



Estimating Challenges & Solutions @ NASA Goddard Space Flight Center: Past, Present, & Future

Cabin Samuels

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Agenda

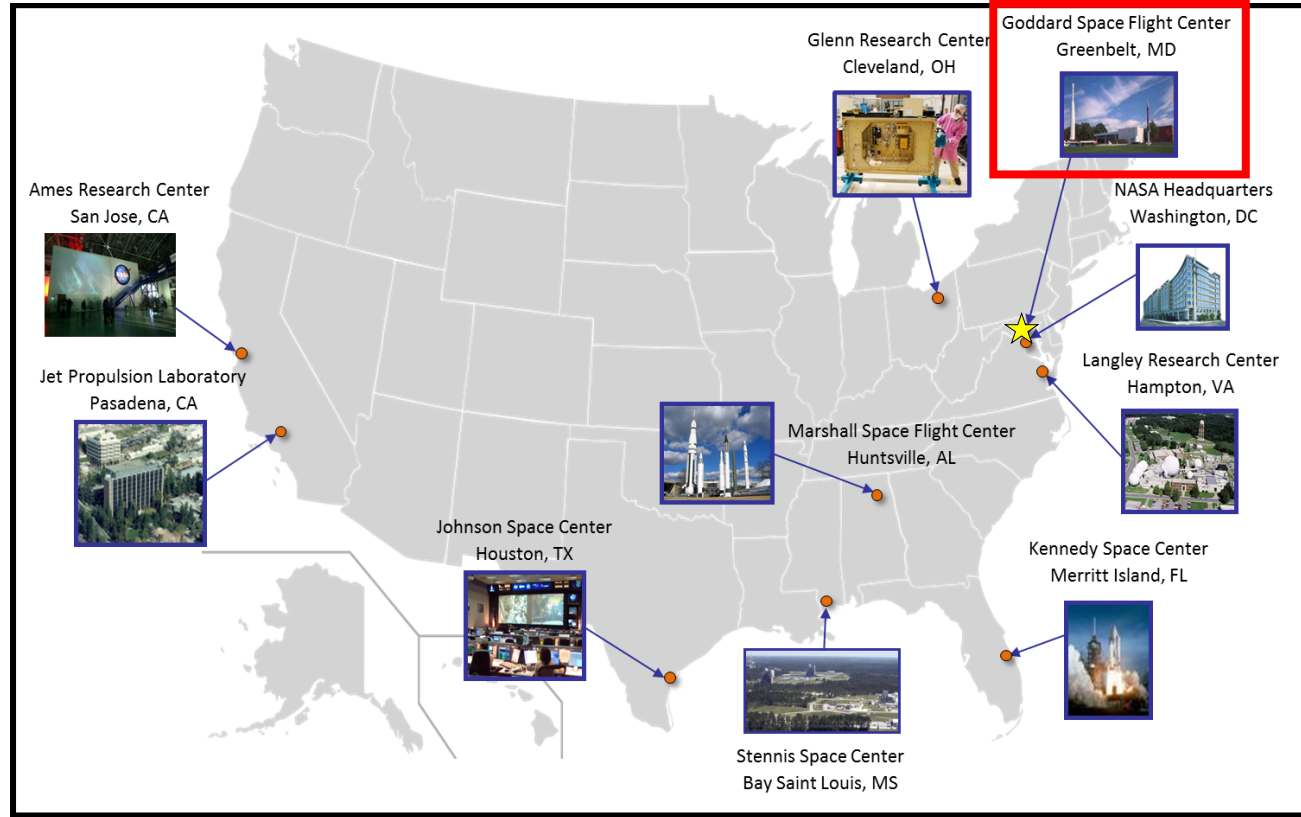
- What is Goddard / Cost Estimating Modeling & Analysis (CEMA) Office?
- Unique Landscape of Space Cost Estimation
- CEMA's Current Approach to Cost Estimating
- Future Considerations



What is Goddard / CEMA Office?



What is Goddard Space Flight Center?



NASA Centers and Affiliates

- First NASA space flight complex
- Earth science, astrophysics, heliophysics focus
- Primarily unmanned missions
- 10,000+ civil servants and contractors
- ~\$5.3B budget in 2016



What is CEMA?



- Cost Estimating, Modeling & Analysis (CEMA) Office
- Established within GSFC Office of the CFO in 2012
- Central focus point for GSFC new business cost estimating guidance and support
- Provides a consistent approach to cost estimating for the Center

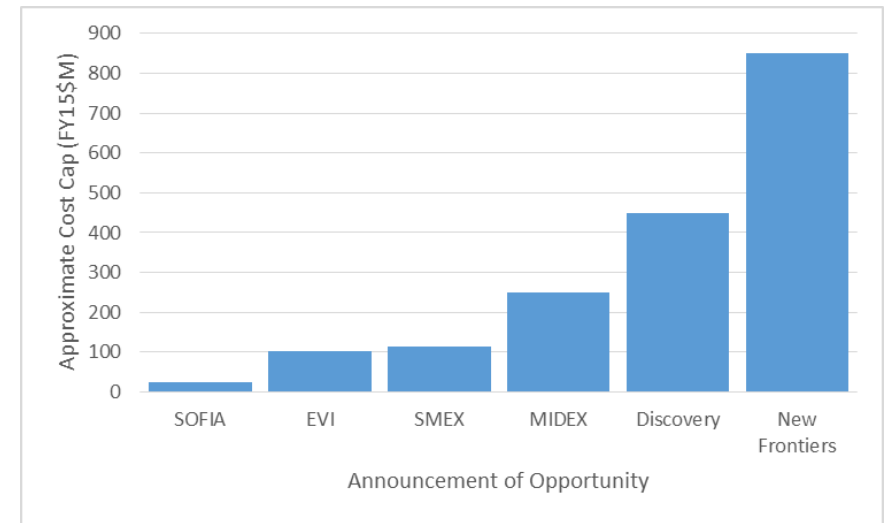


Unique Landscape of Space Science Cost Estimation



Competed Work

- NASA Announcement of Opportunity (AO) Response Process
 - Cost Caps – Design-to-Cost
 - Time constraints for cost estimating
 - Various mission risk requirements
 - Design & cost iterations



Recent missions GSFC led or partnered on:



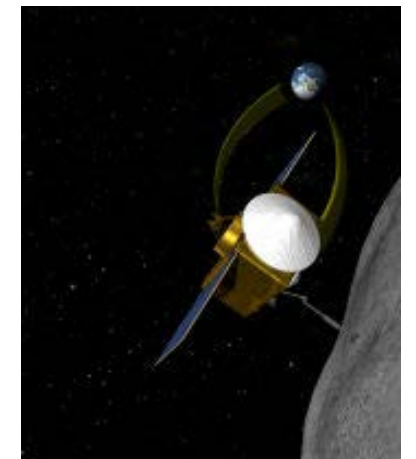
SOFIA



TESS - MIDEX



LUCY - Discovery



OSIRIS-REx – New Frontiers

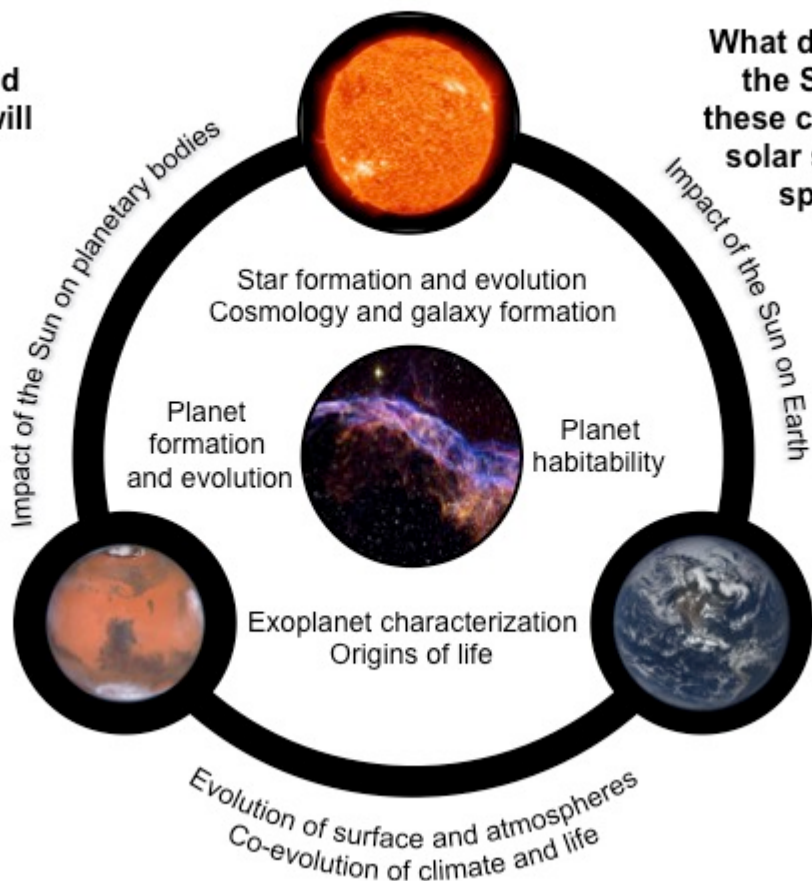


Diverse Environments

NASA Science Is Interconnected

How did the universe begin and evolve, and what will be its destiny?

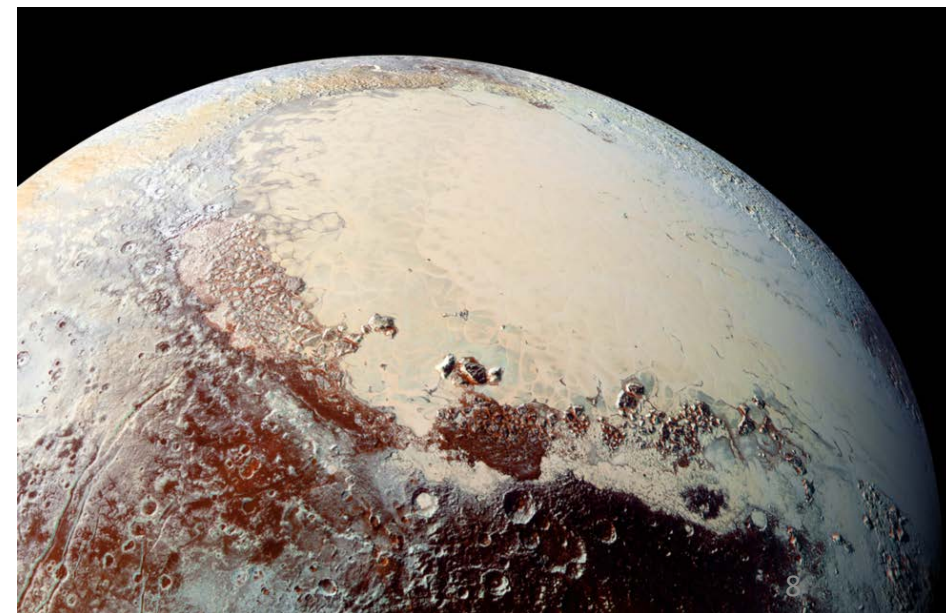
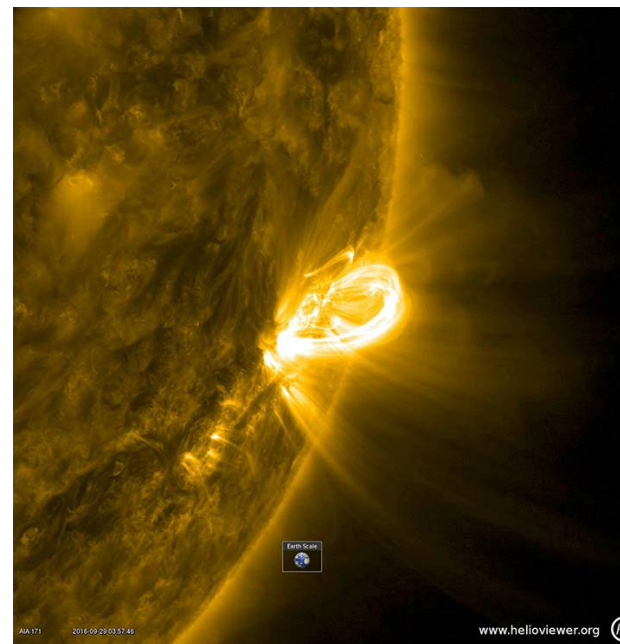
What drives variations in the Sun, and how do these changes impact the solar system and drive space weather?



How did our solar system originate and change over time?

How and why are Earth's climate and environment changing?

How did life originate, and are we alone?

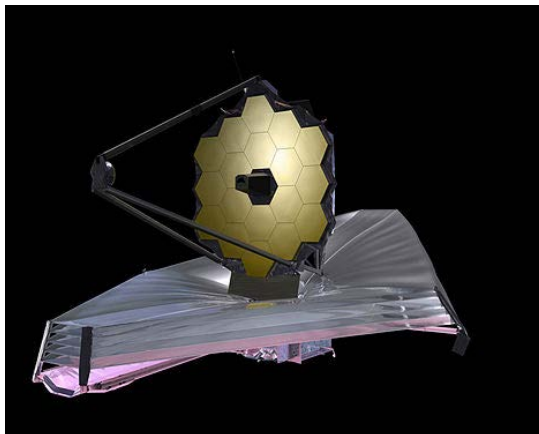




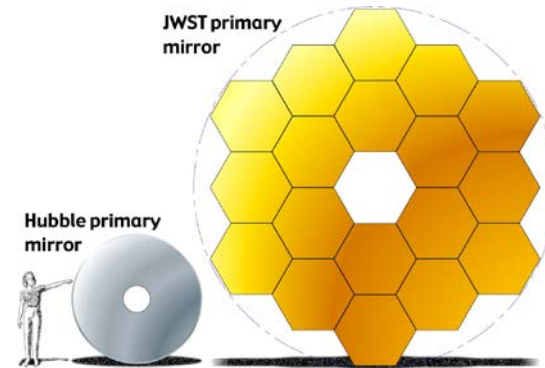
Limited Heritage



Hubble Space Telescope



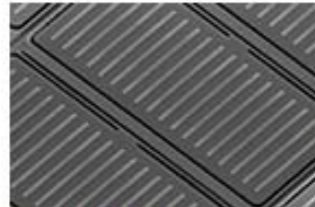
James Webb Space Telescope



HST vs JWST Primary Mirror



HST vs JWST Orbit



Microshutters



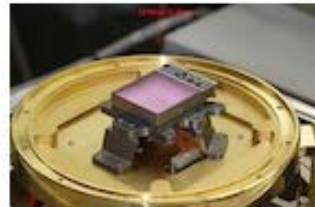
Backplane



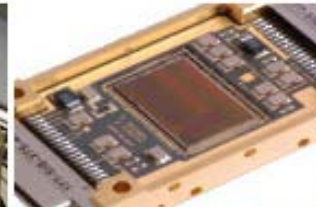
Lightweight Cryogenic Mirrors



Wavefront Sensing and Control



Infrared Detectors



Cryogenic Data Acquisition Integrated Circuit



Sunshield Coating



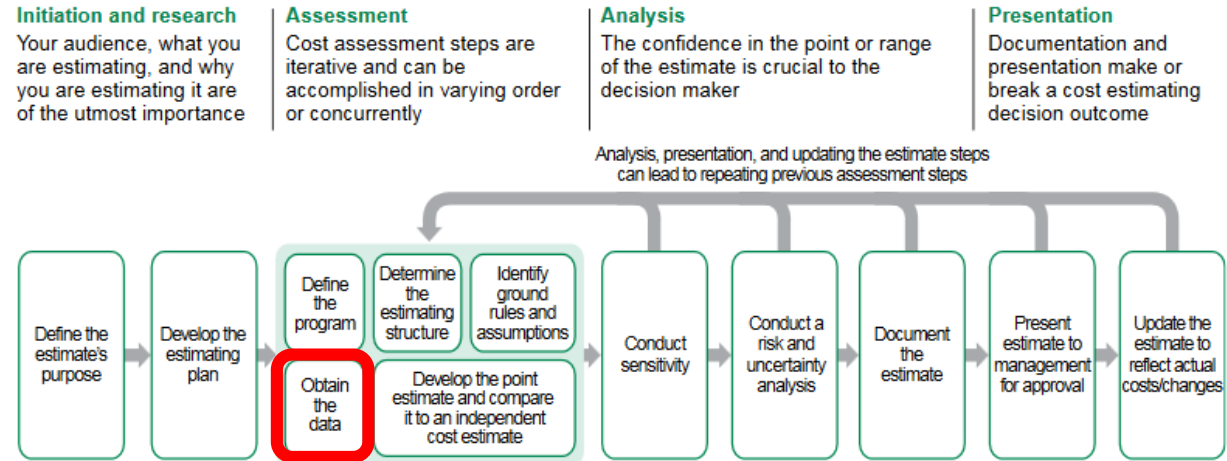
Cryocooler



Data Limitations

- Full cost accounting
 - Implemented in 2004*
- Lack of Relevant Historical Data
 - Obsolescence
 - Incomplete Data
 - No Analogs
 - Insufficient Granularity

Figure 1: The Cost Estimating Process



Source: GAO.

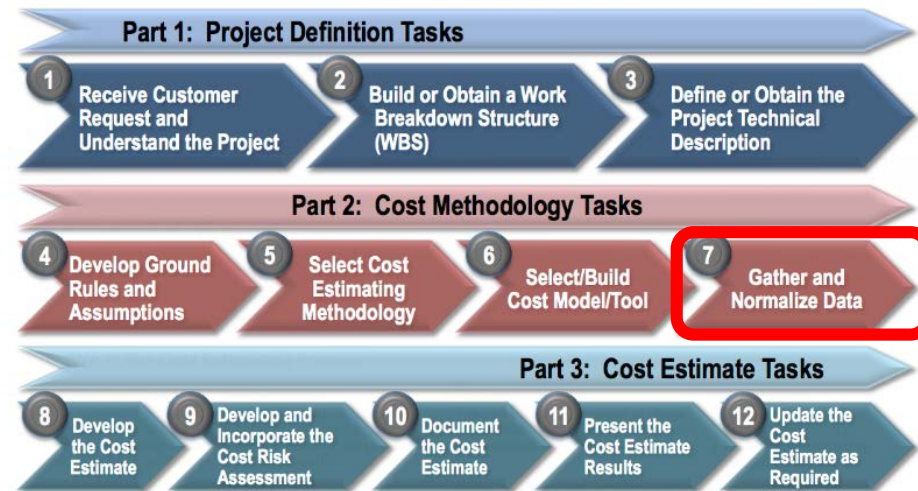


Figure 2. The NASA Cost Estimating Process

*https://www.nasa.gov/pdf/1964main_fullcost.pdf



Historical GAO Findings





CEMA's Current Approach to Space Science Cost Estimation



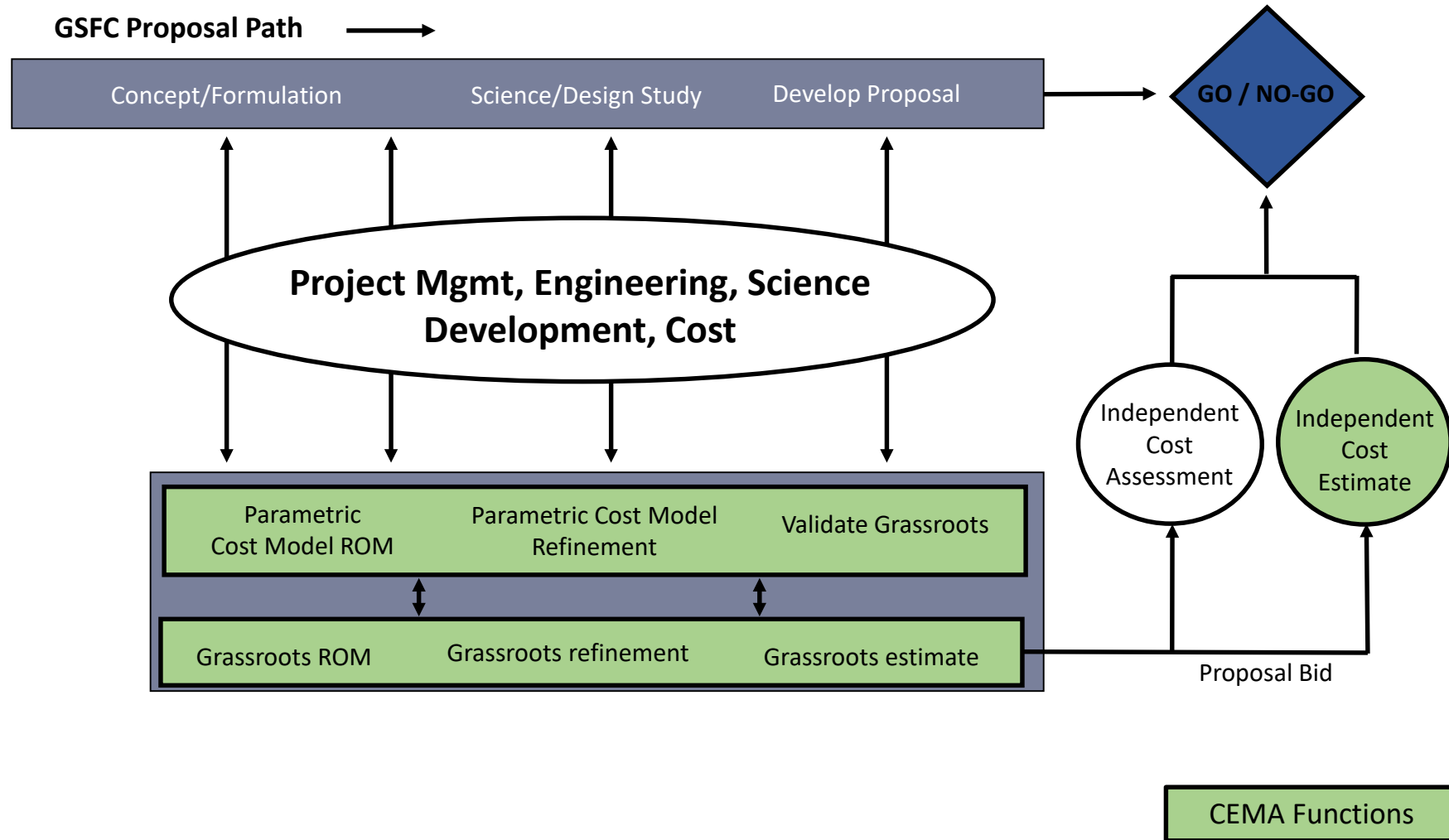
CEMA Work Scope

- CEMA primarily provides cost support to:
 - GSFC's Integrated Design Center (IDC)
 - Condensed conceptual design studies
 - ~20 IDC studies / yr.
 - Mission/Instrument Proposal Teams
 - Responsible for developing GSFC's proposal submissions in response to NASA HQ announcements of opportunity (AOs)
 - ~25 proposals / yr. (3+ iterations ea.)
- Both efforts represent early lifecycle cost estimating





GSFC Proposal Cost Estimating Process





Parametric Tools

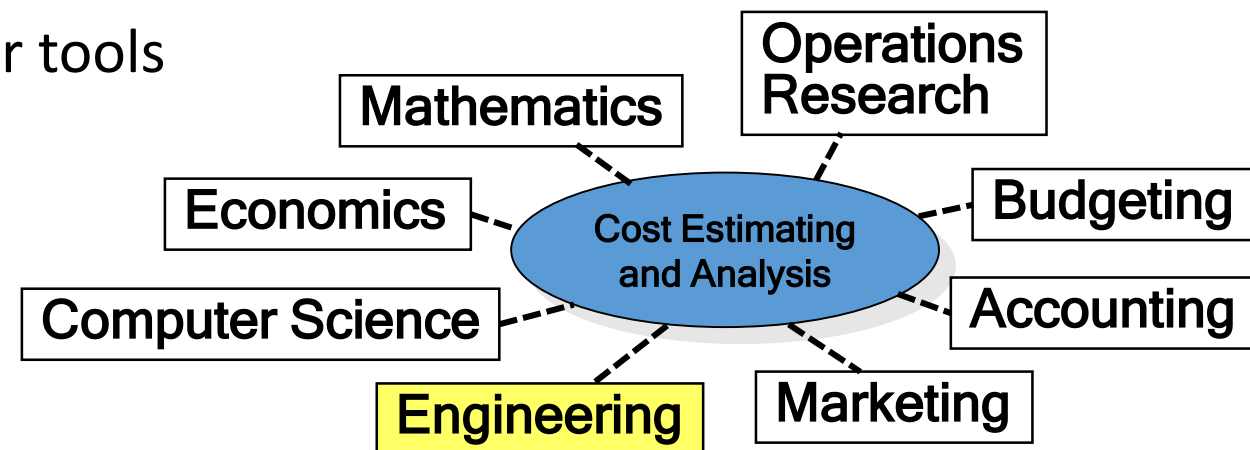
- CEMA utilizes multiple parametric tools in an effort to increase traceability and align our parametric cost estimating approach with
 - NASA HQ guidance
 - NASA HQ proposal evaluation
- Picking the right tool for the job
 - A few key pieces of known data
 - NASA Instrument Cost Model (NICM)
 - NASA Project Cost Estimating Capability (PCEC)
 - More detailed data (e.g. Master Equipment List)
 - NASA HQ recommended commercial parametric tools

Tool Type	Estimating Methodology Applicability		
	Parametric	Analogy	Build Up
NASA-Sponsored Models and Tools			
Project Cost Estimating Capability (PCEC)			ONCE Portal ¹ ✓
NASA Air Force Cost Model (NAFCOM) <i>(Transitioning users to PCEC)</i>			✓
NASA Instrument Cost Model (NICM)	X	✓	✓
Technology Cost and Schedule Estimation (TCASE) Tool	X	✓	✓
Schedule Management and Relationship Tool (SMART)	soon	✓	✓
Phasing Model	X	✓	
Schedule Estimating Relationship Risk Analysis (SERRA)		✓	✓
Quantitative Techniques Incorporating Phasing and Schedule (QTIPS)		✓	✓
QuickCost		✓	
One NASA Cost Engineering (ONCE) Database	X	✓	✓
REDSTAR Database		✓	✓
Models and Tools with NASA-Provided Licenses			
Polaris ² <i>(JCL Analysis)</i>	X	✓	✓
Argo (Monte Carlo simulation)	X	✓	✓
Automated Cost Estimating Integrated Tools (ACEIT)	X	✓	✓
CO\$TAT (statistical analysis package)	X	✓	✓
Joint Analysis of Cost and Schedule (JACS) <i>(JCL Analysis)</i>	X	✓	✓
SEER for Hardware, Electronics, & Systems (SEER-H)	soon	✓	
SEER for Software (SEER-SEM)	soon	✓	
PRICE [®] TruePlanning™		✓	
PRICE [®] Estimation Suite (PES)		✓	



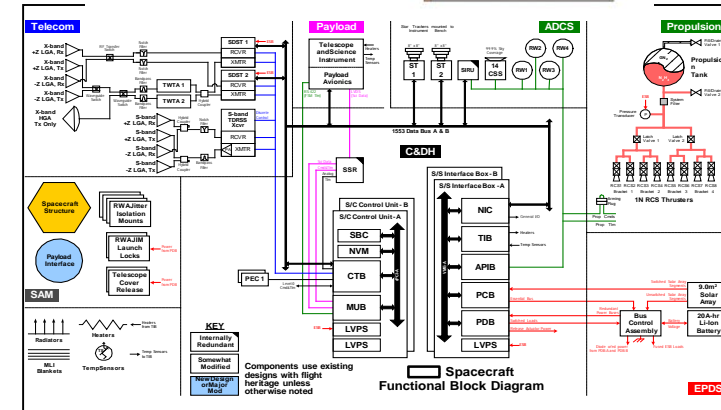
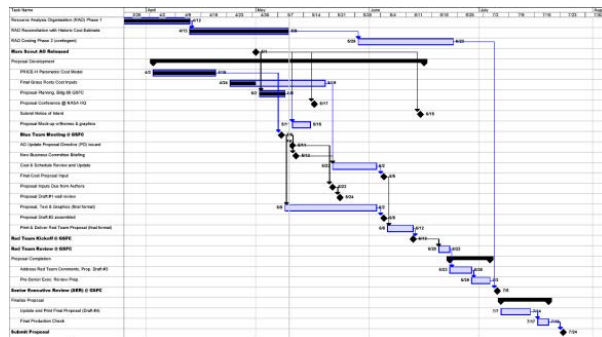
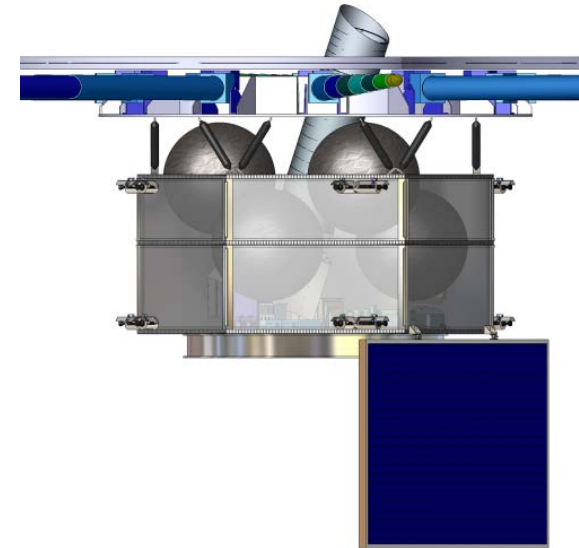
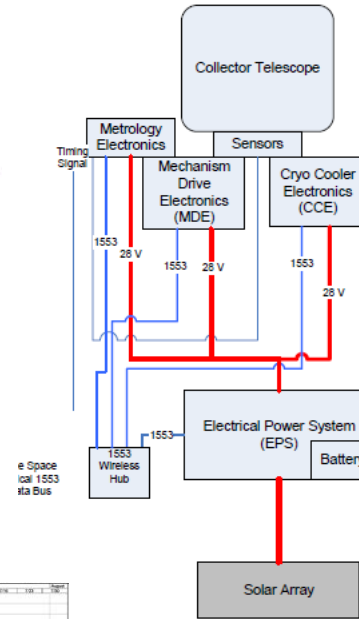
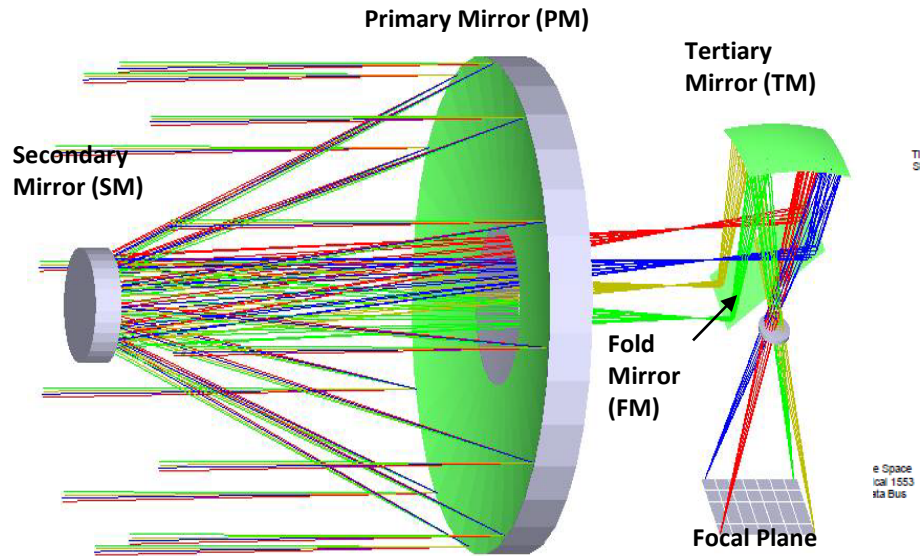
Master Equipment List (MEL)

- Captures major subsystems, components, integration hierarchy, & technical information relevant to cost modeling
- Necessitates strong systems engineering understanding of mission
 - Design maturity, engineering, manufacturing, I&T strategy, etc.
 - Objective technical parameters and subjective parameters
- Importance of Technology Readiness Level
 - Linked to multiple parameters in our tools
- MEL Evolution
 - Design iteration
 - Engineering judgment





Design Driven Cost Estimating



Engineering/Design Process: Sometimes, we end up driving the design to a level of maturity we can cost (i.e., facilitating refinement seeking a more credible estimate)



Master Equipment List Example

Please see the companion Word document "Common MEL Guidance" for instructions prior to completing this MEL template.

Recommended but not required in MEL for proposals.

MASTER EQUIPMENT LIST																									
LEVEL	NAME (Mission or Payload Name)	UNIT MASS	# OF UNITS					LIGHT HARDWARE MASS			NOMINAL FLIGHT HARDWARE POWER				PEAK FLIGHT HARDWARE POWER				QUIESCENT	Quoted Unit Price (\$K)	Composition	ADDITIONAL INFORMATION (As applicable: Vendor, make, model, part #, volume, quote information, notation of identical items, instrument / component characteristics, ETU approach...)			
			Unit Mass [kg] (CBE)	Cold Units	Hot Units	Flight Units	Flight Spares	Non-Flight ETU / Qual Units	EM / EDU / Proto-type	Total Mass [kg] (CBE)	Contingency [%]	Total Mass [kg] w/ Contingency (MEV)	Unit Power [W] (CBE)	Total Power [W] (CBE)	Contingency [%]	Total Power [W] w/ Contingency (MEV)	Unit Power [W] (CBE)	Total Power [W] (CBE)					Contingency [%]	Total Power [W] w/ Contingency (MEV)	Total Power [W] (CBE)
TOTAL FLIGHT HARDWARE							3.20		3.84																
1	INSTRUMENT NAME						3.20		3.84		0.00		0.00		0.00		0.00		0.00						
2	Subassembly						3.20		3.84		0.00		0.00		0.00		0.00		0.00						
3	Electronics Card	0.50		1	1	1		0.50	20%	0.60		0.00		0.00		0.00		0.00						Digital	
3	Sensor Electronics	0.50		1	1	1		0.50	20%	0.60		0.00		0.00		0.00		0.00						90%A / 5%D	
3	Backplane	0.50		1	1	1		0.50	15%	0.58		0.00		0.00		0.00		0.00							
3	Enclosure	1.00		1	1	1		1.00	15%	1.15		0.00		0.00		0.00		0.00						Machined Al	
3	Harness	0.70		1	1	1		0.70	30%	0.91		0.00		0.00		0.00		0.00						RS422	

MEL & Heritage

Heritage Columns are for proposals - these cells will be used for a separate Heritage Foldout, with Columns A & B & TRL Repeated.

TECHNOLOGY READINESS LEVEL	VENDOR MATURITY DESCRIPTION	LOCATION	HERITAGE VS ENVIRONMENTAL REQUIREMENT				NEW TECHNOLOGY or ENGRG CHANGE?	OWNERSHIP?	PERFORMANCE CHANGE?	HERITAGE SUMMARY							REFERENCE MISSION(S)	HERITAGE JUSTIFICATION and ADDITIONAL INFORMATION							
			TEMP -X TO Y	PRESSURE X to Y mPa	ENTRY LOAD <X G	RADIATION TID < X krad-Si				DESIGN	MANUFACTURE	SOFTWARE	PROVIDER	USE	OPERATING ENVIRONMENT	PRIOR USE									
6								EC	Own All	No	F	F	NA	F	F	P	F	Mission A							
6								NT	NA	Yes	P	F	P	F	P	P	F	Mission B	This new widget has been fully tested in mission environment. It is built by the						
7								Neither	Own All	No	F	F	F	F	F	F	F	Mission A							
5								NT	NA	Yes	P	F	P	F	N	N	N		This new widget does a new function and we haven't tested it in the						
6								EC	Own IP	Possibly		F	F	F	N	F	F		This is the exact same thing by a different provider. We used the same exact design and it has been fully verified in the target environment. We own the IP.						



Cost Estimating Input Screens

NASA Developed Tool Parameter Screens

Commercial Tool Parameter Screens

Costs in \$K FY

Instrument Type

Environment

Flagship Mission?

	Minimum	Most Likely	Maximum
Max Power:	139.0 W	147.0 W	147.0 W
Total Mass:	139.6 kg	149.9 kg	149.9 kg
Electronics Mass:	19.4 kg	21.5 kg	21.5 kg
Optics Mass:	81.4 kg	87.7 kg	87.7 kg
Detector Mass:	4.1 kg	4.4 kg	4.4 kg
Thermal Mass:	17.5 kg	20.2 kg	20.2 kg

Dewar/Cryocooler/ActiveCool

Detector Type

Monte Carlo # iterations:

Automatic Monte Carlo

NCM Help

NCM VII Rev2, February 2016

Heritage & Parts Rating	Included in Effort Review?	Direct Entry Rating (Heritage)	Second Entry Parts Rating
Structure	Y	5.39	4.66
Thermal Control	Y	6.45	7.33
Electrical Power & Data Subsystem	Y	2.44	9.12
Absolute Determination & Control	Y	4.99	8.48
Reaction Control (Prop)	Y	3.99	8.48
W/Comms/antenna	Y	2.86	6.48
Command & Data	Y	4.71	6.97

Structures & Mechanisms	Weight Per Unit (kg)	Subsystem Design Time (days)	Qty Most Higher Assembly
Structure	22.08		
Subsystem Design Time (days)	22.08		
Primary Structure Material	1		
Qty Most Higher Assembly	1		

Thermal Control	Weight Per Unit (kg)	Subsystem Design Time (days)	Qty Most Higher Assembly
Thermal Control	69.42		
Subsystem Design Time (days)	69.42		
Qty Most Higher Assembly	1		

Electrical Power	Weight Per Unit (kg)	Subsystem Design Time (days)	Qty Most Higher Assembly
Electrical Power	483.13		
Subsystem Design Time (days)	483.13		
Qty Most Higher Assembly	1		

ELECTRO / MECHANICAL

Complex Electronics Card

Input Form | LM Sheet | ID Sheet | Risk Input | Distributions | Worksheet

Validate | Notepad | Override | Reset | Schedule | Help

QTY	PROTOS	WT - Klg	VOL - Liters	HSINT	
2	1.00	0.125000	.125	0.00	
Total QTY	Total PROTOS	Manually Allocate	DEVFRAC %		
0	0.00	Development Engineering	100.0		
QTYNHA	INTEGE	INTEGS	PLTFM	YRTECH	
2	2.0000	0.7000	2.000	0	
WS - Kg	MCPLXS	NEWST	DESRPS	MREL	
0.0250000	6.360	0.000	0.000	0.00000	
WECDM	MCPLXE	NEWEL	DESRPE	EREL	USEVOL
0.7529	11.721	0.000	0.000	0.00000	0.00000
DSTART	DFPRO	DLPRO	ECMPLX	DTLGTS	PROSUP
105	0	0	1.00	0.00000	0.00
PSTART	PFAD	PEND	MPI	PTLGTS	RATOOL
107	0	309	0.0000	0.00000	0.0000000

Inputs

Schedule & Qty | Labor Rates, Costs & Factors | Ops & Support | Labor Category Allocation

EOS Detector: Least Likely Most Note

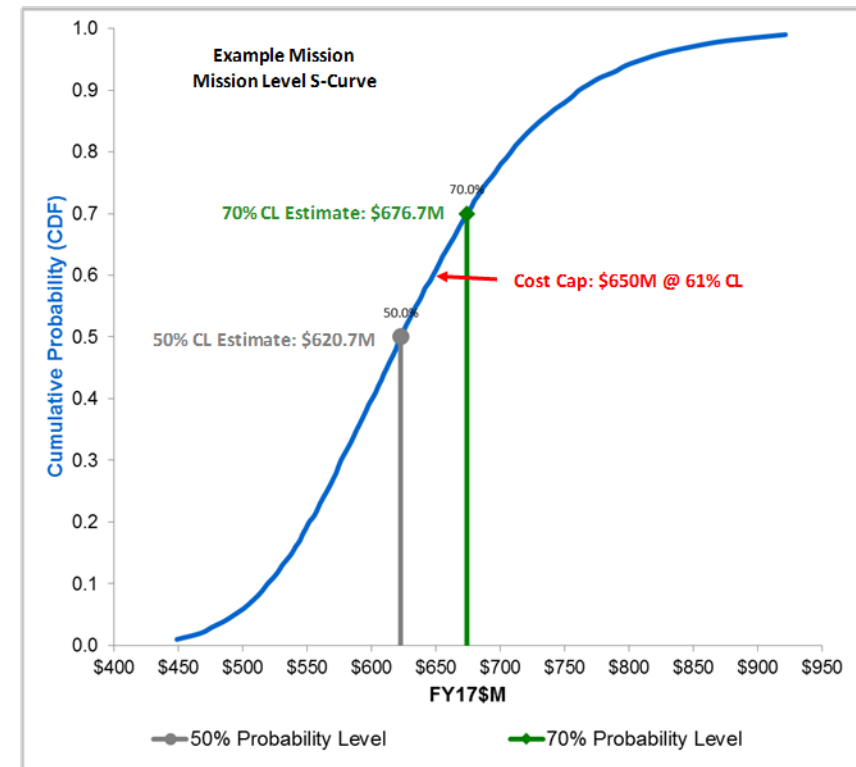
PRODUCT DESCRIPTION

- Technology: Area Silicon CCD
- KEY TECHNICAL/PERFORMANCE PARAMETERS**
- Array Size (pixels): 589,824 1,048,576 1,638,400
 - Rows (pixels): 768 1,024 1,280
 - Columns (pixels): 768 1,024 1,280
 - Frame Rate (frames/sec): 8 10 12
 - Readout Noise (electrons/root Hz): 4 5 6
 - Radiation Tolerance (rad): 5,000 10,000 15,000
 - Pitch (microm): 472 551 630
- MISSION DESCRIPTION**
- Environment: Moderate
- Vehicle: Space Unmanned
- PROGRAM DESCRIPTION**
- New Design: 70.00% 80.00% 100.00%
- Design Replication: 0.00% 0.00% 0.00%
- Design Complexity: Nom Nom Nom
- Subsystem Integration Level: Nom Nom+ Hi
- Reliability Standard: 10+ 10+ 10+



Risk Analysis

- Create uncertainty distribution
 - Right skewed triangular distribution on input parameters
 - Proposal defined contingency and margin for mass
- Monte Carlo analysis
- Cumulative Distribution Function Curve

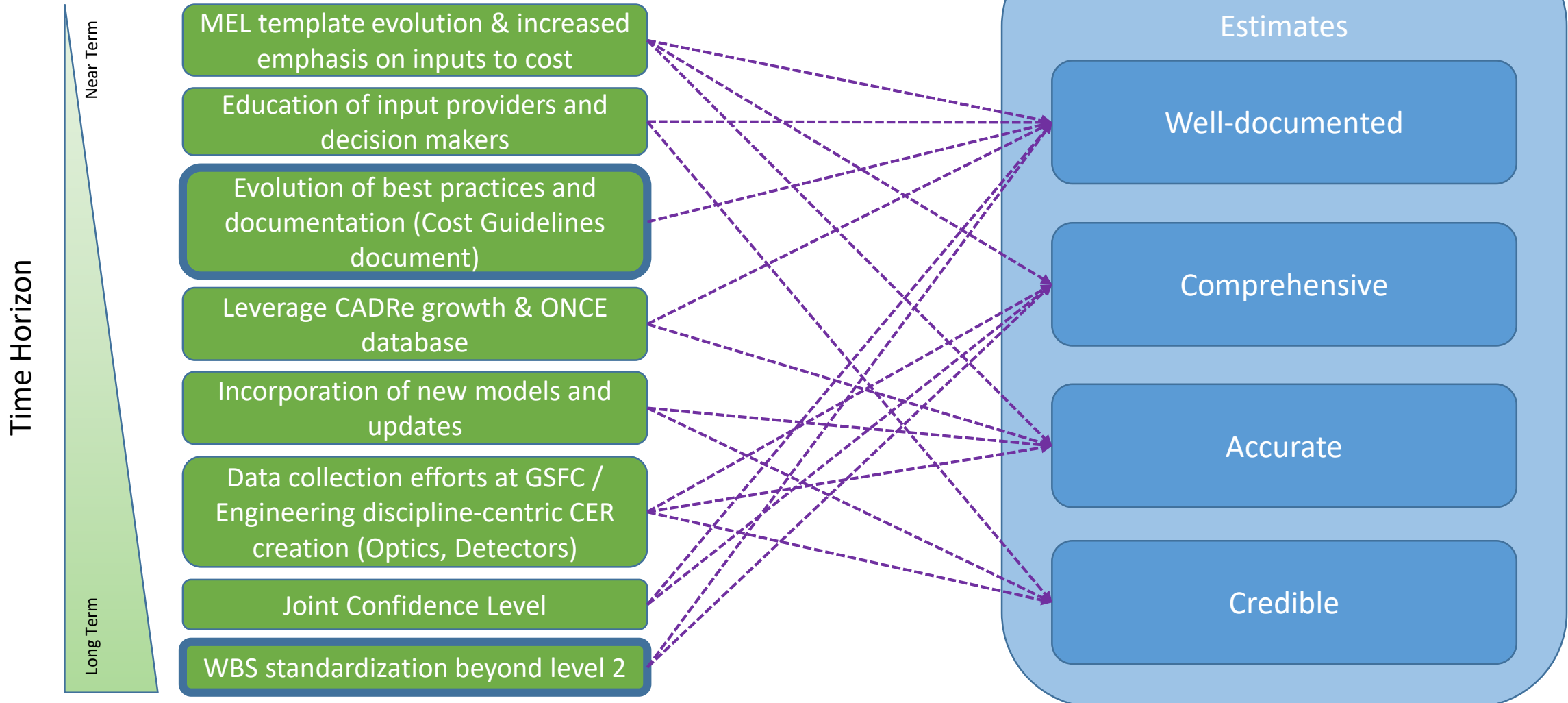




Future Considerations



Future Considerations





Evolving Policy, Guidelines, Best Practices

NASA GODDARD SPACE FLIGHT CENTER (GSFC)
OFFICE OF THE CHIEF FINANCIAL OFFICER (OCFO)
COST ESTIMATING, MODELING AND ANALYSIS (CEMA) OFFICE

GSFC Cost Estimating
Guidance & Policy Document

3/12/2015

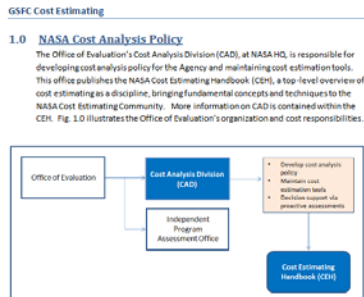


Fig. 1.0 NASA Office of Evaluation CAD publishes the Agency's Cost Estimating Handbook

The latest version of the CEH handbook is available for download from the agency website at: <http://www.nasa.gov/offices/ocfo/cad/nasa-cost-estimating-handbook-ceh/>

The handbook serves as a cost estimating reference resource providing guidance to program/project managers, new hires and the cost estimating community.

- External to CEMA – documentation to educate the center/agency on cost estimating policy
- Internally – cost templates for various systems, components, rates, output, briefings, etc.
 - Add new types of systems (ex. Cubesats)
 - New and updated tools require best practices
 - Engineering Judgment is hard to standardize

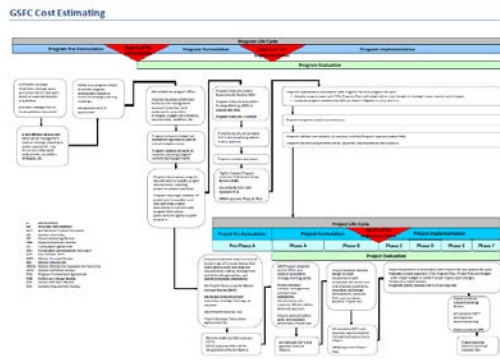


Fig. 2.1 Space Flight Program and Project Management Process Overview

Power [TBD]
Power System Electronics [PSE] Assembly [TBD]
PSE Housing [TRL 6] [TBD]
Wiring, Diodes, Connectors, Etc. [TRL 6] [TBD]
SA Module 1 & 2 [power] [TRL 6] [TBD]
Battery Module [power] [TRL 6] [TBD]
Control Module [digital/analog] [TRL 6] [TBD]
Output Module 1 & 2 [power] [TRL 6] [TBD]
Low Voltage Power Converter [LVPC] [power] [TRL 7] [TBD]
Backplane [analog/power] [TRL 6] [TBD]
PSE Integration & Test [TBD]
Optional Energy Storage [Battery] [TRL 6] [TBD]
Lithium Ion Battery Assembly [TBD]
Structure [TRL 5] [TBD]
Battery Cells [0] [TRL 5] [TBD]
Lithium Ion Battery Integration & Test [TBD]
Solar Array Assembly [Flt. units = 2, TBD]
Solar Array Cell Panels [TRL 8] [TBD]
Solar Array Composite Face Sheet [TRL 8] [TBD]
Honeycomb Panels Substrate [TRL 8] [TBD]
Wiring, Diodes, Connectors, Etc. [TRL 6] [TBD]
Solar Array Assembly Integration & Test [TBD]
Solar Array Deployment Mechanism [Flt. Units = 2, TBD]

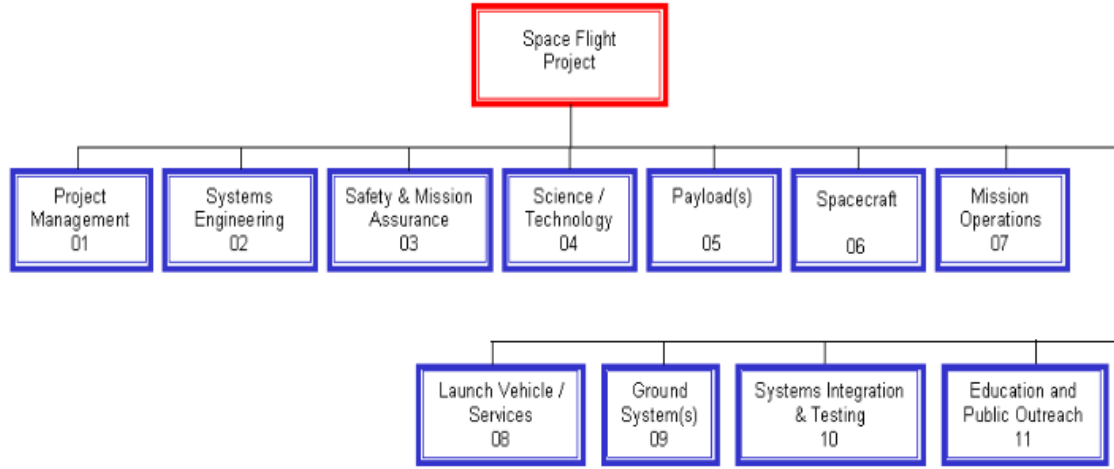
Template for Power Systems Components



WBS Comparison

MIL-STD-881C WBS				MIL-STD-881C WBS				MIL-STD-881C WBS				MIL-STD-881C WBS				
Code	Description	Code	Description	Code	Description	Code	Description	Code	Description	Code	Description	Code	Description	Code	Description	
1.0	Program Management	1.0	Program Management	1.0	Program Management	1.0	Program Management	1.0	Program Management	1.0	Program Management	1.0	Program Management	1.0	Program Management	
1.1	Program Management	1.1	Program Management	1.1	Program Management	1.1	Program Management	1.1	Program Management	1.1	Program Management	1.1	Program Management	1.1	Program Management	
1.1.1	Program Management	1.1.1	Program Management	1.1.1	Program Management	1.1.1	Program Management	1.1.1	Program Management	1.1.1	Program Management	1.1.1	Program Management	1.1.1	Program Management	
1.1.1.1	Program Management	1.1.1.1	Program Management	1.1.1.1	Program Management	1.1.1.1	Program Management	1.1.1.1	Program Management	1.1.1.1	Program Management	1.1.1.1	Program Management	1.1.1.1	Program Management	
1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	1.1.1.1.1	Program Management	
1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	1.1.1.1.1.1	Program Management	
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1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1	Program Management	
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1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1	Program Management	
1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1	Program Management	
1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1	Program Management	1.1.1.1.1.1.1.1.1.1.1.1

VS.



NPR 7120.5E NASA WBS

MIL-STD-881C WBS for Space Systems*

*http://www.navair.navy.mil/nawctsd/Resources/Library/Acguides/MIL-STD%20881C%203%20Oct%202011.pdf



Key Takeaways

- Unique challenges
- Early conceptual estimating
- Commercial tools estimating esoteric hardware
- Systems engineering emphasis





Questions?