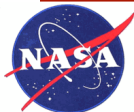


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# An Assessment of the Inherent Optimism in Early Conceptual Designs and its Effect on Cost and Schedule Growth

Presented to the  
Planetary Science Subcommittee, NASA Advisory Council  
23 June, 2008, NASA GSFC

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# Abstract

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- When missions experience cost growth, cost estimators are often criticized for underestimating the cost of missions in the early conceptual design stage
- The final spacecraft and instrument payload configuration at launch, however, can be significantly different as the project evolves, thereby leading to cost “growth” as compared to these lower initial estimates
- In order to make a more robust initial estimate, historical mass, power, data rate, and growth rates can be used to provide a reasonable upper bound for inputs into the cost estimating methodologies
- This paper illustrates this problem by showing examples of the evolution of a design, and its respective cost, complexity and schedule estimates, throughout its lifecycle
- This paper reveals that the issues behind the cost and schedule growth are varied, but may be attributed in part to systems that have changed substantially from those examined at initial concept through to launch
- In addition, historical resource growth is investigated for a variety of missions to provide guidelines for cost estimators to be used during the initial conceptual design stage



# Background

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- The results from a recent study of 40 NASA missions over the past decade (1992-2007) indicated that the average cost and schedule growth of these missions, over and above programmatic reserves, was 26.9% and 21.5%, respectively
- Although the study mentioned several potential reasons why cost and schedule might grow, one potential causative factor postulated was the inherent optimism in initial concept designs due to competitive pressures
- This inherent optimism can translate to the underestimation of the technical specifications such as mass, power, data rate, and the complexity of a system
- Since most cost models use some form of system resources as a predictor of mission cost, the underestimation of these resources can lead to the underestimation of the final cost of the mission
- To compound problems, the desire to launch a system as early as possible, in order to obtain science quickly, can lead to a success oriented schedule that may be shorter than historical comparisons would indicate
- This combination of underestimated resources providing an optimistic cost estimate basis combined with a success oriented schedule can contribute to the observed history of cost and schedule growth
- The cost estimators, in effect, are trying to estimate a moving target as the system resources grow



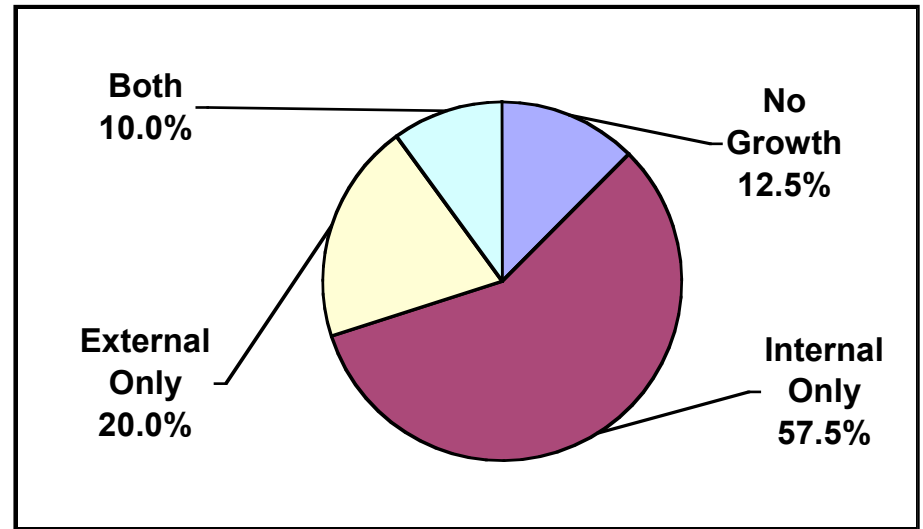
# Growth Categories

- Internal Growth (within Project's control)

- Technical
  - Spacecraft development difficulties
  - Instrument development difficulties
  - Test failures
  - Overly optimistic heritage assumptions
- Programmatic
  - Contractor management issues
  - Inability to properly staff an activity

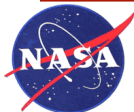
- External Growth (outside of Project's control)

- Launch vehicle delay
- Project redesign/requirements growth
- Budget constraint
- Labor strike
- Natural disaster

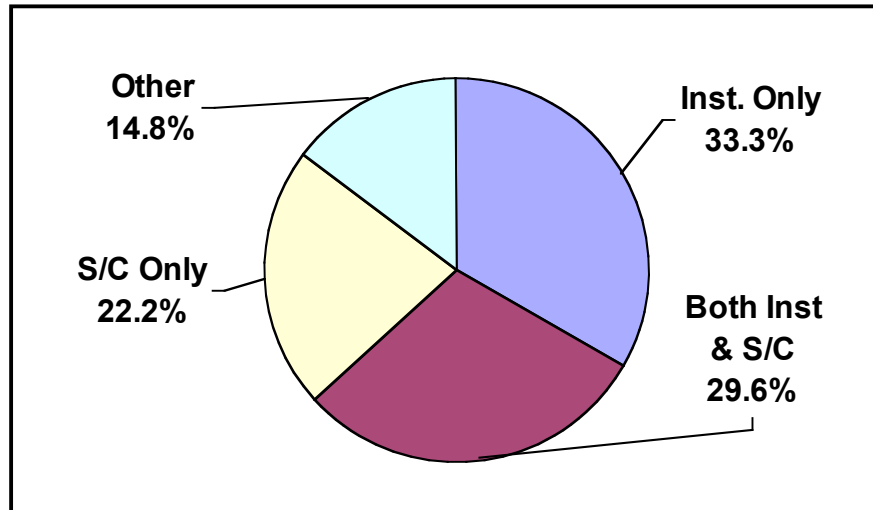


**Distribution of Internal versus External Growth**

- Of the forty-mission data set, 27 missions (67.5 %) experienced internal growth, and 12 missions (30 %) experienced an external growth. Only 4 missions (10%) had both internal and external growth.

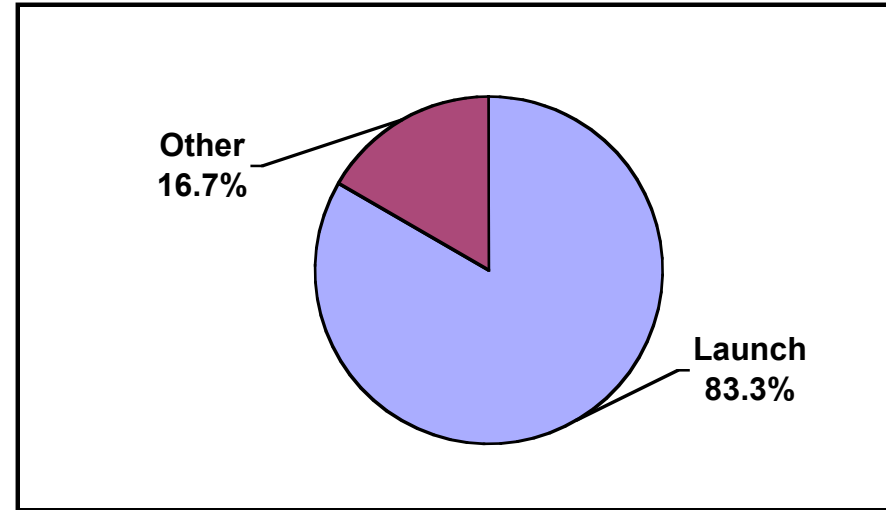


# Internal versus External Factors Driven-Growth



**Distribution of Internal Growth**

- Data indicates that instrument problems are the largest contributor to project cost and schedule growth



**Distribution of External Growth**

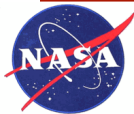
- Of the launch vehicle-related growth, almost all were caused by smaller launch vehicles such as the Athena, Pegasus and Taurus launch vehicles or the dependence upon a foreign launch vehicle



# Best Practices for the Control of Cost and Schedule

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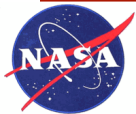
- *Proper Mission Scoping*
  - A paper authored by Tony Spear on lessons learned on the Mars Pathfinder mission stated: “Fundamental to our approach was starting the project with an adequate pot of \$ reserves: This we did by carefully scoping the Mission properly at the outset.”
- *Robust Initial Cost and Schedule Estimate*
  - As stated in a paper describing the cost approach of the Applied Physics Laboratory at John Hopkins University (JHU/APL) which managed two projects that returned funding to NASA, NEAR and ACE: “The ability to generate accurate program cost estimates and control these costs through program completion has become an important attribute to JHU/APL over the years”
- *Monthly Estimates to Complete*
  - “Each month, all elements of the Project Team got together to assess fiscal, technical and schedule performance. We then allocated some of our \$ and schedule reserves as needed, revising our ‘Estimates to Complete’. If necessary, we re-planned an activity if it exceeded its target completion cost-- either by descoping it or allocating additional \$ to it from reserves. We then added up these individual estimates to derive the total Project Cost to Complete estimate.”



# Best Practices for the Control of Cost and Schedule (2)

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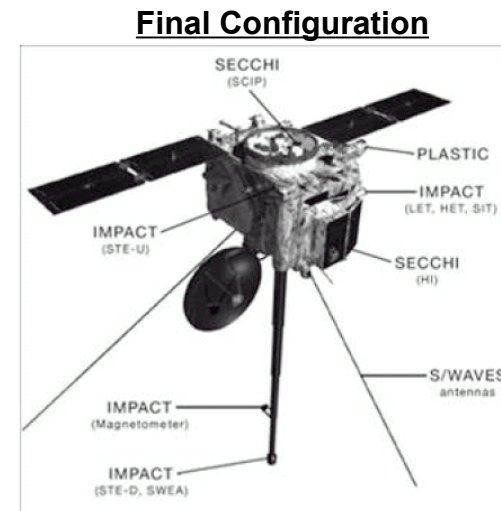
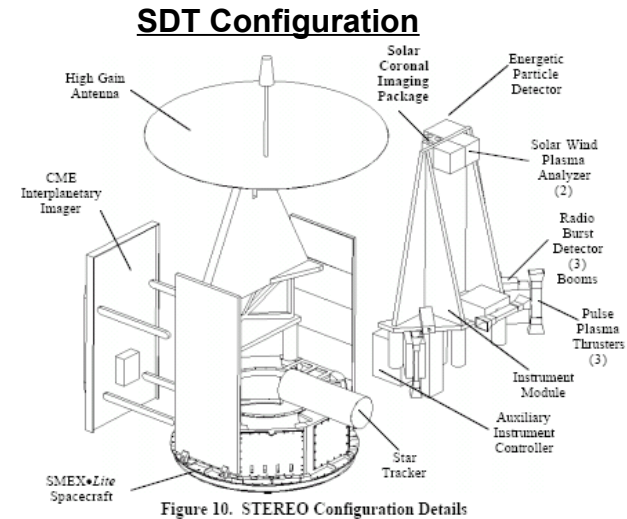
- *Importance of Managing to Schedule*
  - Dr. Jim Burch and Mr. Bill Gibson stated: “The IMAGE team believed that if we missed our launch date, the mission would be cancelled” and “Critical to overall project success, cost cannot be controlled if the schedule is not controlled.”
- *Effective Use of Earned Value Management (EVM)*
  - Both the IMAGE and Stardust missions used EVM as an early warning device to identify potential cost and schedule issues. As stated for the IMAGE mission: “The Earned Value system worked well as an early indicator of cost problems ahead”



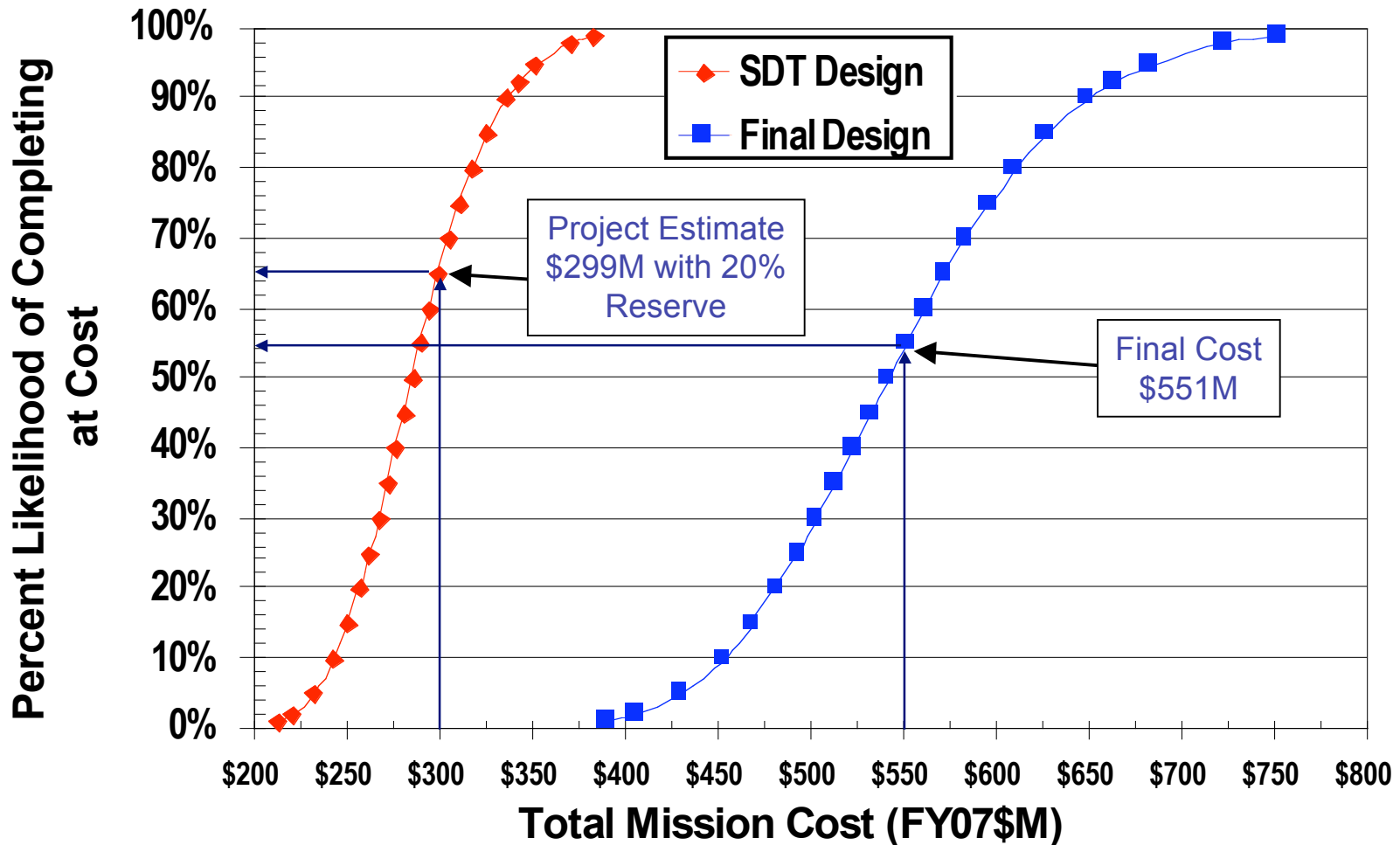
# An Example of Concept Growth: Substantial Differences Exist between STEREO Initial Concept and Final Implemented Configuration

	STEREO <u>SDT*</u>	STEREO <u>Final</u>
<b>Programmatics</b>		
Schedule (months)	40	70
Launch Vehicle	Taurus	Delta II
<b>Technical</b>		
<b>Mass (kg)</b>		
Satellite (wet)	211	630
Spacecraft (dry)	134	421
Payload	69	149
<b>Power (W)</b>		
Satellite (Orbit Average)	152	503
Payload (Orbit Average)	58	116
<b>Other</b>		
Transponder Power (W)	20	60
Downlink Data Rate (kbps)	150	720
Data Storage (Gb)	1	8

\* Science Definition Team (SDT)



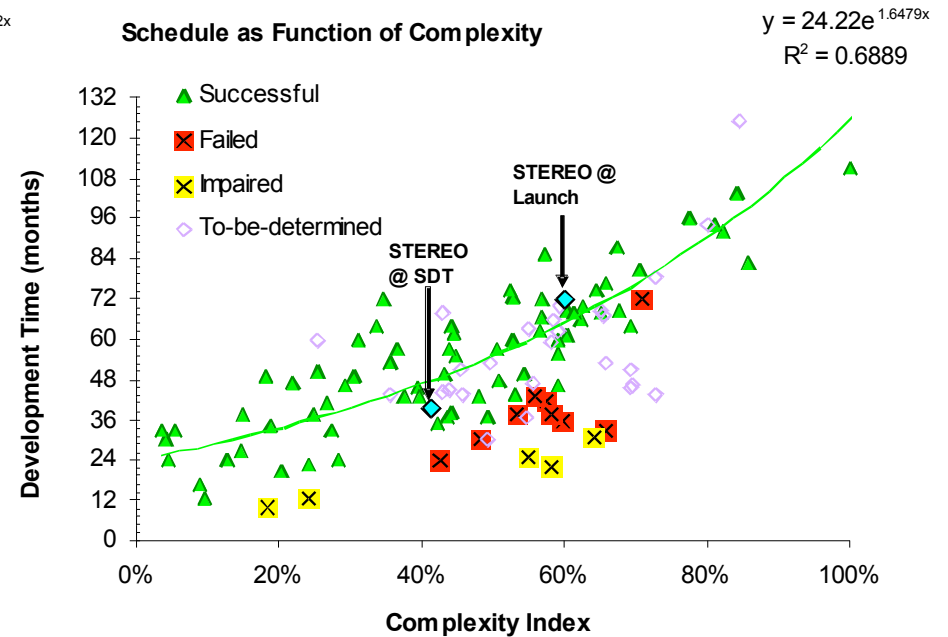
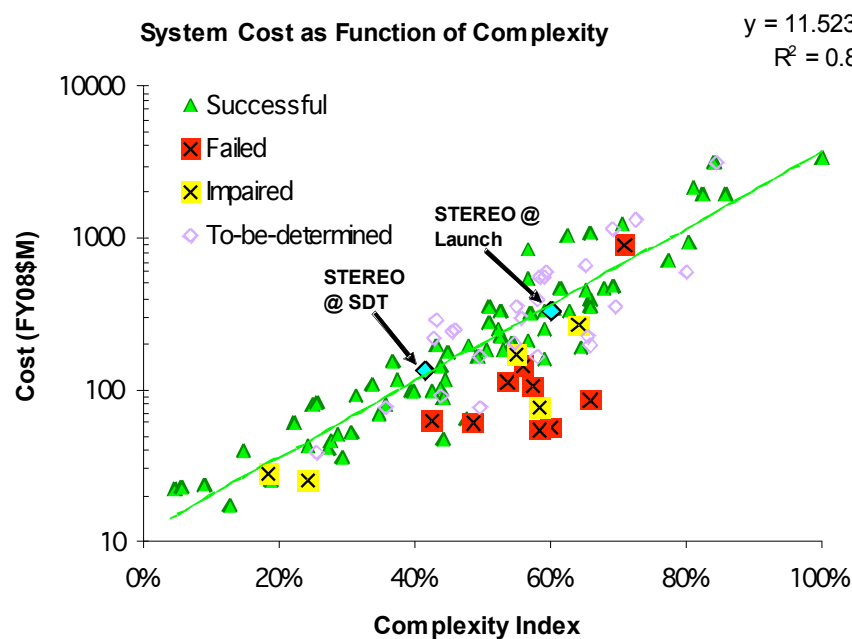
# Mission Cost Estimate Would be Representative for As-Built Design



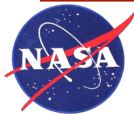
Typical Cost-risk analyses will not capture this type of concept evolution



# Effect of Design Changes on Complexity Based Risk Assessment (CoBRA) Complexity Index



Complexity of System Increased Along with Development Cost and Schedule



Note: Development cost does not include launch vehicle cost, or mission operations and data analysis (MO&DA).



# Study Approach

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- For a set of 10 missions in the study, the mass, power, cost, schedule and other parameters were identified at the beginning of Preliminary Design phase (NASA Phase B) of a mission
- These values were then compared to values presented at the Preliminary Design Review (PDR), Critical Design Review (CDR) and at the time of launch to understand the growth over time of each of these resources
- The resource growth is then compared to industry guidelines to understand if these guidelines would have adequately predicted the growth for the mission data set studied
- The CoBRA complexity index was also calculated at the beginning of Phase B and at Launch to identify how the system complexity has changed
- Additional missions were desired for this study, but at the time of writing, complete CADRes had not been written for any additional missions



# Database Description

- Ten recent missions were selected to study trends
- Missions consisted of a mix of Competed and Directed, Earth and non-Earth Orbiting missions covering all categories of NASA science missions

Study Mission Database

	Planetary	Non- planetary	Program	Science Type	Key Center(s)	Launch Year	Acquisition Type	# Instruments launched	# Instruments descope	Comments
<b>Cloudsat</b>		x	ESSP	Earth Science	JPL	2006	Competed	1	1	Radar observation of clouds
<b>SWIFT</b>		x	Explorers	Astrophysics	GSFC	2004	Competed	4	0	Gamma Ray burst detector
<b>DAWN</b>	x		Discovery	Planetary Science	JPL	2007	Competed	2	2	investigate Ceres and Vesta protoplanets
<b>Messenger</b>	x		Discovery	Planetary Science	APL	2004	Competed	7	0	Investigate Mercury
<b>SIRTF</b>		x	Spitzer	Astrophysics	JPL	2003	Directed	4	0	IR space telescope, initially meant to be last of great observatories, down-sized eventually
<b>EO-1</b>		x	NMP	Earth Science	GSFC	2000	Competed	5*	3#	Advanced land imaging technology demonstrator
<b>GALEX</b>		x	Explorers	Astrophysics	JPL/CalTech	2003	Competed	1	0	UV space telescope
<b>MRO</b>	x		MEP	Planetary Science	JPL	2005	Directed	7	0	Investigate history of water on Mars
<b>STEREO</b>		x	STP	Heliospheric Science	GSFC/APL	2006	Directed	4**	0	2 spacecraft looking at solar dynamics - Earth leading and trailing orbits
<b>New Horizons</b>	x		New Frontiers	Planetary Science	APL	2006	Competed	7	0	Investigate Pluto

\* 1 added after mission start

\*\* each spacecraft

# Technologies descope

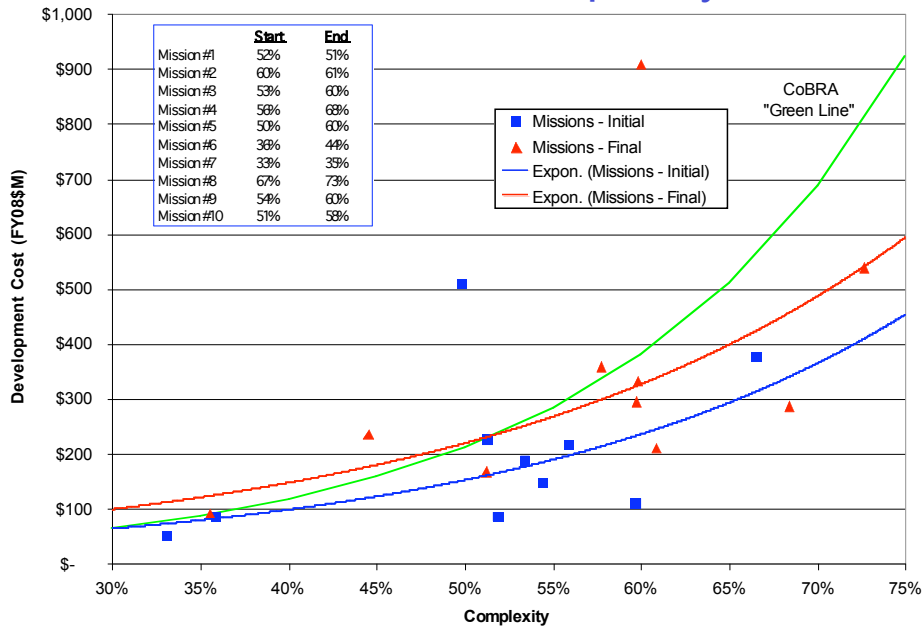
These 10 missions represent a wide range of recent NASA missions. The missions include 3 Directed missions vs. 7 Competed missions, 4 Planetary missions vs. 6 Earth Orbiters or near-Earth Orbiters, 4 Planetary Science vs. 3 Astrophysics vs. 2 Earth Science vs. 1 Heliophysics mission, 5 JPL vs. 2 APL vs. 2 GSFC vs. 1 APL/GSFC Mission.



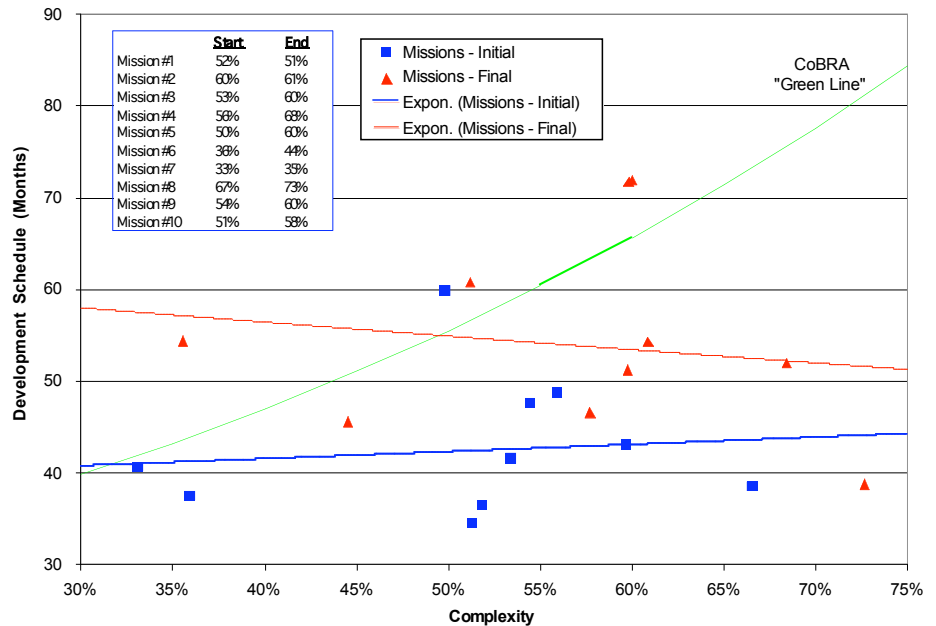
# Complexity Changes Over Time

- Almost all missions investigated experienced an increase in complexity according to the CoBRA complexity index
  - Mission #1 is an exception as it had a significant descope during its development

Cost vs. Complexity



Schedule vs. Complexity



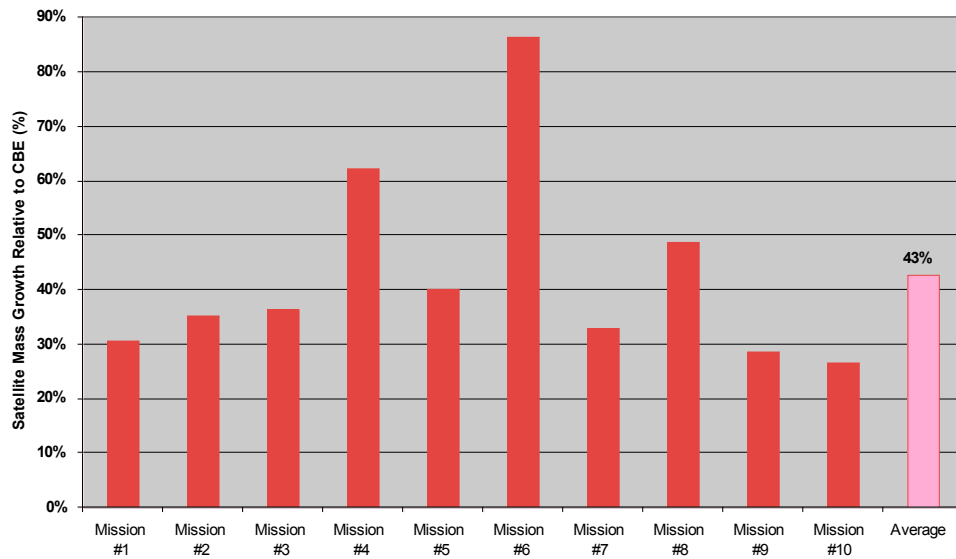
Collective Result implies an inherent optimism in Complexity, Cost & Schedule



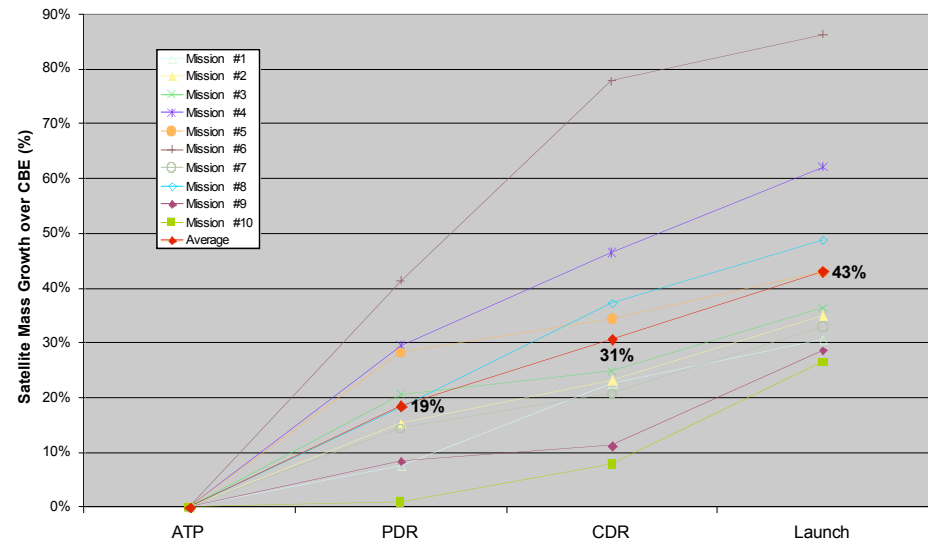
# Summary of Mass Growth

- Average mass growth for missions studied is 43% which exceeds the typical industry guidelines of 30% mass reserves (over CBE) at the start of Phase B

### Growth Per Mission



### Growth Over Time



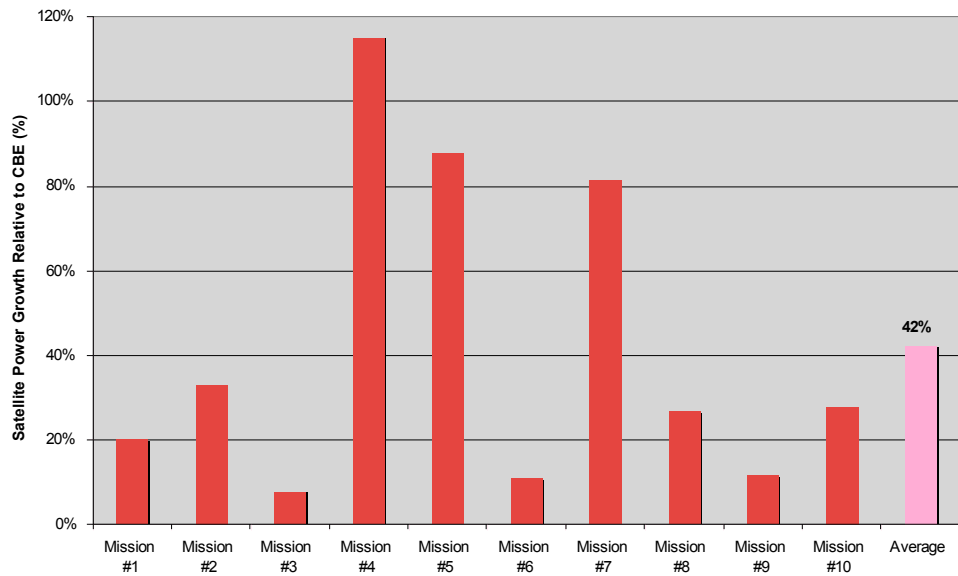
Mass Growth Occurs Primarily After PDR and Exceeds Typical Guidance



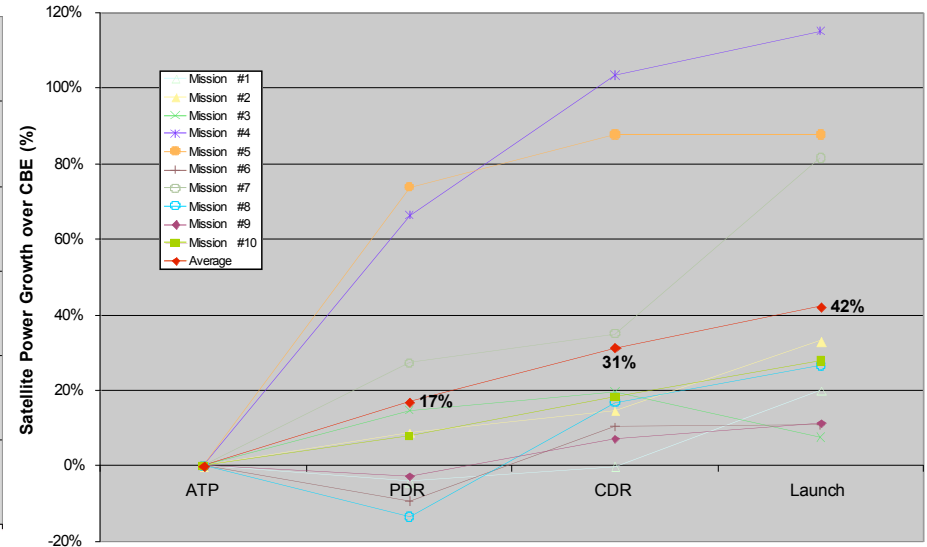
# Summary of Power Growth

- Average power growth for missions studied is 42% which exceeds the typical industry guidelines of 30% power reserves (over CBE) at the start of Phase B

Growth Per Mission



Growth Over Time



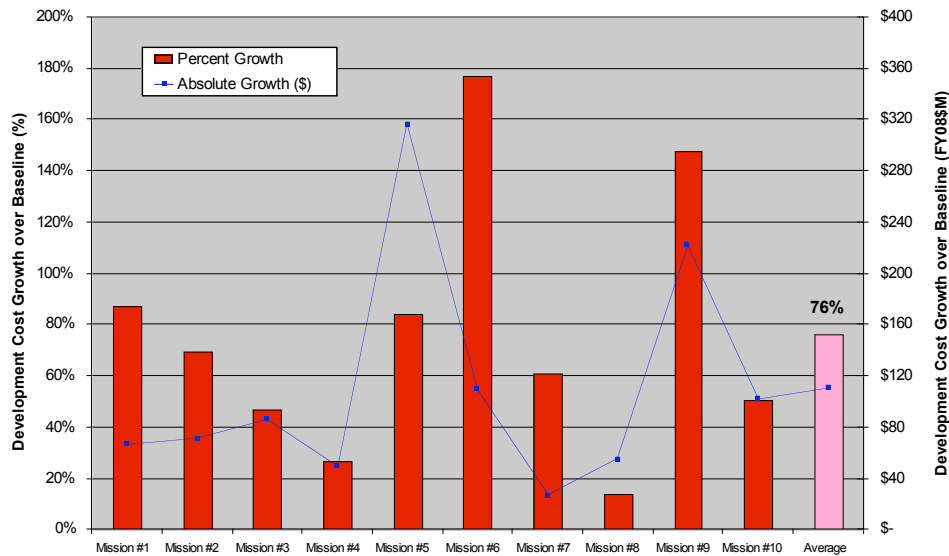
Power Growth Occurs Primarily After PDR and Exceeds Typical Guidance



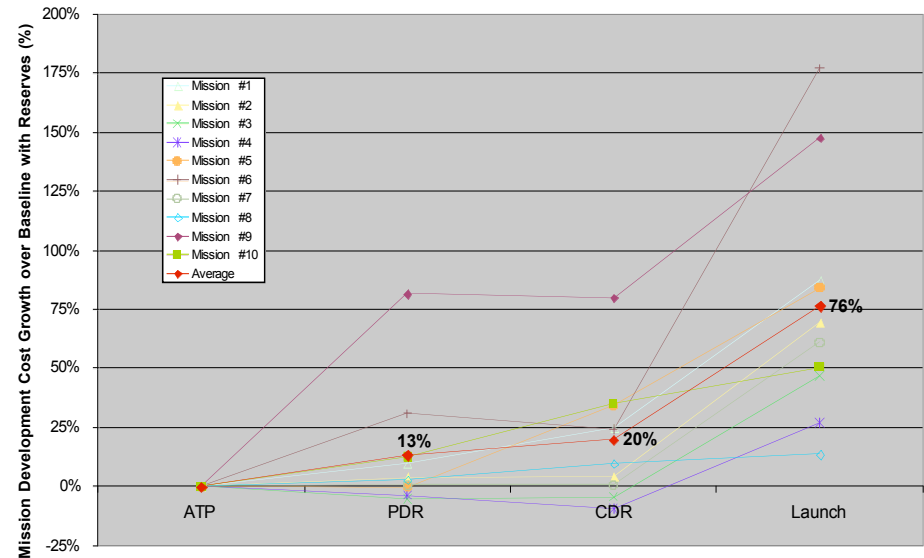
# Summary of Cost Growth

- Average cost growth for missions studied is 76% over baseline with reserves (and 113% over baseline without reserves) which exceeds the typical industry guidelines of 30% cost reserves (over CBE) at the start of Phase B

## Growth Per Mission



## Growth Over Time



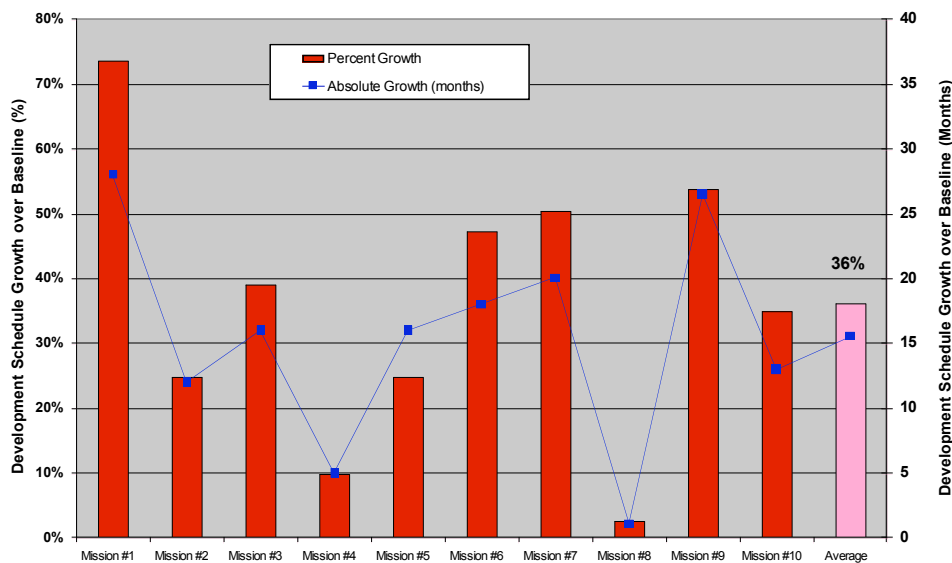
Cost Growth Occurs Primarily After CDR and Exceeds Typical Guidance



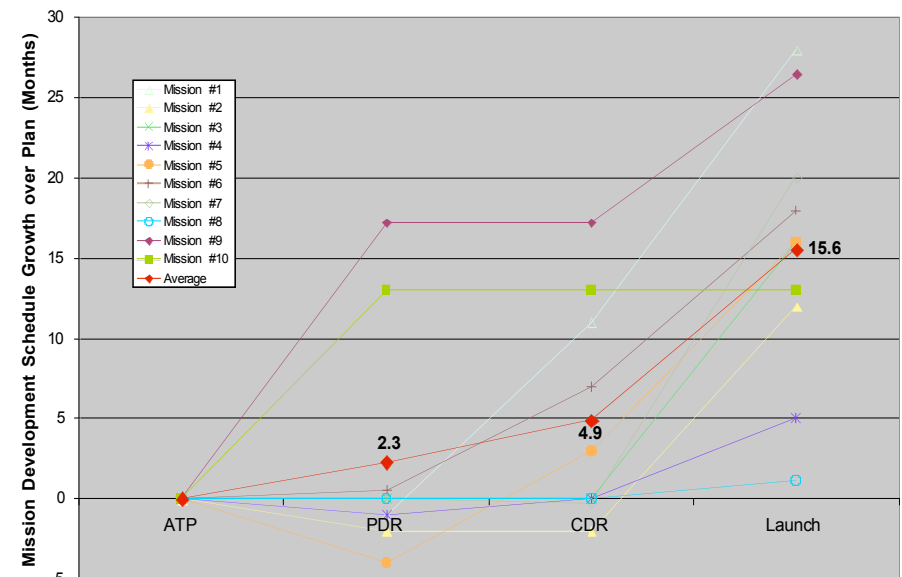
# Summary of Schedule Growth

- Average schedule growth for missions studied is 36% over baseline with reserves, or 16 months on average, which exceeds the typical industry guidelines of 8-12%, or one to 1.5 months per development year, at the start of Phase B

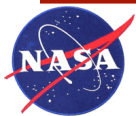
## Growth Per Mission



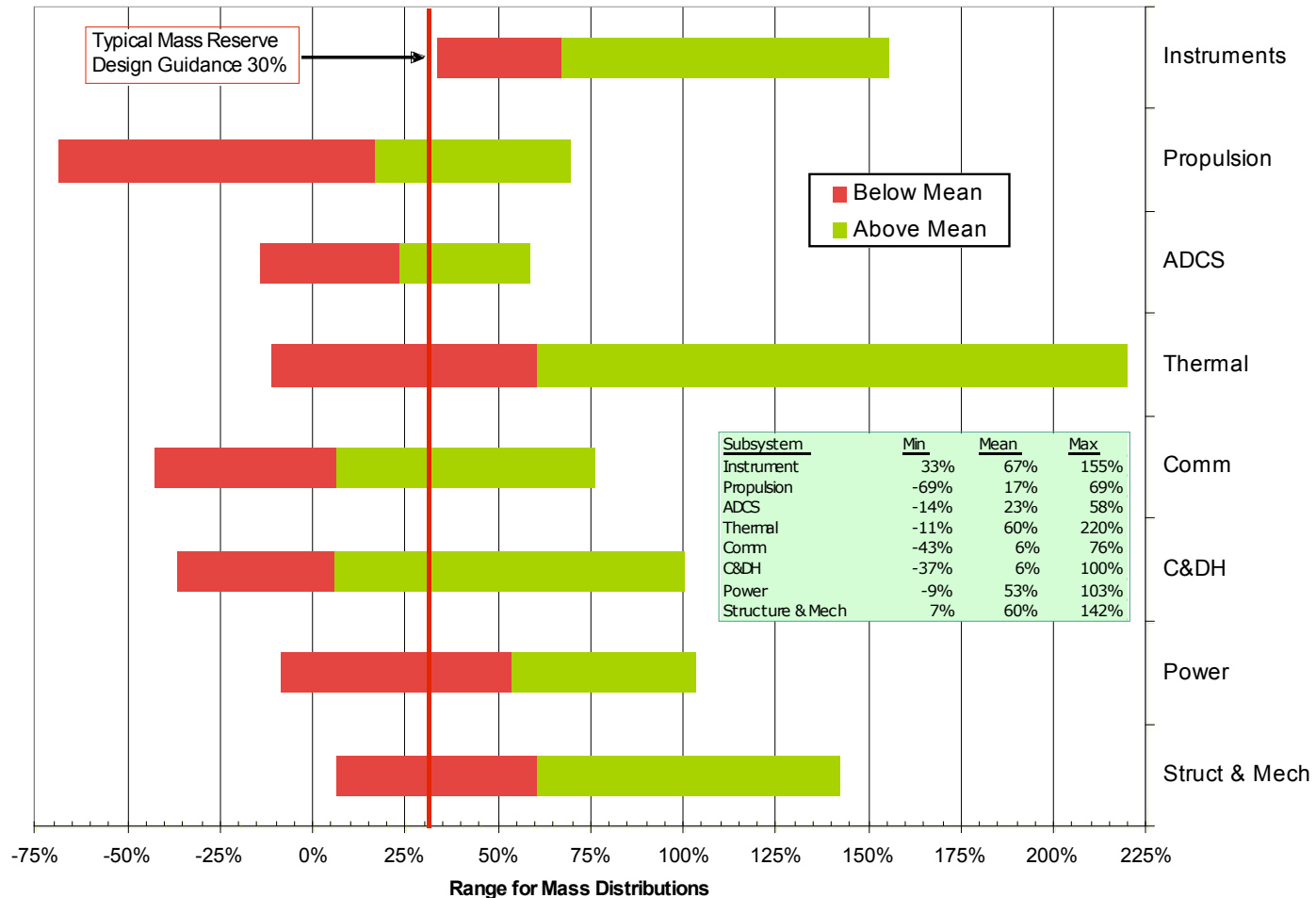
## Growth Over Time



Schedule Growth Occurs Primarily After CDR and Exceeds Typical Guidance



# Range of Mass Growth at Instrument & Subsystem Level

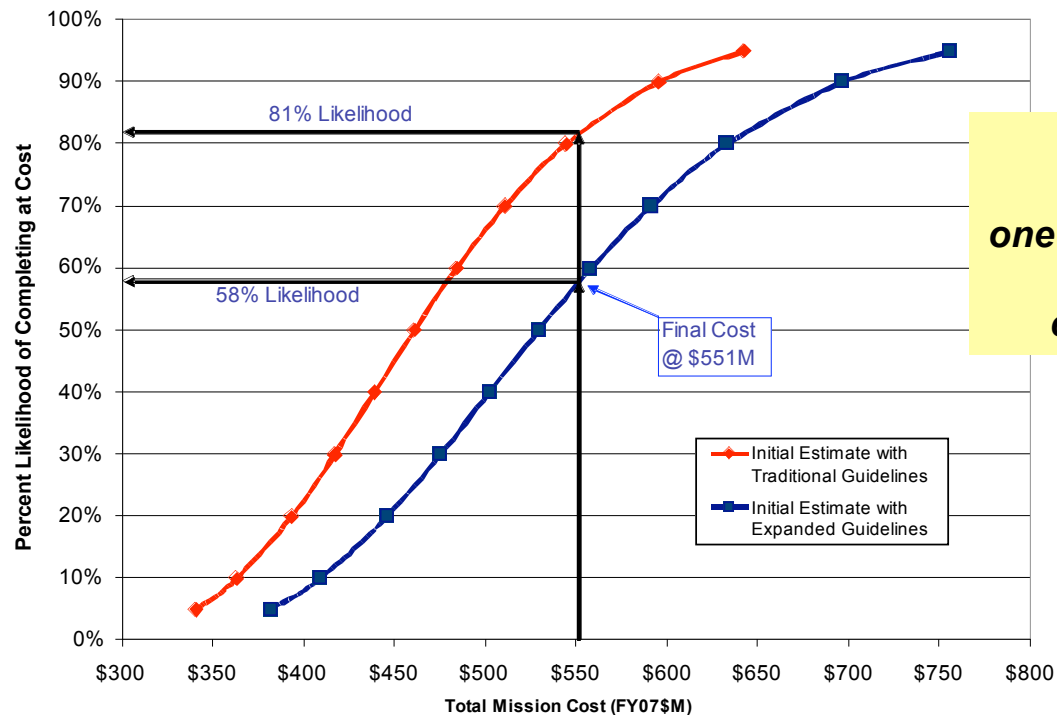


Range of Mass Growth is Large and Exceeds Typical Industry Guidance



# Impact of Expanded Design Reserve Inputs Used for Cost-Risk Estimating

- Expanded mass reserve inputs from previous slide were applied to STEREO design at start of Phase B to understand impact
- Difference between red and blue S-curves show impact of expanded design reserves vs. traditional guidelines



*Represents the impact in only one resource dimension of the overall cost-risk process*

Use of Expanded Design Reserves Accounts for Greater Future Design Uncertainty



# Recommendations & Future Work

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- One means of producing a more accurate estimate is to have better input data up front. Independent validation of instrument resources and resulting spacecraft resources needed to meet mission requirements would allow more accurate estimates.
- For Directed missions, requirements should be set, a preliminary design should be developed that meets these requirements with **conservative** assumptions on resources (mass, power, data rate, etc.) and THEN an independent cost estimate should be conducted as the basis of budget.
- For competed missions, this becomes more difficult, as the missions vary widely in the science they are trying to achieve, the orbits they need, and the launch constraints imposed by planetary alignments.
  - One method to identify the uncertainty in the data driving the cost estimate would be for estimators to prepare their uncertainty distributions using the variations we have shown in Slide 14
- As CADRes are developed on additional NASA missions, the subsystem database should be expanded to include new missions to provide more of statistical basis for the preliminary recommendations made in this paper.



# Summary

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- Power and mass resource growth for mission data sample was significant and increased throughout the design lifecycle
  - Complexity increased for 9 out of 10 missions
  - Cost and schedule increased for 10 out of 10 missions
- Industry guidelines do not in general adequately predict the uncertainty in the initial physical and programmatic parameters claimed in the proposals.
- Current Cost risk process appears to be underestimating the resource growth, which essentially implies an underestimation of the S-curve (mean and slope)
- Estimators cannot be expected to check the validity of the designs that they are estimating
- Independent validation of instrument resources, and the resulting spacecraft resources needed to meet mission requirements, would allow more accurate estimates
- Projects should be properly scoped early in conceptual design to provide executable program plans
- Cost estimators can use wider ranges on parameters for estimating the input values used for cost risk analysis
- More detailed study of a greater mission set is required to develop better guidelines

