estimate

estimate • analyze • plan • control

SEER Validation Study Results for NASA Space Science Missions

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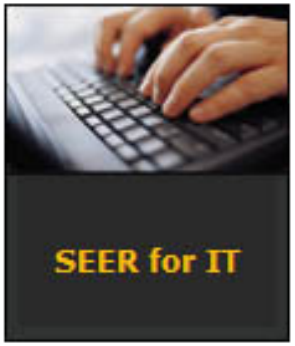
Background: About Galorath

Galorath's consultants and SEER products help clients estimate effort, duration, cost, and gauge risk

- Over 30 years in business conducting mil/aero cost research
- Hundreds of customers, many Fortune 500
- Small business (NAICS 541330, 541511, 541611, 541712)
- Professional services organization provides consulting and training
  - Supporting NASA with ~15 cost estimators
  - Over 100 unique instruments estimated for NASA during the last 2-3 years
- A software publisher / research firm with four flagship products:



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Study Scope: Validation

- A validation study was completed in Fall of 2014 comparing SEER Models to CADRe data on 16 missions.
- Missions used as data points were identified by NASA staff. These came from New Frontiers, Discovery and Explorer class missions.
- The Validation Case ("as built") was chosen to assess model performance.
- A standardized modeling approach was utilized, which formed the basis of a Space Guidance document to be released in the future.

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Study Scope: Validation Points

NASA Life-Cycle Phases	*Pre-Systems Acquisition*	FORMULATION		Approval for Implementation	IMPLEMENTATION			
					Systems Acquisition		*Operations*	*Decom-missioning*
Project Life-Cycle Phases	**Pre-Phase A:** Concept Studies	**Phase A:** Concept and Technology Development	**Phase B:** Preliminary Design and Technology Completion	**Phase C:** Final Design and Fabrication	**Phase D:** System Assembly, Integration and Test, Launch		**Phase E:** Operations and Sustainments	**Phase F:** Closeout

As Built

- Used latest CADRe milestone
- Captured realized risks
- Final MEL configuration
- Actual heritage benefit

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Study Scope: Methodology

- The purpose of the study was to assess the accuracy of the SEER cost modeling tools for use in estimating Space Science missions.
- The study compared "As built" model results to subsequent actual costs for these missions.
- Only costs that the models could estimate were used within the cost actuals in the comparison (No Science, Missions Operations, etc)
- The study sought to refine modeling subjective judgment and standardize setting specific inputs. The goal was to determine the most appropriate settings for the modeling of Space Science missions.

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Study Scope: SEER Models Used

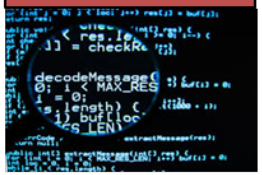
Electro Optical Systems

Optics, Detectors, Coolers, Calibrators, EOS Mechanism, Laser, Optical Bench

Integrated Circuit

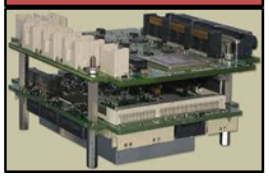
FPGAs, Custom ICs, RFICS, ASICS

SEER for SW



Payload and Spacecraft Software

SEER for HW



Mechanical Systems, Structures, Mechanism, Bus components, Electromechanical Electronics. Also used to calculate Program Management, Systems Engineering and Mission Assurance at rollup levels.

NASA WBS Covered	
1,2,3	PMSEMA
5	Payload
6	Spacecraft
10	System Integration

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Study Scope: Included Missions

Discovery	Explorer	New Frontiers
Grail	Wise	New Horizons
Messenger	IBEX	MAVEN
Contour	NuStar	
Deep Impact	SWIFT	
Genesis	THEMIS	
Dawn	IRIS	
Kepler		

Missions covered 46 instruments

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Study Results:
Process Example - Deep Impact Summary

Description:

- Mission is to comet Tempel 1to expand knowledge of solar system formation
- Mission comprised of fly-by spacecraft and impactor
  - Impactor launched into comet from fly-by spacecraft
  - Fly-by spacecraft observes results of collision of comet by the impactor

Cost:

Actual cost*: $331.0 $M

* Normalized costs: Costs in BY 2014 $, includes Mission level program management, systems engineering, and ATLO, payload and spacecraft costs.

Heritage:

Deep Impact drew from STIS, NICMOS, BMDO, MISTI, Giotto 1P/Halley, Hubble, AXAF aspect camera, and various BATC missions

Mission Risks/Issues:

- Eliminated proposed IR spectrometer from the MRI instrument and the scan mirror from the HRI IR spectrometer.
- The Impactor spacecraft design changed at PDR
- Major software changes resulted in cost growth and schedule slip.
- JPL & BATC NIAT activities added to the project cost

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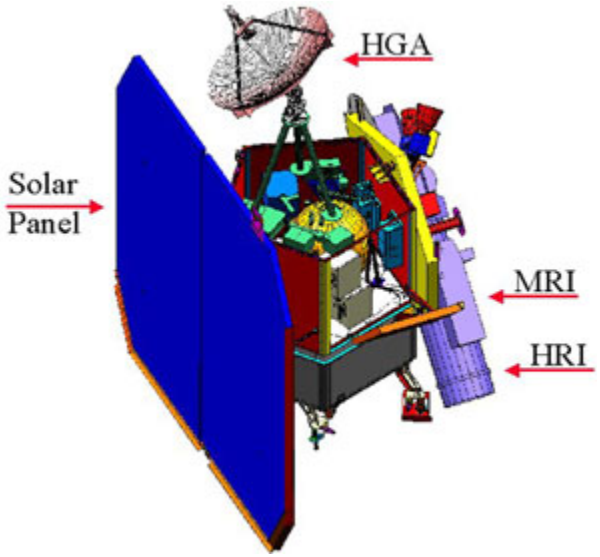
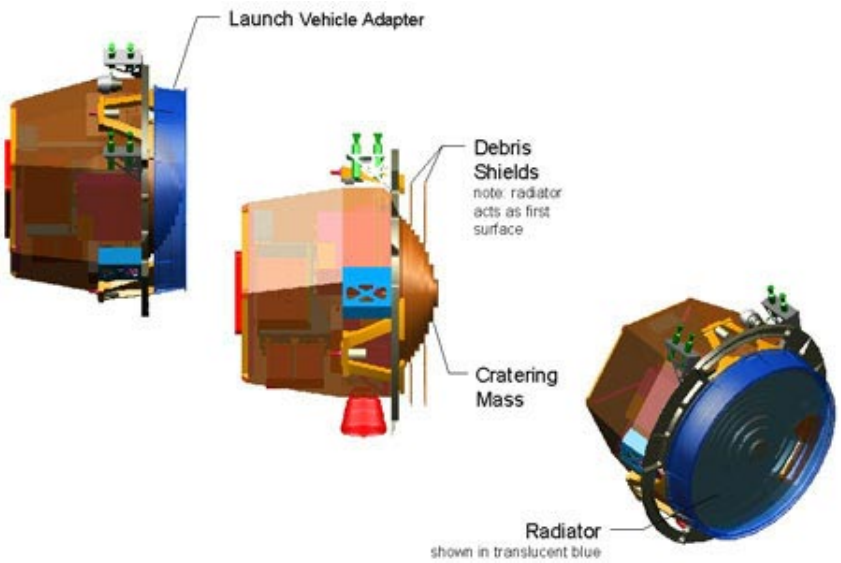
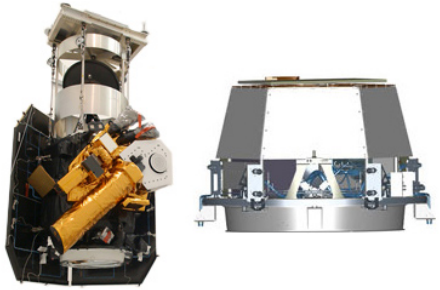
Study Results:
Process Example - Deep Impact Spacecraft







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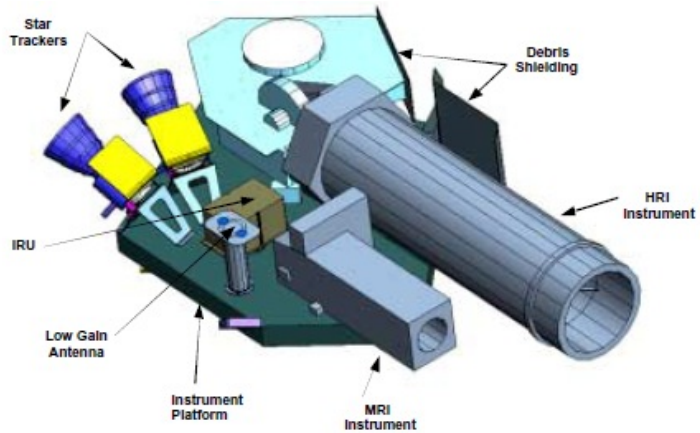
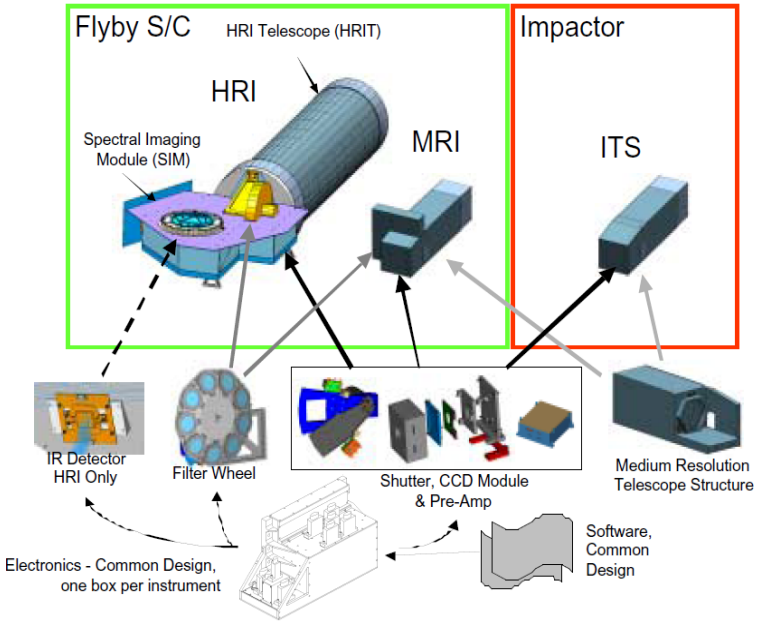
Study Results:
Process Example - Deep Impact Instruments



- System consisted of two spacecraft. Each with its own instruments.
- High Resolution Instrument (HRI)
- Medium Resolution Instrument (MRI)
- Impactor Targeting Sensor (ITS)



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Study Results:
Process Example – Developing the WBS

D99 - # 27 - Flyby S/C					
		Dev Start	*Dev End*	*Prod Start*	*Prod End*
		100		*1001*	*702*
Subsys/Component	# of Units	CBE	Cont (%)	CBE+Cont	
Structure					
Primary					
Secondary					
Solar Panel Substrate					
Mechanisms					
Impactor Release					
Impactor-S/C Disconnect					
HGA Gimball					
Electrical Power & Distr					
Solar Array					
Power Control Unit					
Terminal Board Assy					
Wire Harness					
Battery					
Command, Cntl, & Data					
S/C Controller Unit					
S/C Controller Storage					
Remote Interface Unit					
Communications					
SDST					
X-band TWTA Pwr Amp					
UHF Transceiver					
X-band Omni Antenna					
10 dBi X-band MGA					
UHF MGA					
30 dBi X-band HGA					
WG, coax, and misc					
Thermal Control					
Heaters					
Thermistors wiring					
Radiators					
Paint/Finishes					
MLI Blankets					

- 1: Deep Impact
  - 1.1: Payload
    - 1.1.1: HRI Telescope
    - 1.1.2: MRI Telescope
    - 1.1.3: HRI Spectal Imaging Module
    - 1.1.4: MRI Spectal Imaging Module
    - 1.1.5: ITS
    - 1.1.6: HRI Common Electronics
    - 1.1.7: MRI Common Electronics
    - 1.1.8: ITS Common Electronics
  - 1.2: Spacecraft
    - 1.2.1: Fly-by Spacecraft
      - 1.2.1.1: Structure
      - 1.2.1.2: Electrical Power & Distr
      - 1.2.1.3: Command, Cntl, & Data
      - 1.2.1.4: Communications
      - 1.2.1.5: Thermal Control
      - 1.2.1.6: Attitude Det & Control
      - 1.2.1.7: Propulsion
    - 1.2.2: Impactor
      - 1.2.2.1: Structure
      - 1.2.2.2: Mechanisms
      - 1.2.2.3: Electrical Power & Distr
      - 1.2.2.4: Command, Cntl, & Data
      - 1.2.2.5: Telecommunication

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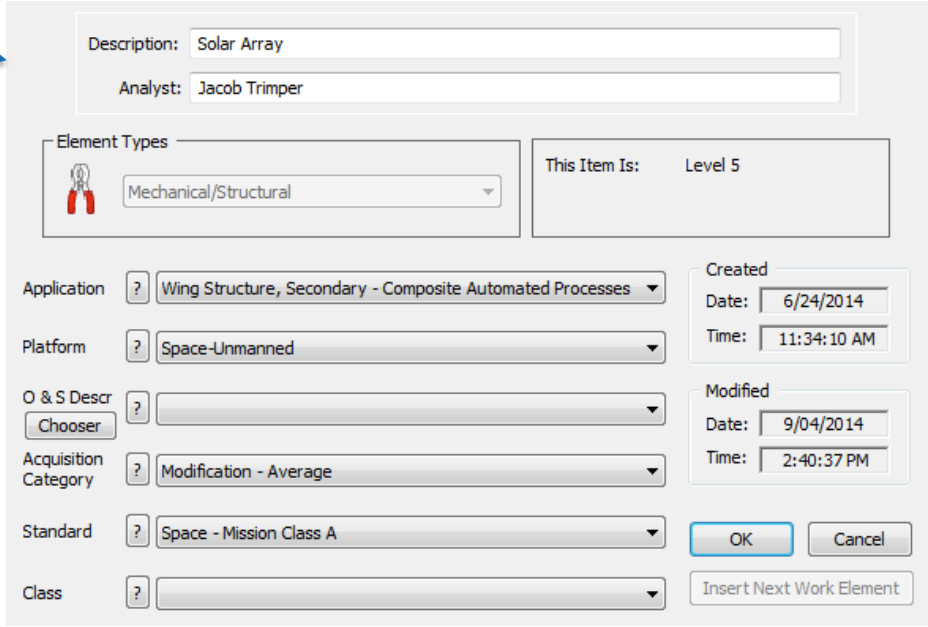
Study Results:
Process Example – Developing the elements

- 1.2: Spacecraft
  - 1.2.1: Fly-by Spacecraft
    - 1.2.1.1: Structure
    - 1.2.1.2: Electrical Power & Distr
      - 1.2.1.2.1: Solar Array
      - 1.2.1.2.2: Power Control Unit
        - 1.2.1.2.2.1: Bus Control Board
        - 1.2.1.2.2.2: Network Interface Card
        - 1.2.1.2.2.3: 1553 Interface
        - 1.2.1.2.2.4: Analog Mux
        - 1.2.1.2.2.5: Discrete Out
        - 1.2.1.2.2.6: General Purpose Switch Board
        - 1.2.1.2.2.7: Chassis
      - 1.2.1.2.3: Terminal Board Assy
      - 1.2.1.2.4: Wire Harness
      - 1.2.1.2.5: Battery
      - 1.2.1.2.6: Solar Panel Substrate
    - 1.2.1.3: Command, Cntl, & Data
    - 1.2.1.4: Communications
    - 1.2.1.5: Thermal Control
    - 1.2.1.6: Attitude Det & Control
    - 1.2.1.7: Propulsion
  - 1.2.2: Impactor
    - 1.2.2.1: Structure
    - 1.2.2.2: Mechanisms



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Study Results:
Process Example – Running the reports

	Total Cost	Elapsed Months
DEVELOPMENT TOTAL	**1,425,841**	**5.74**
Design	130,481	
Prototype Hardware	558,509	
Engineering Test	172,684	
Integration and Test	126,393	
Systems Engineering	78,558	
Program Management (Dev)	110,576	
Engineering Data	36,305	
Management Data	16,779	
Support Data	47,739	
Peculiar Support Equipment	55,849	
Tooling	91,968	

	Total Cost	Average Unit
PRODUCTION TOTAL	**754,494**	**754,494**
Material*	5,720	5,720
Fabrication	159,845	159,845
Integration and Assembly	328,088	328,088
Production Support	106,491	106,491
Sustaining Engineering	63,130	63,130
Program Management (Prod)	84,403	84,403
Tool Maintenance	6,816	6,816

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Study Results:
Process Example – Mapping the results

CADRe WBS Item	Estimated by SEER
01, 02, 03 SE/PM/MA	01, 02, 03 SE/PM/MA
04 Science	04 Science
05 Payload	05 Payload
05.XX Software	05.XX Software
06 Flight System	06 Flight System
06.XX Software	06.XX Software
07 Mission Operations	07 Mission Operations
08 Launch Vehicle Services	08 Launch Vehicle Services
09 Ground Systems	09 Ground Systems
10 Systems Integrations and Testing	10 Systems Integrations and Testing
11 EPO	11 EPO

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Study Results: Validation Case

Model

- Error in data
- KTPP weighting

CADRE "As Built" data

- Hidden SW costs
- Bucketing: Science, ATLO
- Hidden Spares inputs
- Hidden Microelectronics
- Efforts-to-date on descoped instruments
- Final heritage picture

% Difference

Mean = -1%
Std Dev = 19%

$$\%\,difference = \frac{(SEER\ estimate) - (CADRe\ "As\ Built")}{CADRe\ "As\ Built"} \times 100\%$$

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Space Modeling Guidance

- New knowledge bases (parameter presets) were created during the validation study that will be released in a future maintenance release for SEER H.
- This validation study also led to the development of many recommendations and guidance principles for modeling.
  - Guidance developed cover the following areas of a Space Science mission:
    - Mission level
    - Payload
    - Spacecraft
- The recommended guidance principles are currently being worked into a Space Guidance document for public release.

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Conclusion: What did the study achieve?

- Validated SEER Models against another 16 Missions.
- Validated standard modeling approaches currently in use
- Improved focus on historical issues which have escalated costs
- Set basis for greater efficiencies in future studies
- Research team achieved greater understanding of CADRe data and key modeling issues.

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Conclusion: Space Estimation Course

- Galorath is working to release more specific Space Guidance that will support the user community in the preparation of cost models.
- Galorath is currently working on curriculum for a new Space Cost Estimation course using SEER component level parametric models. Course will employ the use of SEER EOS, IC, SW and H models.
- This 3-day course will include:
  - Statistics, regression & cost risk analysis overview
  - Standardized space modeling guidance for spacecraft buses, payloads, PMSEMA
  - Optimizing use of IC and EOS for more accurate estimating of space technologies
  - Use of SEER for trade space analysis

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