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

**Mission X**

- Research, Management, Discovery

**Planetary Funding Profiles**

- President’s FY11 Budget + inflation
- President’s FY12 Budget
- Assumed Flat Budget

**Fiscal Year**

- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022
- 2023
- 2024
- 2025
- 2026
- 2027
- 2028
- 2029
- 2030
- 2031
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
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 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

**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

- **Estimated Cost (FY15$M)**
  - Project
  - Aero
  - Model 1
  - Model 2
  - Analogy 1
  - Analogy 2
  - Analogy 3
  - Analogy 4

- **Adjusted Analogy**
- **Model**
- **Aerospace**
- **Project**

- **Notional Results**
Cost Risk Process Overview

*Used to estimate reserves*

**Multiple Cost Estimates for Each WBS Element**

- Adjusted Analogy
- Model
- Estimate

**Triangular Distribution of Possible Element Cost**

- Lower Limit
- Most-Likely
- Upper Limit

- DMF: Design Maturity Factor added to high estimate to capture worst case

**Total Distribution is a Combination of Cost Distributions for WBS Elements**

- WBS Element 1
- WBS Element 2
- WBS Element N

**Example Total Cost Distribution**

- Sum of Most-likely Costs
- 70th Percentile
- Initial Cost Reserves Estimate

**Estimated Cost (FY09$M)**

- $1,000
- $1,200
- $1,400
- $1,600
- $1,800
- $2,000
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*

![Bar chart showing growth in spacecraft and payload masses from SDT.](chart.jpg)
Payload Mass Contingency Values for Threat Estimate

CATE contingency values are an extrapolation of historical Astrophysics mission data

Used for Astrophysics CATEs

Actual Past Mission Contingency

Average
- CATE Guideline
- Other Guidelines

% Growth or Recommended Contingency
- 60%
- 45%
- 30%

Pre-Phase A, Phase A, Phase B Start, PDR, CDR, Launch
Spacecraft Mass Contingency Values for Threat Estimate

CATE contingency values are an extrapolation of historical Astrophysics mission data
Analogy Based Schedule Risk Process Overview

Multiple Estimates for Each Schedule Phase

Total Distribution is a Combination of Triangular Distributions for Milestone Durations

Example Schedule Distribution

Cumulative Probability

Estimated Development Time (months)

Project Schedule

70th Percentile
Example Cost Risk S-Curve
## Example Cost Estimate Table

<table>
<thead>
<tr>
<th>WBS Element</th>
<th>Project Estimate</th>
<th>CATE Estimate</th>
<th>Basis of Aerospace Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase A</td>
<td>$44</td>
<td>$44</td>
<td>Pass-through</td>
</tr>
<tr>
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<td>$183</td>
<td>MO costs from analogous projects. DA passed-through.</td>
</tr>
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<td>$220</td>
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<td>70th Percentile from cost risk Analysis</td>
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<td></td>
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<td>Potential slip from ISE multiplied by project burn rates</td>
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<td></td>
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</table>
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 underestimated 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

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

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

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