Cost and Risk Estimating and Analysis in a Concurrent Engineering Environment

TEAM X
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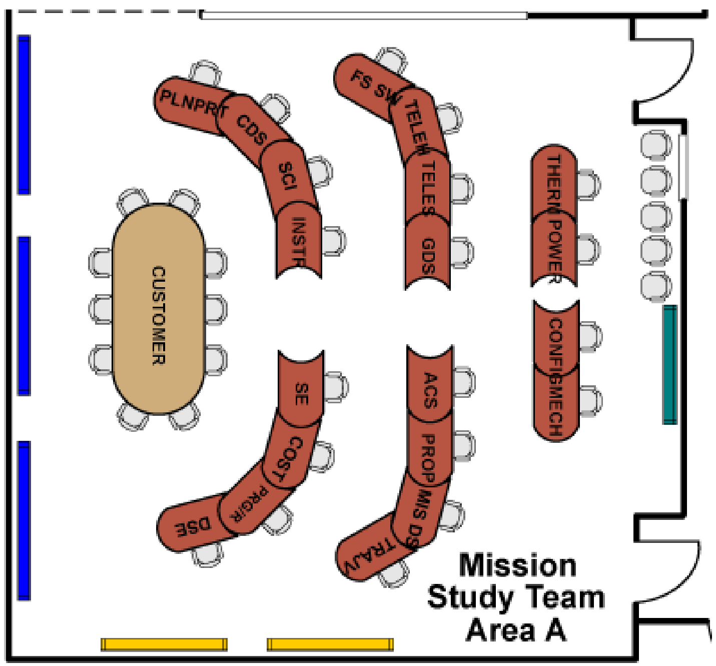
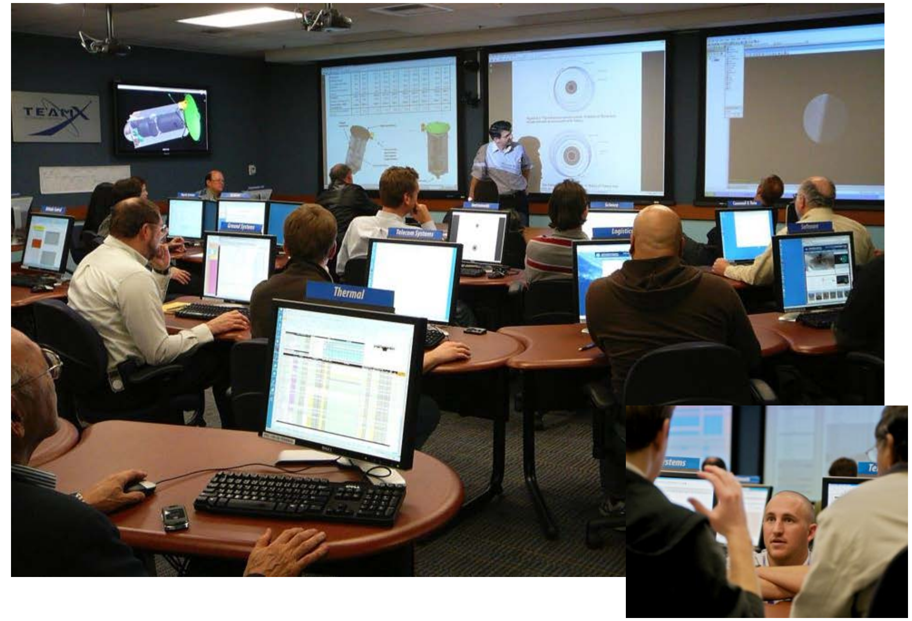
This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

What is Team X?

Team X is a concurrent engineering team for rapid design and analysis of space mission concepts





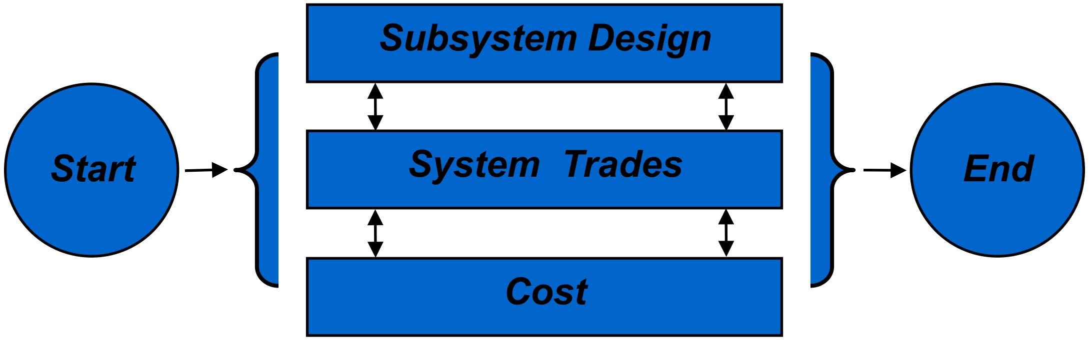
Team X profiled in *Time* magazine, October 2005
Previous New York Times article

- **Developed in 1995 by JPL to reduce study time and cost**
- **More than 1100 studies completed**
- **Institutionally endorsed**
- **Emulated by many institutions**

Concurrent Engineering – What is it?

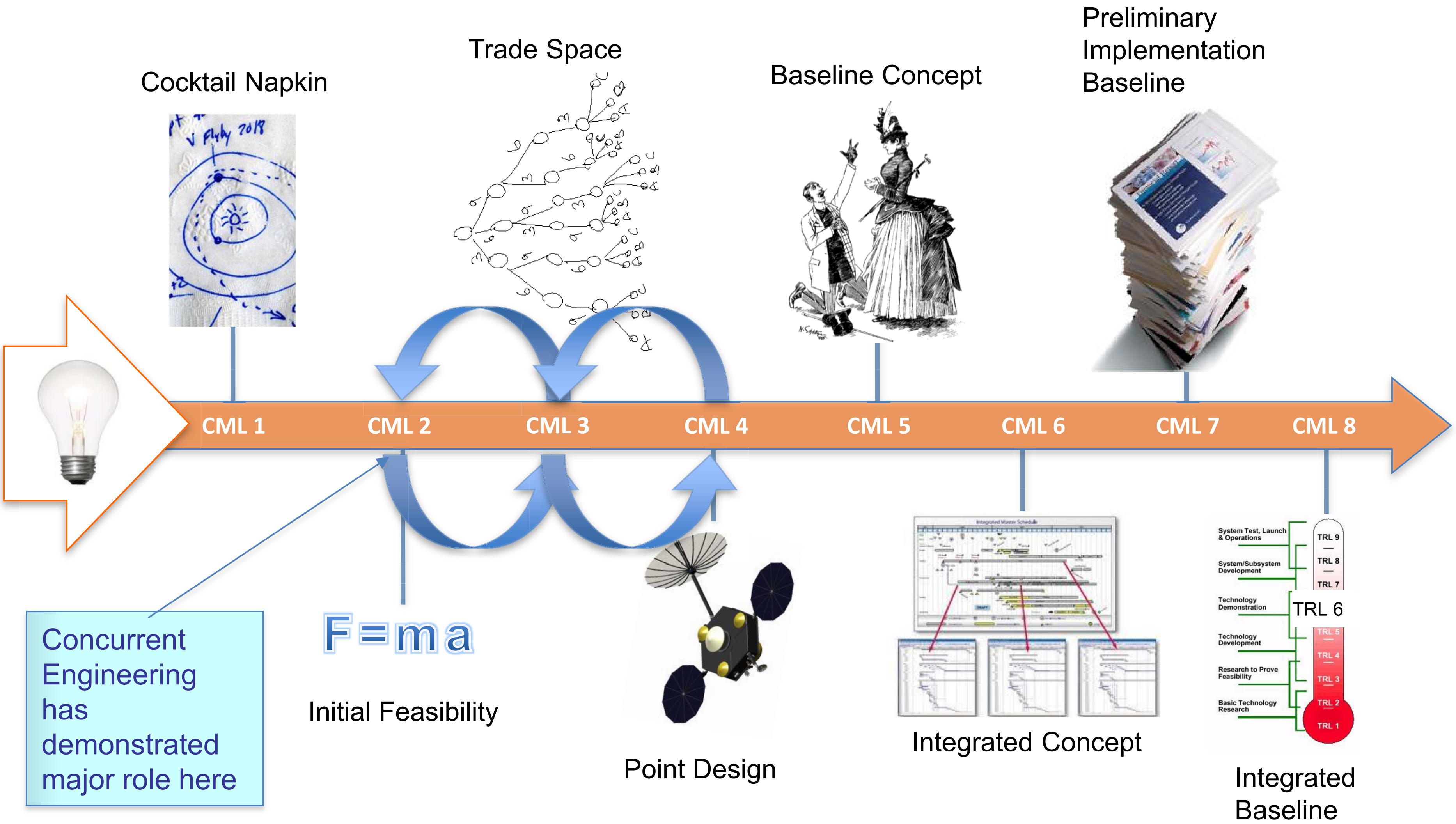
Concurrent Engineering

- Diverse specialists working in real time, in the same place, with shared data, to yield an integrated design
- As part of the study system evaluation, system design trades involving cost are performed



Within this setting cost is a tradable parameter, like mass, power, etc.

Concurrent Engineering has Demonstrated a Major Role in the Early Life Cycle



Current Team X Cost Estimation Methodology

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Current Team X Cost Estimation Methodology

- **Subsystem cost estimates are predominantly grass roots model-based owned by the doing organizations**
  - A few are parametric and wrap factors
  - Models provide expected mission costs by level 2 and level 3 WBS elements
  - Models generate expected resource expenditures that are accumulated to dollar amounts

- **Cost Chair accumulates costs from Team X subsystem chairs**
  - Cost engineering station generates systems engineering, management, mission assurance, and reserves
    - Reserves are calculated to meet JPL Design Principles.
  - Rates and factors are provided by the JPL financial organization.
  - L/V costs come from AO information. Can also be provided by customer
  - WBS estimates and cost profiles are generated

Cost Tool Validation and Review

- The responsible organizations update and validate their models to keep them current
- The updated models are reviewed and approved by a Change Control Board (CCB)
- The cost models are subject to a Configuration Management (CM) system

Team X Risk Process

Risk Mental Models

- **Risk Identification**
- In the early stages of the lifecycle it is difficult to distinguish between an Issue, Concern, or Risk
- Everyone applies some type of risk threshold
  - Normal risks are not worth writing down as they are part of the 'risk' of doing business
  - Risk Chair becomes the 'Normalizer'
- **Scoring is a fuzzy hybrid of qualitative and quantitative assessment**
  - Some researchers describe risk assessment in the early life-cycle as 'pre-quantitative risk
- **Rather than thinking about risk quantitatively, engineers appear to have a better sense of levels of risk**
  - A representation of the thought process might be:
  - This is something to keep an eye on (green risk).
  - This is something that I am very worried about and it could cause total mission loss (red risk).
  - This is something to worry about and it might be even worse than I realize since there is limited information currently available (yellow risk).

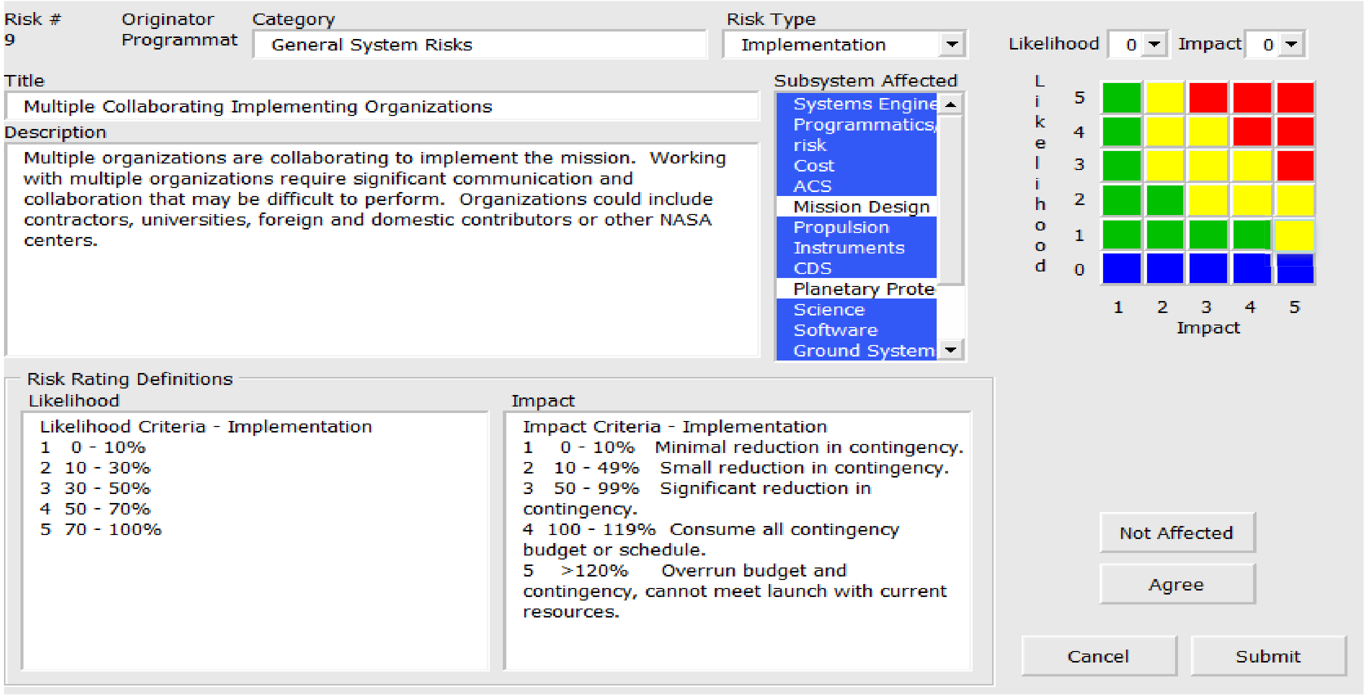
Example Risk Checklist: Propulsion

Propulsion	Implementation	Mission
Organizational		
Outside development of mission parts/contractor relations		
Multiple collaborating implementing organizations		
Technology Development and Heritage		
Low TRL /New Technology		
Lack of experience with technology at JPL		
Scaling of existing technology (significant increase in size, power, mass)		
Technology inheritance from future missions		
Optimistic heritage assumptions		
Reliance on availability of residual hardware (such as Galileo heat shield, or SEP from DAWN)		
Availability of commercial parts		
Redundancy/Critical Failure		
Lack of Redundancy		
Dependencies on other flight systems within the mission		
Inability to test certain components in a relevant environment		
Very long mission (impact on component reliability)		
Environmental		
Harsh environment		
Unknown environment		
Environmental contaminants		
Subsystem Specific		
Restricted configuration to avoid contamination of other subsystems		
Meeting deorbit maneuver fuel requirements		
Unbalanced Thrusters		

- Checklist of common risks developed for each subsystem, through review of a subset of prior Team X studies
- Checklists validated during interviews with Team X subsystem chairs
- Use of checklists during Team X studies revealed:
  - Lists were useful to Risk chair
  - Subsystem chairs felt the general lists were long, should be tailored to the specific study

All updates done here

- **Team X Risk Tool enables communication between all chairs/subsystems**
  - Risk chair reviews checklist and enters potential risks and impacted subsystems
  - Subsystem chairs can reject, edit, and propose alternative risks as well as score the risks
  - Risk chair reviews wording and scores and revises risks for consistency and to provide a system level perspective
  - Tool is built into Team X Workbooks



Proposed Team X Integrated Cost-Risk Process

Justification for a New Cost Risk Methodology

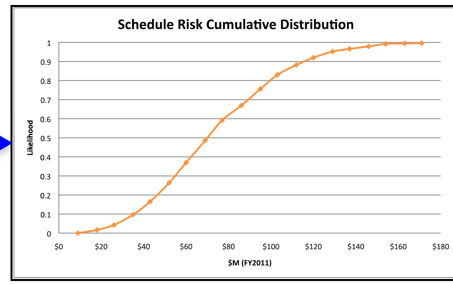
- **Some Team X customers have asked for S-curves for various studies over the years**
- **Probabilistic analysis is required as per NPR 7120.5E 2.4.3.2**
- **Concurrent engineering teams need a method that is transparent and fast**
- **Current methods have problems in a concurrent engineering environment**
  - Many of the existing cost-risk methods are overly complex and require data that is not available at the time of estimate
  - For various reasons previous attempts at generating S-curves within Team X have not succeeded
    - Too many inputs
    - Too slow – can lock up Excel
    - Results did not pass the laugh test – steep S-curves where for a few dollars more, likelihood of meeting cost goal increases significantly
- **New method was developed and has been successfully piloted**

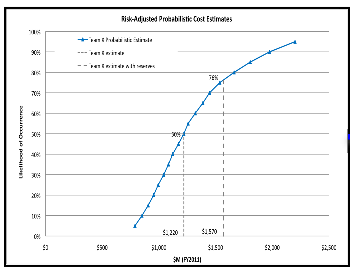
Proposed Team X Cost Estimation Process

- **Cost Risk Assessment on Team X has three primary elements that enable the generation of a cost distribution and support risk analysis**
  - 1. Parametric Cost Models
    - There are two parametric cost models used: Parametric Mission Cost Model (PMCM) and NASA Instrument Cost Model (NICM)
    - Each Parametric model has a known output uncertainty, derived from the underlying data
    - Each model input can be specified as a distribution
  - 2. Launch slip prediction model
  - 3. Implementation and mission risks, which are identified by the subsystem chairs and with final scores scrubbed by the Risk Chair

Risk-Adjusted Probabilistic Cost Estimate Methodology

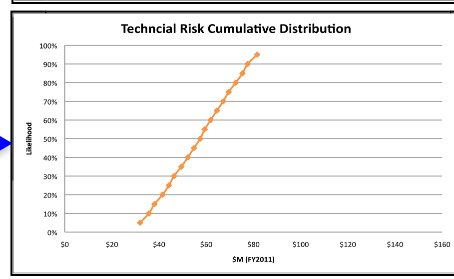
2. Estimated schedule risk based on inputs from Mission Design





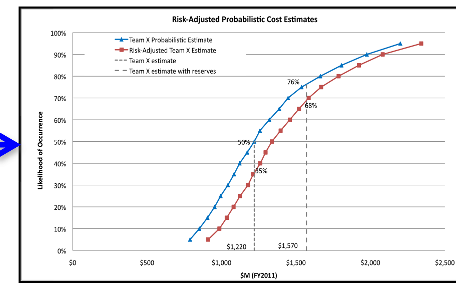
1. Estimate/Model Uncertainty

Convolve



3. Implementation and Mission risks based on key risks that are based on risks identified by Team X

Yields



Risk-Adjusted Probabilistic Cost Estimate

Risk-Adjusted Probabilistic Cost Estimate Methodology
Schedule Risk

Schedule distribution is derived from analysis and historical data

- Likelihood of slip is based on analysis of 19 historical JPL in-house and contracted missions
- Impact is based on Team X effort profiles and mission design determination of months between launch opportunities
- Launch opportunities identified by Mission Design

Schedule Risk Defaults

Destination	Distribution Type	Schedule Slip (months)
Earth	Uniform	0-36 months
Planetary (non Mars/Jupiter)		
Jupiter		
Mars Orbiter		
Mars In-Situ		

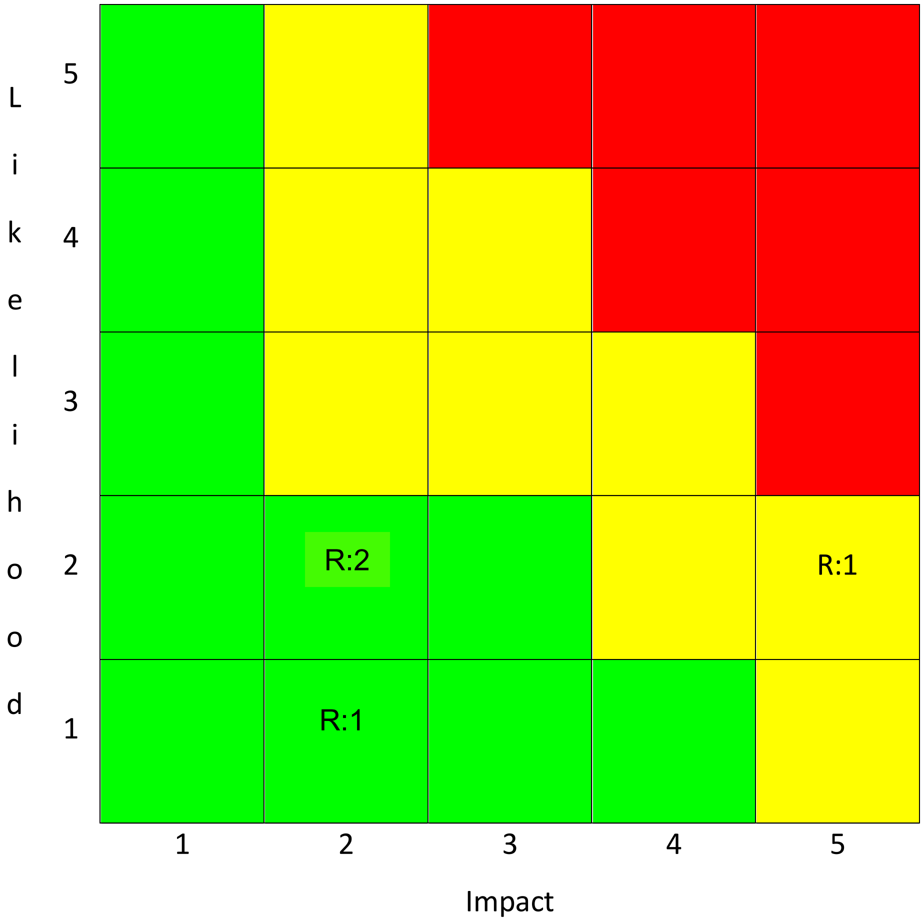
Schedule Risk Inputs

Use Defaults?	No
Type of Distribution	Bimodal

See example charts below for help in selecting type of distribution

Percent Probability	Distribution of Slip	Number of Months Slip: Low	Most Likely	High	Mean	Standard Deviation
90%	Uniform	0		0.75		
10%	Uniform	9		9.75		

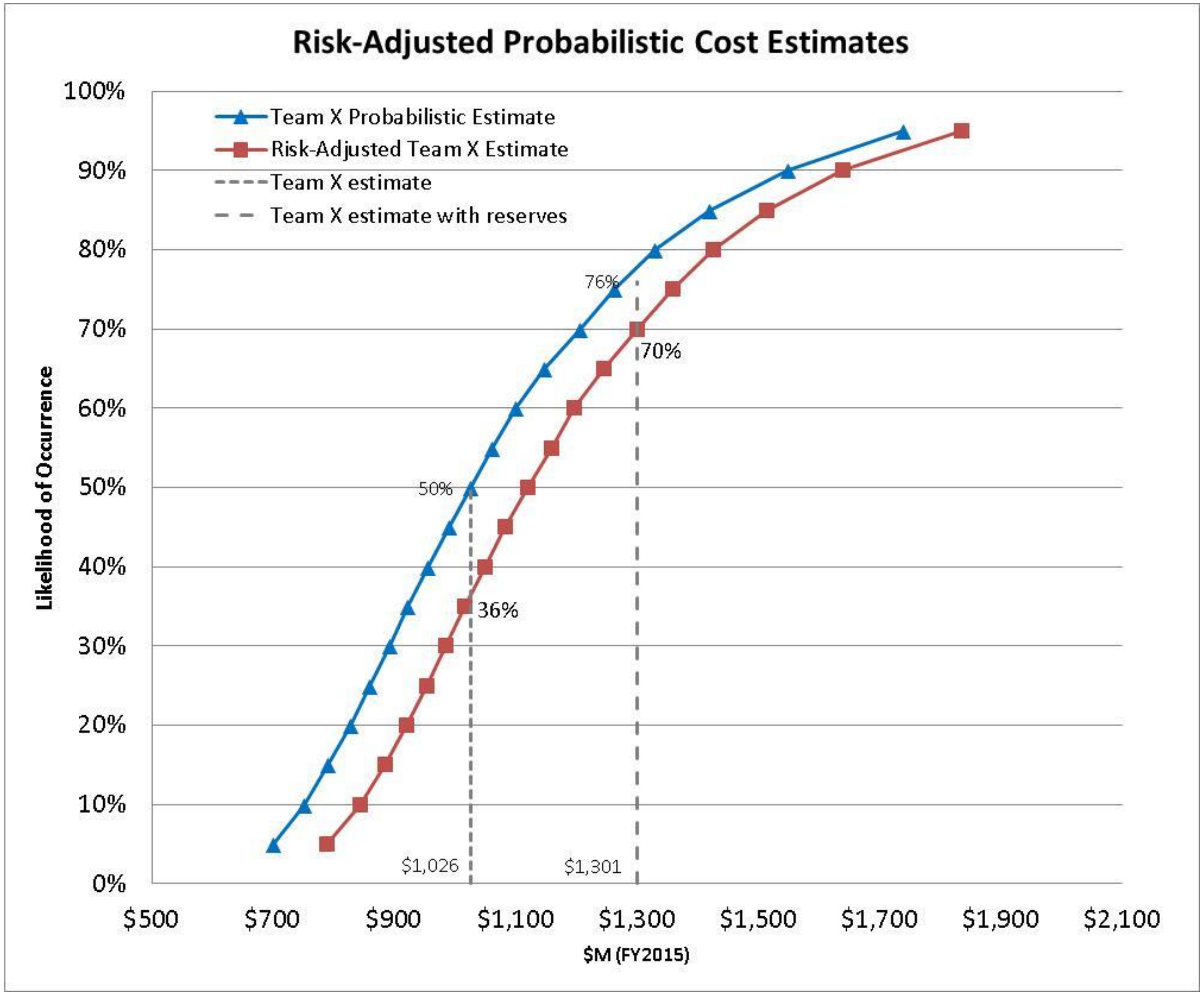
Implementation Risks
Risk Idenitification and Scoring



- **Mission X is a relatively low risk mission compared to other similar space science missions.**
  - SC has relatively high heritage
  - Moderate number of instruments
- **There is one significant risk that needs to be addressed.**
  - ASRG performance and delivery date of flight is still highly uncertain
  - Specific mitigations are not identified but the impact is based on a best estimate for the cost impact should the risk manifest

Risk-Adjusted Probabilistic Cost Distribution (S-Curve)

Example Mission



- **Estimate uses parametric cost model based on the Team X 50th-percentile estimate**
- **Cost risk analysis indicates that proposed mission has a high likelihood of success**
  - Estimated cost with reserves is 70% to 76%. Typical NASA goal is 70%.
  - Identified risks consume less than 1/3rd of planned reserves leaving sufficient reserves to cover 'unknown-unknowns'
  - The 50th percentile team X estimate becomes 36% when the identified risks are taken into account

Conclusion

- **We have successfully piloted this new Cost-Risk Methodology in 3 concurrent engineering design sessions**
  - It worked very well for large missions
  - For smaller missions, we ran into problems with the lack of granularity in the mission and implementation risk categories
- **The piloted method is transparent and fast and addresses many of the problems associated with current cost risk estimation approaches**