AEROSPACE REPORT NO.
ATR-2013-00108

Cost Estimating of Space Science Missions

April 16, 2013

Robert E. Bitten, Eric M. Mahr and Robert C. Kellogg
NASA Program Division
Civil and Commercial Operations

Prepared for:

NASA Headquarters
300 East Street, SW
Washington, DC 20024

Authorized by: Civil and Commercial Operations

Approved for public release.

AEROSPACE
Assuring Space Mission Success

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Approved by:

Matthew J. Hart, Principal Director
Advanced Studies and Analysis
Directorate
NASA Programs Division
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Cost Estimating of Space Science Missions

Presentation to the
NASA Advisory Council (NAC)
Astrophysics Subcommittee

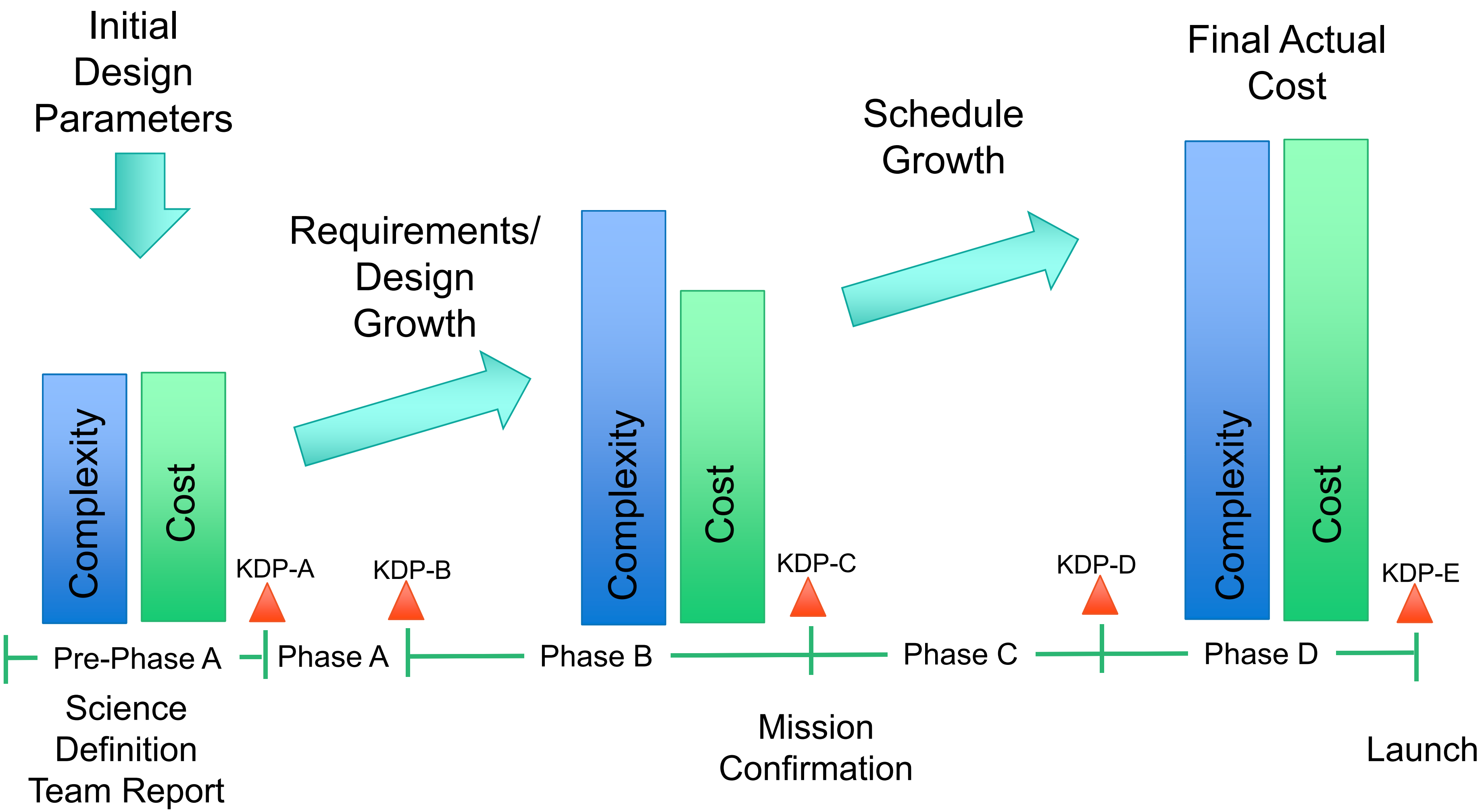
The Aerospace Corporation

16 April 2013

Agenda

- Background
- Cost Estimating Basics
- Probabilistic Cost/Schedule Estimating
- CATE Process
- Summary

Cost Evolution Throughout A Project's Lifecycle



Goal of cost estimating is to forecast the final actual cost of system

An Example of Concept Growth: Substantial Differences Exist between Initial Concept and Final Implemented Configuration

	STEREO SDT*	STEREO Final
Programmatics		
Schedule (months)	40	70
Launch Vehicle	Taurus	Delta II
Technical		
Mass (kg)		
Satellite (wet)	211	630
Spacecraft (dry)	134	421
Payload	69	149
Power (W)		
Satellite (Orbit Average)	152	503
Payload (Orbit Average)	58	116
Other		
Transponder Power (W)	20	60
Downlink Data Rate (kbps)	150	720
Data Storage (Gb)	1	8

* Science Definition Team (SDT)

SDT Configuration

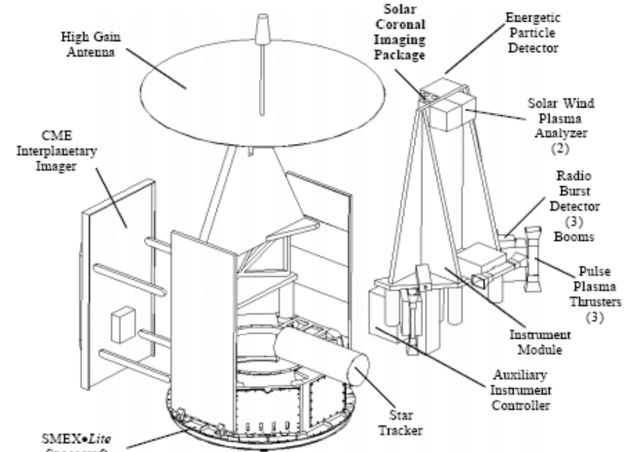
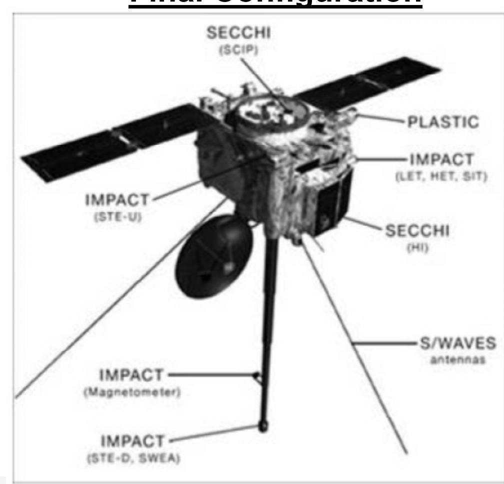


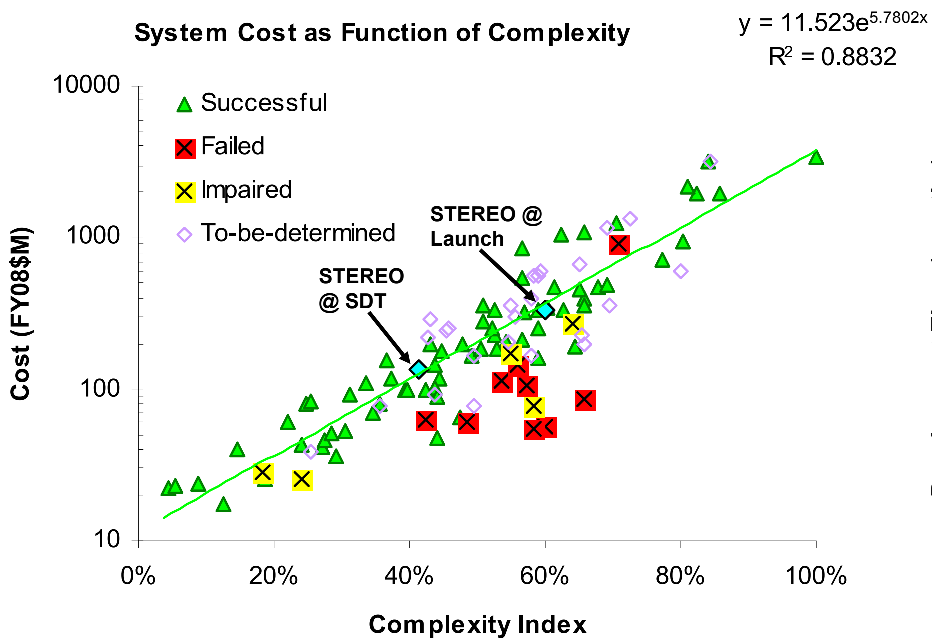
Figure 10. STEREO Configuration Details

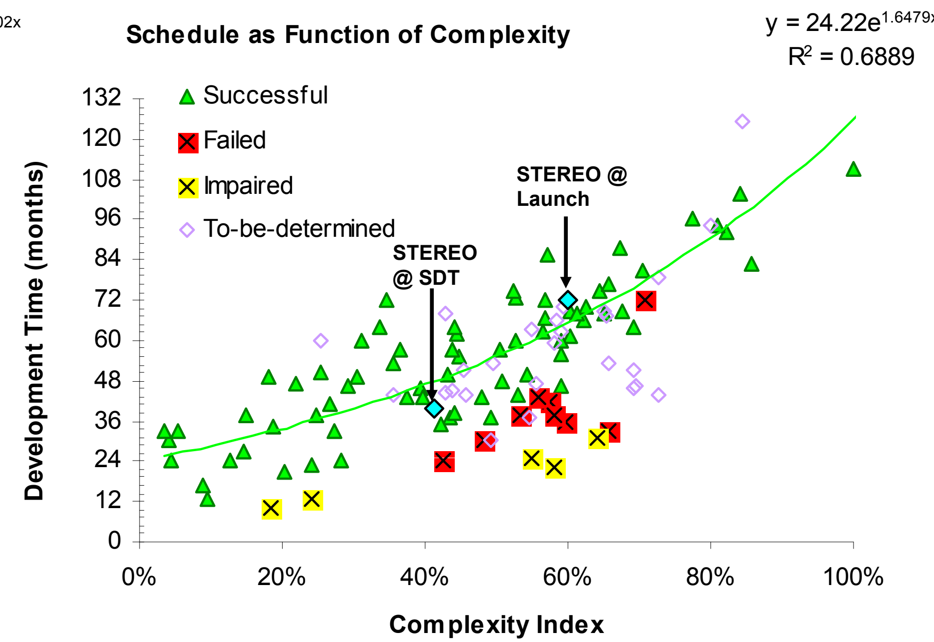
Final Configuration



Reference: "An Assessment Of The Inherent Optimism In Early Conceptual Designs And Its Effect On Cost And Schedule Growth"

Effect of Design Changes on Complexity, Cost & Schedule



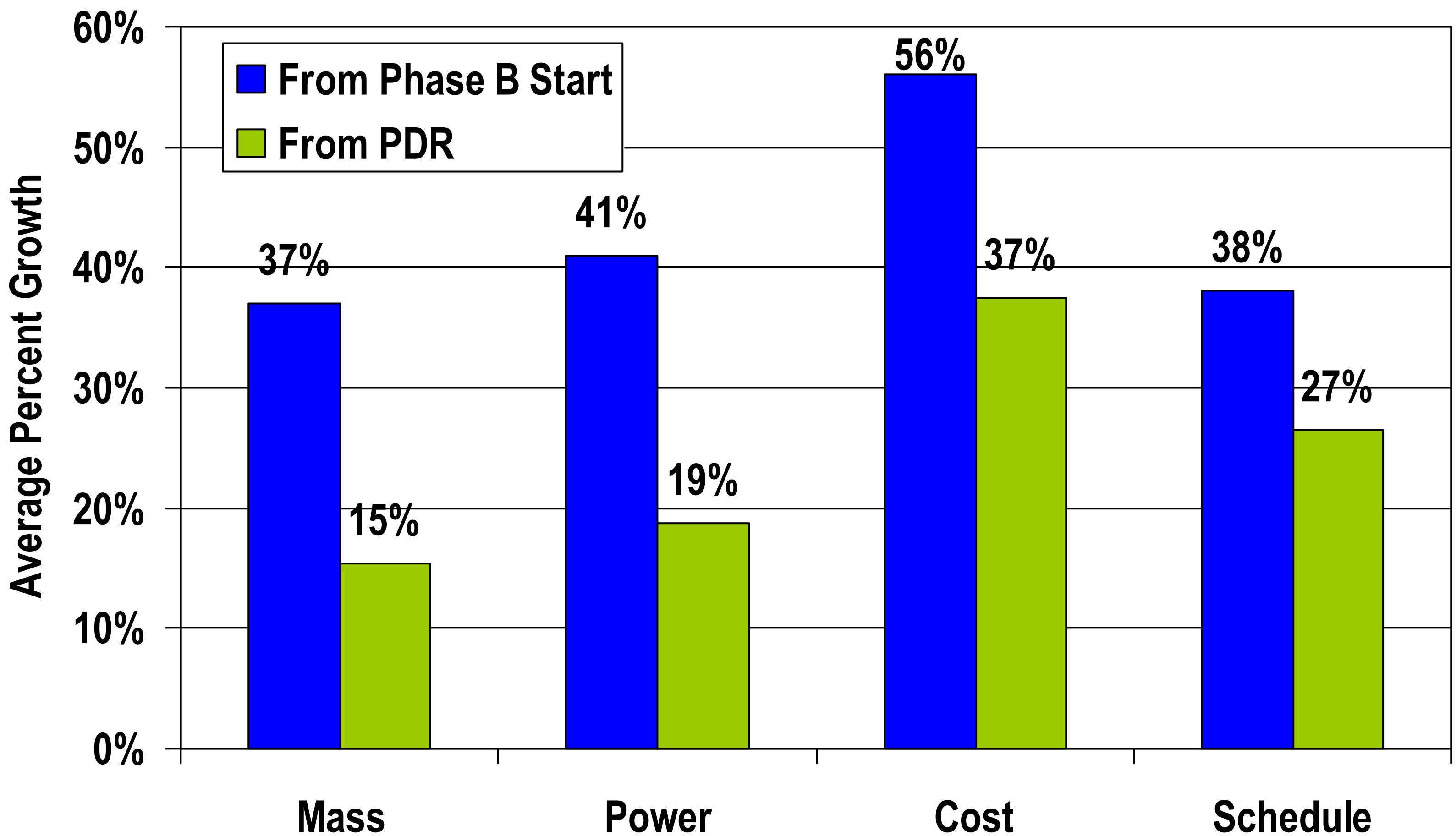


Complexity of System Increased Along with Development Cost and Schedule

Note: Development cost does not include launch vehicle cost, or mission operations and data analysis (MO&DA).

Reference: "An Assessment Of The Inherent Optimism In Early Conceptual Designs And Its Effect On Cost And Schedule Growth"

Cost & Schedule from 20 Missions Show Significant Increase from Baseline Established at PDR



Over Half of Uncertainty for Mass & Power is Retired by PDR while 2/3rds of Cost & Schedule Uncertainty Remain

Reference: "Optimism in Early Conceptual Designs and Its Effect on Cost and Schedule Growth: An Update"

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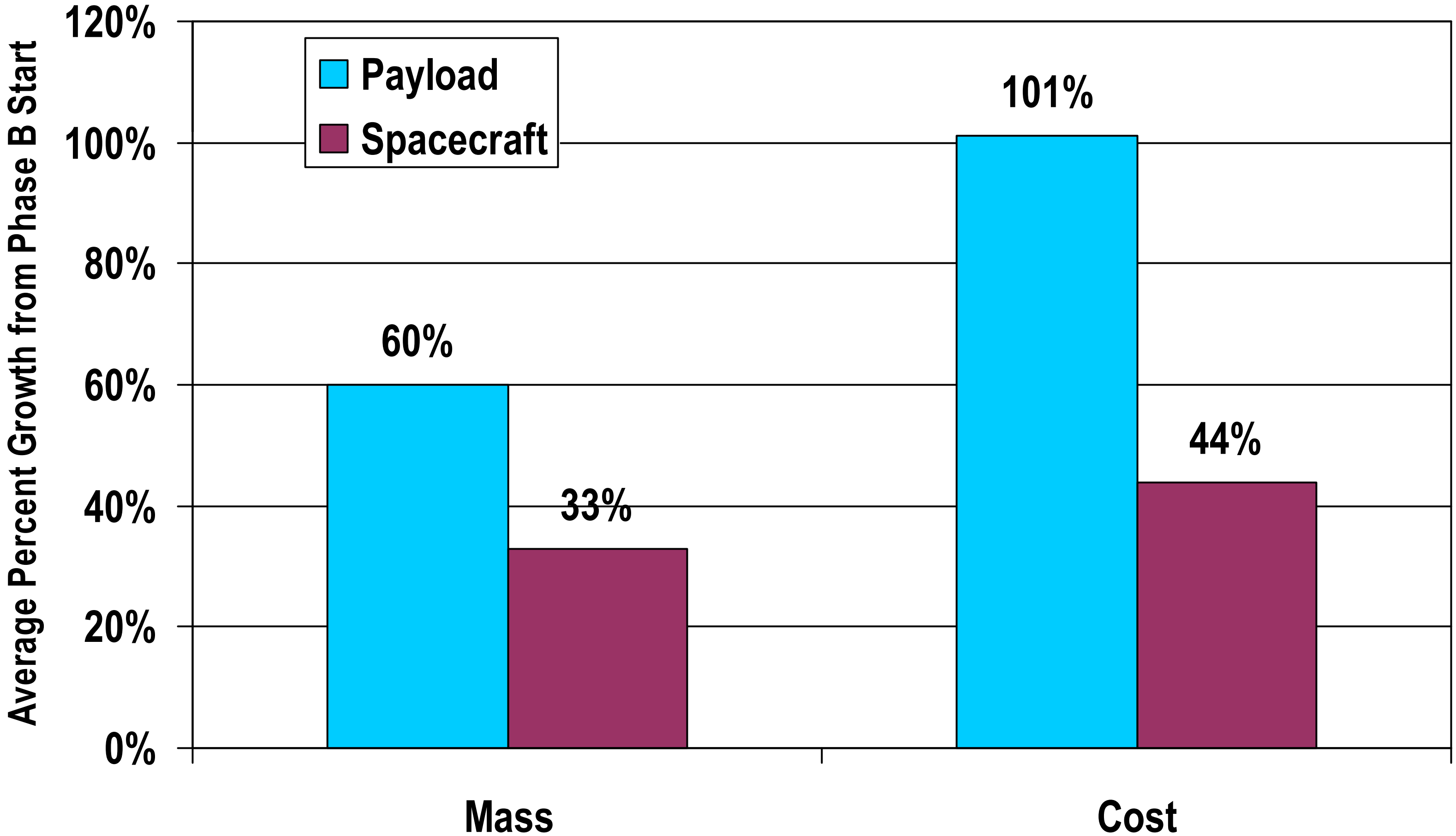
Payload Mass and Cost Increase from 20 Missions Significantly Greater than Spacecraft Mass & Cost Increase



Data Indicates Payload Resource has Greater Uncertainty than Spacecraft

Reference: “Optimism in Early Conceptual Designs and Its Effect on Cost and Schedule Growth: An Update”

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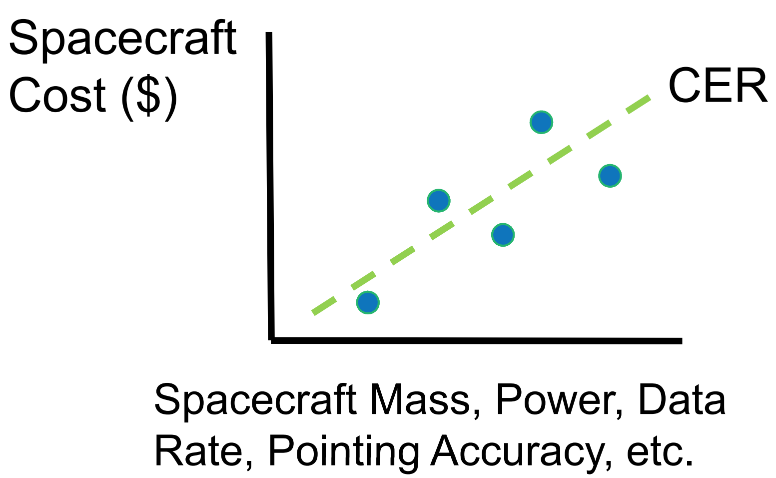
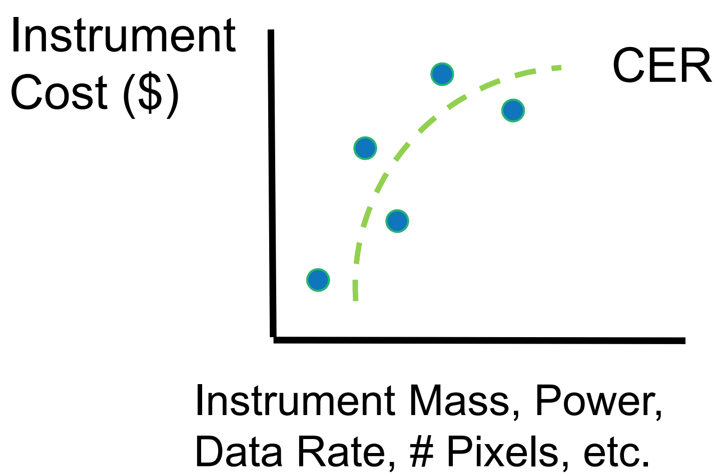
Cost Estimating Basics – The Cost Estimating Relationship

- A cost estimating relationship (CER) is a mathematical equation that uses regression techniques to establish a relationship between independent variables that are representative of the design, and cost as the dependent variable

- CERs can be applied at the system level (e.g. spacecraft, instrument), subsystem level (e.g. attitude determination & control, optics) or component level (e.g., star tracker, CCD)

- All cost models, in their basic form, have some underlying CER defined





CERs are based on historical data

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Cost Estimation Methodology Examples

Model	Developer	Spacecraft Estimating	Instrument Estimating
NASA Instrument Cost Model (NICM)	JPL	N/A	X
Multivariable Instrument Cost Model (MICM)	GSFC	N/A	X
Space Based Optical Sensor Cost Model (SOSCM)	Aerospace	N/A	Optical Only
NASA/Air Force Cost Model (NAFCOM)	SAIC	X	X
PRICE H	PRICE Systems	X	X
SEER-H	Galorath	X	X
Small Satellite Cost Model (SSCM)	Aerospace	Small Spacecraft	N/A
Adjusted Analogy	Aerospace	X	X
Aerospace Method	Aerospace	X	X

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Cost Database Characteristics

Database	Developer	Number of Spacecraft	Number of Instruments	Restrictions
Cost Analysis Data Requirement (CADRe)	NASA HQ	~100	From ~100 missions	NASA Cost Community
NASA/Air Force Cost Model (NAFCOM)	SAIC	>100	>350	NASA-Air Force Cost Community
NASA Instrument Cost Model (NICM)	JPL	N/A	160	NASA Cost Community
Small Satellite Database (SSDB)	Aerospace	~140	N/A	Aerospace Only
Aerospace Space-based Instrument Database	Aerospace	N/A	~600	Aerospace Only

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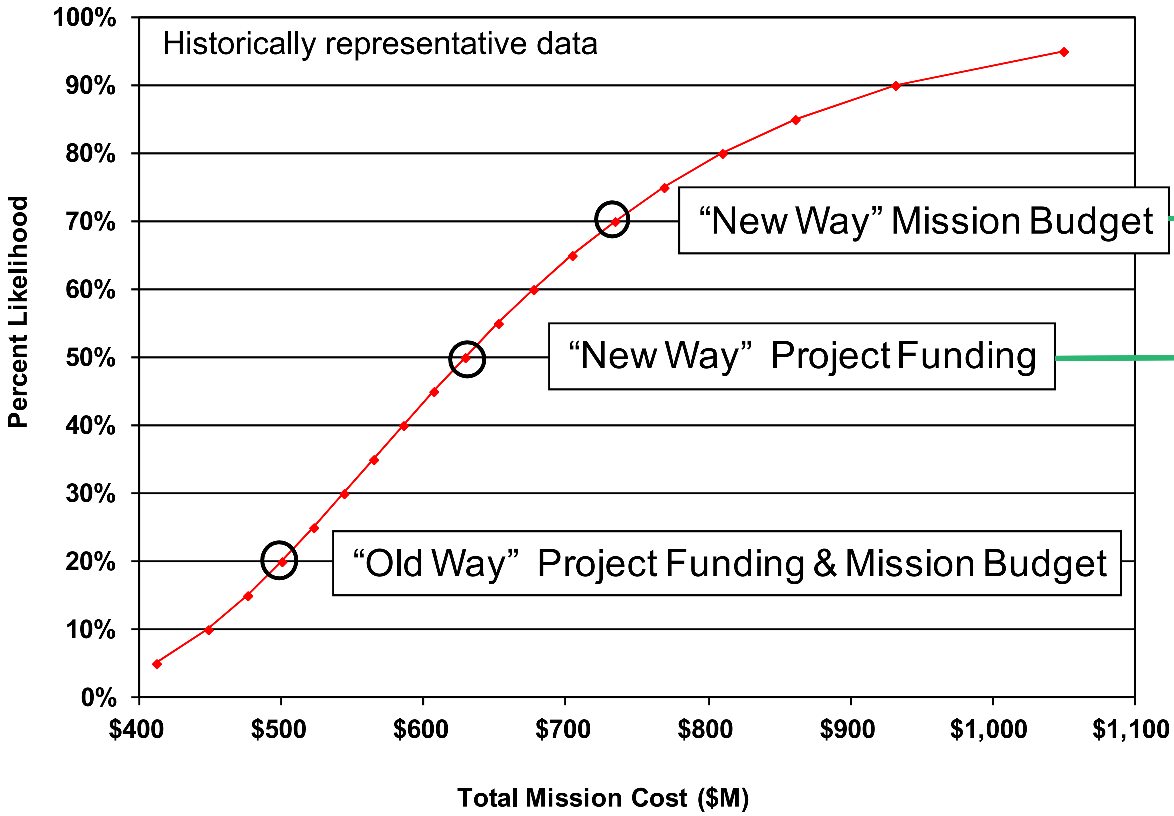
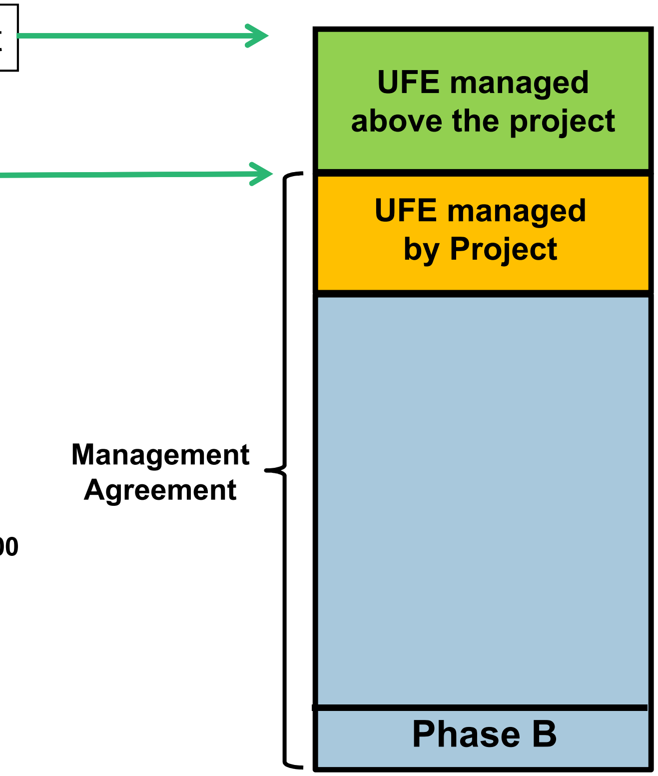
NPD 7120.5E Requires a New Way to Budget





Note: UFE = Unallocated Future Expense as stated in NPD 7120.5E

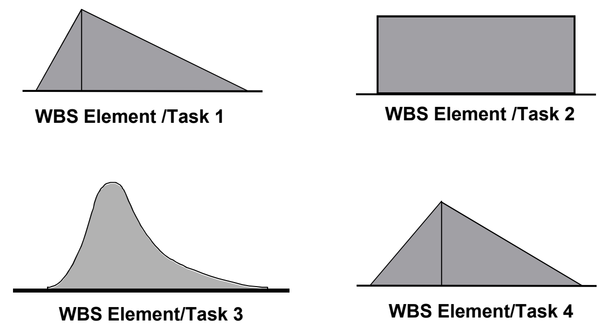
Budgeting at the 70th Percentile should reduce historical overruns

Generic Cost/Schedule Risk Process Overview – Methodology Independent

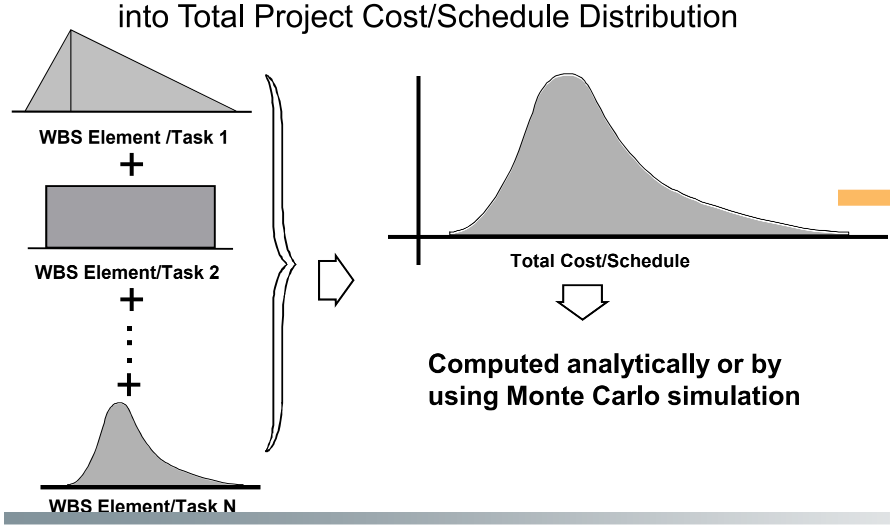
Initial Cost Estimate Distributed over Baseline Schedule

Project Management	Phase A
Systems Engineering	Phase B
Safety and Mission Assurance	Phase C
Science/Technology	Phase D
Payload(s)	Phase E
Flight System \ Spacecraft	
Launch Vehicle/Services	
Mission Operations System (MOS)	
Ground Data System (GDS)	
System Integration, Assembly, Test & Check Out	
Education & Public Outreach	

Develop Distributions for WBS Elements/Tasks

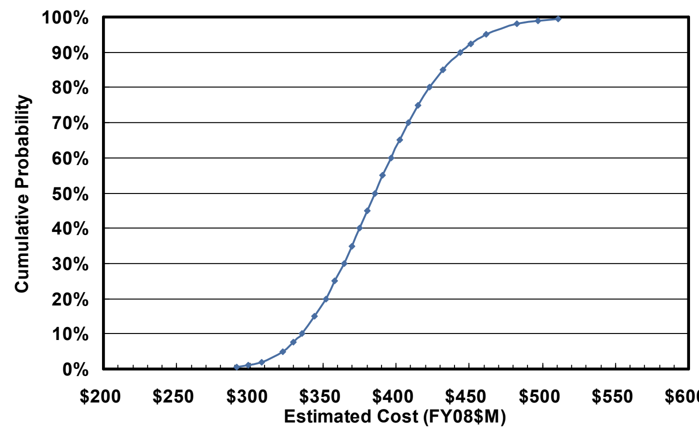


Combine WBS Element/Task Distributions into Total Project Cost/Schedule Distribution



Computed analytically or by using Monte Carlo simulation

Example Joint Cost/Schedule Distribution



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Cost and Technical Evaluation (CATE) Background

- **CATE Process developed by NRC for Astro2010 Decadal Survey**
  - *Previous Decadal Surveys significantly underestimated mission costs*
  - *US Congress required NRC to use an Independent CATE Contractor*
  - *Need to provide level treatment of projects of varying maturity*
  - *Realistic CATE estimates needed for future budget analysis & decisions*
    - CATE estimates needed to reflect historical project growth
      - *Not just analyze the specific proposed point design*

- **CATE process is the same as NASA ICE range of estimates for KDP-B**
  - *Begins with typical Independent Cost Estimate, ICE*
  - *Adds three types of cost threats, where appropriate:*
    - Schedule, design (mass & power growth) and launch vehicle

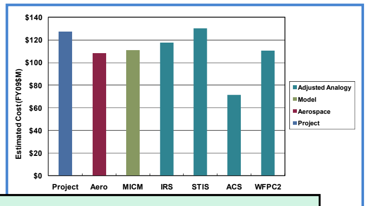
Primary Tenets of Aerospace Cost Estimating

- **Use Multiple Methods**
  - *Ensures that no one model/database biases the estimate*
    - Industry Standard Methods
    - Aerospace Developed Models

- **Use Analogy Based Estimating**
  - *Ties cost to systems that have been built with known cost*
  - *Allows contractor specific performance to be addressed*
  - *Forces estimator and project to look at cost and complexity of new concepts with respect to previously built hardware*

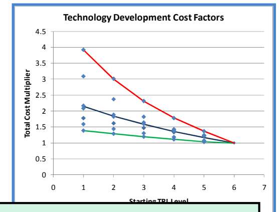
- **Use Both System Level and Lower Level Approaches**
  - *Ensures that lower level approaches do not omit elements or under/overestimate overall cost relative to system level complexity*

CATE Cost Estimating Approach Overview



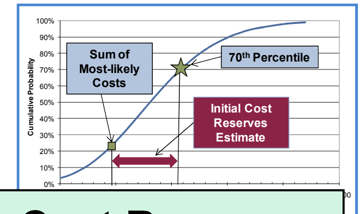
Estimate Instruments & Spacecraft

Multiple analogies and models



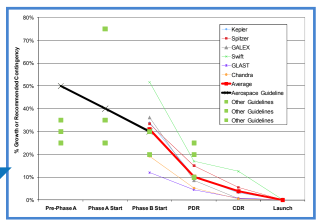
Estimate Other Elements

Based on historical data



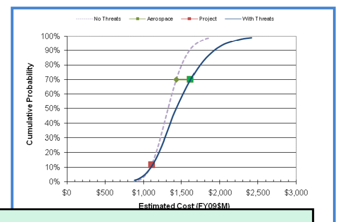
Estimate Cost Reserves

Based on probabilistic cost risk analysis



Estimate Mass and Power Contingency Threat

Re-run estimate with Aerospace contingencies



Estimate Schedule Threat

Based on ISE results and project burn rates

WBS Element	Project Estimate	Aerospace Estimate	Basis of Aerospace Estimate
Phase A	$ 44	$ 44	Pass-through
Mission PM/SE/MA	$ 45	$ 98	Wrap factors from Kepler, Spitzer, Chandra, JWST, LRO, GLAST
Instruments	$ 251	$ 308	MICM, analogies (Spitzer, Kepler, WISE, IRS, STIS, ACS, WFPC2)
Spacecraft	$ 174	$ 243	NAFCOM, analogies to Kepler, Spitzer, SDO, LRO
Pre-launch Ground and Science	$ 98	$ 92	Wrap factors from Spitzer, Chandra, and JWST
Phase E Costs and EPO	$ 160	$ 183	MO costs from HST, Spitzer, Chandra. DA passed-through.
Total Reserves	$ 172	$ 309	70th Percentile from cost risk Analysis
Launch Vehicle/Services	$ 161	$ 154	Atlas 511 assumed. Costs from Flagship Mission Studies
Total Mission Cost Without Threats	**$ 1,105**	**$ 1,432**	
Schedule Threats		$ 82	9 months at project burn rates
Mass and Power Cont. Threats		$ 76	Additional 288 kg and 186 Watts
LV Threats			

Integrate Results & Level Across Concepts

Cross-check with CoBRA

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Summary

- Cost estimating methods attempt to predict cost of final configuration
- Cost estimating methods are based on actual costs of historical items
- Early project concepts are typically optimistic in complexity, schedule, and cost
- CATE process was developed to "level out" some of the initial optimism and provide a common process for all assessments

Back-up

Recent Aerospace Publications – Cost & Schedule Growth

- <u>**Cost & Schedule Growth Research**</u>
  - ***"Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines,"*** *Bitten R., Emmons D., Freaner C., IEEE Aerospace Conference, March 2007*
  - ***"In Search Of The Optimal Funding Profile: The Effect Of Funding Profiles On Cost And Schedule Growth,"*** *Robert E. Bitten, Debra L. Emmons, and Claude W. Freaner, ISPA / SCEA 2008 Joint International Conference, May 2008*
  - ***"An Assessment Of The Inherent Optimism In Early Conceptual Designs And Its Effect On Cost And Schedule Growth,"*** *Claude W. Freaner, Robert E. Bitten, David A. Bearden, and Debra L. Emmons, SSCAG / SCAF / EACE 2008 Joint International Conference, May 2008*
  - ***"Optimism in Early Conceptual Designs and Its Effect on Cost and Schedule Growth: An Update,"*** *Claude W. Freaner, Robert E. Bitten, & Debra L. Emmons, IEEE Aerospace Conference, March 2010*
  - ***"Impact of Instrument Schedule Growth on Mission Cost and Schedule Growth for Recent NASA Missions,"*** *Kristina Kipp, Stephen Ringler, Erin Chapman and Claude Freaner, IEEE Aerospace Conference, March 2012*
  - ***"A Historical Schedule Growth Basis for Schedule Risk Analyses,"*** *Dean A. Bucher, NASA Cost Symposium, July 2012*
  - ***"Phase E Cost Analysis for NASA Science Missions,"*** *Robert Bitten, Mark Hayhurst, Debra Emmons, Claude Freaner, Voleak Roeum, AIAA Space 2012 Conference, September 2012*
  - ***"Explanation of Change (EoC) Study: Approach and Findings,"*** *Robert Bitten, Debra Emmons, Francesco Bordi, Christopher Scolese, IEEE Aerospace Conference, March 2013*
  - ***"Explanation of Change (EoC) Study: Considerations and Implementation Challenges,"*** *Robert Bitten, Debra Emmons, Francesco Bordi, Matthew Hart, Christopher Scolese, Noel Hinners, IEEE Aerospace Conference, March 2013*

Recent Aerospace Publications - Methodology

- <u>Cost Analysis Methodology</u>
  - ***"Space-Based Optical Sensor Cost Model Final Report,"*** *Aerospace Report No. ATR-99(7626)-1, Robert Kellogg, Norman Lao, and Robert Bitten, June 15, 1999*
  - ***"An Analogy-based Method for Estimating the Costs of Space-based Instruments,"*** *Robert Kellogg and Samson Phan, IEEE Aerospace Conference Proceedings, March 2003.*
  - ***"An Analogy-based Method for Estimating the Costs of Spacecraft,"*** *Robert Kellogg, Eric Mahr, and Marcus Lobbia, IEEE Aerospace Conference Proceedings, March 2005*
  - ***"Small Satellite Cost Model 2007 (SSCM07) User's Manual,"*** *Aerospace Report No. ATR-2007(8617)-5, Eric Mahr, September 30, 2007*
  - ***"An Assessment of Different Approaches for Conducting Joint Cost and Schedule Confidence Level Analyses"*** *Robert Bitten, Robert Kellogg, Debra Emmons, NASA Cost Symposium, April 2009*

- <u>Schedule Analysis Methodology</u>
  - ***"The Effect of Schedule Constraints on the Success of Planetary Missions,"*** *Robert Bitten, David Bearden, Norm Lao, and Timothy Park, Fifth IAA International Conference on Low-Cost Planetary Missions, September 2003*
  - ***"A Quantitative Approach to Independent Schedule Estimates of Planetary & Earth-orbiting Missions,"*** *Debra Emmons , 2008 ISPA-SCEA Joint International Conference, May 2008*

- <u>Complexity Based Risk Assessment (CoBRA)</u>
  - ***"A Complexity-based Risk Assessment of Low-Cost Planetary Missions: When is a Mission Too Fast and Too Cheap?",*** *Bearden, David A., Fourth IAA International Conference on Low-Cost Planetary Missions, JHU/APL, Laurel, MD, 2-5 May, 2000*
  - ***"Perspectives on NASA Robotic Mission Success with a Cost and Schedule-constrained Environment,"*** *Bearden, D.A., Aerospace Risk Symposium, Manhattan Beach, CA, August 2005.*
  - *"**A Quantitative Assessment of Complexity, Cost, And Schedule: Achieving A Balanced Approach For Program Success,"** Bitten R.E., Bearden D.A., Emmons D.L., 6th IAA International Low Cost Planetary Conference, Japan, 11-13 October 2005*
  - ***"Complexity Analysis of the Cost Effectiveness of PI-Led NASA Science Missions,"*** *David A. Bearden, Robert C. Kellogg, Mark A. Cowdin, Justin S. Yoshida, Taylor S. Mize, IEEE Aerospace Conference, March 2013*

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