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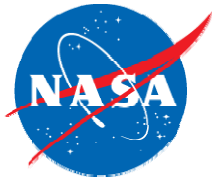

The Parametric Mission Cost Model and Model-Based Design

ISPA / SCEA

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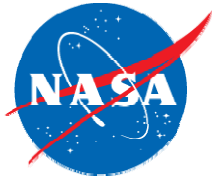
* The research described in this presentation was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.



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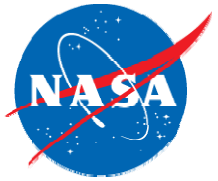
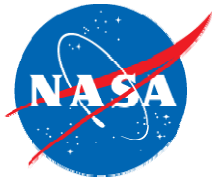
  - **Karen Lum**
  - **Erik Monson**
  - **Leigh Rosenberg**
  - **Keith Warfield**



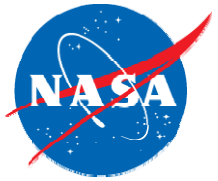
Objective

- The culture of cost estimation at JPL has changed in recent years.
  - Focus on risk aversion
  - More detailed WBS
  - Specific risk factors that can cause cost growth have been identified
  - Priorities shift frequently - more studies are performed
  - New design factors/subsystems added to design teams
  - Increased focus placed on parametric models and risk assessment
  - Added responsibility assigned to performing subsystem organizations (must sign off cost estimates)
- Therefore, the tools used to estimate accurate costs also must evolve over time in order to be relevant.



Background

- **The Parametric Mission Cost Model (PMCM)** has been in use at JPL since 1998. Its objective is to provide project cost estimates by WBS element for unmanned space missions that are implemented at JPL. A PMCM cost estimate is similar to one obtained from JPL's Advanced Projects Design Team (Team X) for early planning studies.



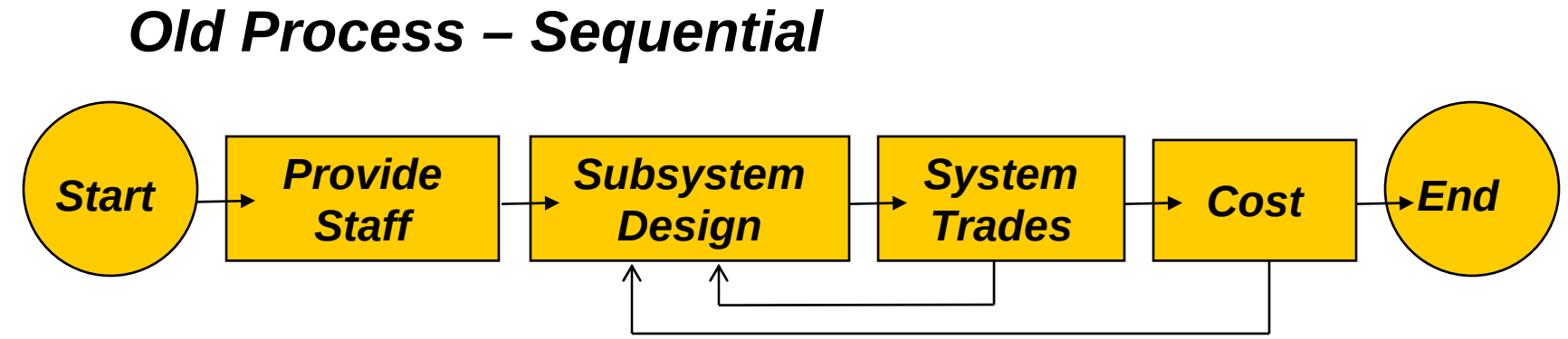
What is Team X?

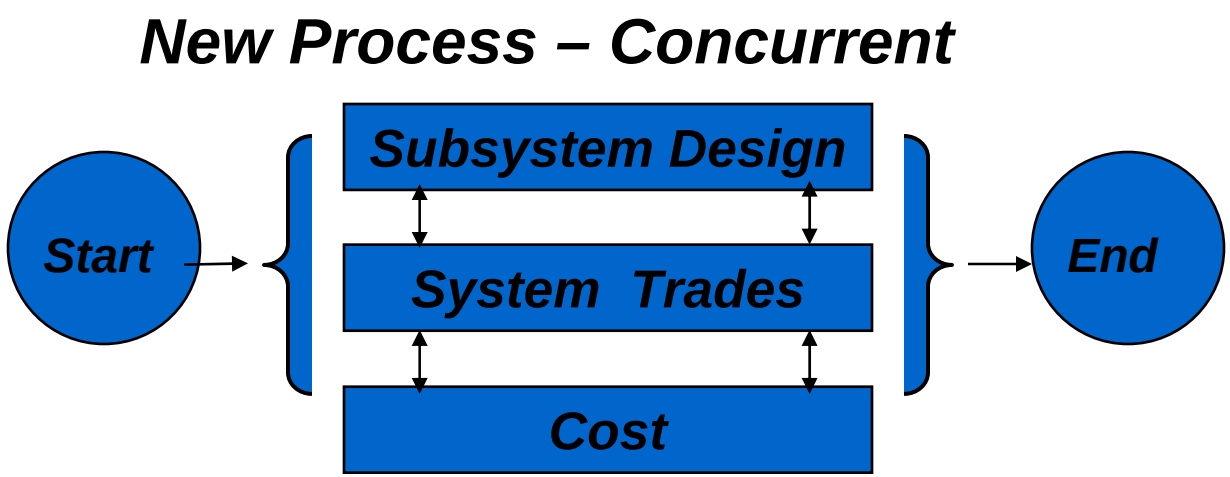
The Advanced Projects Design Team ("Team X") was started in April of 1995. The team is chartered to:

- Improve the speed and quality of JPL's new mission concepts.
- Create a reusable study process with dedicated facilities, equipment, procedures, and tools using concurrent engineering methods.
- Develop a database of initial mission requirements that can be easily updated and electronically transferred for use in subsequent project phases.
- Develop mission generalists from a pool of experienced engineers.

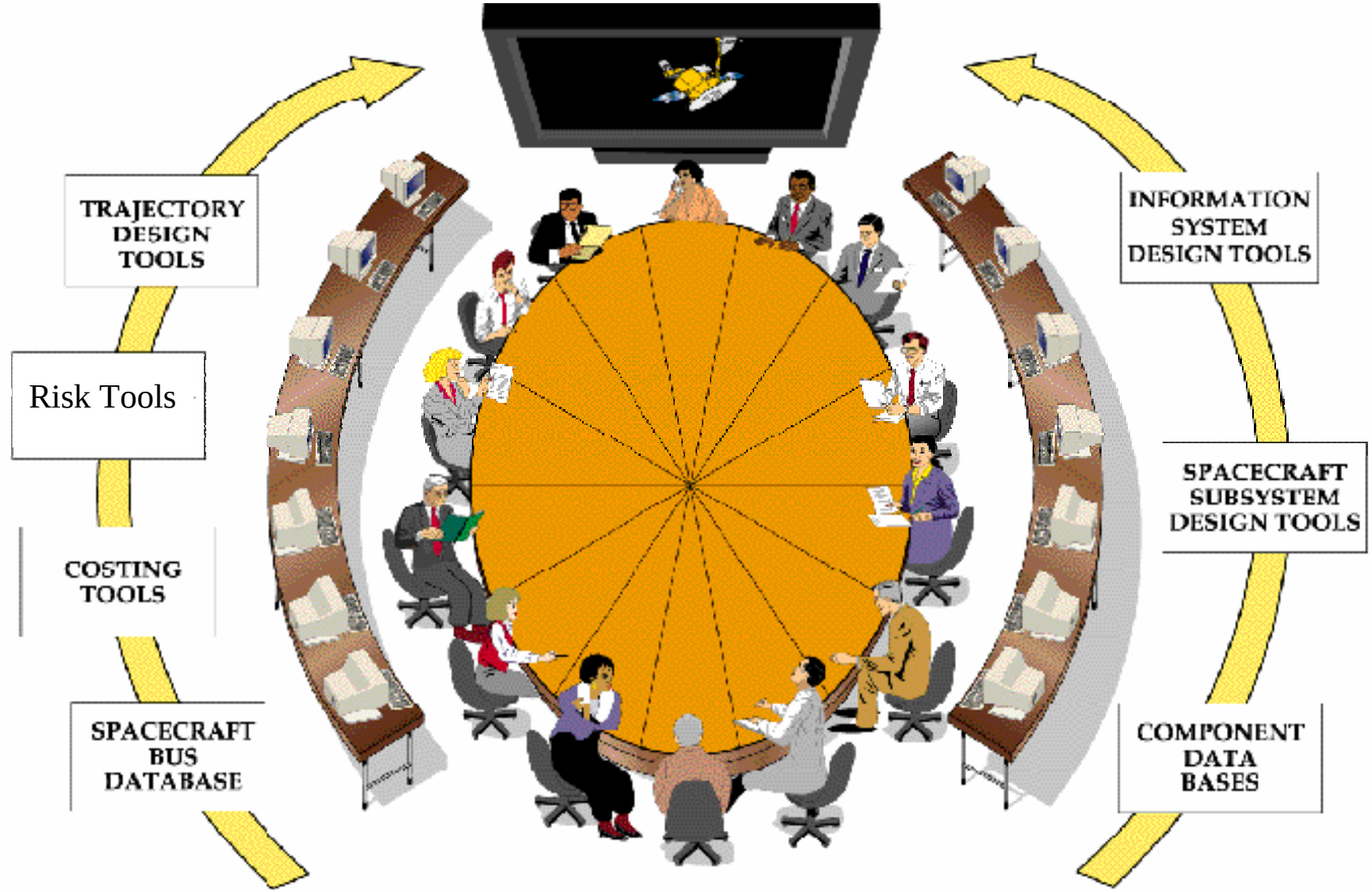
800+ completed studies to date

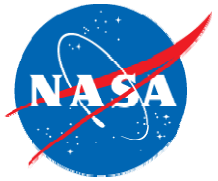
Concurrent Design Process





Design Team Tools



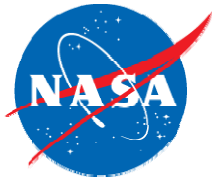


Changing Environment

- More mission studies being requested than ever before
  - Increased detail has made mission studies more costly
  - Schedule crunch
    - Many studies have quick turnaround requirements
    - Team X is as busy as ever!
- Focus on identifying cost risks earlier in the process

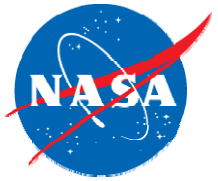
Parametric estimation is quickly becoming more prevalent and important in the mission conceptualization process

- Increased use of parametric estimation models in Team X for the purposes of high-quality cost estimates
- Use of PMCM for quick-turnaround estimates
  - Prior to Team X study
  - As a validation of more detailed estimates



Parametric Mission Cost Model (PMCM)

- Incorporates a series of cost estimating relationships (CERs) which report cost by WBS element.
- The baseline CERs were developed through multivariate linear regression, with some use of lookup tables and use of JPL Design Principles
- Based on studies conducted by JPL's Advanced Projects Design Team (Team X).
- Intended to provide cost estimates similar to those provided by Team X. These estimates are a most likely cost within a statistical range.
- Originally constructed in 1998, version 4 was built in 2004 based on ≈100 Team X studies. Currently working on version 5 (web-based)
- Includes over 100 technical inputs. The number of subjective inputs have been minimized.
- Outputs at an element-level WBS down to level 2 or 3.
- Can provide a statistical range on output costs based on probabilistic inputs and normally distributed CER coefficients when run in Monte Carlo mode
- Validated against actual JPL missions and compared to grassroots proposal estimates
- Used to estimate proposed mission costs when grass roots costs have not been estimated.
- Applied to various proposed missions as an independent check on grass roots costs for Mars Scout, Discovery, New Frontiers, etc.



Example of Model Inputs

Command and Data Handling System
- Avionics Mass (kg)
- Design Heritage (major, minor, new)
- Onboard flight computer (y/n)

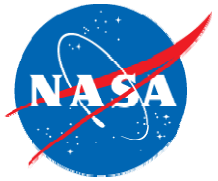
Power System
- Beginning of life power (watts)
- Size of Battery (watt-hours)
- Type of power system (RTG, Solar)

Mission
- Launch Vehicle Type
- Mission Class
- Destination (Earth, Inner Planets, Mars, etc.)
- Fiscal Year of Estimate

System
- Sample Return Mission (y/n)
- Radiation Dose

Model inputs can be detailed or simplified, depending on what data is known at the time

- Simplified
  - Useful for early conceptualization when only analagous parameters are available
  - Typically mass-only for subsystems
- Detailed
  - Useful when detailed technical parameters are available, or adequate analogies exist



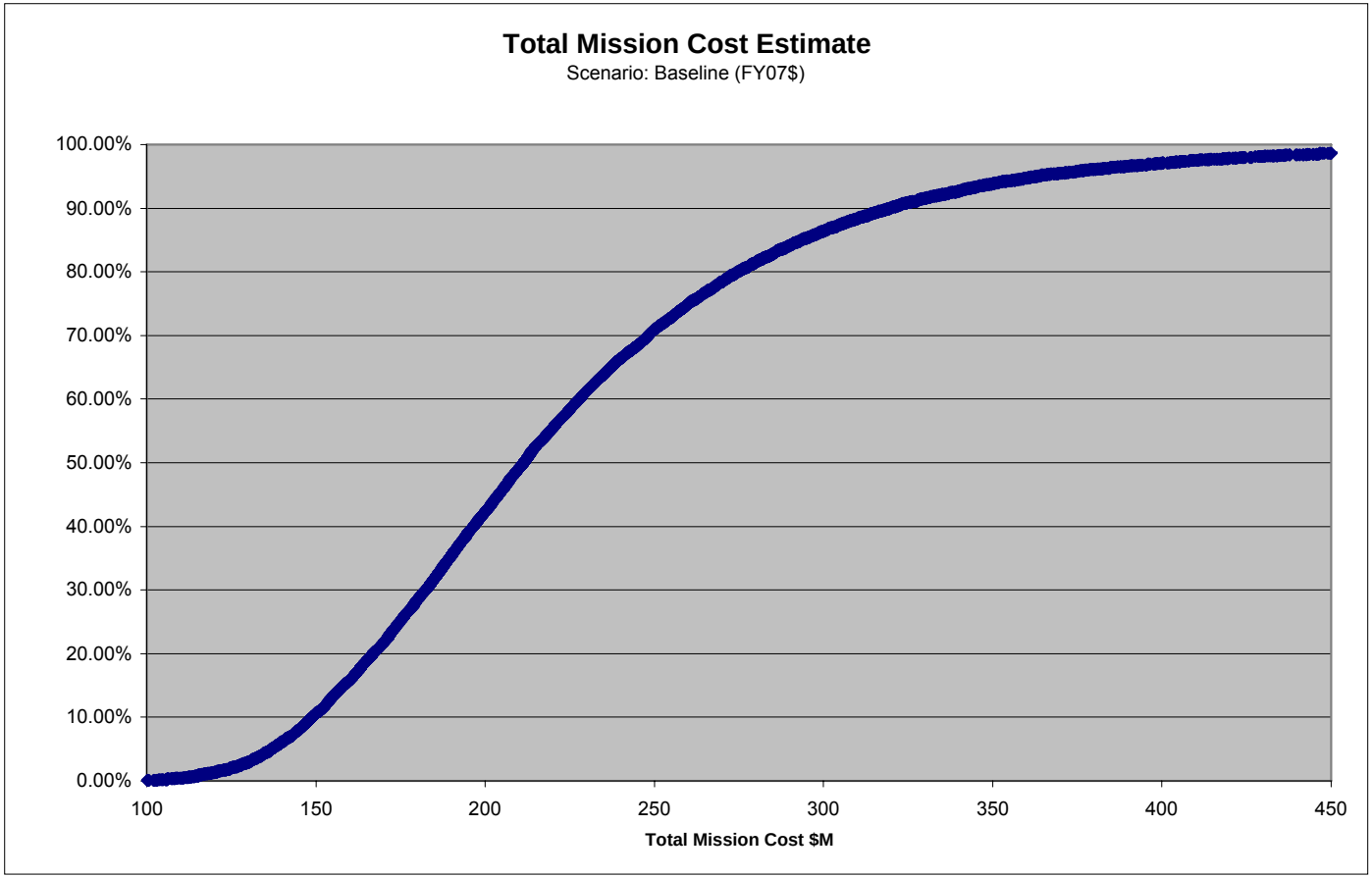
PMCM WBS Output

		Formulation (Phase A/B) ($M)	Implementation (Phase C/D) ($M)	Development Total ($M)	Operations (Phase E) ($M)	Project Total (FY 2003$M)	Notes/Models
Total Project Costs ($M)		$27.0M	$261.9M	$365.1M	$186.5M	$551.6M	
1.0	Project Management	$2.7M	$24.0M	$26.7M	$18.6M	$45.3M	
1.1	Project Manager & Staff	$0.4M	$3.7M	$4.1M	$14.4M	$18.4M	
1.2	Launch Approval	$1.4M	$12.2M	$13.5M		$13.5M	
1.3	Planetary Protection Approval	$0.0M	$0.0M	$0.0M		$0.0M	
1.4	Education & Public Outreach	$0.1M	$0.8M	$0.9M	$2.6M	$3.5M	
1.5	Mission Assurance	$0.8M	$7.4M	$8.2M	$1.6M	$9.8M	
2.0	Science Team	$0.1M	$0.9M	$1.0M	$1.1M	$2.1M	
3.0	Mission Design & Project Engineering	$0.3M	$2.8M	$3.1M		$3.1M	
4.0	Instruments	$10.6M	$95.5M	$106.1M		$106.1M	
5.0	Spacecraft	$6.5M	$58.8M	$65.3M		$65.3M	
5.1	Spacecraft	$6.5M	$58.8M	$65.3M		$65.3M	2001 PMCM v3 (Subsystem Level)
5.2	Stage 2			$0.0M		$0.0M	
5.3	Stage 3			$0.0M		$0.0M	
5.4	Stage 4			$0.0M		$0.0M	
5.5	Stage 5			$0.0M		$0.0M	
6.0	ATLO		$13.5M	$13.5M		$13.5M	2001 PMCM v3 (Subsystem Level, same as
7.0	Mission Operations & Development	$1.4M	$14.0M	$15.4M	$142.5M	$157.8M	
8.0	Other			$0.0M		$0.0M	
9.0	Reserves	$5.4M	$52.4M	$57.8M	$24.3M	$82.1M	AB:25%,CD:25%,E:15%
10.0	Launch Vehicle			$76.2M		$76.2M	
11.0	Upper Stage / SRM			$0.0M		$0.0M	

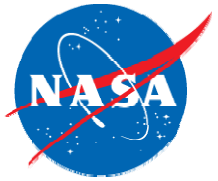
Mission Name: Baseline
Cost Analyst: Leigh Rosenberg
Date: Wed 22 May 2002

More detailed output on spacecraft, instruments, mission operations, & statistical cost range is also available.

Probabilistic Cost Estimate



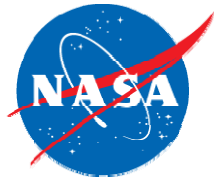
Cost estimate is provided as an ‘S-curve’



Major Cost Risk Factors

(used in developing risk curves)

- MISSION COMPLEXITY
  1. Mission with multiple flight elements
  2. Operation in harsh environments
- SIGNIFICANT TECHNICAL DEVELOPMENT
  1. Mission enabling spacecraft technology with TRL<5
- TECHNICAL MARGINS
  1. New design with multiple parameters not meeting margin requirements specified in the design guidelines
- SYSTEM ARCHITECTURE
  1. New system architecture
  2. Level 1 requirements not well defined in formulation phase
  3. Excessive reliability requirements
- CONTRACTOR CAPABILITIES MATCH
  1. Contractor inexperienced in mission application
- PROGRAMMATIC/COST & SCHEDULE MARGIN
  1. Schedule margins below guidelines
- MANAGEMENT & ORGANIZATION
  1. Inadequate team & management experience
  2. Selection of science instruments late in Phase B



PMCM Validation Studies

Comparison	Version	Cases	Average Cost Δ	Standard Deviation	Minimum Δ	Maximum Δ
Discovery Proposals (1998)	1	16	12.4%	26.9%	-16.2%	92.0%
Actual Projects Total Cost (1999)	**2**	**11**	**4.7%**	**35.2%**	**-45.6%**	**89.4%**
Discovery Proposals (2000)	2	13	6.7%	14.8%	-6.0%	44.7%
Mars Scout Proposals (2002)	2	13	-2.6%	6.8%	-10.3%	11.9%
Actual Spacecraft Costs (2003)	**2**	**11**	**2.1%**	**31.0%**	**-33.1%**	**60.1%**
Actual Spacecraft Costs (2003)	**3**	**11**	**16.8%**	**42.5%**	**-24.8%**	**98.5%**
New Frontiers Proposals (2004)	2	4	-1.4%	6.3%	-9.8%	4.3%
Discovery Proposals (2006)	4	7	2.7%	8.5%	-3.0%	-12.0%
Mars Scout Proposals (2006)	4	11	2.9%	9.1%	0.2%	24.2%
		Version 1	12.4%	26.9%	-16.2%	92.0%
		Version 2	1.9%	18.8%	-21.0%	42.1%
		Version 3	16.8%	42.5%	-24.8%	98.5%
		Version 4	2.8%	8.8%	-1.4%	6.1%
		Average (all studies)	4.9%	20.1%	-16.5%	45.9%
		Average (actuals only)	7.9%	36.2%	-34.5%	82.7%

Version 4.0 validation against ‘actuals’ is nearly complete

Changes in WBS

Original WBS

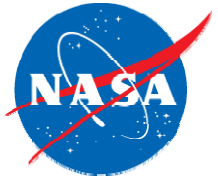
Total Project Costs ($M)

- 1.0 Project Management
  - 1.1 Project Manager & Staff
  - 1.2 Launch Approval
  - 1.3 Planetary Protection Approval
  - 1.4 Education & Public Outreach
  - 1.5 Mission Assurance
- 2.0 Science Team
- 3.0 Mission Design & Project Engineering
- 4.0 Instruments
- 5.0 Spacecraft
  - 5.1 Spacecraft
- 6.0 ATLO
- 7.0 Mission Operations & Development
- 8.0 Other
- 9.0 Reserves
- 10.0 Launch Vehicle
- 11.0 Upper Stage / SRM

Updated, Standard WBS

Total Project Costs ($M)

- 1.0 Project Management
  - 1.1 Project Manager & Staff
- 2.0 Mission Design & Project Engineering
  - 2.1 Project Systems Engineering
  - 2.2 Mission and Navigation Design
  - 2.3 Project Software Engineering
  - 2.4 End-To-End Information System
  - **2.5 Information Systems Engineering & Comm**
  - **2.6 Configuration Management**
  - 2.7 Planetary Protection
  - **2.8 Launch Approval**
  - 2.9 Launch System Integration
  - 2.10 Project V & V
- 3.0 Mission Assurance
- 4.0 Science Team
  - 4.1 Science Team
  - 4.6 Education & Public Outreach
  - 7.3 Experimental Flight Data Products
- 5.0 Instruments
- 6.0 Spacecraft
  - 6.1 Spacecraft
  - 6.2 ATLO
- 7.0 Mission Operations & Development
  - 7.1 Command, Telemetry, & Mission Data Management
  - 7.2 Navigation
  - Sequence Engineering, Science Observation Planning, Ground
  - 7.4 Communications & Information
  - 7.5 Project Provided Tasks
  - 7.6 Antenna Charges
- 8.0 Launch System
  - 8.1 Launch Vehicle
  - 8.2 Upper Stage / SRM
- #.# Other
- 9.0 Reserves



Future WBS

1.0 Project Management
- 1.1 Project Management
- 1.2 Business Management
- 1.4 Review Support
- 1.5 Facilities
- 1.6 Launch Approval

2.0 Project Systems Engineering
- 2.1 Project Systems Engineer
- 2.2 Project Software Engineering
- 2.3 End-To-End Information Systems
- 2.5 Configuration Management
- 2.6 Planetary Protection
- 2.7 Contamination Control
- 2.9 Launch Systems Engineering
- 2.10 Project Verification and Validation
- 2.11 Risk Management

3.0 Safety and Mission Assurance
- 3.1 SMA Management
- 3.2 Systems Safety
- 3.3 Environmental Engineering
- 3.4 Reliability Engineering
- 3.5 Parts Engineering
- 3.6 Hardware Quality Assurance
- 3.7 Software Quality Assurance
- 3.8 Software IV&V
- 3.9 Mission Operations Assurance

4.0 Science
- 4.1 Science Management
- 4.2 Science Implementation
- 4.3 Science Support

5.0 Payload System
- 5.1 Payload Systems Management
- 5.2 Payload Systems Engineering
- 5.3 Payload Product Assurance
- 5.30 Science Instrument Purge
- 5.31 Common Payload System
- 5.32 Payload M&P
- 5.33 Payload System I&T

6.0 Flight System
- 6.1 Flight System Management
- 6.2 Flight System Systems Engineering
- 6.3 Flight System Product Assurance
- 6.4 Power Subsystem
- 6.5 C&DH Subsystem
- 6.6 Telecom Subsystem
- 6.7 Mechanical Subsystem
- 6.8 Thermal Subsystem
- 6.9 Propulsion Subsystem
- 6.10 GN&C Subsystem
- 6.11 Harness
- 6.12 Flight Software
- 6.13 Materials and Procedures
- 6.14 Flight System Testbeds
- 6.15 Flight System I&T

7.0 Mission Operations System

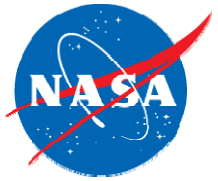
8.0 Launch System

9.0 Ground Data System

10.0 Project Systems I&T

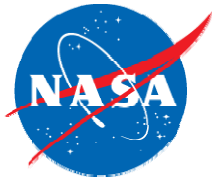
11.0 Education and Public Outreach

12.0 Mission Design
- 12.1 Mission Design Management
- 12.2 Mission Analysis
- 12.3 Mission Engineering
- 12.4 Navigation Design



Changes on the Horizon

- **Web-based implementation of PMCM**
- **New NASA Instrument Cost Model (NICM) to be added to PMCM**
- **Mission Operations System / Ground Data System model overhaul**
  - A simplified, derived model to be included in PMCM, providing useful cost breakout
- **Team X Cost Model Overhaul - all subsystem teams will build new cost models in 2007**
  - Standardized operation based on system-level requirements
  - Requires detailed model output
  - Integrates into Team X environment
  - Management 'sign-off' on generated estimates
  - **Will serve as the basis for the next version of PMCM, providing unprecedented levels of fidelity in a quick-turnaround parametric cost model**

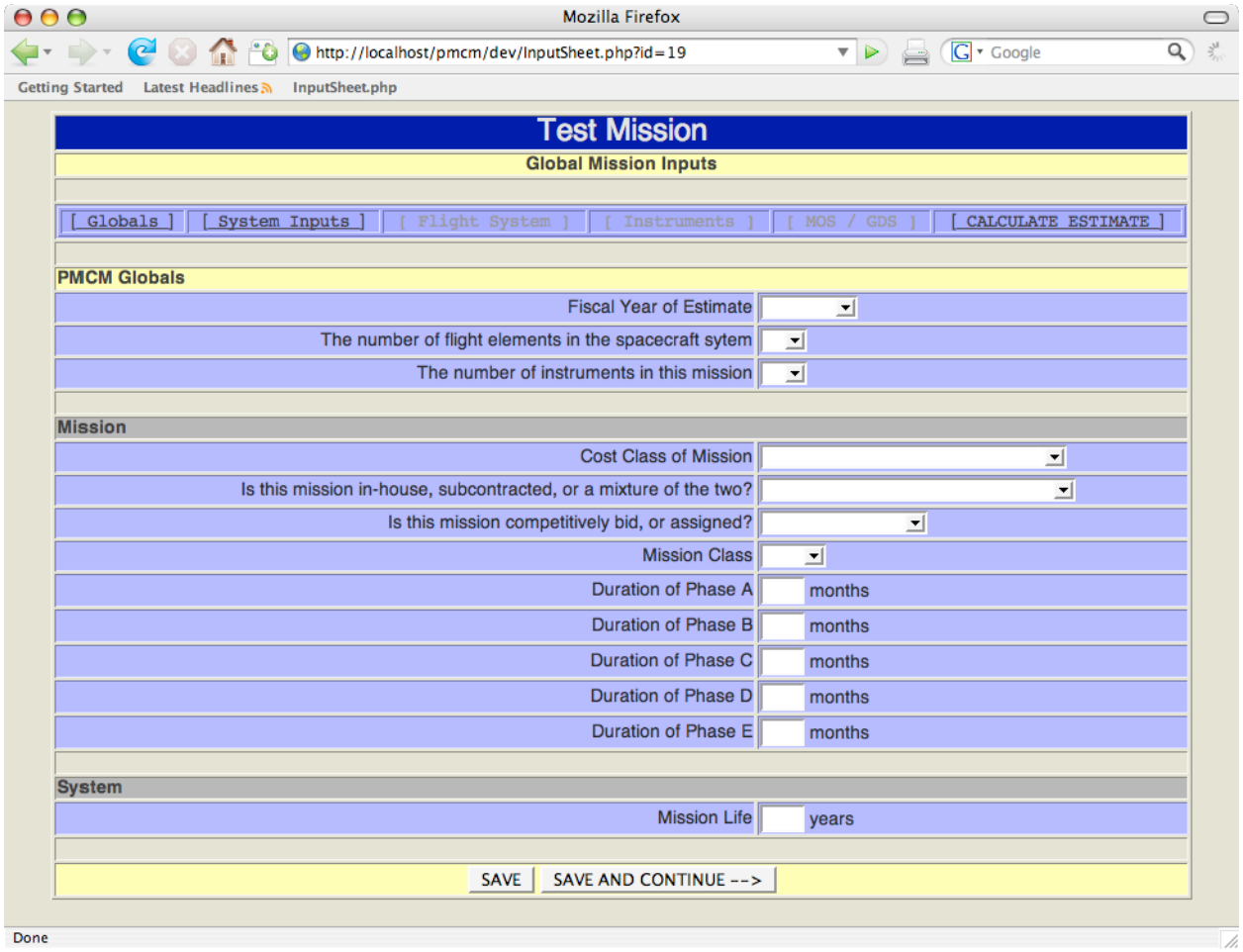


Web-based Model

PMCM is currently being ported to a web-based system. Our goals are to:

- Increase ease-of-use
  - Web-based form with the minimum number of inputs necessary to run the model
  - Allow for pre-population of data and interactive help
- Add flexibility
  - Model estimates task costs and is WBS-independent
  - User can run the full model or selected CERs
  - Server-based architecture allows user to re-run an existing study with new CERs by entering only the necessary (previously unentered) parameters to run under the new CERs
    - This allows for easy validation of new CERs using historical data

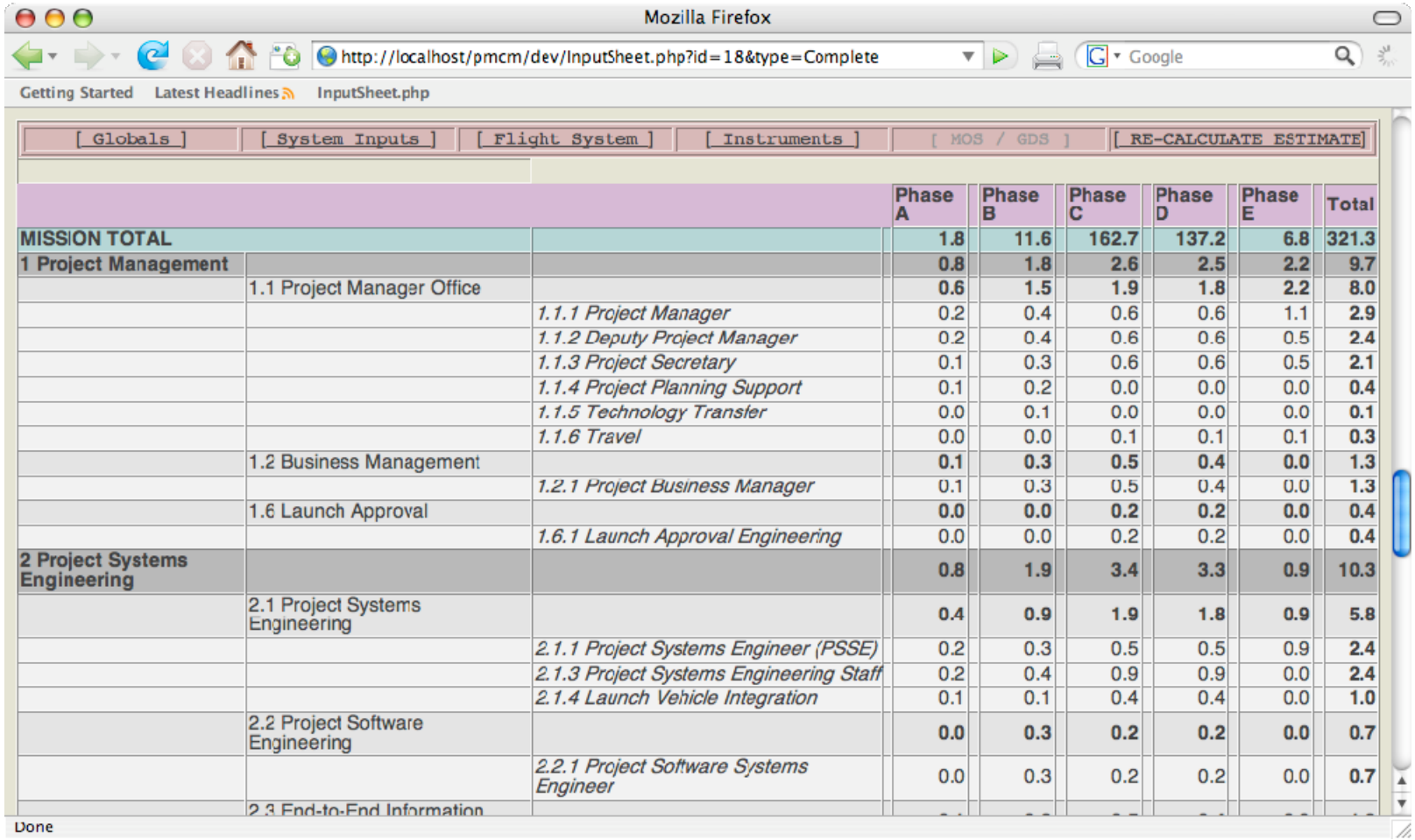
Example Web Input Sheet



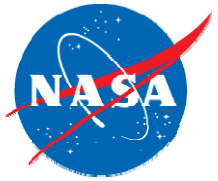
Input page is dynamically generated based on the CER versions selected

- Cuts down on clutter - only required parameters are displayed
- Primary (simple) inputs displayed first; determines which questions need to be subsequently asked
- User can save changes and return later

Example Web Output



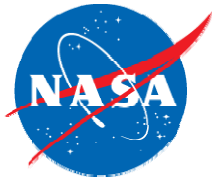
			Phase A	Phase B	Phase C	Phase D	Phase E	Total
MISSION TOTAL			**1.8**	**11.6**	**162.7**	**137.2**	**6.8**	**321.3**
1 Project Management			**0.8**	**1.8**	**2.6**	**2.5**	**2.2**	**9.7**
	1.1 Project Manager Office		**0.6**	**1.5**	**1.9**	**1.8**	**2.2**	**8.0**
		1.1.1 Project Manager	0.2	0.4	0.6	0.6	1.1	**2.9**
		1.1.2 Deputy Project Manager	0.2	0.4	0.6	0.6	0.5	**2.4**
		1.1.3 Project Secretary	0.1	0.3	0.6	0.6	0.5	**2.1**
		1.1.4 Project Planning Support	0.1	0.2	0.0	0.0	0.0	**0.4**
		1.1.5 Technology Transfer	0.0	0.1	0.0	0.0	0.0	**0.1**
		1.1.6 Travel	0.0	0.0	0.1	0.1	0.1	**0.3**
	1.2 Business Management		**0.1**	**0.3**	**0.5**	**0.4**	**0.0**	**1.3**
		1.2.1 Project Business Manager	0.1	0.3	0.5	0.4	0.0	**1.3**
	1.6 Launch Approval		**0.0**	**0.0**	**0.2**	**0.2**	**0.0**	**0.4**
		1.6.1 Launch Approval Engineering	0.0	0.0	0.2	0.2	0.0	**0.4**
2 Project Systems Engineering			**0.8**	**1.9**	**3.4**	**3.3**	**0.9**	**10.3**
	2.1 Project Systems Engineering		**0.4**	**0.9**	**1.9**	**1.8**	**0.9**	**5.8**
		2.1.1 Project Systems Engineer (PSSE)	0.2	0.3	0.5	0.5	0.9	**2.4**
		2.1.3 Project Systems Engineering Staff	0.2	0.4	0.9	0.9	0.0	**2.4**
		2.1.4 Launch Vehicle Integration	0.1	0.1	0.4	0.4	0.0	**1.0**
	2.2 Project Software Engineering		**0.0**	**0.3**	**0.2**	**0.2**	**0.0**	**0.7**
		2.2.1 Project Software Systems Engineer	0.0	0.3	0.2	0.2	0.0	**0.7**
	2.3 End-to-End Information							



What's Next

JPL is planning to implement a completely model-driven design process for costing. This new paradigm includes:

- PMCM used for quick-turnaround cost estimates and 'what-if' analysis
- Team X cost models to generate a high-fidelity cost estimate for mission studies
- Goal of 100% model-based estimation for competitive mission proposals



Conclusion

- Parametric cost estimation is becoming an important activity in the mission conceptualization and design process
  - Fast turnaround allows for easy design trades
  - Adds consistency to costing process
  - Increased acceptance allows parametrics to be incorporated into the mainstream costing process