A New Approach to Building a “Grassroots” S-Curve

Utilizing Expertise and Historical Performance Data to Produce a More Meaningful Cost Risk Assessment

Michael DiNicola

Kelli McCoy

Systems Modeling, Analysis & Architecture

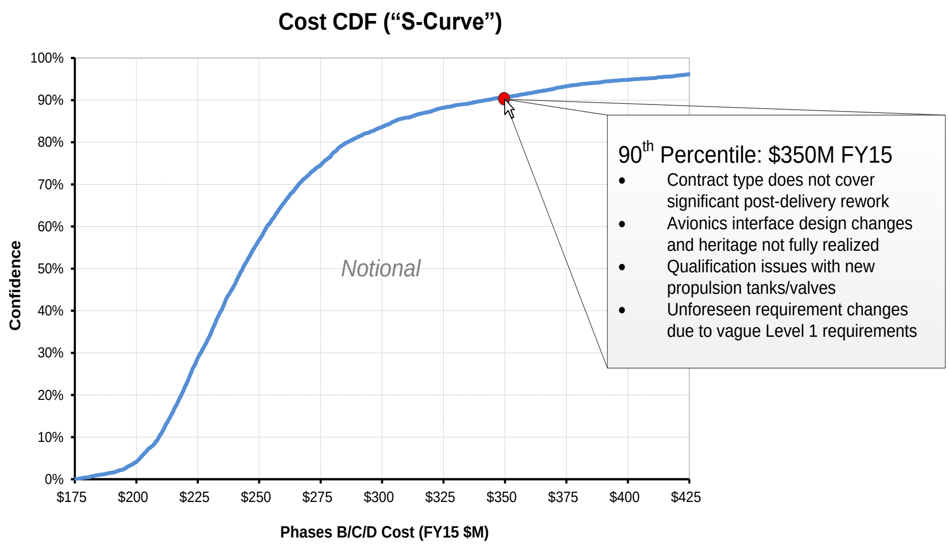
Jet Propulsion Laboratory

Michael.Dinicola@jpl.nasa.gov

Kelli.J.Mccoy@jpl.nasa.gov

What We Set Out To Do

- Establish a flexible process for assessing cost risk on grassroots estimates that brings together institutional/project expertise and actual historical data
- Incorporate historical performance data on similar programs as an indicator of how an organization will manage cost risk
- Produce an S-Curve that enables management and stakeholders to have **intelligent discussion** regarding cost risk and **navigate the path forward**.



Every point on the S-Curve should mean something real.

S-Curve Methods

Compare two different S-Curves methods:

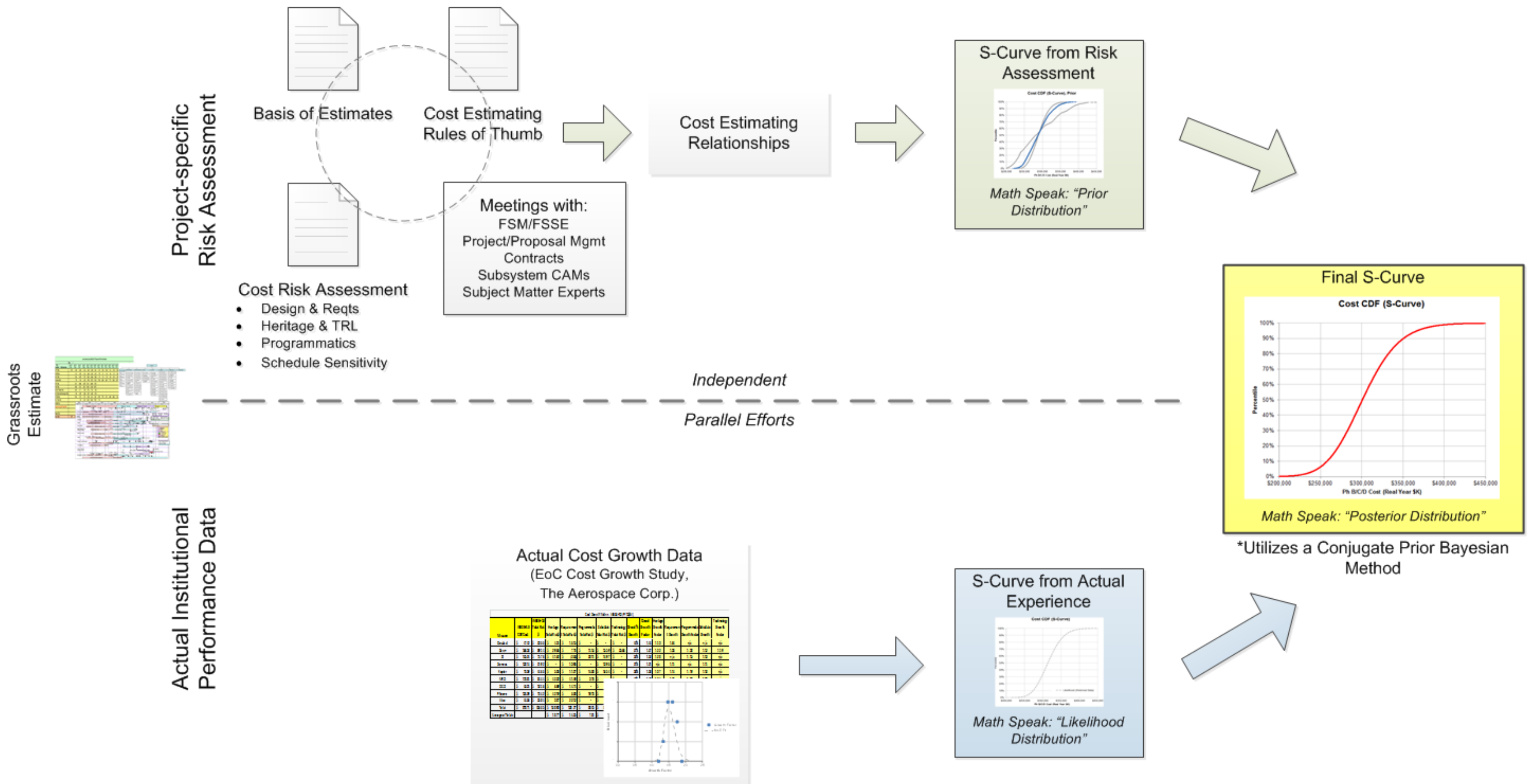
- **Grassroots-based S-Curve:** Derived from grassroots estimates and technical understanding of risks affecting the baseline
- **Model-based S-Curve:** Derived from cost model uncertainty, calibrated to actual experience; typically uses cost models like PRICE, SEER and NICM

	Grassroots-based	Model-based
Pros / Benefits	• Higher fidelity, more tangible • More closely linked to the concept proposed • Allows for more of a reserve conversation • Variance in S-Curve can be more tuned to the concept being evaluated • **Opportunity to be very informative**	• Typically calibrated to actual data • Process is more well-defined • Supportable to outside evaluators and cost modelers, appears less subjective • **Captures uncertainty for early development phases reasonably well**
Cons / Pitfalls	• Typically success-driven • Many times do not consider uncertainty beyond the baseline, underestimating risk and uncertainty at early phases of development • Risk assessments for one subsystem many times do not fully consider interdependencies with other subsystems • **The resulting S-Curve can be too tight**	• Not as tangible • Many cost models used are “black boxes” • Does not facilitate a strong reserve discussion • S-Curve may have cost intervals of questionable applicability (esp. in the tails) • **Loses insight into sources of risk and communicability**

The approach taken here: Retain the information afforded by the “Grassroots-based” approach, while calibrating with actual data as done in the “Model-based” approach.

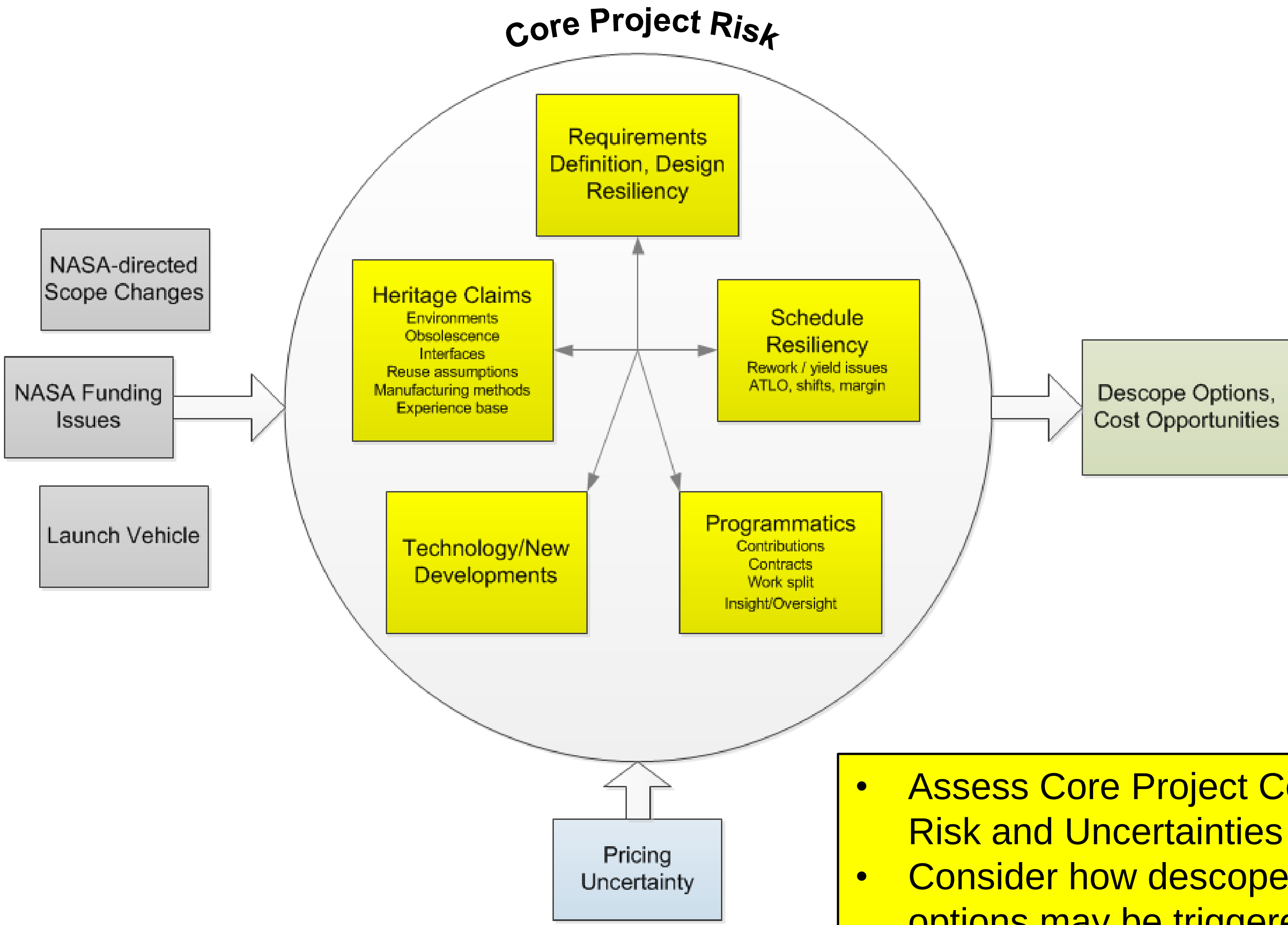
S-Curve Assembly & Integration

Captures Unique Aspects of a Project and Incorporates Breadth of Engineering and Management Experience into Assessment



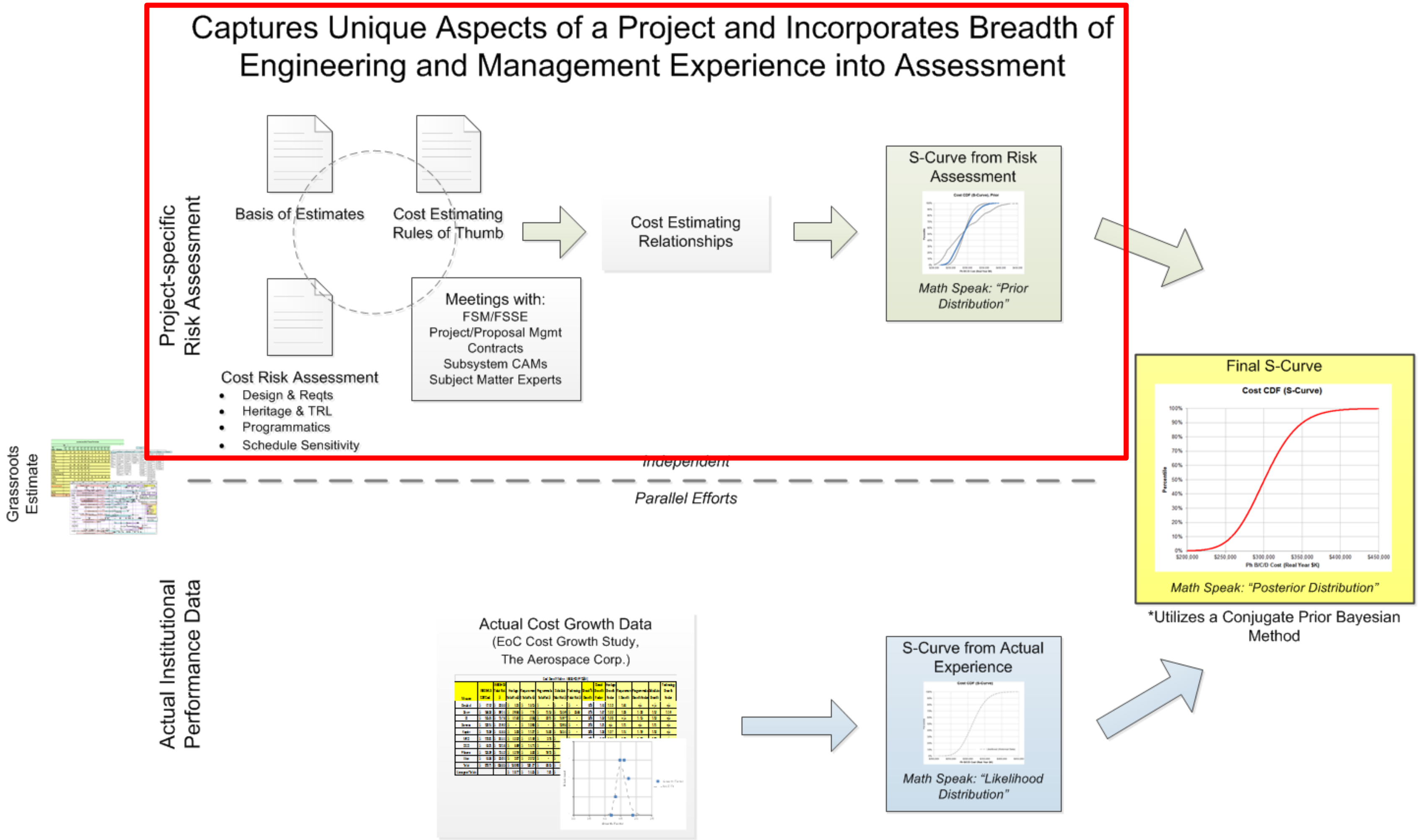
Actual data calibrates engineering judgment with actual institutional performance on previous missions.

Assess Risk Themes & Uncertainty



- Assess Core Project Cost Risk and Uncertainties
- Consider how descope options may be triggered

S-Curve Assembly & Integration

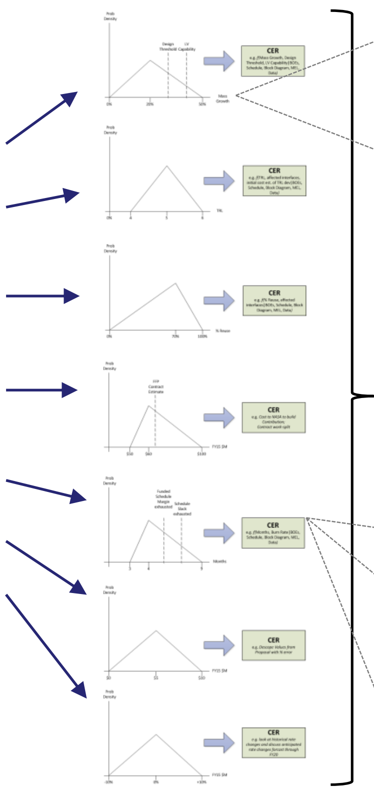


Actual data calibrates engineering judgment with actual institutional performance on previous missions.

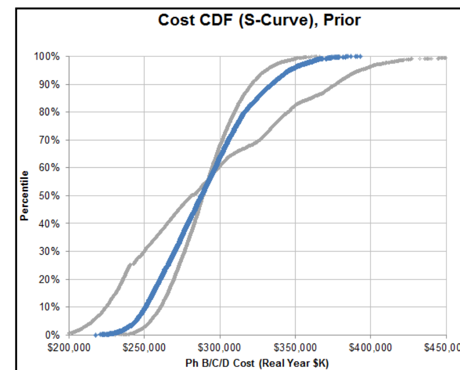
Quantifying the Risk – Project-specific Risk Assessment

1. Top-level Risks Identified | **2. Determine Risk Characteristic Probability Distr.** | **3. Apply CERs & Assess Interdependencies** | **4. Monte Carlo Simulation for S-Curve**

Risk Theme	Consideration
Requirements Definition, Design Resiliency	Mass margins satisfy JPL Design Principles. Science/mission requirements well-defined for Phase A. Capability driven bus.
Technology/New Developments	Nothing significant identified. NASA funded technology infusion which is descopable.
Heritage Claims	• New radiation environment • BTP GN&C hardware may be optimistic • Avionics interface is new and heritage may not be realized
Programmatics	• Foreign partner delivering critical instrumentation • New subcontractor partnership • Contractual arrangement may not be optimal • Phase B / Formulation effort to mature instrument design
Schedule Resiliency	• Heritage SSs and Subcontractor delivery impact on schedule • Few/no multiple shifts in current ATLO plan • No subsystem rework planned in current estimate
Descope Options	None
Pricing Uncertainty	+/- 5-10%
NASA Induced Risk	Not considered (funding issues, LV, scope changes)



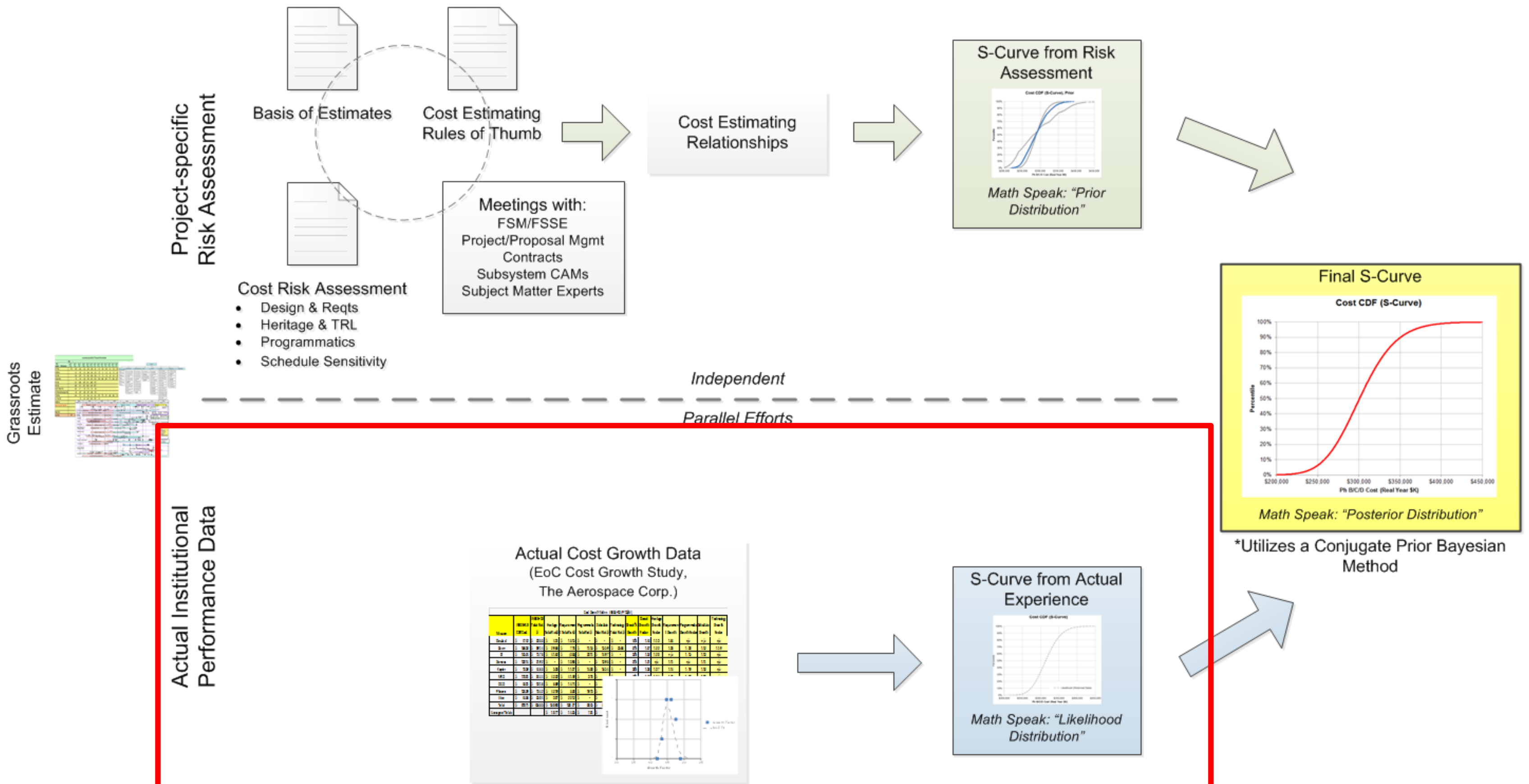
Probabilistic assessment of risk characteristics



CERs from BOE and Rules of Thumb used to dollarize risk

S-Curve Assembly & Integration

Captures Unique Aspects of a Project and Incorporates Breadth of Engineering and Management Experience into Assessment



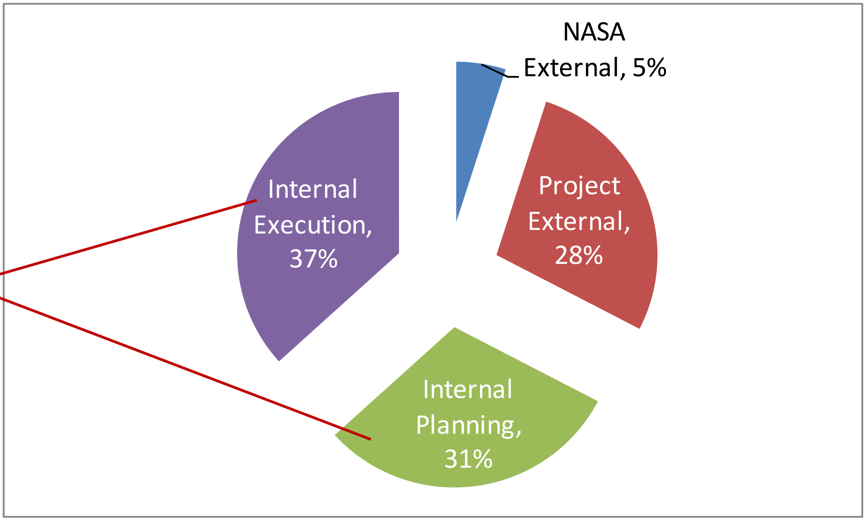
Actual data calibrates engineering judgment with actual institutional performance on previous missions.

Explanation of Change (EoC) Study Overview

Bob Bitten, The Aerospace Corp, 2011

- **Goal**: determine the potential causes of cost growth in NASA science missions in order to reduce cost growth on future missions
- **Methodology**: using CADRe data, milestone review packages, monthly status reports, and interviews with key project personnel, cost growth root causes were categorized into four bins for 25 missions.

Relevant data was decomposed from these detailed bins and summarized



Distribution of Cost Growth Categories

The EoC Study data can be leveraged for analysis and tailored to the user's scope of risk.

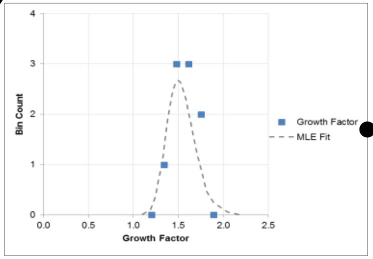
Quantifying the Risk – Actual Performance & the EoC Study

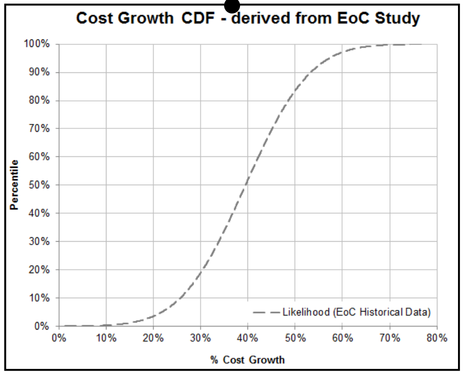
1. Determine Relevant Missions & Work Elements

2. Map EoC Risk Categories to Risk Themes, by Mission

3. Calculate Growth Factors by Risk Theme, by Mission

4. Construct Distribution of Growth Factors



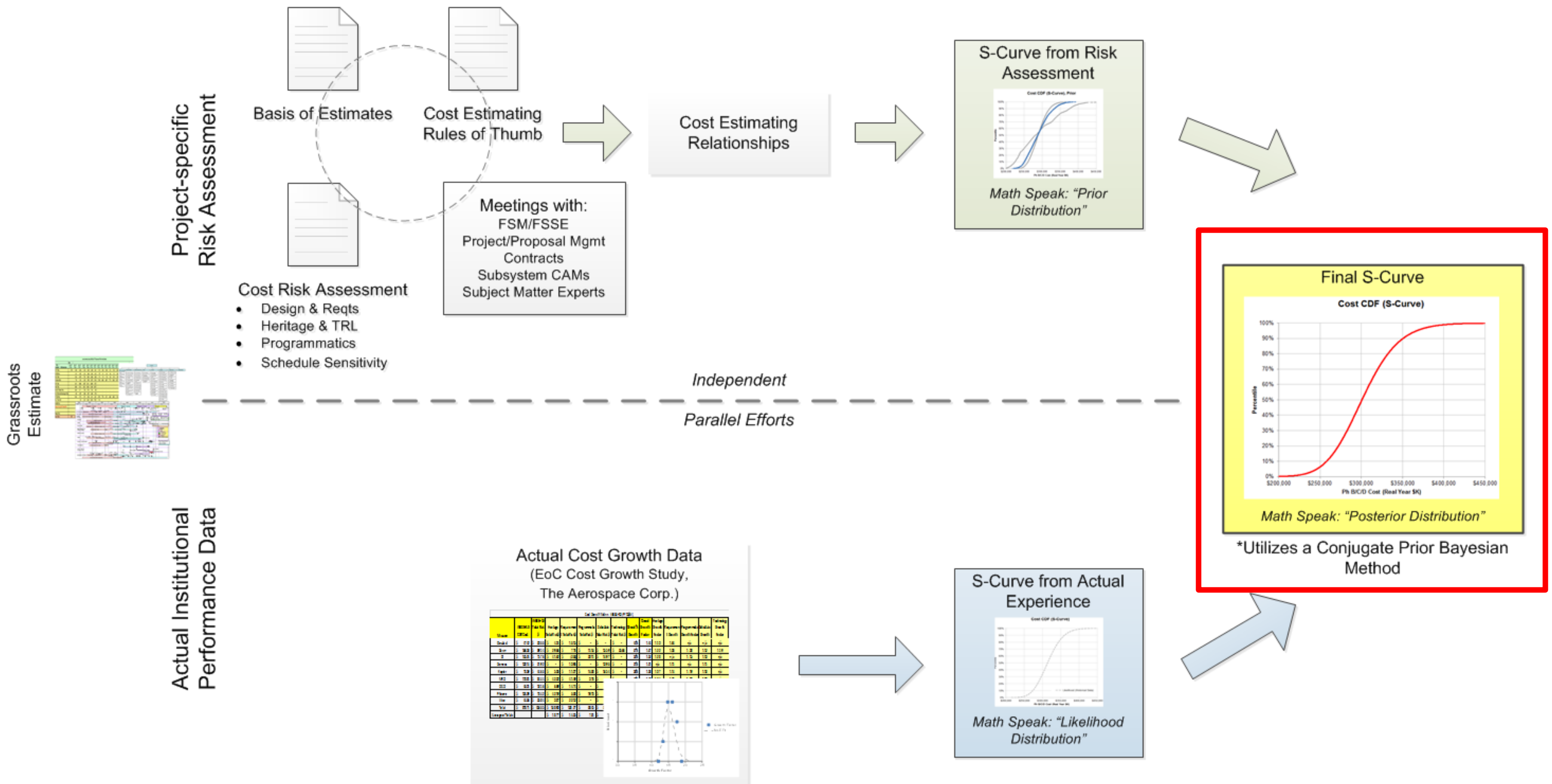


Cost Growth Matrix for Specified Work Elements

Mission	Aggregate Growth Factor	Heritage Growth Factor	Req't Growth Factor	Prog. Growth Factor	Schedule Growth Factor	Technology Growth Factor
Cloudsat	1.44	1.10	1.34	n/a	n/a	n/a
Dawn	1.67	1.22	1.06	1.08	1.12	1.19
DI	1.52	1.28	n/a	1.15	1.10	n/a
Genesis	1.21	n/a	1.11	n/a	1.11	n/a
Kepler	1.58	1.07	1.14	1.19	1.18	n/a
MRO	1.47	1.24	1.23	1.00	1.00	n/a
OCO	1.39	1.07	1.32	n/a	n/a	n/a
Phoenix	1.73	1.40	1.06	1.19	1.07	n/a
Wise	1.58	1.02	1.50	n/a	1.06	n/a

S-Curve Assembly & Integration

Captures Unique Aspects of a Project and Incorporates Breadth of Engineering and Management Experience into Assessment



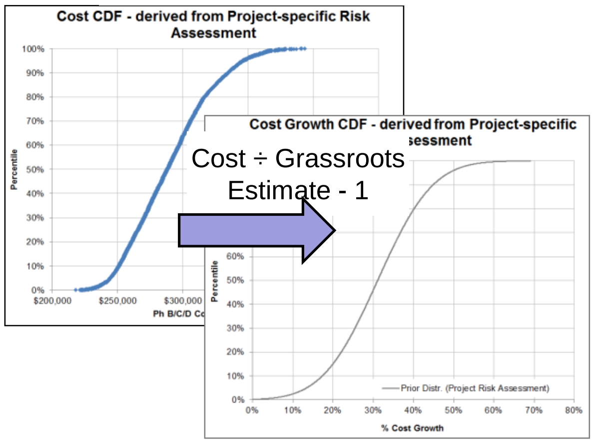
Actual data calibrates engineering judgment with actual institutional performance on previous missions.

Engineering & Science Directorate

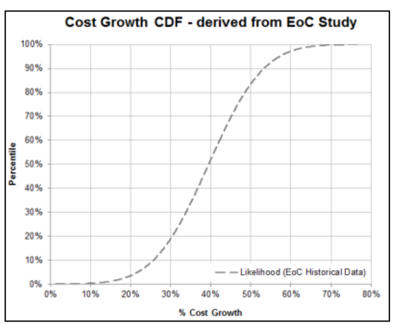
Combining Risk Assessment & Performance Information

A Bayesian method is applied to bring together the Project-specific Risk Assessment and EoC Study data into the final S-Curve.

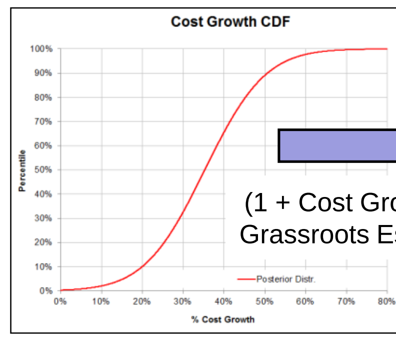
Project-specific Risk Assessment ("Prior")



Cost ÷ Grassroots Estimate - 1

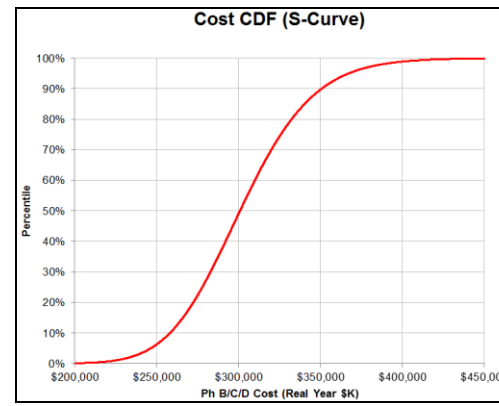


Relevant EoC Study Cost Growth Data ("Likelihood")



"Posterior" Cost Growth Factor

(1 + Cost Growth) x Grassroots Estimate

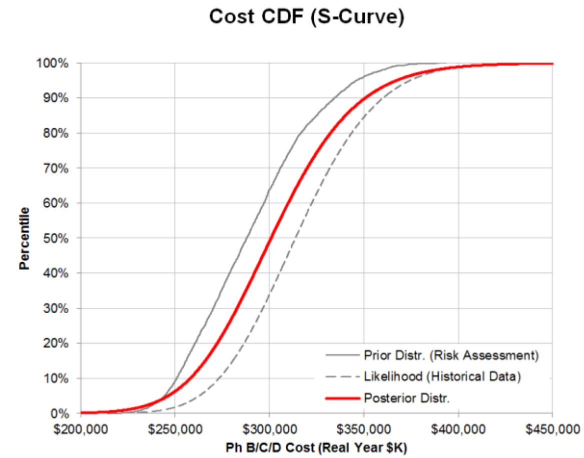


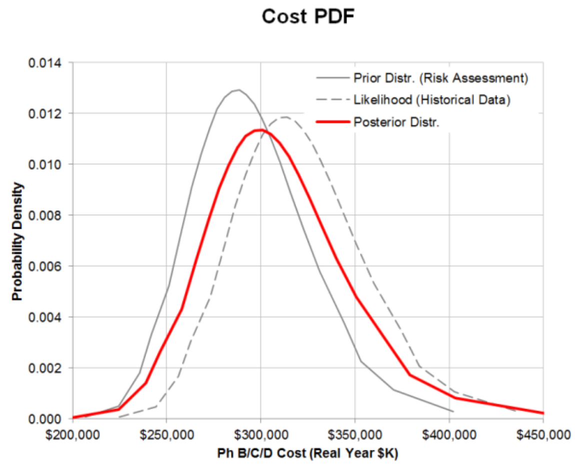
Final Cost S-Curve

"Cost Growth" Ph B/C/D = Actual Cost @ Launch ÷ Cost Est. @ CSR (w/o reserve) - 1

S-Curve Results

- **Solid Grey Curve: Project-specific Risk Assessment**
  - Derived from BOEs, Cost Risk Assessment Questionnaire and Engineering Judgment
- **Dashed -- Grey -- Curve: Cost Growth Data Analysis**
  - Includes relevant data from EoC Study
- **Red Curve: Final S-Curve**
  - Represents the probability of cost, starting with our engineering assessment of risk, calibrated (conditioned) on actual data (evidence)
  - Allows comparative analysis of expert knowledge with actual performance data as part of the probabilistic model





This S-Curve is a "balance" or "compromise" of both the Project-specific risk assessment and an analysis of actual cost growth data.

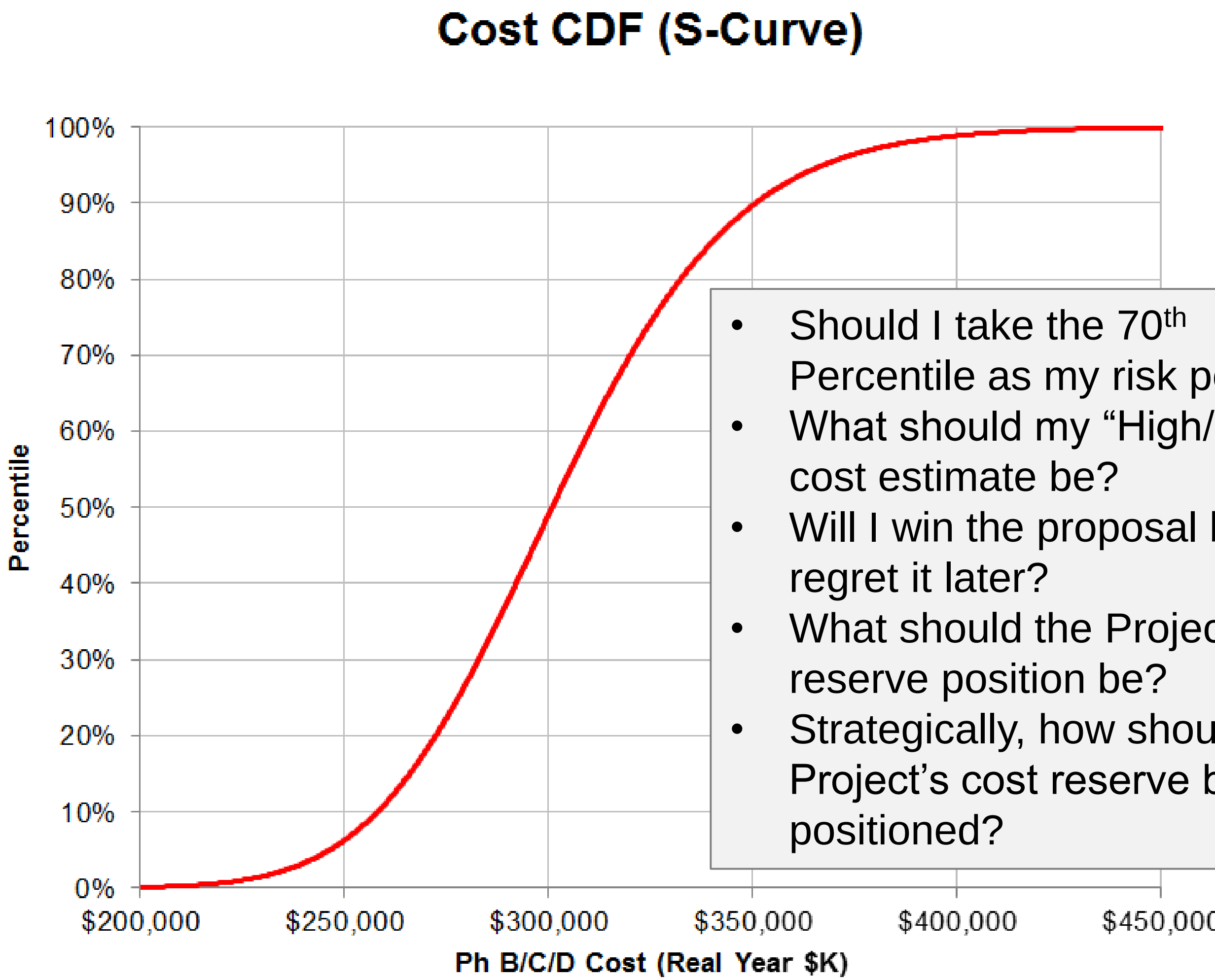
Example: Next-Generation Starfighter

Next Generation Starfighter

- High heritage to X-wing and ARC-170 fighters
  - Heritage Torplex avionics interfaces with X-wing
  - Leverages FSW from X-wing and Y-wing
- Up to 2 months of consumables
- Build-to-print cryogenic power cell
- Requalification of prop tanks/thrusters for hyper-drive being investigated in Phase A
- GN&C controls have heritage to X-Wing, but new environment
  - Currently have capability for Hyperdrive Class 1.5; need to get to 3.0.
- Various contracts explored with Incom Corp. for propulsion, thermal, structural and shielding design of spacecraft

Grassroots Estimate:
$210M w/o reserve

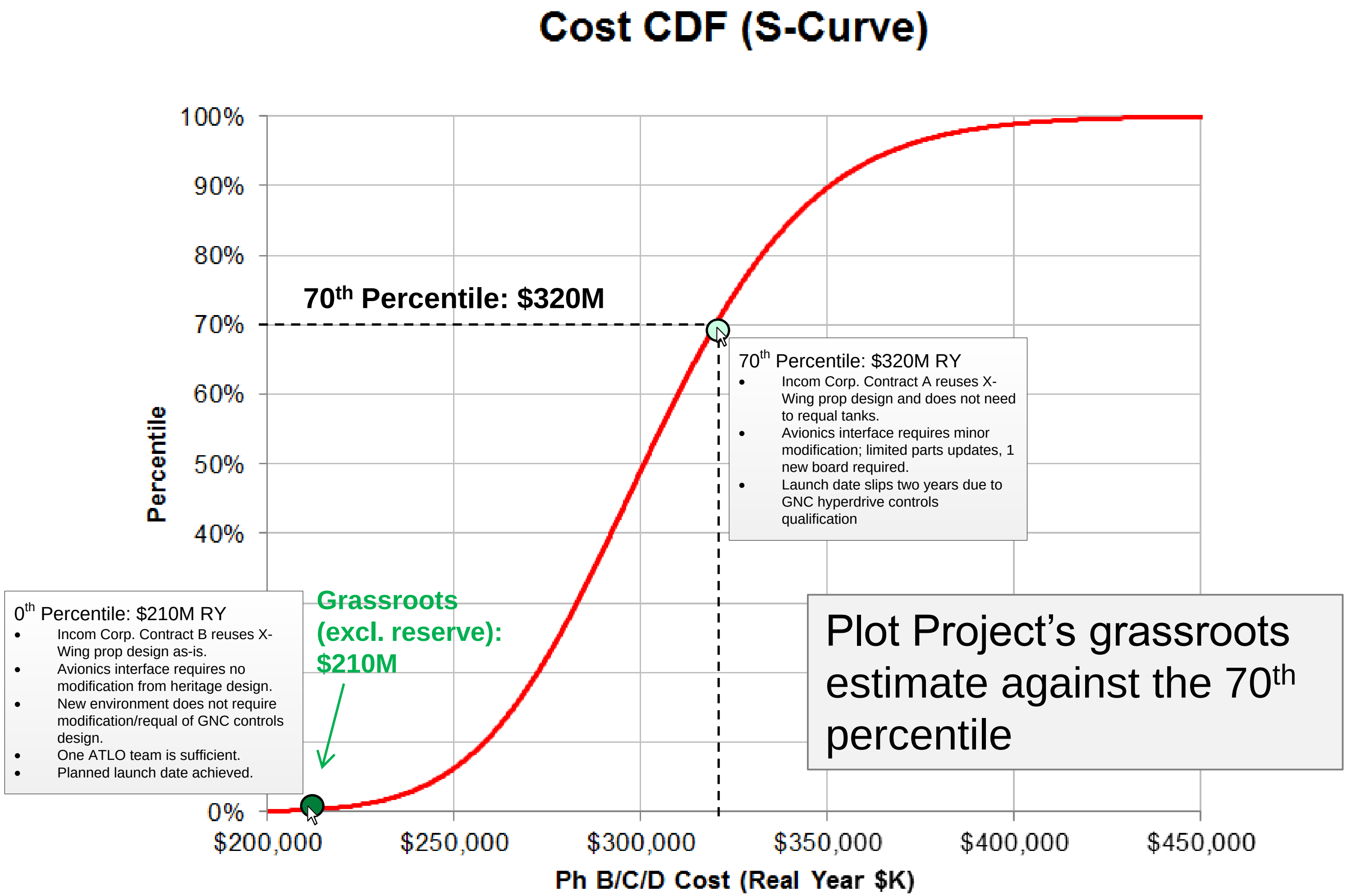
Example: Next-Generation Starfighter



- Should I take the 70th Percentile as my risk posture?
- What should my "High/Low" cost estimate be?
- Will I win the proposal but then regret it later?
- What should the Project reserve position be?
- Strategically, how should my Project's cost reserve be positioned?

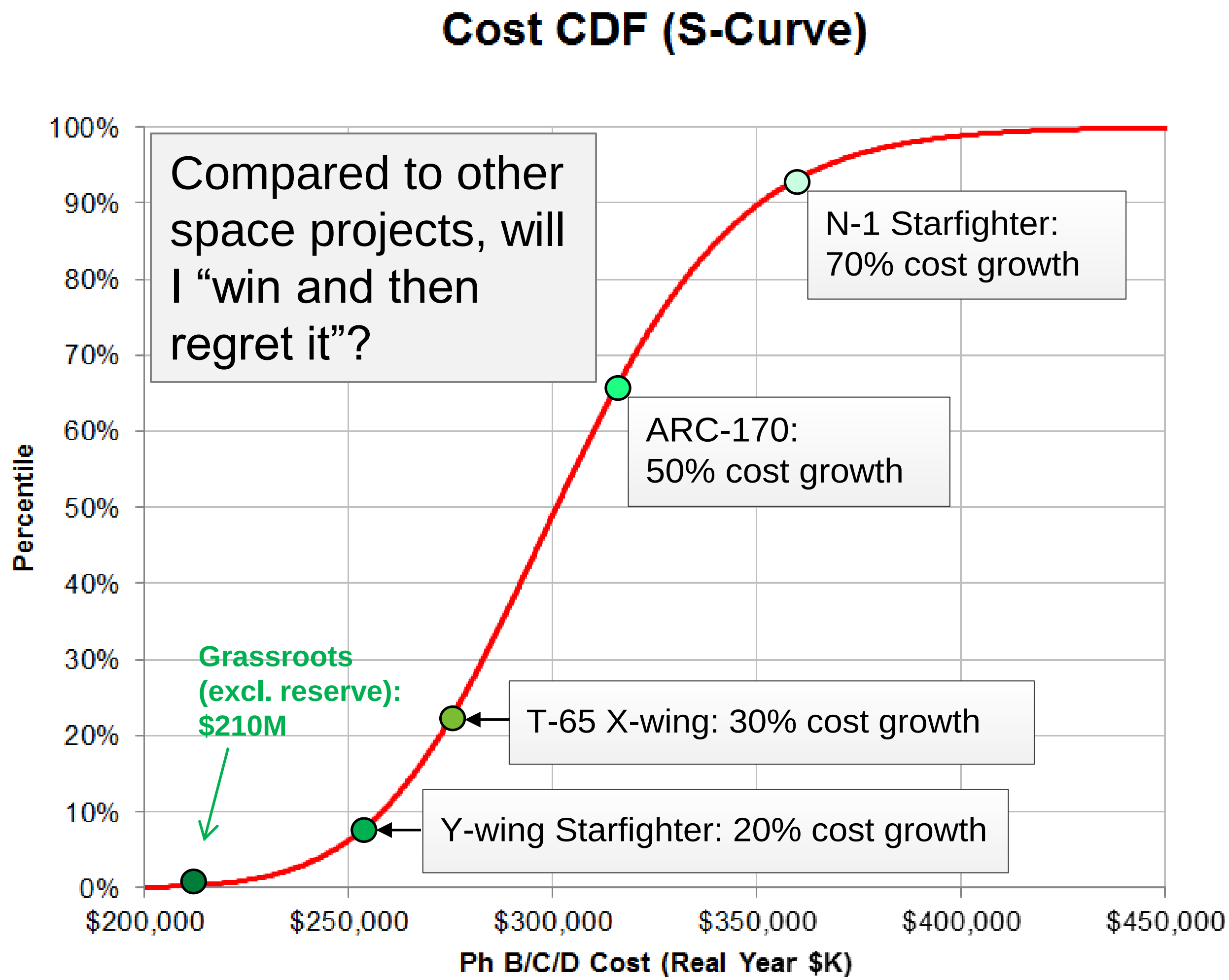
The S-Curve should provide a meaningful context at each percentile to inform management when making risk decisions.

Example: Next-Generation Starfighter



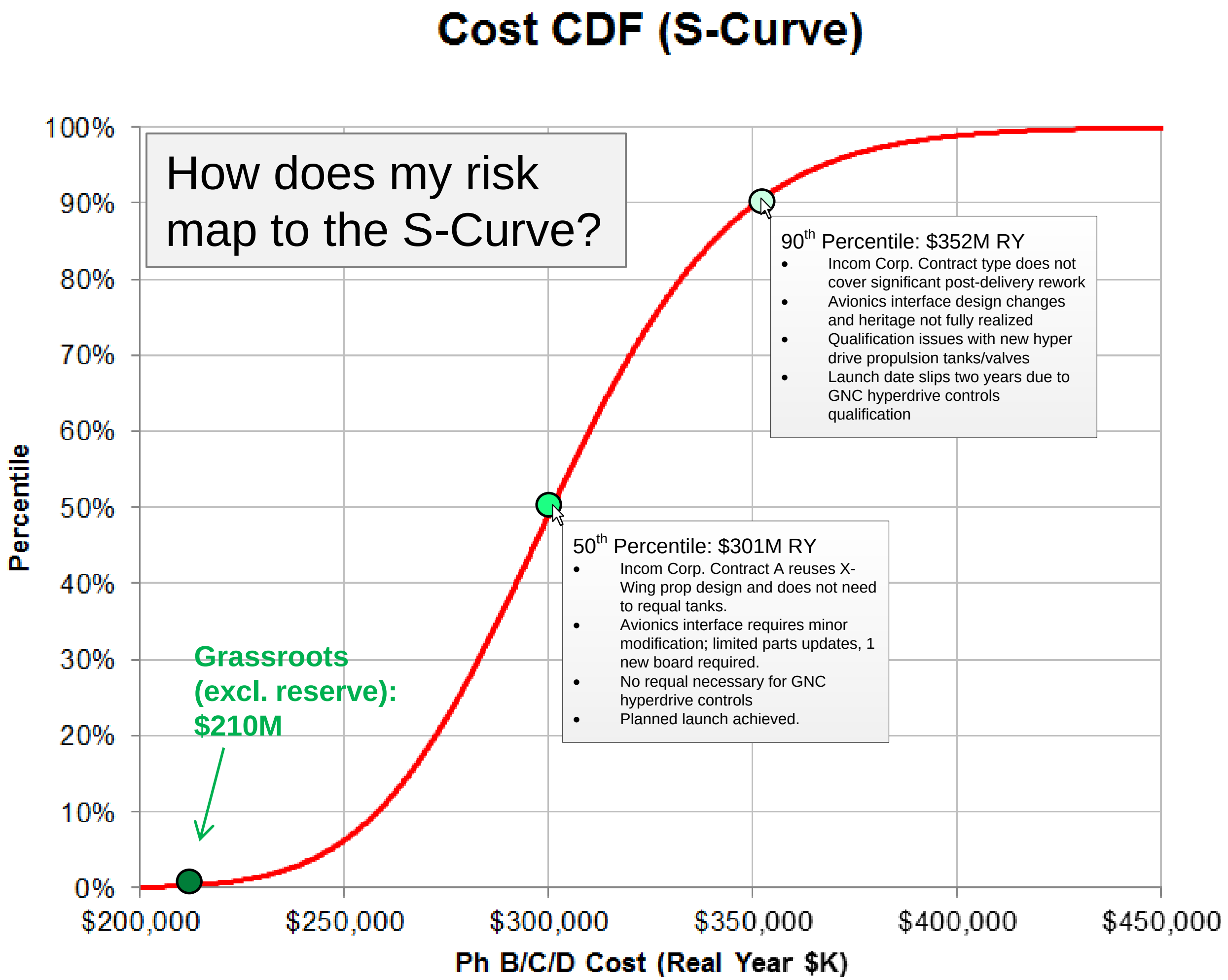
The S-Curve should provide a meaningful context at each percentile.

Example: Next-Generation Starfighter



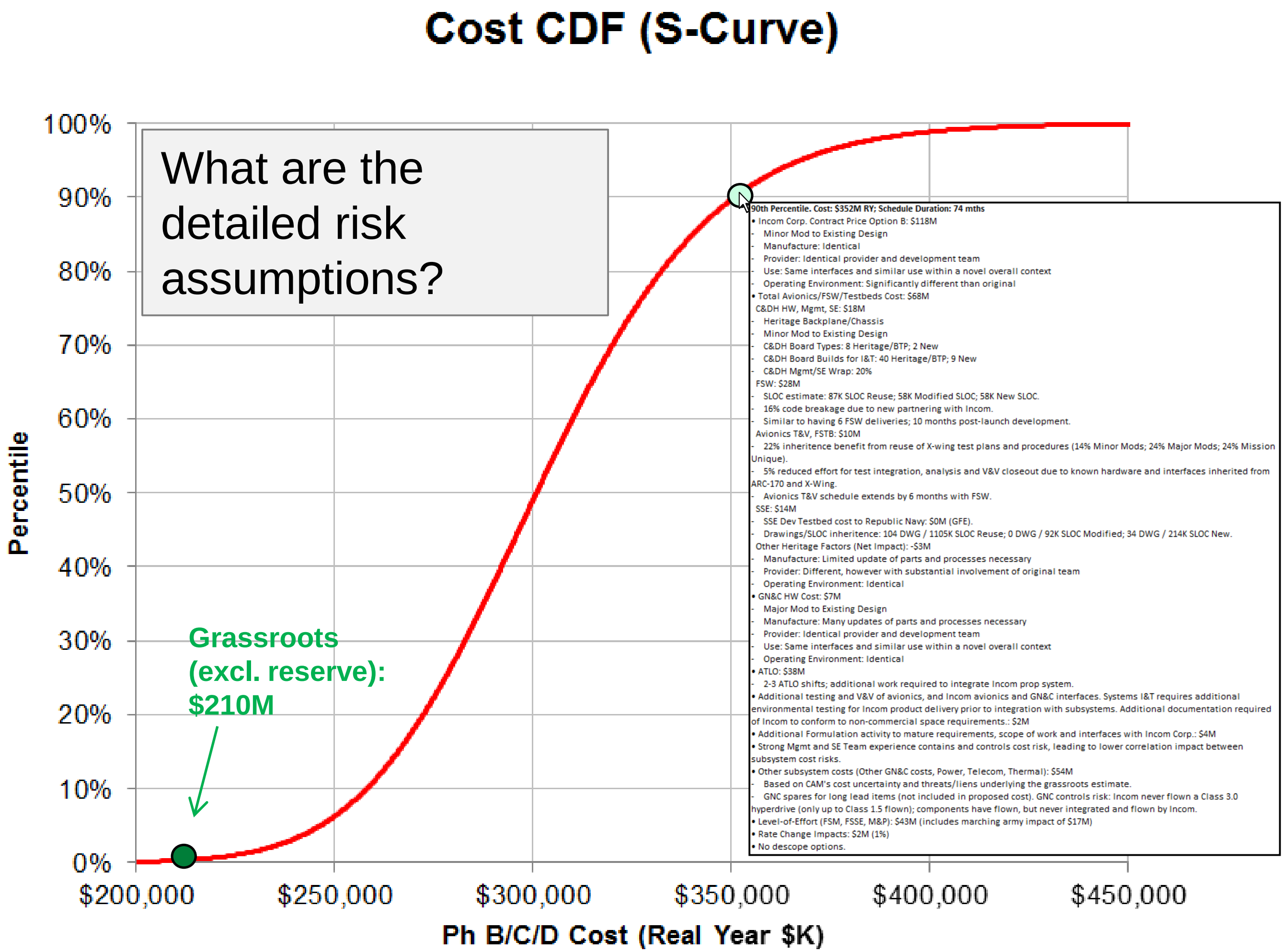
The S-Curve should provide a meaningful context at each percentile.

Example: Next-Generation Starfighter



The S-Curve should provide a meaningful context at each percentile.

Example: Next-Generation Starfighter



The S-Curve should provide a meaningful context at each percentile.

Concluding Remarks

- The S-Curve should enable management to:
  - Have an **intelligent discussion** of an appropriate cost reserve posture
  - Understand better the cost risk being has assumed
  - To make clear how the analysis was performed, assumptions, etc.
  - To make clear the driving cost risks and help navigate the path forward
- Balancing subject matter expertise and NASA/JPL's experience base with past performance on similar programs can provide a very informative context to the S-Curve.
- This methodology can be tailored along a broad spectrum of applications
  - Quick turnaround proposal evaluation
  - Very in-depth project analysis
  - Can be applied to any phase of development
- The Explanation of Change (EoC) study is a very useful resource.

The cost risk assessment is successful if it can further enable management to find an appropriate reserve posture and understand cost risk.

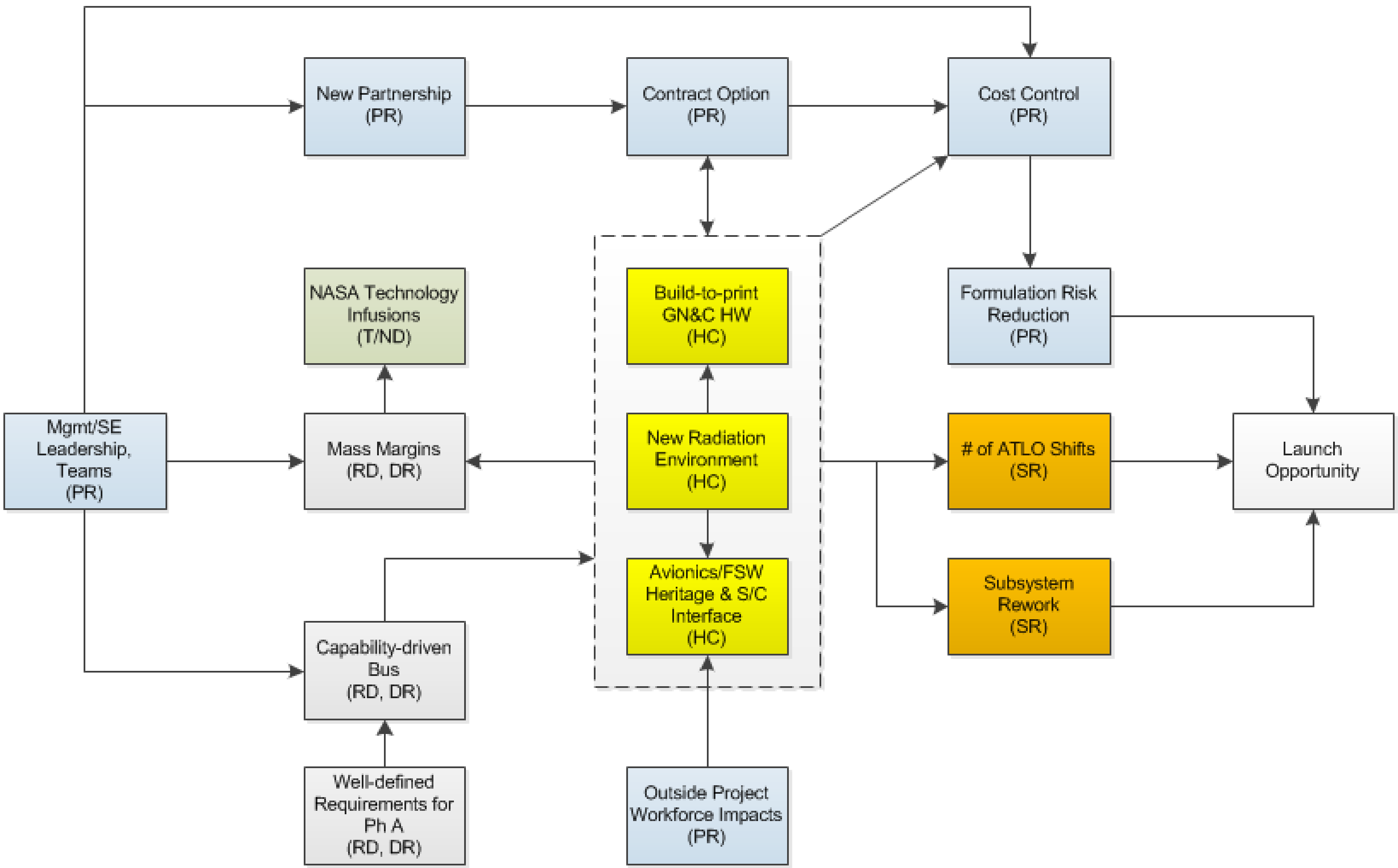
Backup

- References
- Further details of Project-specific Risk Assessment
- Application of the Explanation of Change (EoC) Study

References

Bitten, Robert E. The Aerospace Corporation. “Explanation of Change (EoC) Cost Growth Study, Final Results and Recommendations”, Aerospace Report No. ATR-2011(5322)-1. Prepared for NASA CAD, July 1, 2011

Risk Themes & Interdependencies (example)

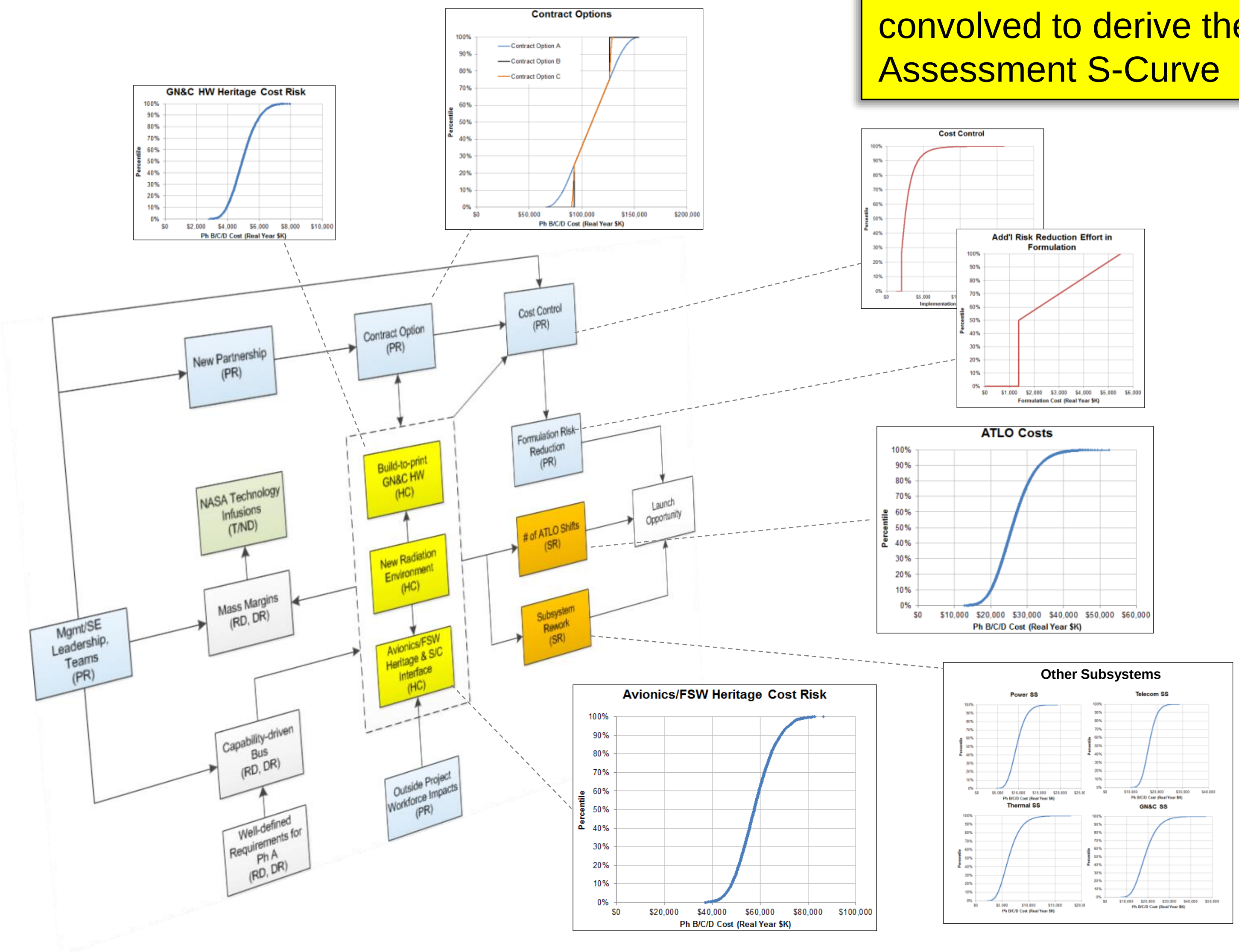


Engineering & Science Directorate

ESD

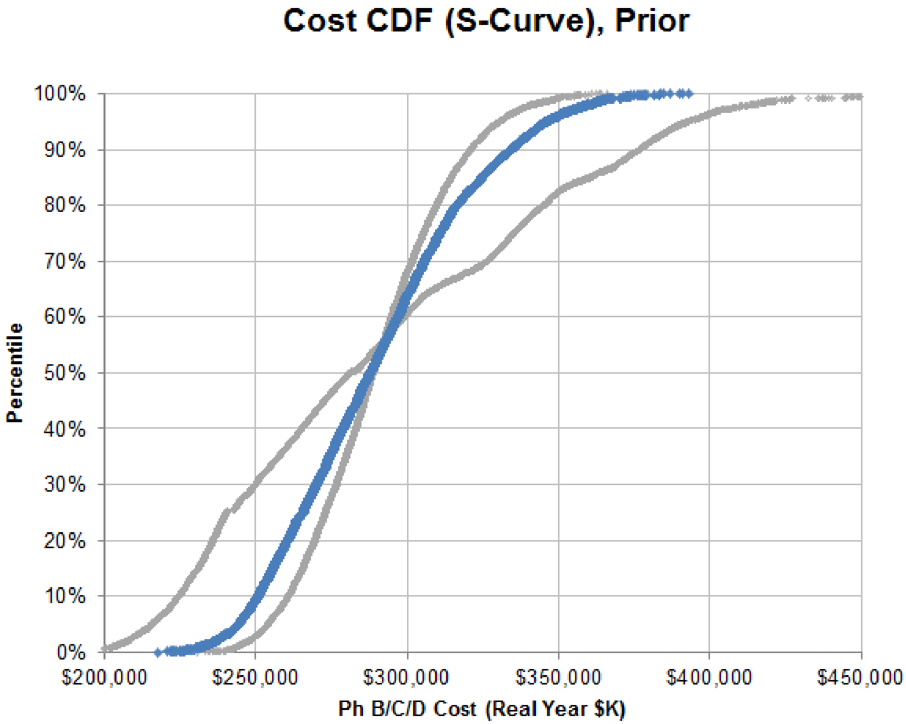
Risk Themes & Interdependencies (example)

Cost risk distributions are convolved to derive the Risk Assessment S-Curve



Project-specific Cost Risk Assessment

- Monte Carlo simulation produces the Project-specific S-Curve
- Project-specific Cost Risk Assessment results are shown on the blue curve
  - 30th Percentile: $270M
  - 50th Percentile: $290M
  - 70th Percentile: $310M
  - Grassroots: $210M (0th Percentile)
- Other curves shown in grey show sensitivity of the curve to correlation assumptions
  - Steep curve: Independence
  - Flatter curve: Perfect Correlation



If the 70th Percentile is taken as an adequate but not excessive cost risk posture, the reserve recommended as this stage of the analysis is ~45%.

An Application of the Explanation of Change (EoC) Study

Kelli McCoy

Systems Modeling, Analysis & Architecture

Jet Propulsion Laboratory

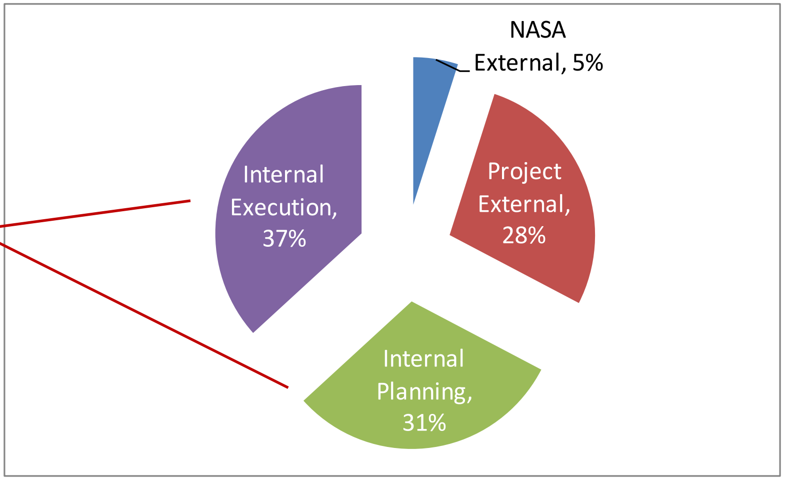
Kelli.J.Mccoy@jpl.nasa.gov

Explanation of Change (EoC) Study Overview

Robert Bitten, The Aerospace Corp, 2011

- Goal: determine the potential causes of cost growth in NASA science missions in order to reduce cost growth on future missions
- Methodology: using CADRe data, milestone review packages, monthly status reports, and interviews with key project personnel, cost growth root causes were categorized into bins.
  - Twenty-five missions were studied
  - Results were binned into 4 primary categories:
    - NASA External – Events that occurred that were outside of NASA's control
    - Project External – Events that were within NASA's control but external to the Project
    - Internal Planning – Events within the project's control relative to planning issues
    - Internal Execution - Events within the project's control relative to execution issues
- Results:

Relevant data was decomposed from these detailed bins and summarized



Distribution of Cost Growth Categories

Translating the EoC Study

1. Using the EoC categorization, cost growth causes were tagged for Spacecraft and I&T content; other data was discarded.

Explanation of Change Categorization	Code	Value ($	Rationale
	Total	$ 66.0	Should match total growth for Project
PP2-Project Planning-Design-Instrument	PP2	$ 7.8	PABSI descoped but cost increase because CPR and HVPS designs were underscoped - The CPR stru
PP1-Project Planning-Design-Spacecraft	PP1	$ 7.4	SC bus design change - Changes include shortening of the bus to fit in DPAF envelop and change to acc
PP5-Project Planning-Programmatic	PP5	$ 2.6	Underscoping of mission assurance and SE effort
PP7-Project Planning-Other	PP7	$ 1.8	Mission design change to formation fly with EOS-Aqua requiring additional reviews and change in MSRD
HQ2-External to the Project-Agency Level (HQ)-Program Requirements	HQ6	$ 5.1	March 2003 to April 2004 launch delay due to adding Calipso co-manifest - estimated as proposed cost t
PE4-Project Execution-System Development-Instrument	PE4	$ 9.2	CPR delivery delay slowing down the SC team and leading to bath tub periods - I&T problems such as th
PE3-Project Execution-System Development-Spacecraft	PE3	$ 5.7	Typical development issues associated with spacecraft development
PE6-Project Execution-System Development-Ground Systems	PE6	$ 3.2	Typical development growth
PE4-Project Execution-System Development-Instrument	PE4	$ 1.2	PM/SE/MA Growth allocated to difficulties with instrument development
PP2-Project Planning-Design-Instrument	PP2	$ 2.1	CPR transmitter being picked up by JPL since CSA could not make it with their proposed budget
HQ2-External to the Project-Agency Level (HQ)-Program Requirements	HQ2	$ 4.0	Additional requirements imposed to project (ex.., 7120.x and 7119.x), additional reviews, ITAR
HQ2-External to the Project-Agency Level (HQ)-Program Requirements	HQ2	$ 2.7	Launch slip from April 2005 to June 2005 due to readiness of CALIPSO and also NOAA's N launch delay
None			
NE1-NASA External-Launch Vehicle	NE1	$ 1.4	Instrument cost due to 11 month LV delay
NE1-NASA External-Launch Vehicle	NE1	$ 5.2	Spacecraft cost due to 11 month LV delay
NE1-NASA External-Launch Vehicle	NE1	$ 2.8	PM/SE/MA cost due to 11 month LV delay
NE1-NASA External-Launch Vehicle	NE1	$ 3.8	GDS/MOS/Science cost due to 11 month LV delay

2. Spacecraft and I&T cost growth data were mapped into Risk Themes by mission:

a. Requirements Definition, Design Resiliency

b. Technology/New Developments

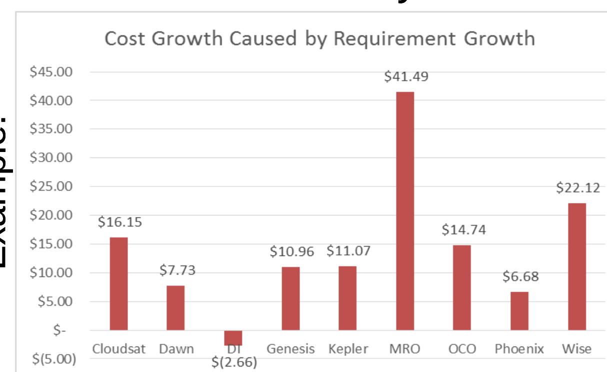
c. Heritage Claims

d. Programmatics

e. Schedule Resiliency

f. Pricing Uncertainty

Example:



Translating the EoC Study (con't)

3. Cost growth factors were constructed for each Risk Theme by comparing the CSR CADRe cost snapshot to the total cost growth by Risk theme.

Cost Growth Matrix for Specified Work Elements

Mission	Aggregate Growth Factor	Heritage Growth Factor	Req't Growth Factor	Prog. Growth Factor	Schedule Growth Factor	Technology Growth Factor
Cloudsat	1.44	1.10	1.34	n/a	n/a	n/a
Dawn	1.67	1.22	1.06	1.08	1.12	1.19
DI	1.52	1.28	n/a	1.15	1.10	n/a
Genesis	1.21	n/a	1.11	n/a	1.11	n/a
Kepler	1.58	1.07	1.14	1.19	1.18	n/a
MRO	1.47	1.24	1.23	1.00	1.00	n/a
OCO	1.39	1.07	1.32	n/a	n/a	n/a
Phoenix	1.73	1.40	1.06	1.19	1.07	n/a
Wise	1.58	1.02	1.50	n/a	1.06	n/a

Finding: Optimistic heritage assumptions is the predominate cost growth factor

4. Construct a likelihood distribution from the overall mission growth factors