,093.3	2,093.3	2,093.3	2,177.3	2,093.3
Agency Management and Operations	787.4	789.8	754.2	754.2	754.2	770.2	754.2
Construction & Environmental Restoration	424.9	464.9	499.2	464.4	464.4	464.4	464.4
Construction of Facilities	373.3	441.2	552.8	359.5	362.9	360.0	360.0
Environmental Compliance and Restoration	59.6	44.8	66.4	90.9	87.5	90.4	90.4
Inspector General	36.3	38.3	37.0	37.0	37.0	37.0	37.0
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Notes:
- FY 2011-2012 are consistent with submitted operating plans however, for comparability purposes, values for Space Technology in those years reflect the funding for Space Technology related activities executed in Exploration, Space Operations, and Cross Agency Support.
- FY 2013 Estimates include the impact to appropriation accounts of the \$30 million recession included in the 2012 Appropriation Act, in addition to \$18 from other prior appropriations included in the total.
- Funds associated with out-year estimates for programmatic construction remain in programmatic accounts.

Situational Awareness

- Uncertainty and the Black Swan.

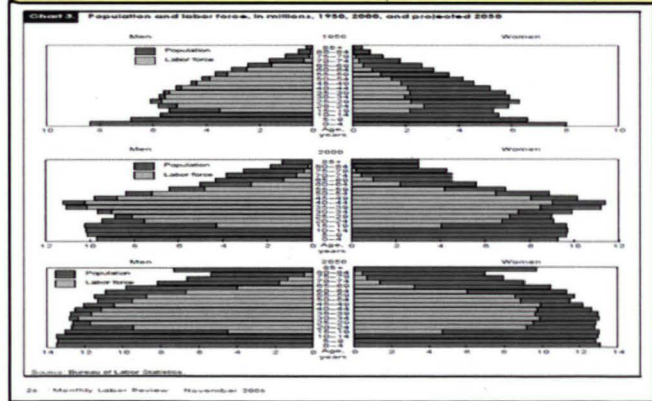


CBO projection in 2007¹

Revenue projections were a little off...

CBO projection in 2010²

- *“Demography is destiny”*
City-scale 6, 7, 8-genarians (10’s of millions); A wholly new phenomenon.



Year
1950
2000
2050

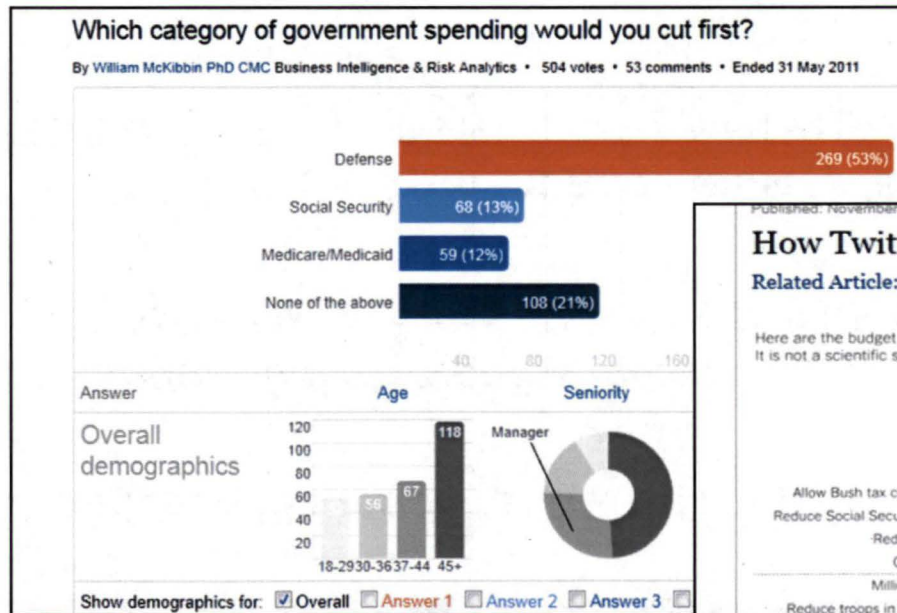
2006 US Monthly Labor Review³



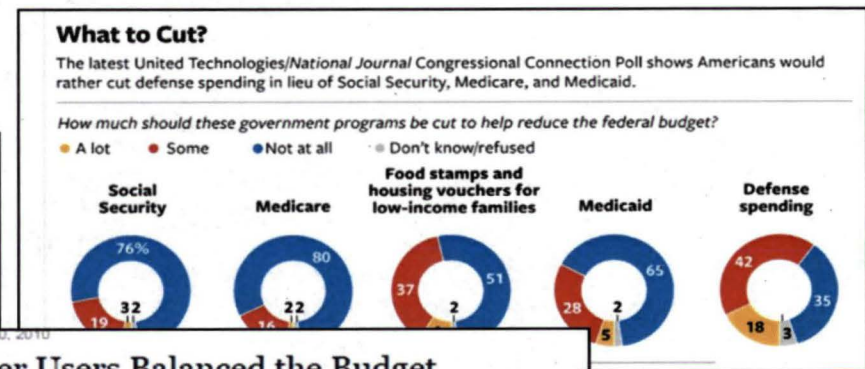
Situational Awareness

- Sequestration: Not in the prior baselines.
 - Complex. Additional DoD cuts ~ 9% per year. Additional non-defense “discretionary” budget cuts ~ 3% per year.
 - (Cuts “baselines”; unknown specifics agency by agency)

- Public opinion.

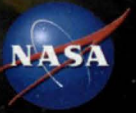


LinkedIn¹



National Journal³

NYT²



The Need (So much for the attention getters...everyone awake now?)

- *Situational awareness tells us?*
Effectiveness and Efficiency in NASA programs/projects is not optional.
- Yet both government and industry “efficiency”, being “how”, not “what”, has traditionally been ignored in cost modeling.
 - Traditionally – cost models, and a “WBS” view, focus on effectiveness (the product, it’s performance, mission, technology, systems, etc.)¹
- Efficiency – even as non-product costs dominate our industry – relegated to cursory “wraps”, or ill-defined notions about overhead, “paperwork”.
- So -how can the environment at hand be addressed via costing - for example as guidance informing acquisition strategy, evaluation and procurement? While still reflecting the real world system?

How can we move to cost models that don't ignore most costs?

(Let me explain...)



Data...but first...

- ***“There was a man on his hands and knees searching and scouring the ground beneath a light post.....a stranger walked by and said what are you doing? The fellow on the ground said with mild panic in his voice...I lost my key’s. The kindly stranger bent down and lowered himself to join in the search. After a few minutes the stranger said to the man, are you sure you lost them here? The man looked up and said no, pointing to the far off parking lot he said I lost them over there but the light is better here.”***¹



Data

Where might the keys really be?

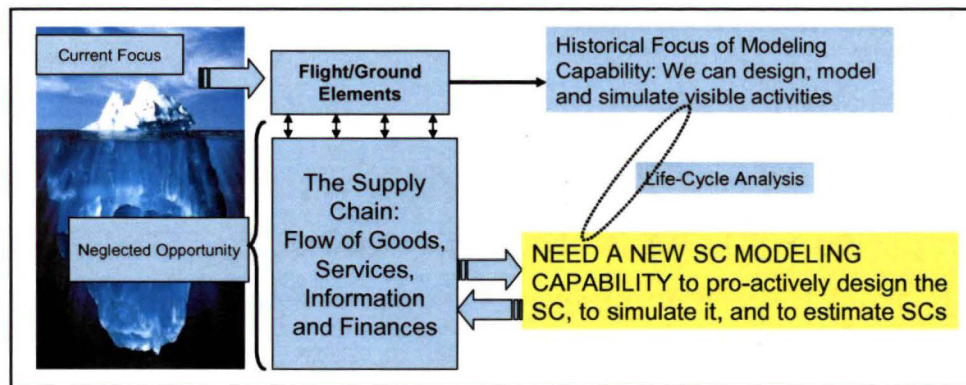
- Well known that **indirect** costs comprise more and more of the costs in aerospace over time.
 - 1990: “For example, in the aerospace industry, **indirect costs** accounted for 58% of total contract costs...”¹
 - 1991: “Experience at these firms indicates that **overhead** had grown from about 38 percent of total business in 1973 to about 49 percent by 1987. Extrapolation of this trend indicates that **overhead** will reach about 54 percent by the year 2000.”²
 - 2011: “About three-quarters of the 84 recommendations in the EELV should-cost review are associated with **overhead** and **indirect costs**”³.

Data

- Space Shuttle ***detailed*** cost data was lacking till the early 1990's (The Zero Base Cost Study¹) but matured quickly by the mid-90's (The Access to Space Study, RAND² study, and numerous others).
- Data confirmed *program wide* what was already observed in segments of the program (such as KSC operations) – that the cost of the effort “close-in”, nearest to the product (the vehicle turnaround, the production, the materials) was the SMALLEST part of total expenses.
- The rest of these costs, making up most of the total costs in our industry, have come to be called assorted names - “*indirect*”, overhead, non-touch, systems engineering³ (in DoD), project, program management, etc.
- Will use the term “indirect” here – though the detailed definition or substance of the term lacks consensus.

Methodologies and Indirect Costs

- 2004: Kennedy cost modeling efforts re-addressed the basic structure of inputs and outputs, causes and effects.

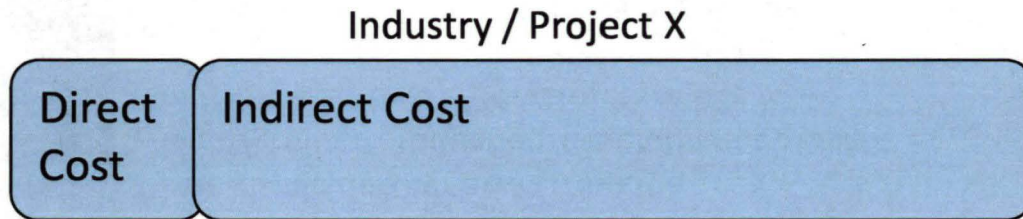
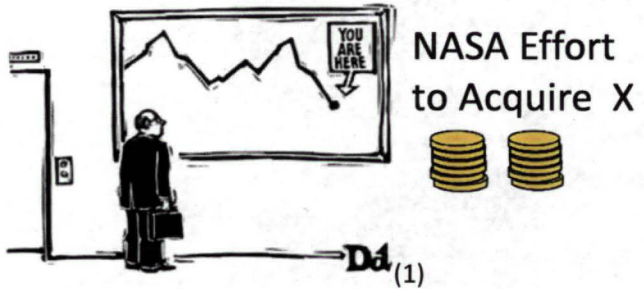


2004 Earth-to-Orbit Supply Chain Simulation¹

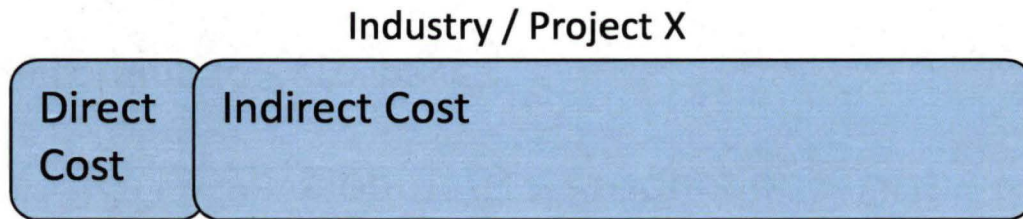
2004 Launch and Landing Effects Ground Operations (LLEGO) Model²

- “Operations Practices”: The term in early ground operations models. These practices drove “indirect” NASA and (mostly) Industry costs.
 - NASA-in so far as how an acquisition was structured.
 - About the efficiency of sourcing the required item, not it’s value.
 - Industry-the largest component of cost-in so far as how the product was provided.
 - All about the efficiency of fulfilling the requirement.

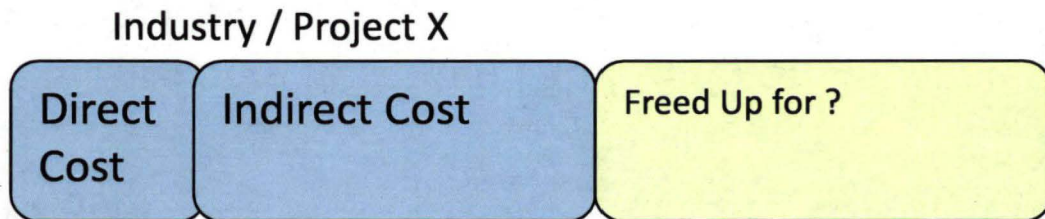
Methodologies and Indirect Costs



Possibility:
NASA
efficiency



Possibility:
Industry
efficiency

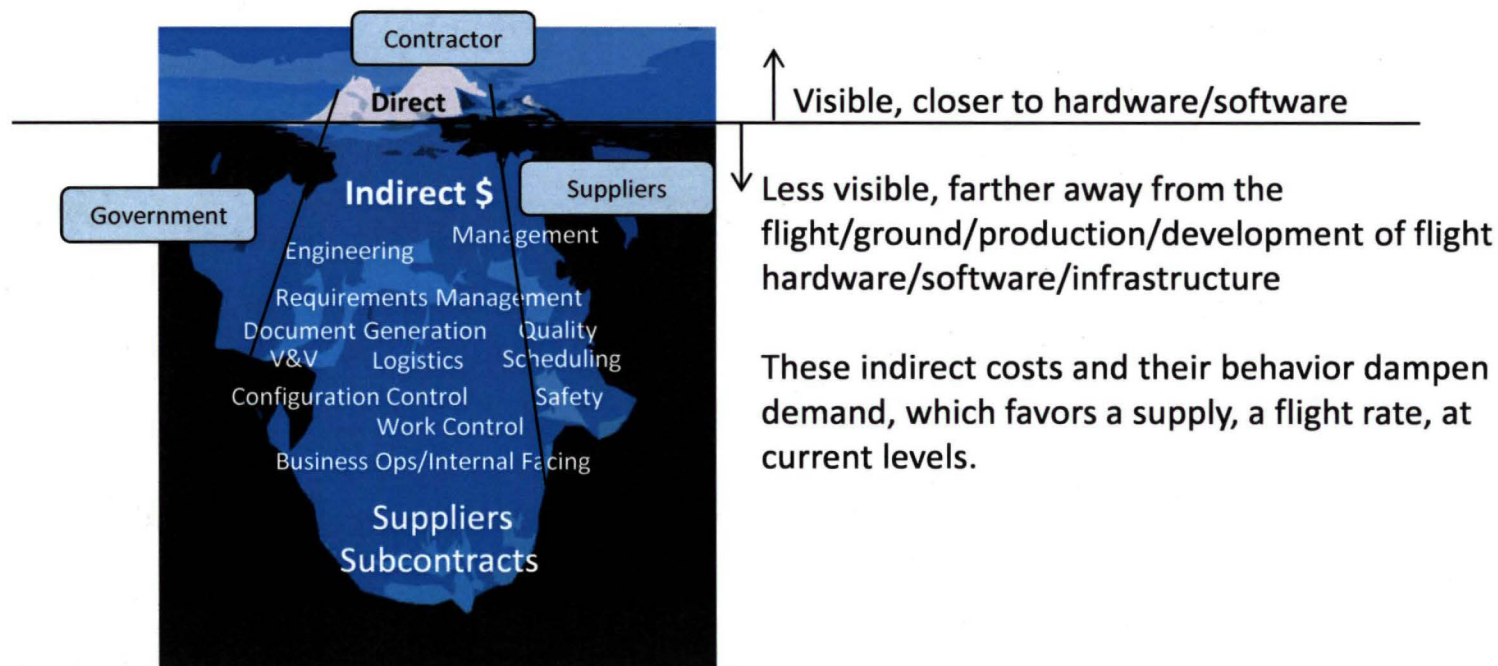


(No change in the product/service/quantity acquired)

Methodologies and Indirect Costs

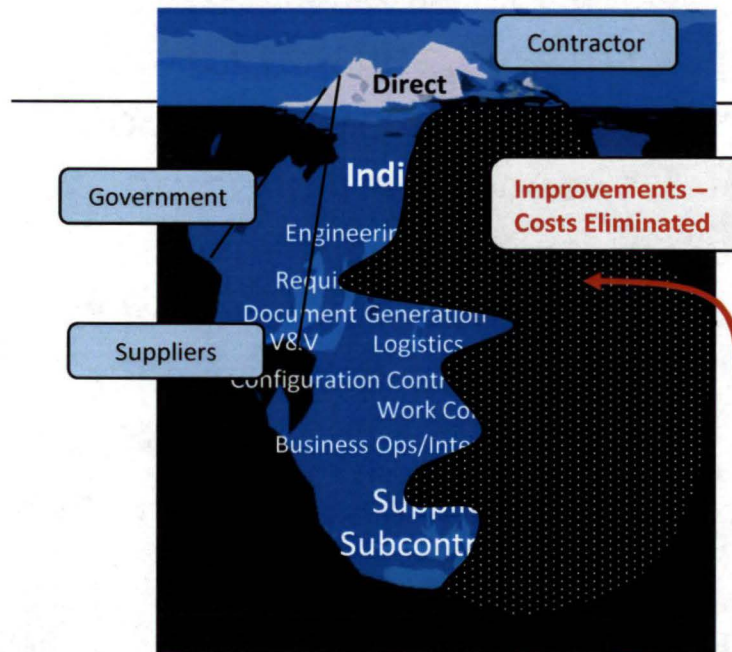
- 2012: Current work with the Air Force Research Lab (AFRL) on Reusable Booster Systems Life Cycle Cost Modeling.
 - The concepts and tools have evolved significantly (if not the figures.)
 - Now all inclusive, from R&D > Development > Production > Ops.

Life According to Aerospace



Methodologies - Technology is not just Technical

- Worthwhile cost estimates include methodologies that explore the attributes of *efficiency* of the performing organization (indirect), process and practices, fixed costs, and their supply chain management (SCM), moving materials *and information*.
- What is different in process/practices (P/p) and SCM technologies? What is their connection to lower costs vs. historical data?



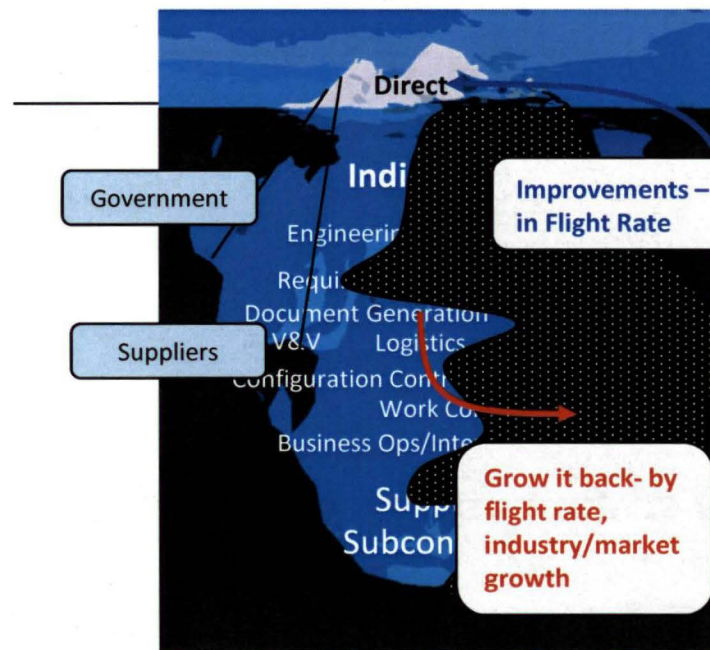
Improvements in **COST** at same productivity

Technology is the making, usage, and knowledge of tools, machines, **techniques, crafts, systems or methods of organization** in order to solve a problem or perform a specific function. It can also refer to the collection of such tools, machinery, **and procedures.**

Ref. "[Making the Case for Reusable Booster Systems: The Operations Perspective](#)" presented to the Aeronautics & Space Engineering Board, National Research Council, [Committee for the Reusable Booster System: Review and Assessment](#), May 7, 2012, Washington DC.

Methodologies - Productivity → Costs → Technology

- Once affordability is achieved, efficient organizations can take advantage of enabling “technology” for improving their “direct” effort/effectiveness, producing MORE flights, responsiveness, a HIGHER tempo of operations or other unique product/services.
- Now the system can scale. Flight rate, sustainability, responsiveness, and industry revenue/growth can follow *causally*.



Then TECHNOLOGY *for greater productivity*

- more electric vehicle, EHA's, EMA's
- non-toxic, higher Isp, more maintainable propulsion
- health management
- automated umbilical's and handling
- simpler propulsion, ceramic NFS engine parts
- materials advances , composites, aluminum lithium...more.

Ref. "[Making the Case for Reusable Booster Systems: The Operations Perspective](#)" presented to the Aeronautics & Space Engineering Board, National Research Council, [Committee for the Reusable Booster System: Review and Assessment](#), May 7, 2012, Washington DC.

Methodologies - and reality...

"There's this farmer, and he has these chickens, but they won't lay any eggs. So, he calls a physicist to help. The physicist then does some calculations, and he says, um, I have a solution, but it only works with spherical chickens in a vacuum."

-Big Bang Theory, Episode 9, Season 1



(There are many models of this joke)



Back to Data – An “Existence Proof” – Falcon 9 and NAFCOM

- Numerous versions to this evolving “existence proof”.
- Cost of Falcon 9 development, initial production and test flight (not recurring operations) has been^{1,2} confirmed by government analyst to have been between 10% to 32% of what government models would otherwise have required.
- Same “what” (medium lift rocket), far different “how”.

and place high PDF file.

Falcon 9 NAFCOM Updated Cost Estimate Comparison							
Updated							
(Cost Plus Fee Vs. Firm Fixed Price)							
Elements	Weight (lbs)	Firm Fixed Price Acquisition			Cost Plus Fee Acquisition		
		DDT&E (FY2010 \$M)	2 Test Flt Units (FY2010 \$M)	Total (FY2010 \$M)	DDT&E (FY2010 \$M)	2 Test Flt Units (FY2010 \$M)	Total (FY2010 \$M)
Stage One (Including Engines)	39,080	\$188.7	\$109.3	\$298.0	\$370.6	\$218.3	\$588.9
Stage Two (Including Engine)	6,506	\$89.0	\$23.6	\$112.6	\$184.7	\$59.6	\$244.4
Fee (12.5%)		\$0.0	\$0.0	\$0.0	\$69.4	\$34.7	\$104.2
Program Support (10%)		\$0.0	\$0.0	\$0.0	\$62.5	\$31.3	\$93.7
Contingency (30% Vehicle, 10% Engine)		\$0.0	\$0.0	\$0.0	\$193.2	\$91.7	\$284.9
Vehicle Level Integration (8%)		\$22.2	\$10.6	\$32.8	\$44.4	\$22.2	\$66.7
Total	45,586	\$299.9	\$143.6	\$443.4	\$924.9	\$457.9	\$1,382.7

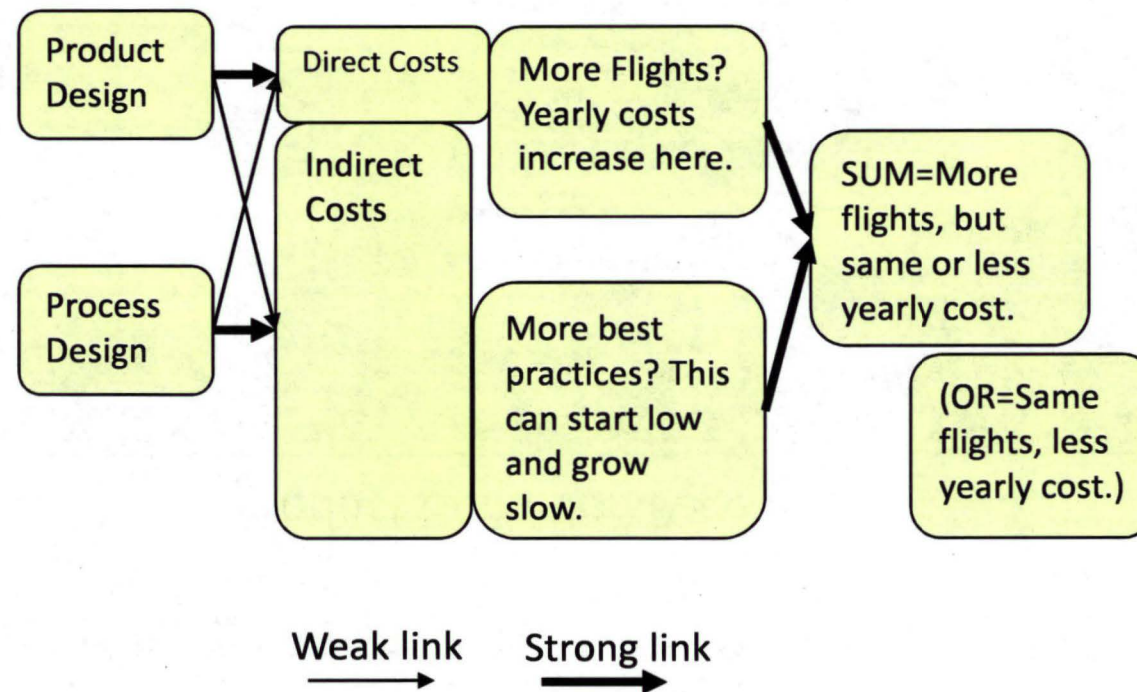
- Based on technical corrections and the additional insight in to the mass summary information as well as hardware heritage gained from a recent trip to the SpaceX facility.
 - Represents DDT&E and two test flight unit
 - Cost plus fee acquisition approach include fee, program support, and contingency where firm fixed price acquisition reflects a space act agreement approach

(1) **PUBLIC:** Commercial Market Assessment for Crew and Cargo Systems, Pursuant to Section 403 of the NASA Authorization Act of 2010 (P.L. 111-267), Appendix B, April 27, 2011. Available at http://www.nasa.gov/pdf/543572main_Section%20403%28b%29%20Commercial%20Market%20Assessment%20Report%20Final.pdf

(2) **PUBLIC:** Falcon 9 Launch Vehicle NAFCOM Cost Estimates, NASA Associate Deputy Administrator for Policy, August 2011. Available at: http://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf

A Model – The Evolving RBS LCC Model

- The current terminology being used is “product” and “process/practices” – with decisions for these that are causes of the estimated costs.
- The Model Framework-





A Model – The Evolving RBS LCC Model

- Model Screen Shots-Product Definition Page

The screenshot displays the 'Product Definition Page' of the Reusable Booster Design software. The interface is divided into several sections:

- Vehicle Thermal Protection:** A series of dropdown menus for defining thermal protection requirements. The 'Windward' and 'Leeward' sections each have options for 'type?' and 'design?'. The 'Leading edges' section has a 'type?' dropdown. A 3D model of the X-37 leading edges is shown below these options.
- Dashboard:** A central panel with buttons for setting values to 'Baseline' or 'Best' for all vehicle pages. It also displays scenario cost data:

Scenario	Cost (\$)
Hi Fixed	79.99
Simplistic	44.47
Likely	18.99

Workforce data: Total 604, Direct 189. Payload Year (kg): 46,880.
- Per Flow Contractor Millions of \$:** A stacked bar chart showing contractor costs for different ground operations categories: Grnd Ops Direct, Grnd Ops Support, Grnd Ops Indirect, Grnd Ops Logistics, and Grnd Ops Subcontractors. The total cost is approximately \$80 million.
- Life Cycle Cost, \$Billions vs. Year:** A line and bar chart comparing the life cycle cost of the EELV (what-if 3-3 Flts/Year) and Space Shuttle (what-if-continued) from 2012 to 2033. The EELV cost is significantly lower and more stable than the Space Shuttle cost.



A Model – The Evolving RBS LCC Model

- Model Screen Shots-Process/Practice Definition Page showing “Help”

The screenshot displays the 'Production and Process' configuration page of the RBS LCC Model. The interface includes a navigation bar with tabs for 'CONOPS', 'Product', 'Processes/Practices', and 'Non-recurring & Production'. The 'Production and Process' section is active, showing a 'Page 4 of 7' view with several dropdown menus for selecting efficiency improvement levels. A 'Help' window is open, providing detailed instructions on setting baseline values and defining practices. To the right, there are two charts: a stacked bar chart for 'Per Flow Contractor Millions of \$' and a line chart for 'Life Cycle Cost, \$Billions vs. Year'. The bottom of the screen shows a taskbar with various dashboard tabs and a system tray with a 97% battery level.

Production and Process < Back Next > Dashboard

Production / Processing Strategies
(?) Relatively significant efficiency improvements

Process and Resource Improvement Strategies
(?) Relatively moderate efficiency improvements

Scheduling / Planning
(?) <Re- HELP (Shuttle Orbiter analog) Baseline ways-of-doing-business

Set to "Baseline" if implementing few to none of these best practices. Select improvement level higher to the degree more of these best practices are both planned and have been demonstrated by the contractor organization. If planned, but not historically demonstrated, select intermediate values to allow margin in planning.

Strategies and systems related to the manufacturing, processing, and refurbishment of the vehicle flight elements.
Related to SCOR Make 3.3, 3.4 and Enable Make 3 and 4, OMI-Operations Maintenance Instructions or equivalent, scheduled work instructions prepared well before work occurs. PR = Problem Report or equivalent for unscheduled work due to a problem, usually prepared after the problem occurs, with degrees of buildup from other prepared documents.

Practices
-On-line real time information system details processing levels for equipment, repair orders and other sub-system processing
-inspections at the source, all responsible for quality
-Self-directed workforce
-Cellular Manufacturing
-Engineering information (reqmt's, specifications, drawings, etc) readily available / linked across process documents (OMIs, PRs, etc).
-Requirements flowed electronically, seamlessly, into engineering processes such as work documents.

Per Flow Contractor Millions of \$

Category	Value
Scenario	\$ 79.99
Hi Fined	\$ 79.99
Simplistic	\$ 44.47
Likely	\$ 24.82
Workforce Total	915
Direct	189

Life Cycle Cost, \$Billions vs. Year

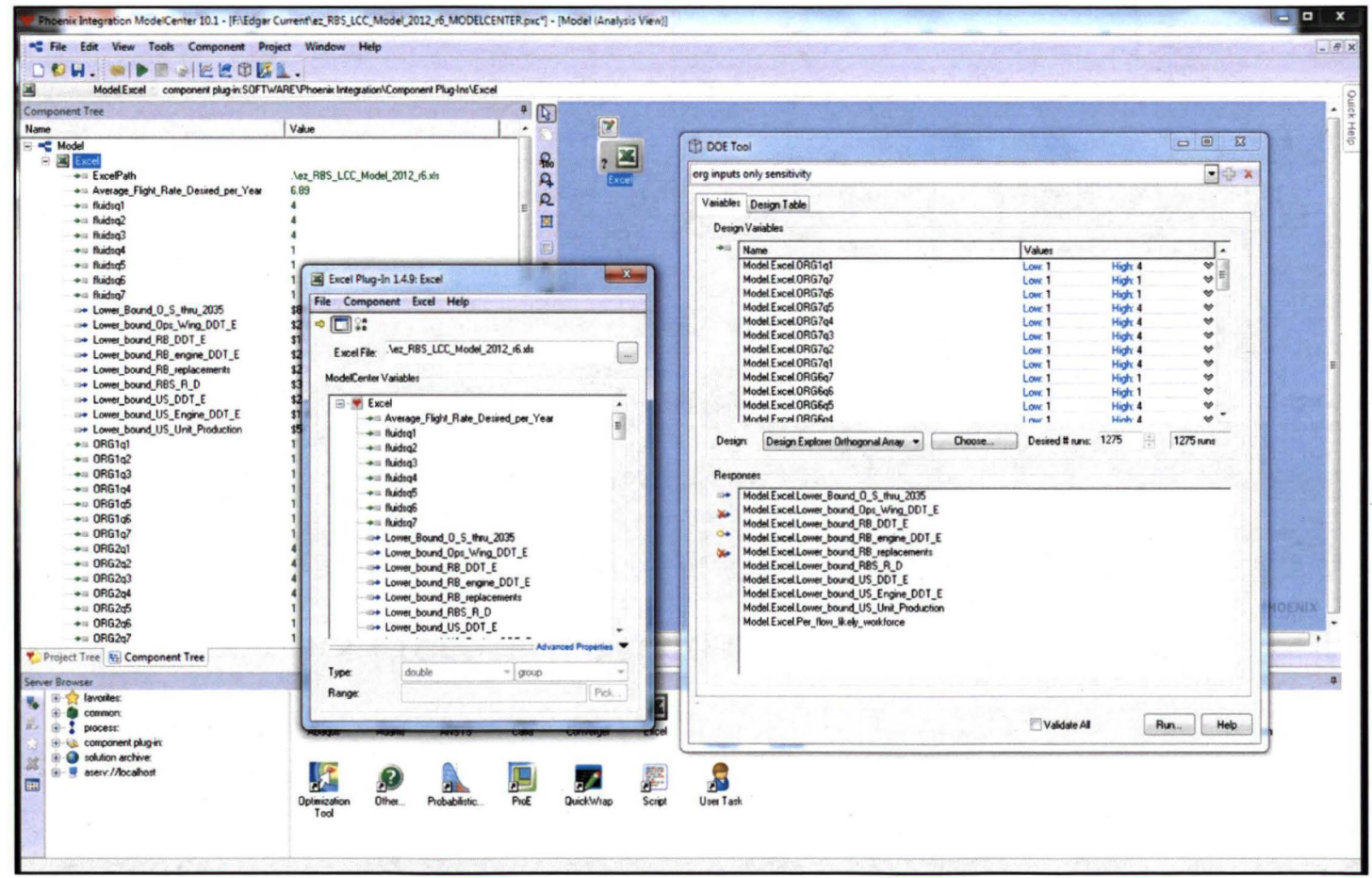
ZOOM

EBLV "what-if 3-5 flts/year" (120-342flts/year LEO)
Space Shuttle "what-if-continued" (220flts/year LEO)



A Model – The Evolving RBS LCC Model

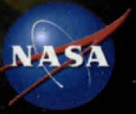
- ModelCenter-automating the work of developing and using the model





Implementation

- Stepping far from established “data points” (EELV, Shuttle, etc.) can be accomplished with relative confidence if listening closely to the data, which tells us very much about *where the keys were probably lost*.
- Cost modeling must step outside of comfort zones – else, no useful insights will be provided into the process, costs will continue to go out of control, while productivity declines.
- NASA/Industry relevance in Spaceflight is now all about enabling productivity (has been a while...).
- None of this is really new (...except applying it to us...)
 - Effectiveness and efficiency have just changed their names over many decades according to what’s in business vogue.
 - 1980’s “middle-management¹” craze already saw this disruption.
 - 1990’s I/T revolution was about efficiency, reducing indirect costs.
 - “Adapt or Die”² still true...



Going Forward

- Our cost models must increasingly address the possibility of transformative, dramatic, productivity and cost improvements – providing insights on the characteristics of our acquisition and our industry process/practices that best co-relate to these advances.
- *Then costing can move into the more challenging issues and economics to change:*
 - Industry may parrot these variables in bids, but lack the experience or desire to actually implement the new ways of doing business.
 - Where industry is ready, the number of these players may be insufficient to shift the paradigm for the industry as a whole, or quickly enough.
 - Within the NASA sourcing process, the desire to see these industry improvements –*highly disruptive to existing players*- has to come along before new NASA processes can enable a new normal.



BACKUP



Abstract

- This paper presents past and current work in dealing with indirect industry and NASA costs when providing cost estimation or analysis for NASA projects and programs. Indirect costs, when defined as those costs in a project removed from the actual hardware or software hands-on labor, makes up most of the costs of today's complex, large scale NASA space/industry projects. This appears to be the case across phases, from research, into development, into production, and into the operation of the system. Space transportation is the case of interest here. Modeling and cost estimation as a process, rather than a product, will be emphasized. Analysis as a series of belief systems in play among decision makers and decision factors will also be emphasized to provide context.*