CATE Overview

Cost & Technical Evaluation

January 4, 2016

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Assuring Space Mission Success

Agenda

- **CATE Overview; What is a CATE?**
- **CATE as applied to a $1 B Probe Class Mission**
- **Audience Questions/Discussion**

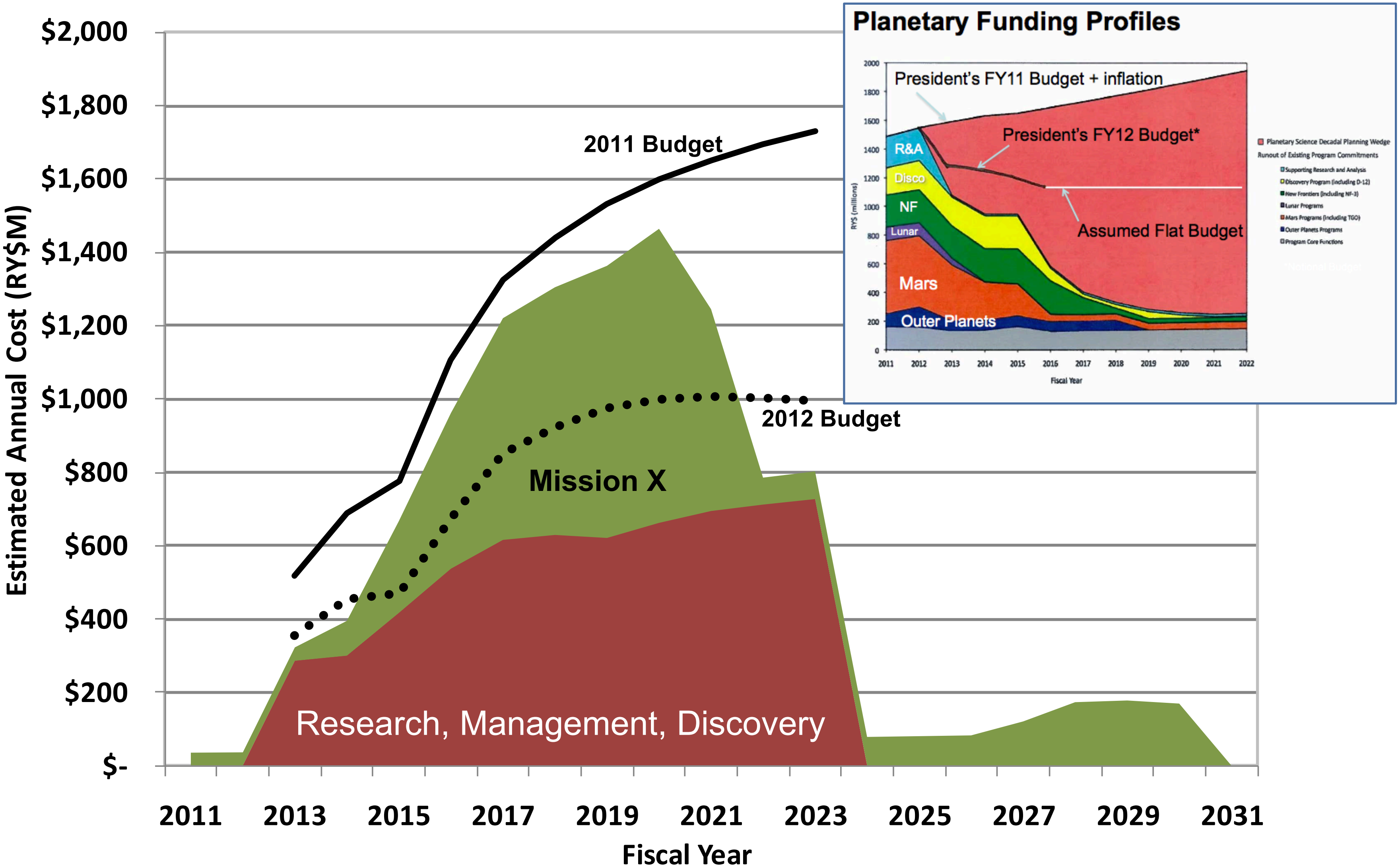
What is a CATE?: Cost and Technical Evaluation

- **CATE developed by NRC/Aerospace for recent Decadal Surveys**
  - *Previous Decadal Surveys had no process to validate advocate mission costs*
  - *US Congress required NRC to use independently validated costs*
  - *CATE estimates needed to reflect historical project growth*
    - CATE estimates needed to reflect realistic NASA/ESA cost sharing
    - Realistic CATE estimates needed for future budget analysis & decisions

- **CATE process differs from typical ICE and process for TMC evaluation**
  - *Begins with typical Independent Cost Estimate, ICE*
  - *Adds three types of cost threats, where appropriate:*
    - Schedule, design (mass & power growth) and launch vehicle

- **CATE is used for future consideration with respect to NASA budgets**
  - *Used to evaluate science value versus budget availability*
    - Sometimes used to re-assess Decadal recommended concept descopes
  - *Incorporates typical growth based on the historical record and design maturity*
    - It is more conservative than an ICE of a “specific” concept presented

CATE Primarily for Prioritization within Budget Constraints



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Aerospace is the Custodian for the NRC CATE Process

- **Requires independent analysis**
  - *Reconciliation with Project teams is recommended, where appropriate*
  - *However, NRC committees are concerned with maintaining confidentiality*

- **Requires consistency across diverse concepts**
  - *CATE process is flexible to handle differences in design maturity*
  - *CATE has been used for Astro2010, Planetary and Heliophysics*
    - Will be used for Earth Science Decadal starting January 2016
    - Will be used for Astro2020 and beyond

- **Stay true to the NRC process**
  - *Advocate teams and NASA HQ do have special requests*
  - *This often can be handled, but the CATE generated S-curve represents the cost risk assessment*
  - *There is a "T" in CATE and committees and decision makers need a consistent technical risk assessment*

General Limitations of Assessment

- **Technical risk assessment**
  - *Limited to top-level maturity and risk discussions*
    - Not meant to be a Proposal Evaluation level of effort

- **Cost and schedule assessment**
  - *Meant for high-level budgetary estimates*
    - Often includes a profile in real year dollars
  - *It is understood that the CATE is likely to be higher than advocate estimate*
    - Decision makers consider the range in the two estimates
  - *When appropriate, reconciliation with the project occurs*
    - Typically when CATE is being presented to NASA HQ
    - Does not occur when under direct evaluation by an NRC committee
  - *Design growth threat is typically the biggest disconnect with project teams*
    - Project often defends specific concept being presented
    - Advocate estimate may not adequately factor in “future” modifications and “growth”

Technical Risk & Maturity Assessment Approach

- **Identify key risks to achieving required performance**
  - *Highlight significant deviations from current state of the art performance*
  - *Trace performance risk to science mission impact*
  - *Evaluate potential of planned risk mitigation efforts*

- **Assess technical maturity risk liens on cost and schedule**
  - *Assess claimed TRL level of key technologies*
  - *Apply mass and power growth contingencies consistent with maturity*
    - Mass growth allowance could result in launch vehicle cost threat
  - *Late technology maturation steps identified as schedule risks*
  - *Complex system integration issues identified as schedule risks*

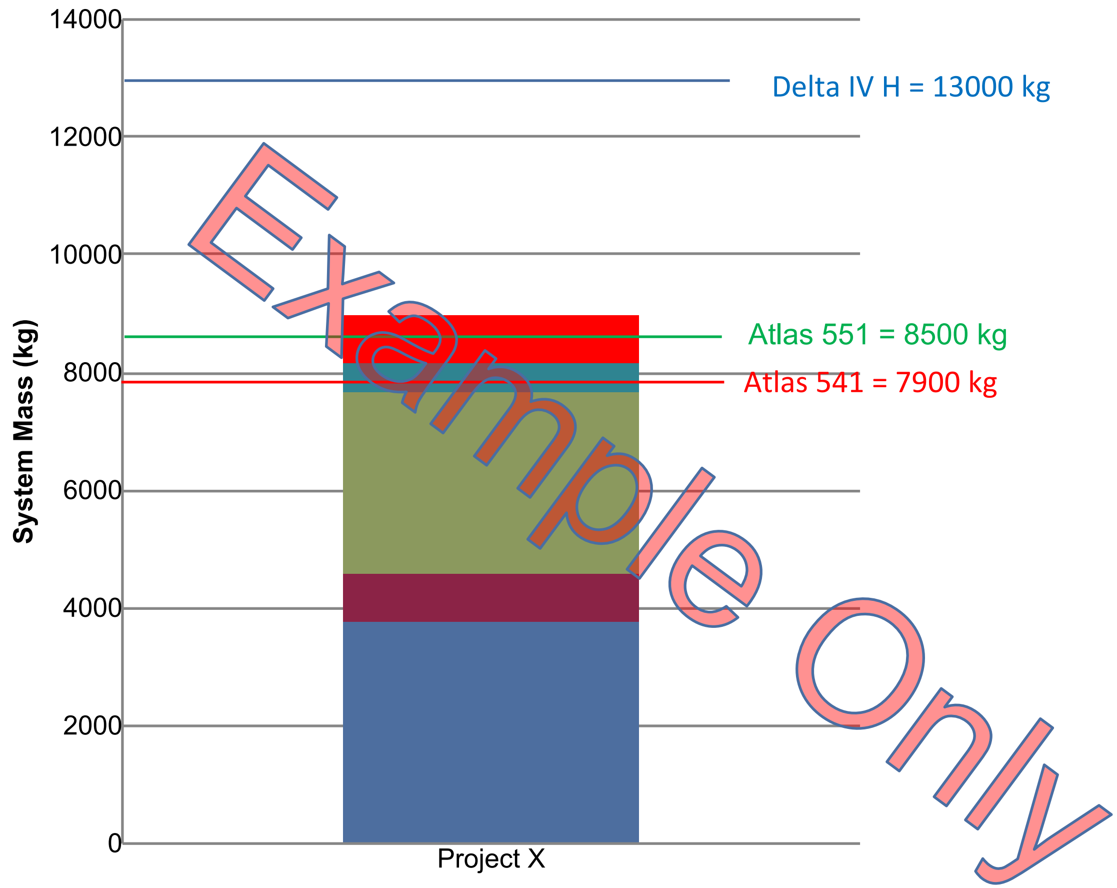
Low	Medium Low	Medium	Medium High	High

Project X Top Technical Risks and Concerns

Project X Technical Risk Rating is Medium

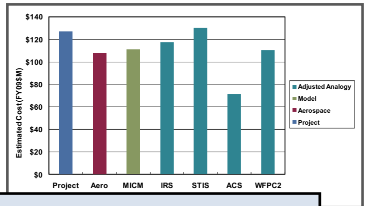
- **Medium new development, mostly in the engineering implementation**
  - *Increase in detector array size*
  - *Migration from FPGAs to ASICs*
  - *Modernization of heritage instrument control unit*
- **Mass margins and power margins are aggressive and launch mass margin is very sensitive to changes in dry mass**
  - *Concept design is closer than recommended to Atlas V 551 capacity limit and the system is very sensitive to changes in mass*
  - *Several mass liens against concept design*
- **Time critical mission operations contributes to medium operational risk**
  - *Fault management for autonomous mode requires further definition*
  - *Sampling operations and hardware need further definition*

Project X Mass versus Launch Vehicle Capability



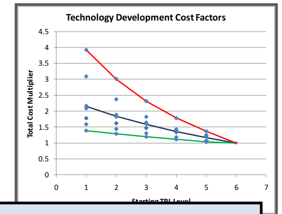
- **Project X concept design has smaller launch margin than recommended when applying CATE growth contingency**
  - *Critical when on the borderline between LV classes*

CATE Cost Estimating Approach Overview



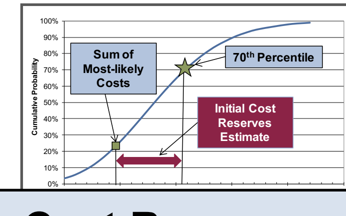
Estimate Instruments & Spacecraft

Multiple analogies and models



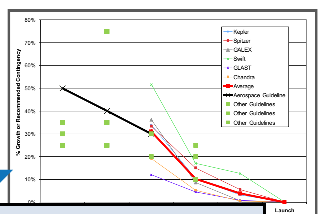
Estimate Other Elements

Based on historical data



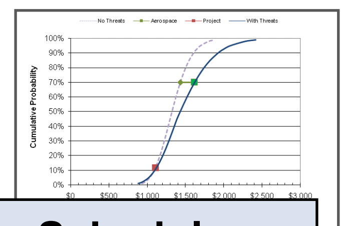
Estimate Cost Reserves

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

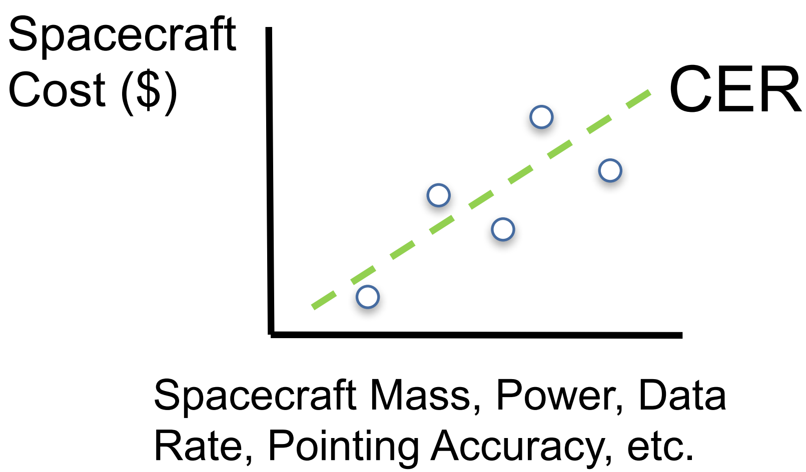
Integrate Results & Level Across Concepts

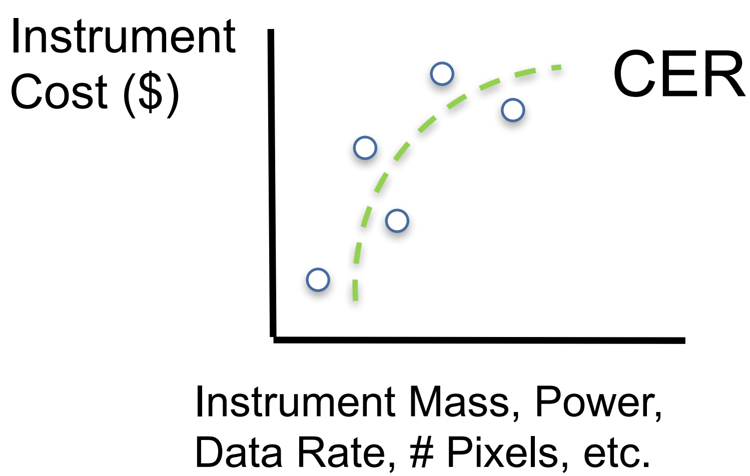
Cross-check with CoBRA

The Cost Estimating Relationship (CER)

- **CERs use regression techniques to establish a relationship between variables that are representative of the design, and cost**

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





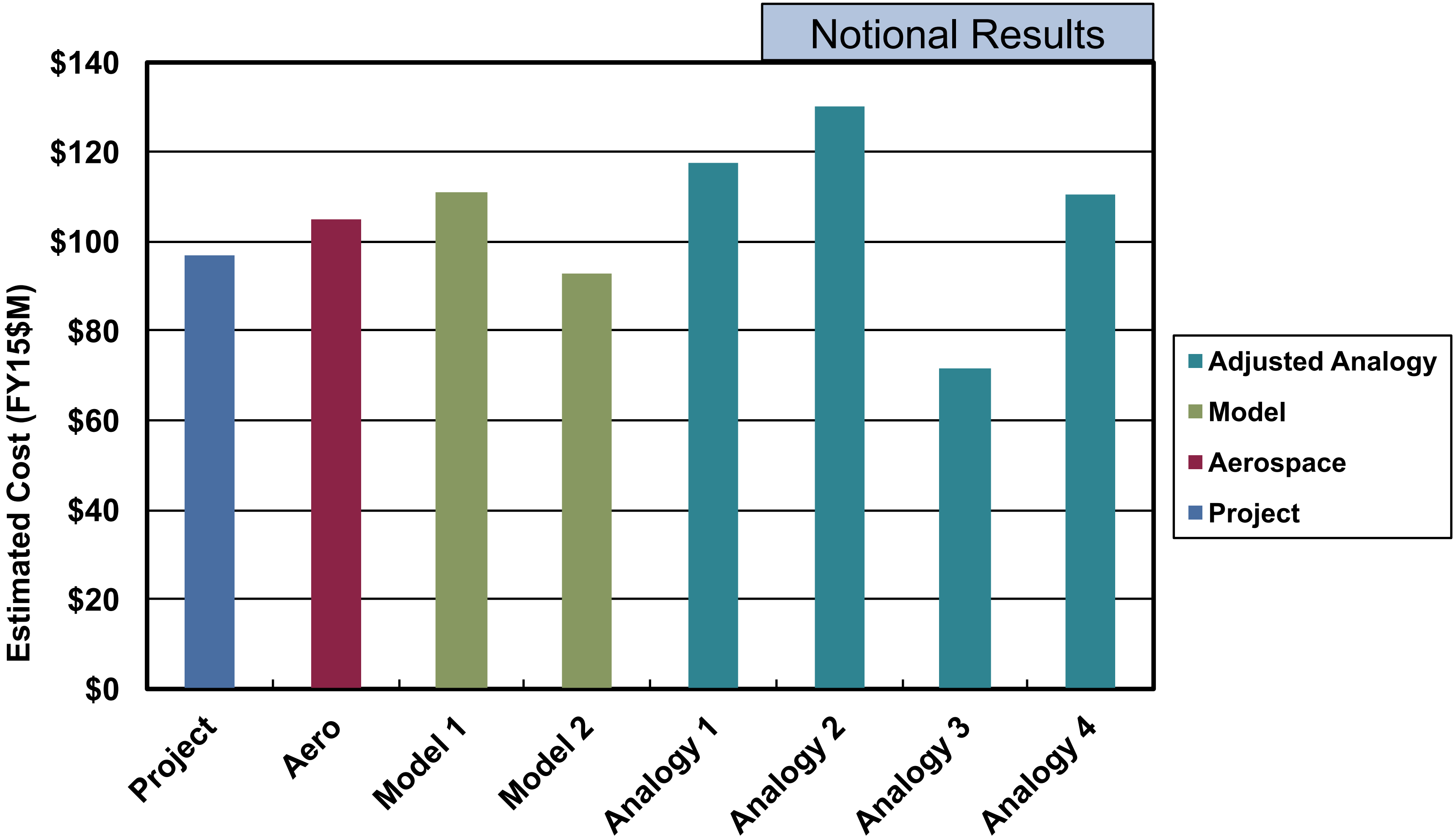
CERs are based on historical data

Hardware Cost Estimates

- **Instruments and spacecraft buses**
  – *Multiple analogies are used for each element*
    - Historical instruments with known cost, schedule and technical parameters
    - Analogies chosen based on similarity to proposed instrument and by supplier
  – *Multiple cost models are also used for each element*
    - Instruments - MICM, SOSCM, NICM
    - Spacecraft - NAFCOM, SSCM

- **Same general philosophy is applied to other hardware elements**
  – *Emphasize analogy-based estimates as much as possible*
  – *System-level cost models are generally not applicable, but subsystem or component-level models can often be used*
  – *Extrapolate from ground-based systems, testbeds, etc.*

Example Hardware Estimate Results



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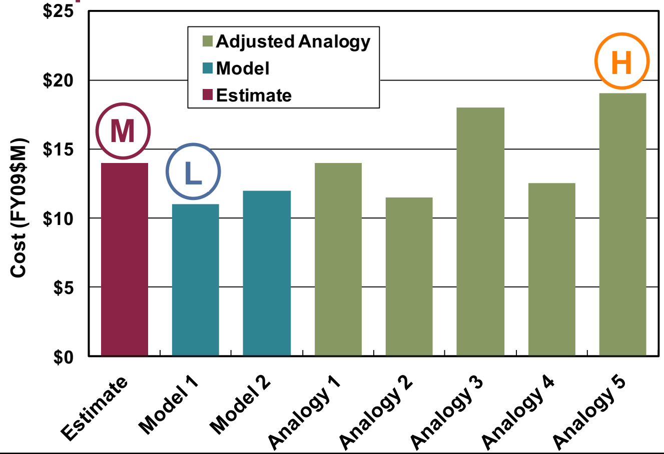
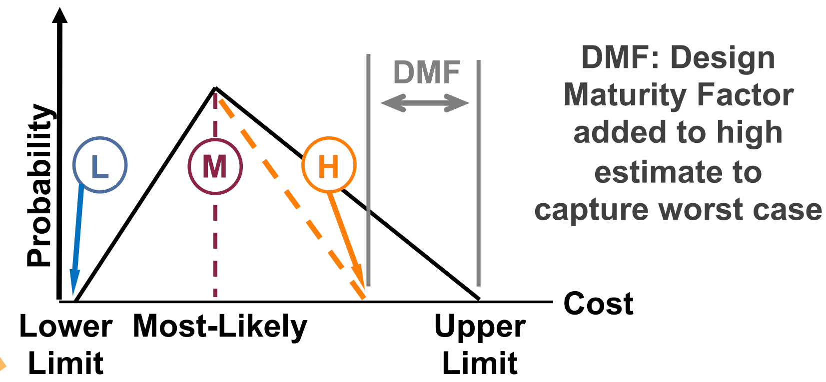
Cost Risk Process Overview

Used to estimate reserves

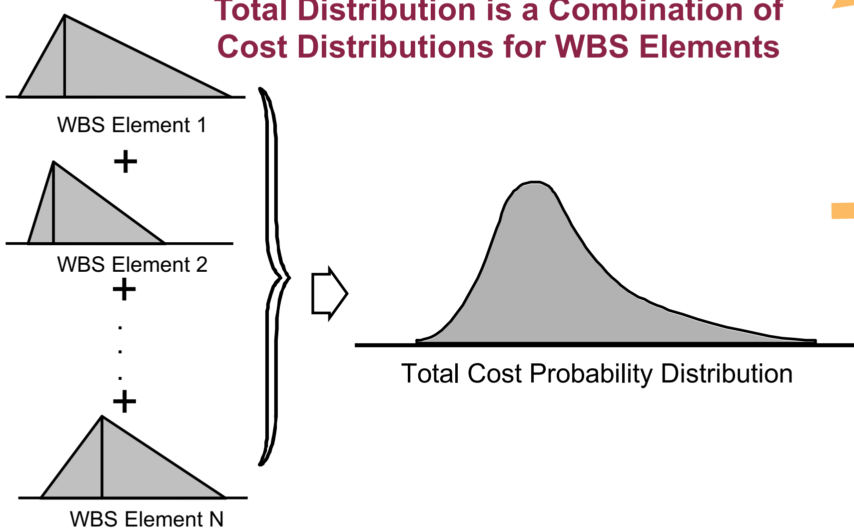
Multiple Cost Estimates for Each WBS Element



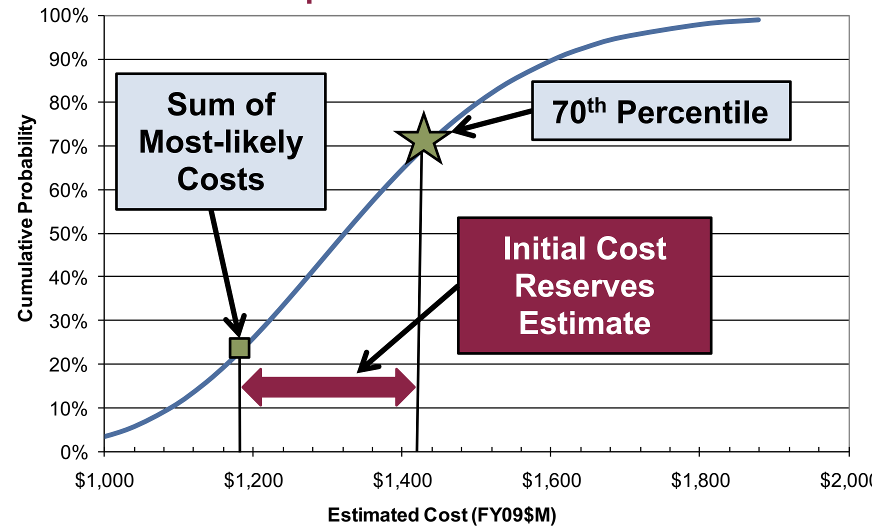
Triangular Distribution of Possible Element Cost



Total Distribution is a Combination of Cost Distributions for WBS Elements



Example Total Cost Distribution

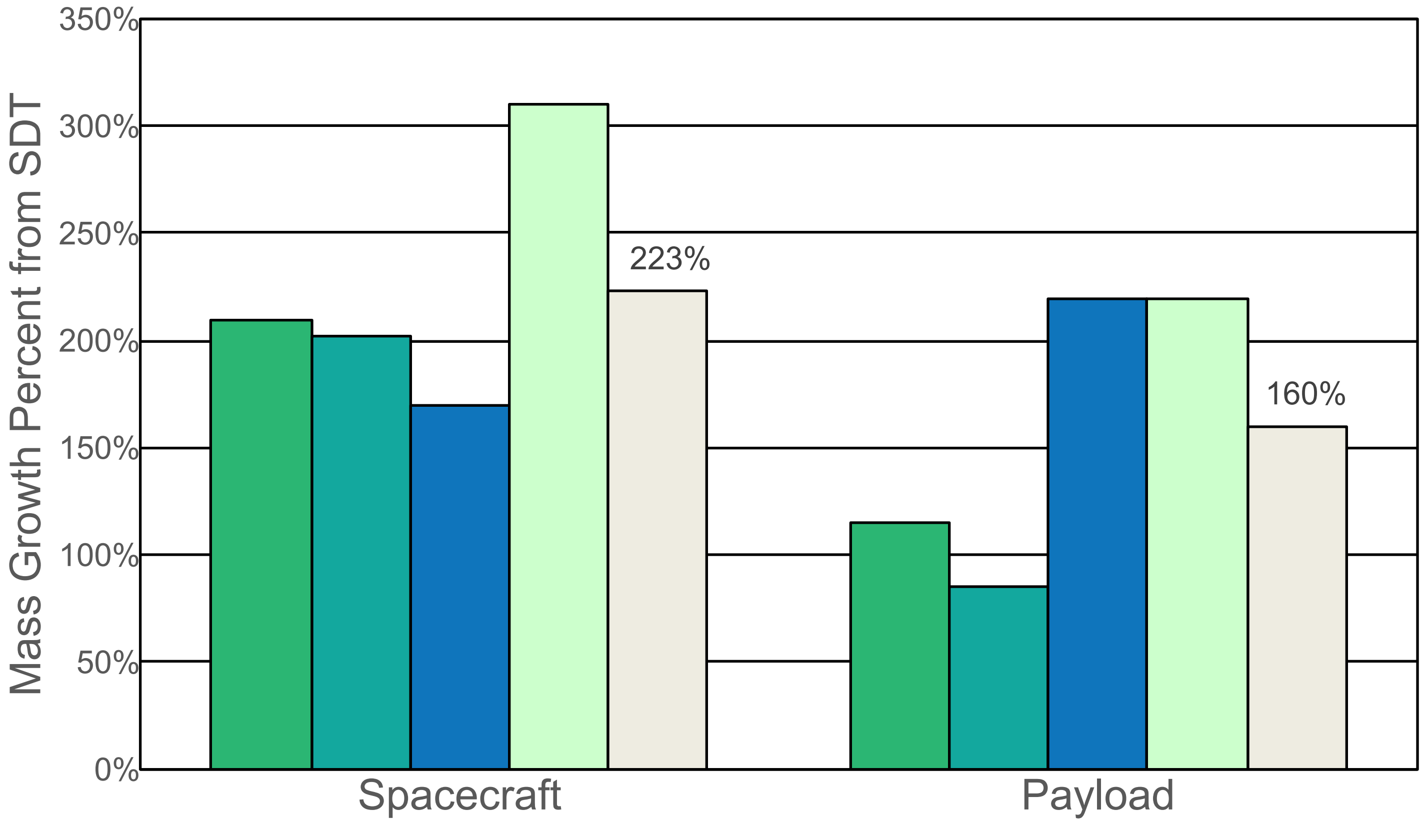


Design Growth and Launch Vehicle Threats

- **All CATE estimates based on project team inputs**
  - *Wide range in the maturity of the designs*
  - *Some responses are essentially concept descriptions*
  - *Others already have had significant investment maturing the design and required technology*
- **Need to ensure that immature projects didn't have an unfair advantage**
  - *Apply higher mass and power contingencies for less mature projects*
    - Mass and power drive cost estimates from both analogies and models
  - *Use project-supplied contingencies for estimate without threats*
- **Aerospace-applied contingencies to develop "Design Growth" cost threat**
- **Add cost of moving to next larger launch vehicle as "Launch Vehicle" cost threat**
  - *If mass contingency results in less than 10% launch vehicle mass margin*

Design Growth from Science Definition Team Report

Heliophysics Missions



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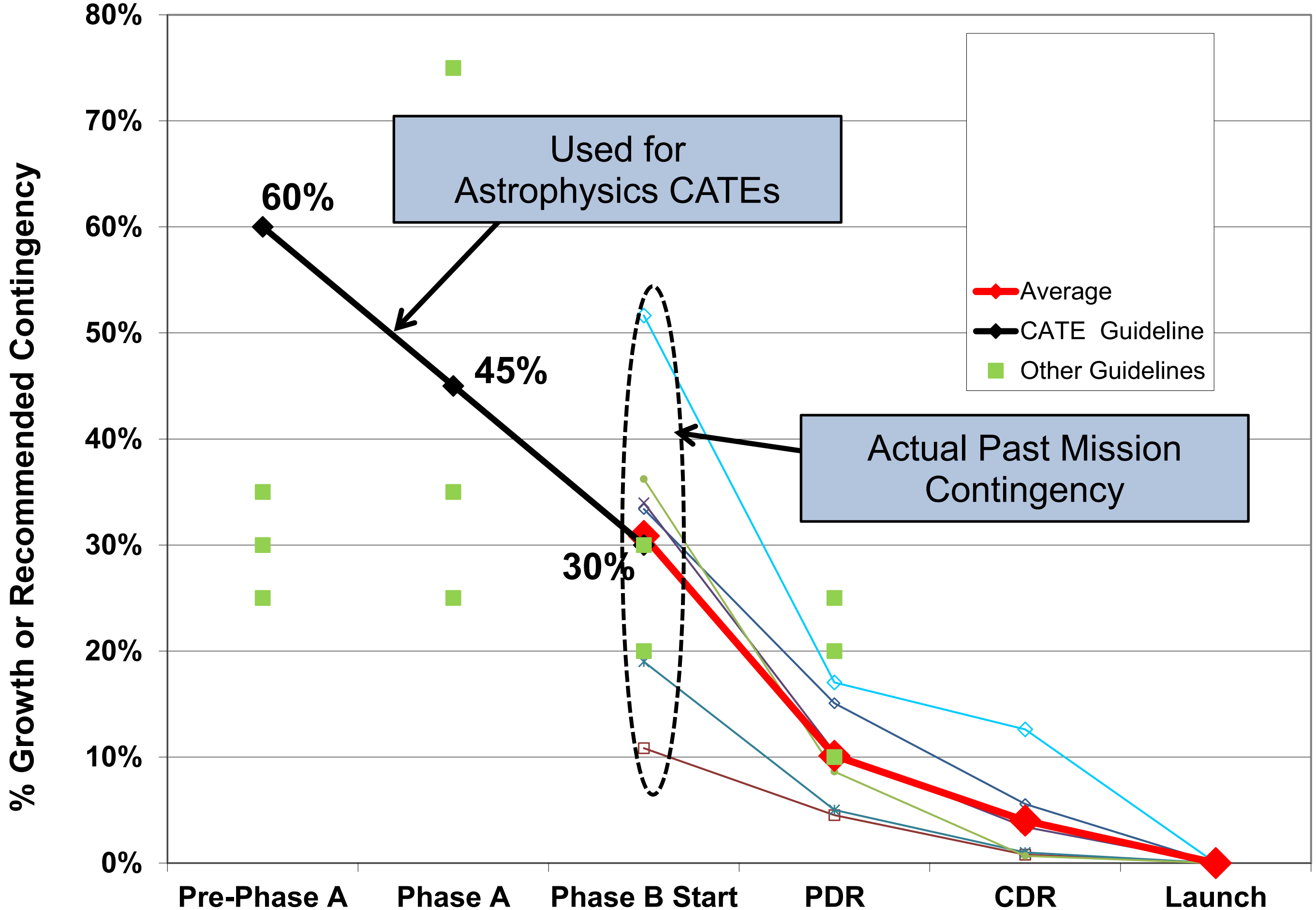
Payload Mass Contingency Values for Threat Estimate



CATE contingency values are an extrapolation of historical Astrophysics mission data

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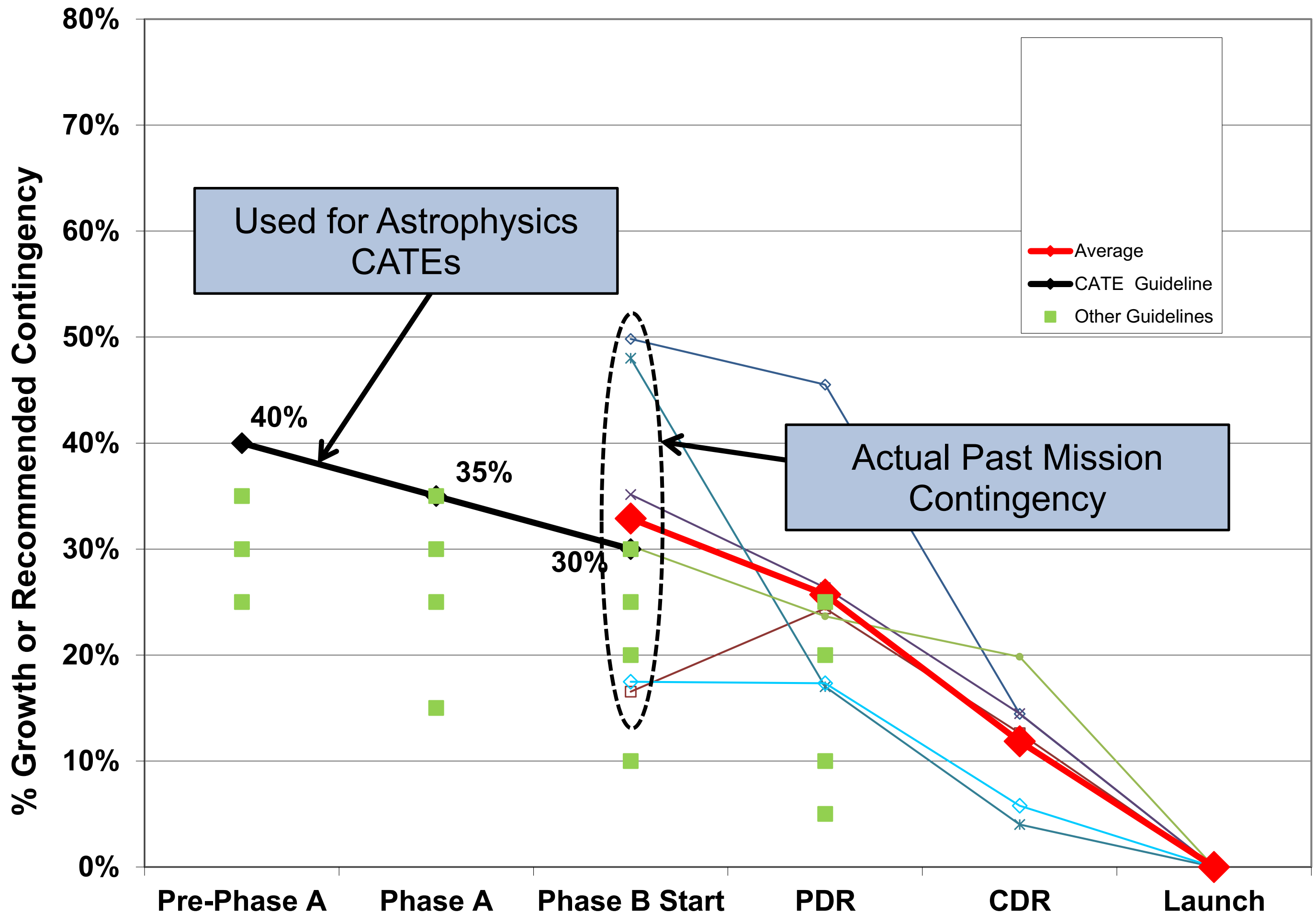
Spacecraft Mass Contingency Values for Threat Estimate



CATE contingency values are an extrapolation of historical Astrophysics mission data

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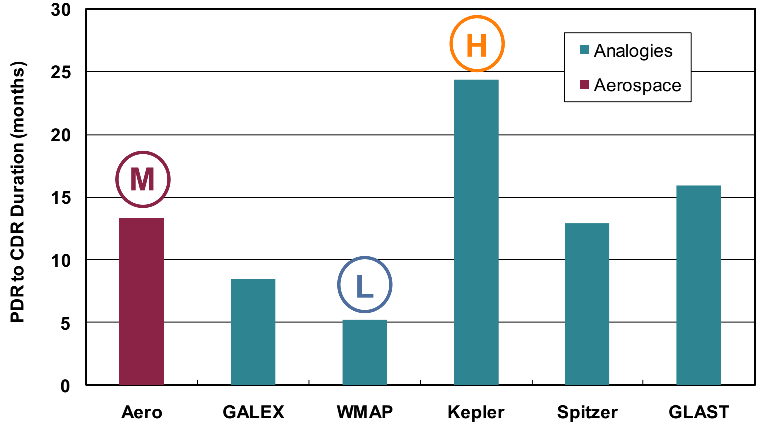
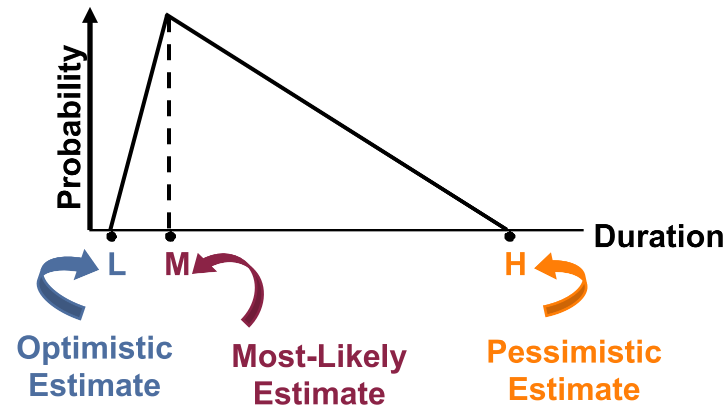
Analogy Based Schedule Risk Process Overview

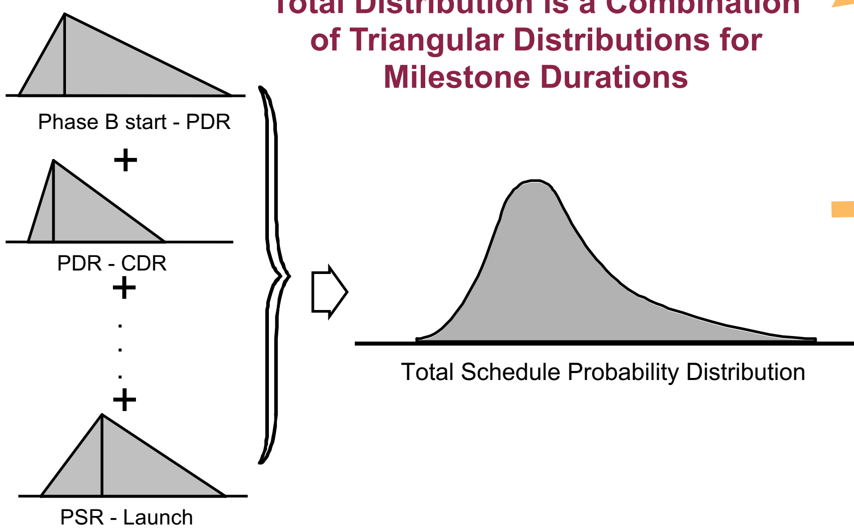
Multiple Estimates for Each Schedule Phase



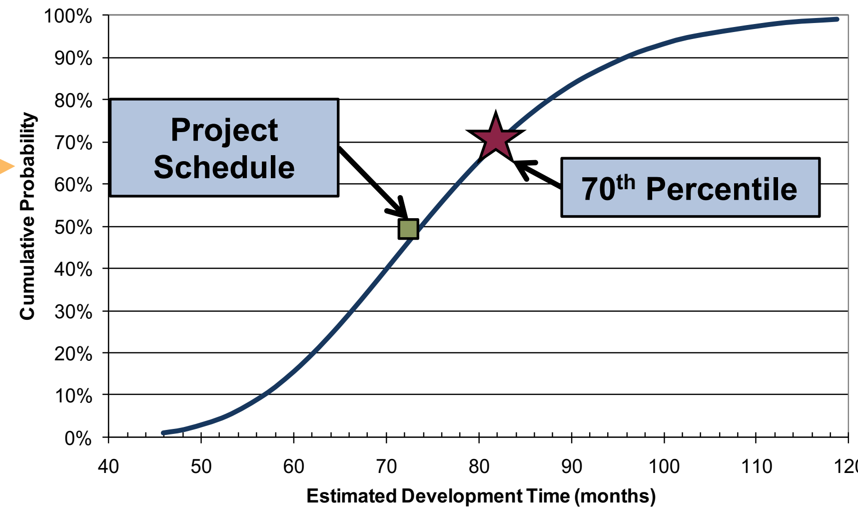
Triangular Distribution of Phase Duration



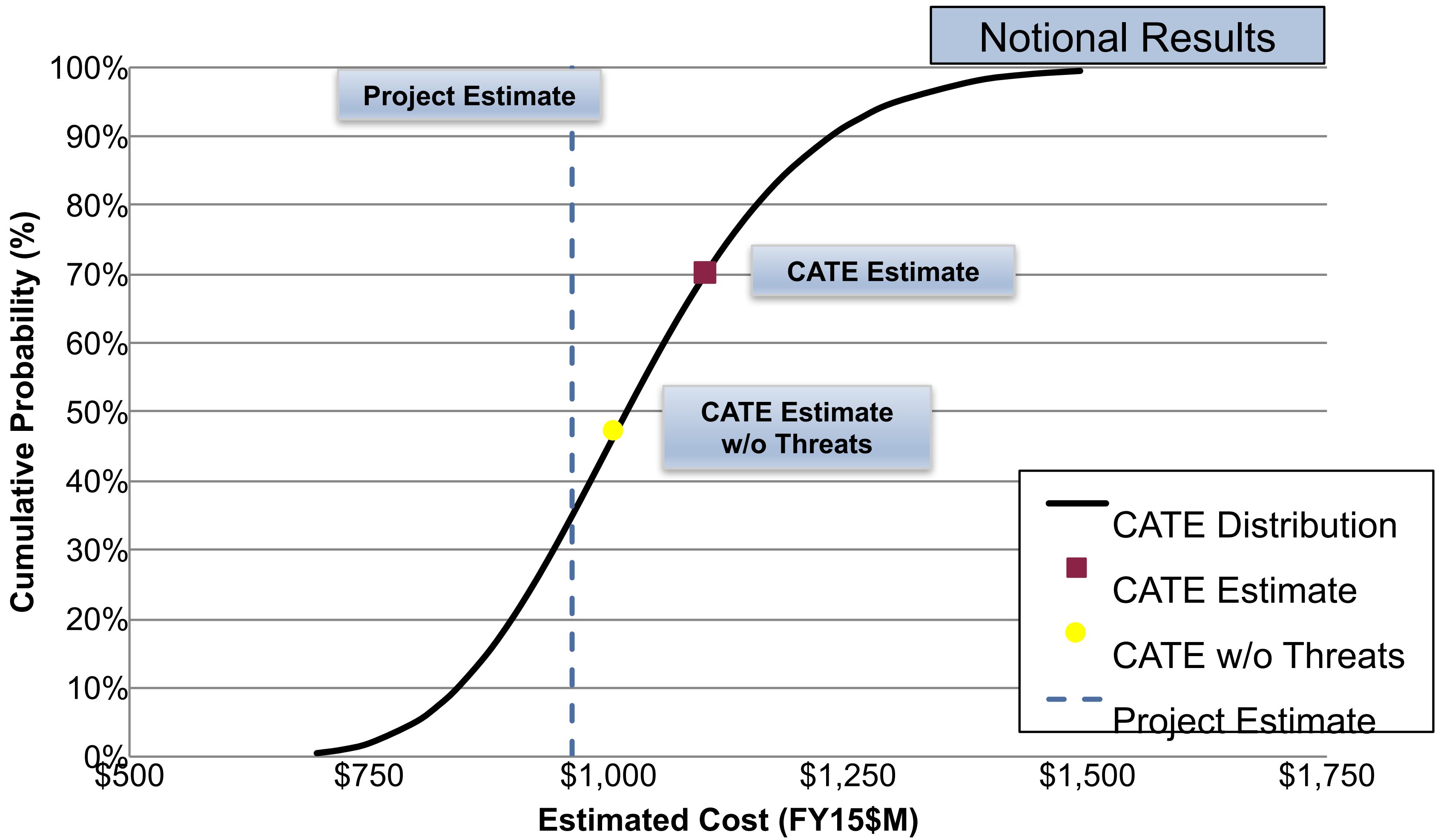
Total Distribution is a Combination of Triangular Distributions for Milestone Durations



Example Schedule Distribution

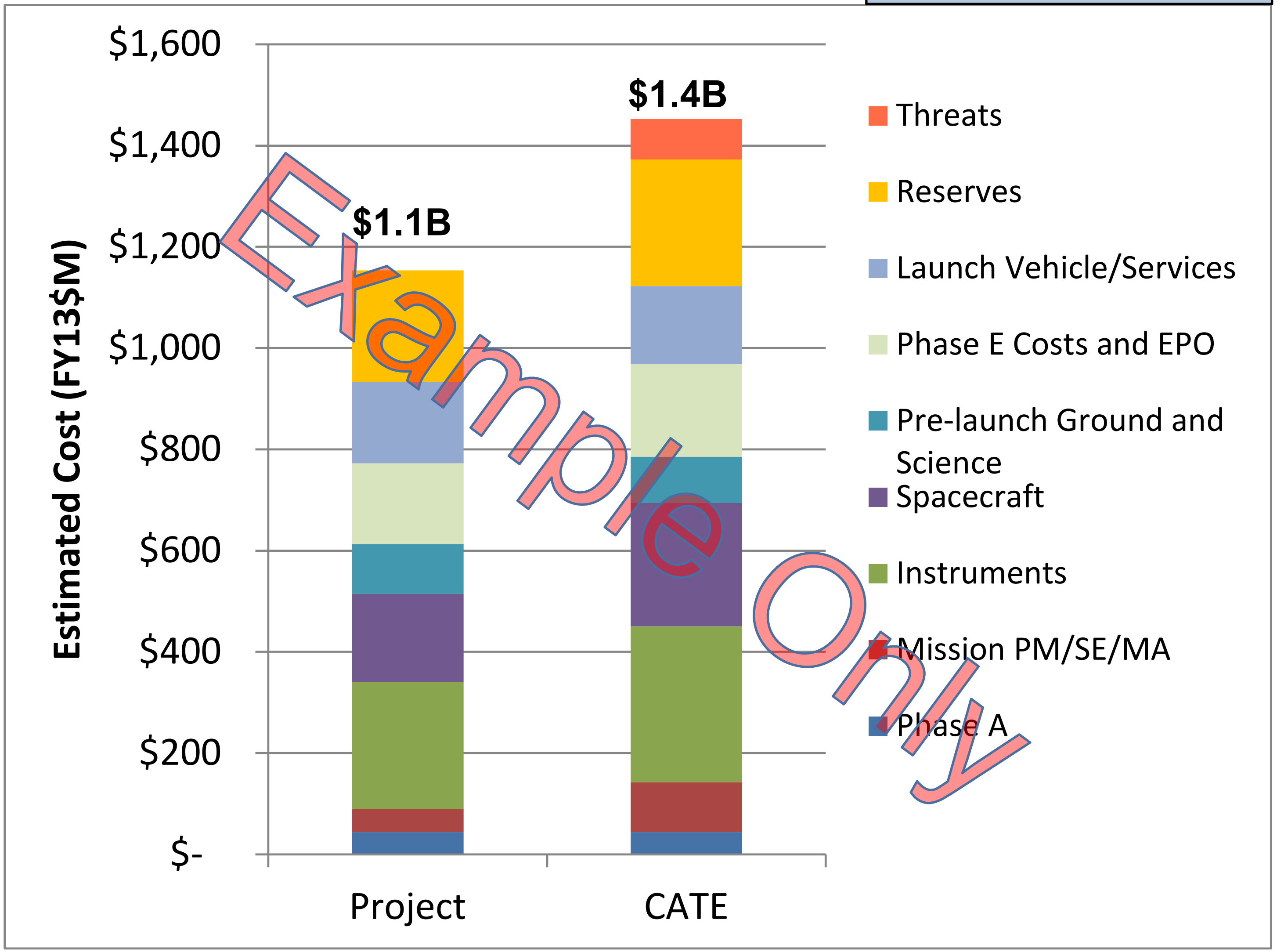


Example Cost Risk S-Curve



Example Cost Bar Charts

Notional Results



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Example Cost Estimate Table

Notional Results

WBS Element	Project Estimate	CATE Estimate	Basis of Aerospace Estimate
Phase A	$ 44	$ 44	Pass-through
Mission PM/SE/MA	$ 45	$ 98	Wrap factors from analogous projects
Instruments	$ 251	$ 308	Instrument models and analogies
Spacecraft	$ 174	$ 243	Bus models and analogies
Pre-launch Ground and Science	$ 98	$ 92	Wrap factors from analogous projects
Phase E Costs and EPO	$ 160	$ 183	MO costs from analogous projects. DA passed-through.
Total Reserves	$ 220	$ 250	70th Percentile from cost risk Analysis
Launch Vehicle/Services	$ 161	$ 154	Cost for proposed LV
Total Mission Cost Without Threats	**$ 1,137**	**$ 1,373**	
Schedule Threats		$ 32	Potential slip from ISE multiplied by project burn rates
Mass and Power Cont. Threats		$ 48	Cost re-estimated using Aerospace contingencies
LV Threats		$ -	Cost difference to move to larger LV
Total Mission Cost With Threats	**$ 1,137**	**$ 1,453**	

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CATE Conclusions

- **CATE is a consistent and robust process to estimate missions for prioritization within a budget constraint profile**
  - *Analogies and parametric models are used*
  - *Instruments and spacecraft are key drivers and often are under estimated by the projects*
  - *Process uses a statistical approach to capture appropriate reserves*
    - Concept maturity
    - Technology readiness
  - *Process uses historical data to address likely cost threats*
    - Design growth
    - Schedule
    - Potential change in launch vehicle

- **Results are suitable for prioritization and long-range planning**

- **CATEs will be incorporated into future NRC Decadal Surveys**

Astrophysics Probe Class Missions

- **Aerospace has performed CATE analysis on Probe Class Missions**
  - *Previously defined as ~$1 B mission including LV and Phase E/F*
  - *Specific astrophysics missions have included:*
    - JDEM
    - Exoplanet C
    - Exoplanet S

- **Many in the community believe Probe Class Missions are important going forward**

- **How does CATE impact Probe Class Missions?**

Example Probe Class Technical Parameters

Technical Parameter	Value
Primary Aperture, m	<1.4
Telescope Mass, kg	328
Instrument Type	Coronagraph
Instrument Mass, kg	96
Payload Power, W	564
Number of Pixels, Mpixels	1 + 1
Spacecraft Dry Mass, kg	646
Observatory Dry Mass, kg	1,067
Propellant Mass, kg	20
Observatory Wet Mass, kg	1090
BOL Power, W	1050
Orbit	Earth Trailing
Launch Vehicle	Atlas V 511
Phase E Duration, years	3

All Mass & Power Values are CBE (Current Best Estimate)

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Nominal Probe Class Payload Available Budget

- **Available Budget Analysis can guide teams to fit within a desired Probe Class Mission budget cap**
  - *Many elements are known like Launch Vehicle and Phase E Costs*
  - *Ultimately, can the science be delivered within Available Payload Dollars?*

Budget Item Probe Class Budget Target; $FYXXM	*$850*	*$1,000*	*$1,250*
Launch Vehicle Cost	-$150	-$150	-$150
Mission Life, Years	3	3	5
Phase E Cost per Year	$30	$30	$30
Total Phase E	-$90	-$90	-$150
Phase A Cost Including Technology Development	-$33	-$33	-$33
Total Available Phase B-D	**$577**	**$727**	**$917**
CATE Threats (assume 5%)	-$29	-$36	-$46
Phase B-D Development Factor	173%	173%	173%
DF = (1+PM/SE/MA+MOS/GDS)(1+ Reserves)			
PM/SE/MA	18.0%	18.0%	18.0%
MOS/GDS	15.0%	15.0%	15.0%
Project Reserves	30.0%	30.0%	30.0%
Available B-D Hardware Dollars	**$317**	**$399**	**$504**
Average Spacecraft Cost	-$175	-$175	-$200
Available Payload Dollars	**$142**	**$224**	**$304**

Example Only

Example Cost Estimate Table

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Lessons Learned in Previous Probe Class Missions

- **Project teams should focus on realistic payload & spacecraft hardware costs**
  - *This is often where biggest discrepancies occur*
  - *Don't forget those Technology Development Costs and Risk Mitigation Plans*
    - Many projects get a yellow risk rating; a green is not required

- **Phase E & F costs are also a large source of discrepancy**

- **Project teams focus too much on added cost threats**
  - *CATE is a look forward evaluation process not a specific cost estimate*

- **A CATE value higher than $1 B is not the end of a Probe mission**
  - *Science value is prioritized on a cost range not a specific value*
  - *CATEs are always full mission costs*

Agenda

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