NEW MILLENNIUM PROGRAM

Managing Advanced Technology Missions – A Unique Challenge

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Presentation Topics

NMP Objectives

- Accelerate the incorporation of advanced technologies into future NASA science missions
  - Capitalize on investments being made in U.S technological capabilities
  - Provide infusion path with validated performance **scalable** to intended uses
    - Balance requirements/scope/cost to remain "affordable"
  - Capability needs/requirements are derived from NASA Science Mission roadmaps ("technology pull")
  - Conduct technology maturation and validation in low cost NMP project rather than during science mission development

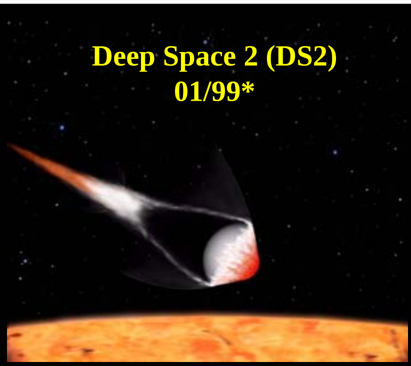
- Focus on technologies ("breakthrough technologies") that will provide a **significant** (~order of magnitude) step forward in performance and/or reduction in cost
  - Enable new capabilities to meet Earth and Space Science needs
  - Target technology capabilities that are broadly applicable to future needs
  - Reduce costs of future missions

- Select and develop advanced technologies for validation in the space environment, when flight validation is required to **validate performance and reduce performance and development risks** to the first users

NASA 2005 Project Management Challenge Conference

Program Overview

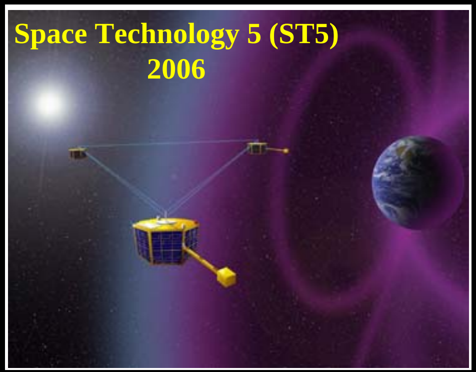
Deep Space 1 (DS1)
10/98*



Deep Space 2 (DS2)
01/99*

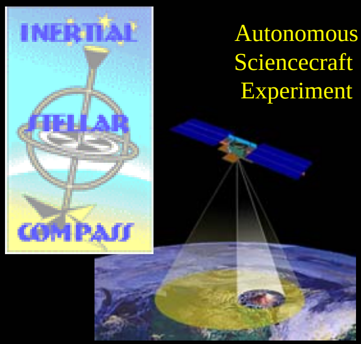
Earth Orbiting 1 (EO1)
11/00*

A cross-Divisional program to identify and flight validate breakthrough technologies that will significantly benefit future Space Science and Earth Science missions.



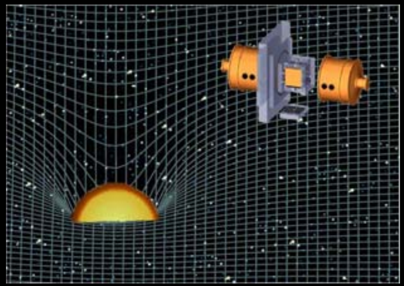
Space Technology 5 (ST5)
2006

Inertial Stellar Compass

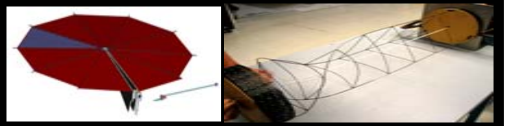


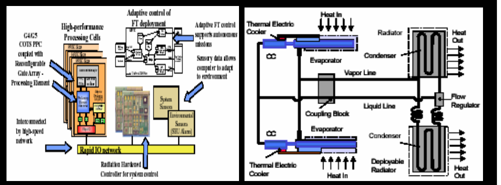
Autonomous Sciencecraft Experiment

Space Technology 6 (ST6)
2004-2005



Disturbance Reduction System
Space Technology 7 (ST7)
2008





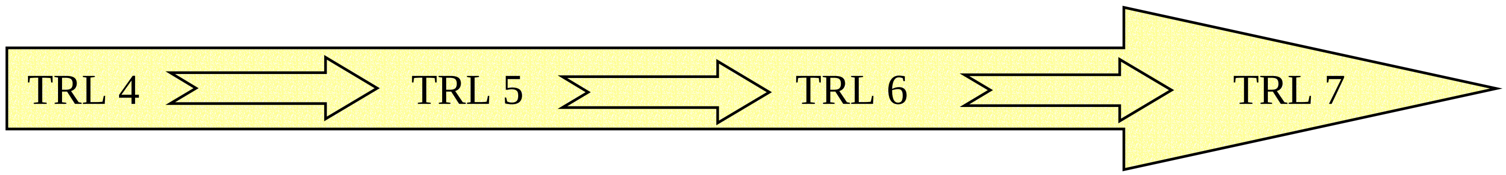
Space Technology 8 (ST8)
2008

* Actual Launch Date

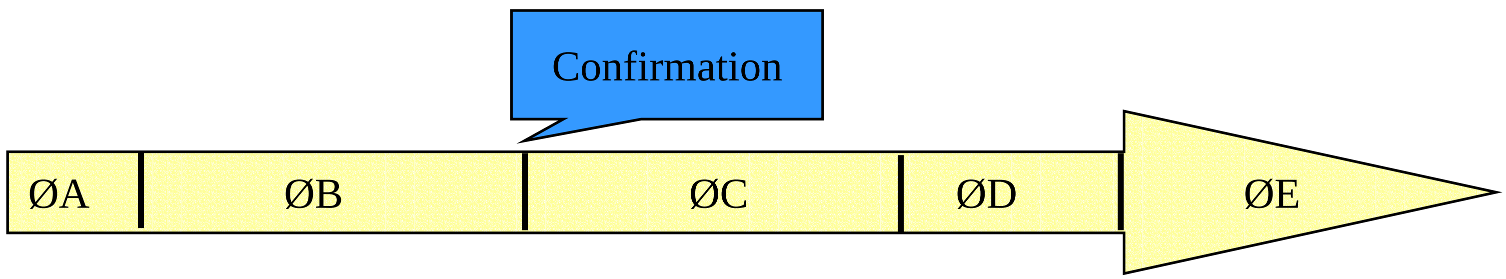
In-Space Technology Validation

- NMP must shoulder both technology **development risks** and **technology performance risks** for high-payoff capabilities
  - Must manage **technology maturation risks** as distinct from engineering design and development risks
  - Requires demonstration that readiness gates are met:
    - TRL 4 at Phase A/B transition
    - TRL 5 at Phase B/C transition
    - TRL 6 at project CDR
- Technology Validation:
  - Provides empirical evidence that the physics or underlying principles of the technology advance in question are understood
  - Analytical models and simulations are used to predict the performance of technology advances on the ground as well as in space
  - Performance data obtained is unique to the space environment
  - Used to refine algorithms and to determine accurate values of parameters used in the models and simulations
  - Validated analytical models of the technology advance permit the envelope of applicability to extend to future applications that are not identical to the flight experiment or to the current version of the technology

NMP Project Management Challenges



- Managing Technology Development (Maturation of technology from TRL 4 to 7) within the flight project lifecycle



- Managing first of a kind engineering development for space flight incorporating new technologies
  - Integrated system validation
  - Standalone subsystem validation experiments

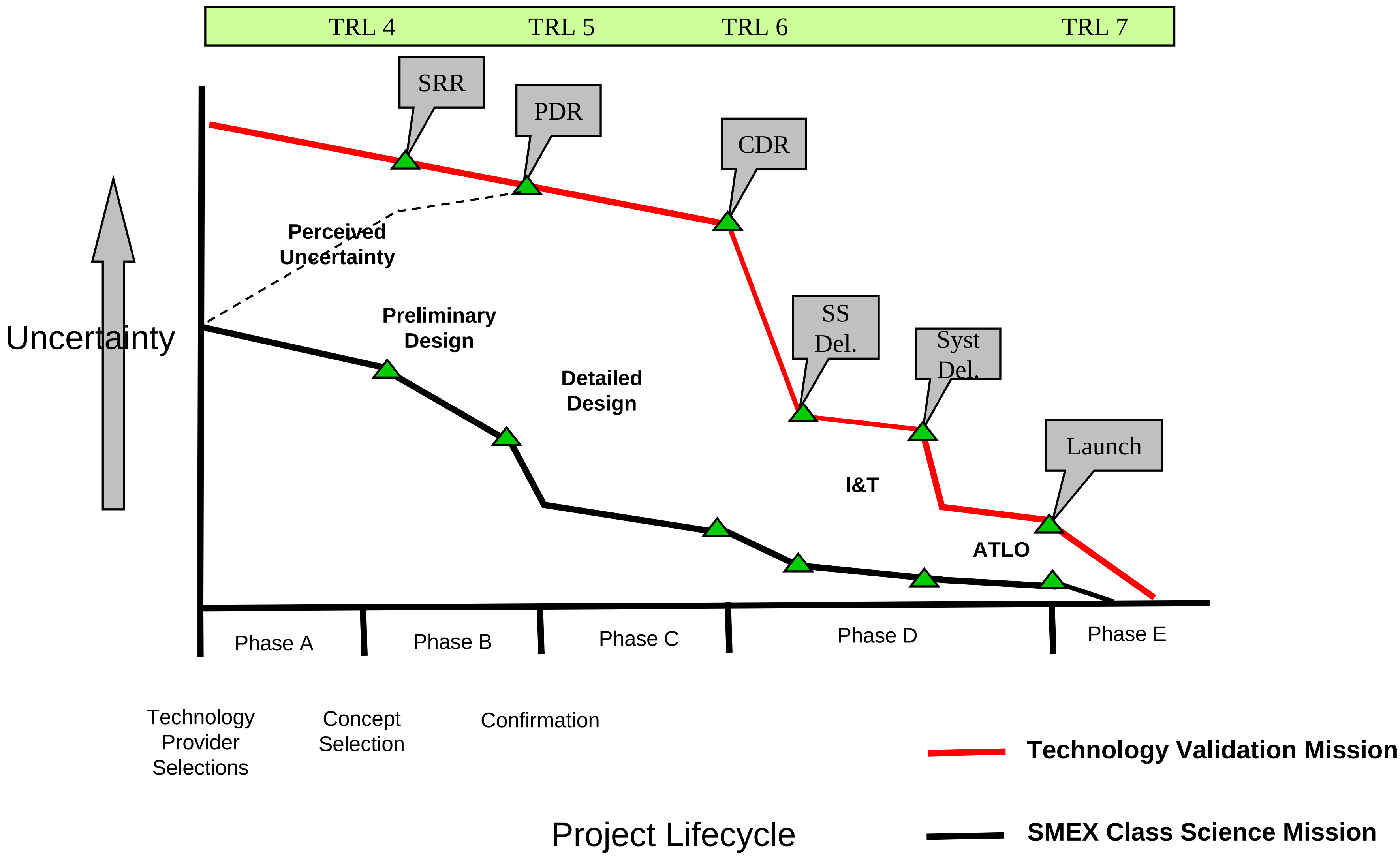
NMP Experience

- Technology maturation risks are high and difficult to estimate in terms of schedule and cost
- Costs estimated at end of Concept Definition are not well substantiated due to maturity of the design approach and uncertainty in technical challenges for maturing technology from TRL 4 to 6
  - Experiment definition, preliminary design and maturation of the technology to TRL 5 provide for higher fidelity cost estimates, but have been shown to underestimate the technology maturation challenges
- Scope of work required to overcome technical/innovation challenges in order to validate the detailed design at CDR is routinely significantly underestimated
  - Maturation of technologies from TRL 5 to 6 is high risk
    - First time see difficulty of producing flight design
      - → Performance
      - → Manufacturability (process development and control)
      - → Subsystem Integration
  - Requires development of new fabrication processes and test approaches
  - Problems surface during peak staffing period in project lifecycle (marching army effects)
  - **Results in significant cost growth after Confirmation**

Mitigation Strategy

- Technology development (maturation) planning
  - Mutually agreed upon maturity "gates"
- Independent Technology Maturity Assessment Team
  - Constituted during Project Concept Definition
- Increased investment (time and $$) in Phase A and B (25-30%) to fund technology maturation along with preliminary design
- Validation plan establishes validation requirements
  - Defines range of technology performance that is scalable to future applications envelope
    - Elasticity in validation requirements used to manage scope and cost proposed at Confirmation
    - Program Level 1 Requirements reflect range of acceptable performance (Full and Minimum Mission Success)
- Risk-based allocation of reserves and funded schedule margin
  - Minimum of 30% reserves at Confirmation (Phase B/C transition)
    - Technologies may require >50% reserves
  - Minimum of 20% funded schedule reserves in project baseline
    - Applied during PDR to CDR and during I&T
  - Program reserves to address unknown unknowns during detailed design
- Set cost cap at Confirmation to focus project on highest priority requirements
- Be prepared to execute descopes at CDR if project not "affordable"

Technical, Cost and Schedule Risks in Project Lifecycles



Additional Strategy for Technology Validation Projects Phase C/D Transition Decision

- Setting cost cap at Confirmation works to focus project on highest priority requirements, but additional decision gate is needed following completion of design validation
  - Transition from TRL 5 to 6 has high technical, cost and schedule risks
  - Bringing technology from laboratory to flight worthy implementation is highest risk step in project development cycle
  - Need flexibility to fund additional cost, when value is high
- Program convene independent review of project status following successful completion of design validation (conduct as part of Project CDR) – do not proceed with Phase D until successful CDR has been achieved.
  - Establish magnitude and probability of occurrence of residual risks with particular emphasis of maturity of technologies
  - Assess credibility of plan to complete and adequacy of risk mitigation approaches, margins and reserves
- Present results of independent review to PMC for approval to proceed with ØD
  - PMC assess value of project to Science Mission Directorate future missions
  - Program provides recommendation on budget within the approved program budget

Managing Small Space Technology Experiments

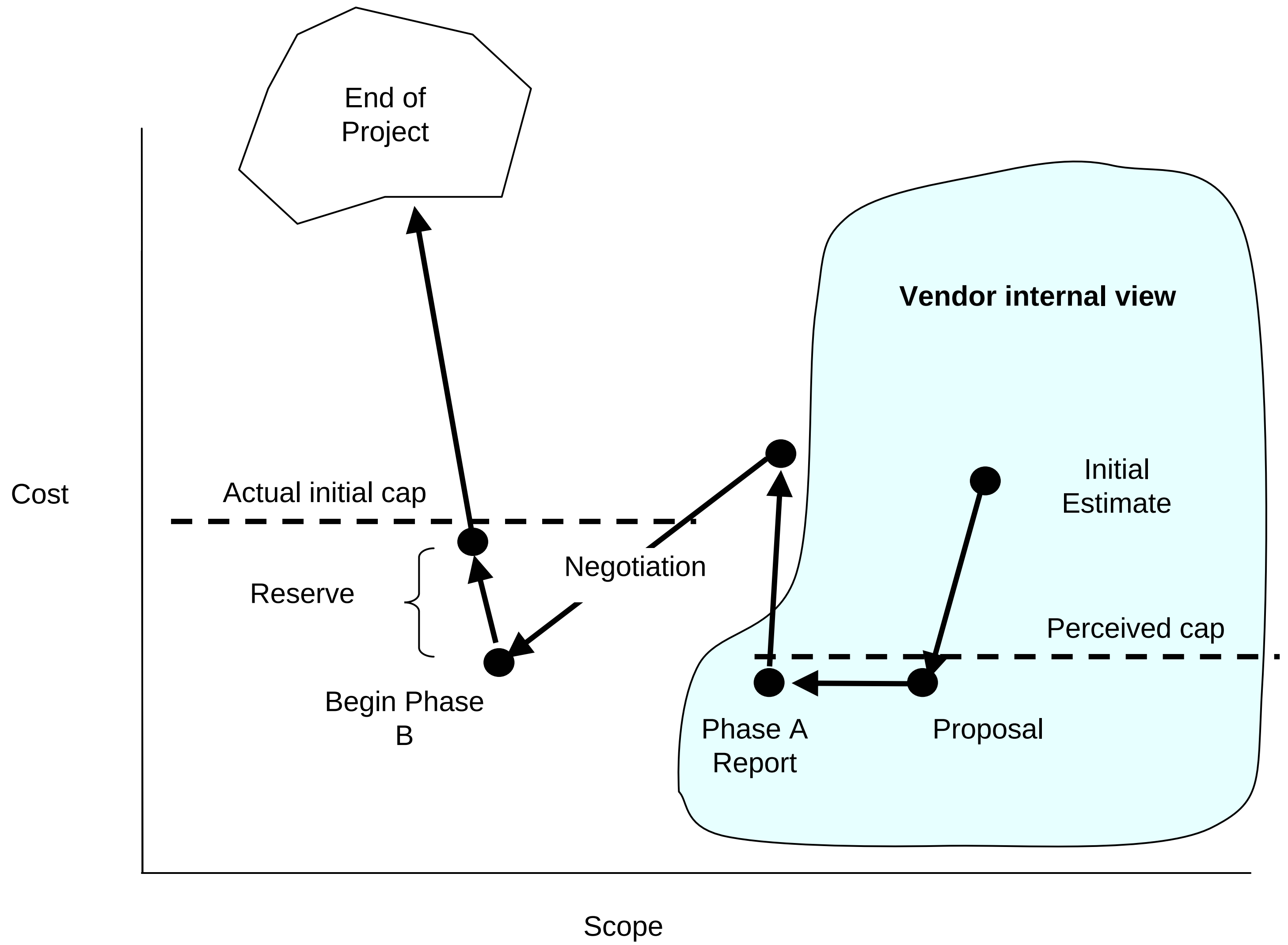
Arthur B. Chmielewski
New Millennium Program
Space Technology 6 Project

Cost Performance of Space Projects

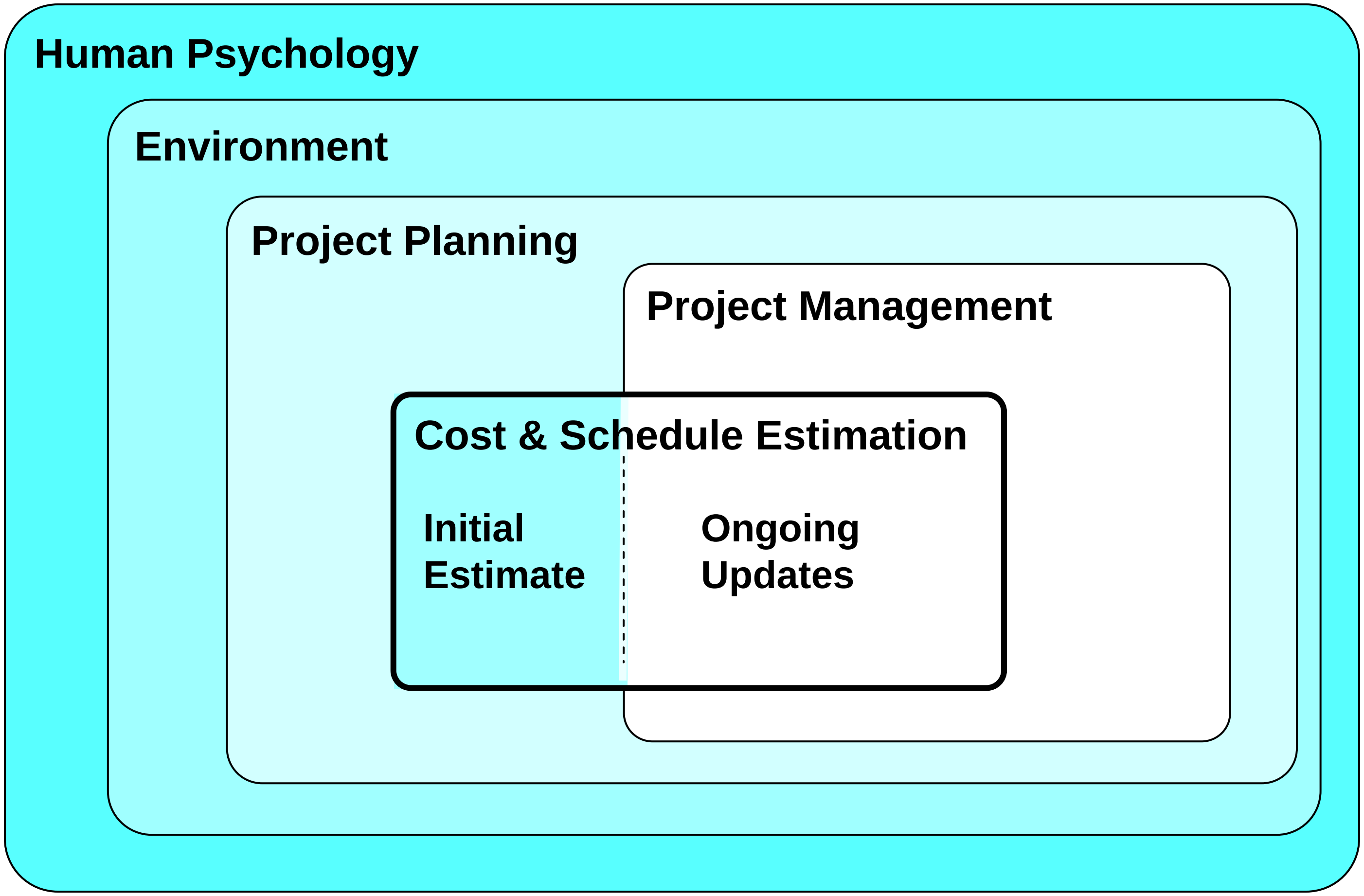
Mission type	Average Overrun	Missions Included
Flagship (> $800M)	31%	Spitzer, MER
Medium size (< $300M)	19%	Cloudsat, Deep Impact, Genesis, Grace, Stardust
Instruments (< $150M)	34%	TES, EMLS
System Technology Experiments (< $150M)	81%	DS-1, ST5, ST7
Small Technology Experiments (<$10M)	315%	In-STEP (11 experiments), Microgravity (26 experiments)

Overrun = Final cost – (cost estimate + requested reserve)

Space Technology "W"



Inaccuracy Components



Credit: Robust Decisions Inc. and JPL

ST6 Solutions to Lowering Inaccuracy Components

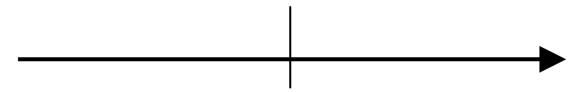
- **Human Psychology**
  - A/B Bipolar shift: be patient with patients.
  - Uncertainty: calculate your reserve, don't guess it!
  - Anchoring: art of getting good initial cost data.
  - Needs and accuracy conflict: hire independent risk analyst.
- **Environment**
  - Organization complexity: simplify or die.
  - Peer review, don't pay for big shows.
  - Technologist vs. flight engineer
- **Planning**
  - Most unknown unknowns are not. Plan for them with sponsors.
  - Face these distasteful programmatic risks.
  - Engineering – bigger enemy than technology.
- **Project Management**
  - Use the unearned value method.
  - Get out of the taxi.

Proposal Phase vs. Design Phase

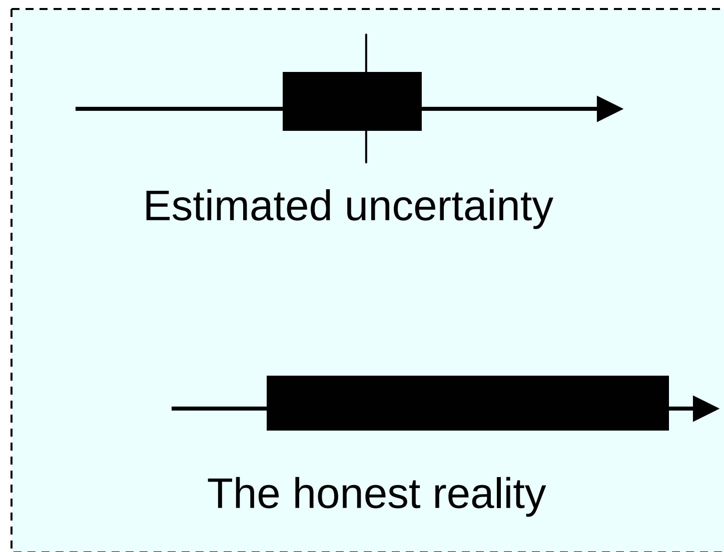
1. Let's win	1. Let's survive!
2. Why do I need 30% reserve?	2. How can I get another 30%?
3. In denial over budget	3. Denied more budget
4. Let's invent some nonthreatening risks	4. The risks are threatening us
5. Descopes, what descopes?	5. We need descopes! Now!
6. Let's get some creative writers/technologists	6. Let's get some flight engineers
7. Programmatic risks- give me a break!	7. Programmatic risks are breaking us!
8. Let's not ask for too much money	8. Why didn't we ask for more money?
9. Converters, FPGA's, noise, software – no problemo!	9. Converters, FPGA's, noise, software- muchos problemos!
10. Very motivated partners provide free services.	10. Partners are motivated to charge you more money.

Human Psychology: Conflict between needs and accuracy

Estimated uncertainty is reduced artificially because:



- Management needs small uncertainty for planning regardless of reality
- Large uncertainty is seen as lack of knowledge
- Large uncertainty scares sponsor



ST6 Solution: Don't guess your reserve, calculate it!

Conclusion

- Large cost overruns of small space technology projects are a symptom of four major contributors:
  - Human psychology
  - Environment
  - Planning
  - Project management

All of these contributors can be greatly diminished by confronting them and controlling with some new and some old management techniques.

Space Technology 5 Mission

Candace Carlisle,

Deputy Project Manager

ST5 Experience with Technology Development

- **ST5 Mission Requirements**
  - Design, development, integration, test and operation three full service spacecraft, each with a mass less than 25kg, through the use of breakthrough technologies
  - Demonstration of accurate, research-quality scientific measurements utilizing a nanosatellite with a mass less than 25 kg
  - Design, development, test and operation of multiple spacecraft to act as a single constellation rather than as individual elements**.**
- **Challenges facing ST5 Mission**
  - Technology maturation of 8 technologies – 3 being mission defining
  - Engineering challenges associated with the development of miniature, highly integrated spacecraft subsystems
  - Successful acquisition of a suitable secondary launch opportunity
  - Aggressive development schedule – 45-month development from phase A to launch

ST-5 Experience with Technology Development

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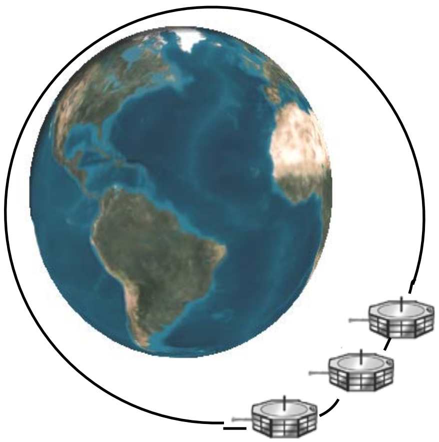

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Management of Technology Maturity

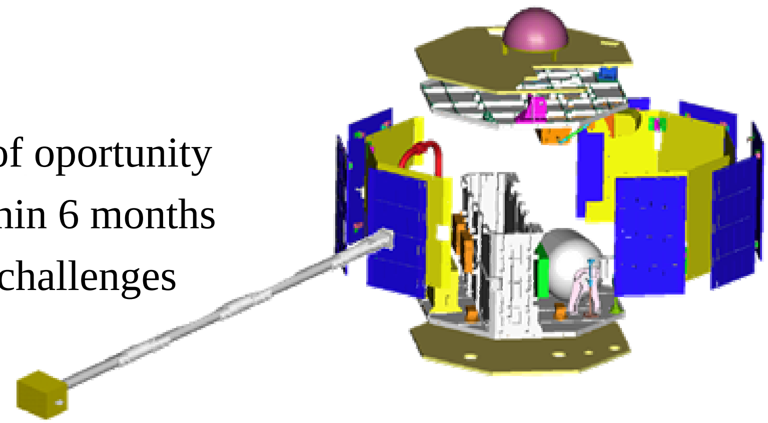
- **Technology development history on ST-5**
  - Three technology providers removed from the mission
    - One due to lack of maturity
    - Two because of provider decision to terminate effort

- **Risk associated with technology "maturity" assessed at systems requirements review**
  - Difficult to accurately assess risk associated with both technology challenges and engineering challenges facing each provider
  - Engineering risk associated with miniaturization challenges very difficult to quantify
  - Underestimated both the technology risk (due to lack of maturity) and the engineering challenges facing the mission

- **Risks clearly evident at Preliminary Design Review not primarily associated with technology readiness**
  - Launch opportunity not under contract
  - Engineering challenges clearly evident – but extent not appreciated
  - Technology maturity obscured by engineering challenges

Early Phase C/D Challenges

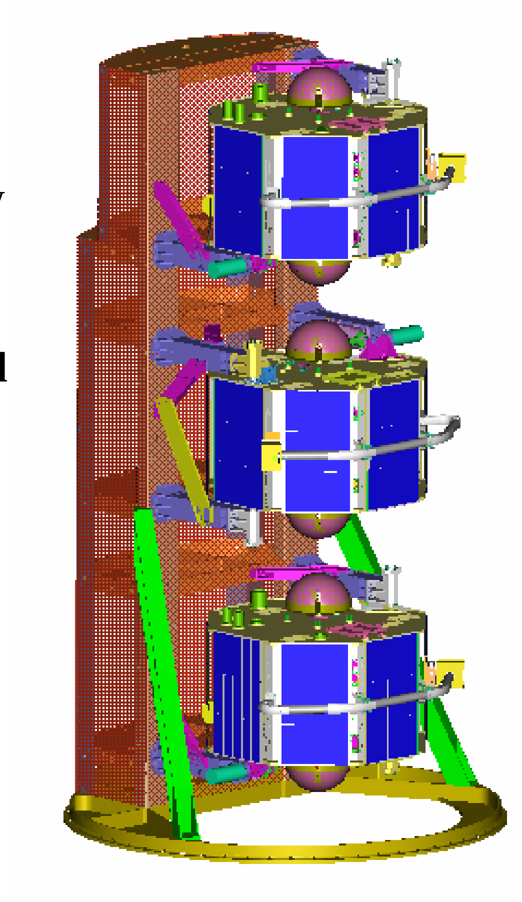
- **Mission Confirmed without Firm Secondary Launch Opportunity**
  - Dominant theme at confirmation review
  - Recognized as acceptable risk for secondary ride of oportunity
  - Assumption that firm ride would be identified within 6 months
  - Technology development at TRL 5 – engineering challenges underestimated



- **CDR Review without Firm Secondary Launch Opportunity**
  - Design against generic secondary interface
  - Engineering challenges associated with manufacturability of miniature avionics not appreciated
  - Assumption that secondary ride would be identified within 6 months
  - Clear understanding of Δ-CDR content (assuming secondary ride met generic interface)
  - Assumed review would occur within 3 to 6 months

CURRENT STATUS

- **Δ-CDR Held 25 Months After CDR**
  - Viable secondary opportunity not found for ST-5
  - Launch as a primary payload on a Pegasus
  - Change in launch vehicle interface, orbit and mission required additional time to complete engineering changes prior to review
  - Review was very successful



- **Additional time required to acquire a launch vehicle put to good use**
  - Technology maturation needs well understood
  - Engineering challenges associated with manufacturability of miniature avionics (both for spacecraft and some technologies
  - Fabrication and test of spacecraft structure and components
- **Management Challenges to the team were substantial**
  - History of schedule relief not easily corrected
  - Technology challenges of NMP missions
  - Uncertainty associated with mission future

Conclusions

- **NMP Missions Present Unique Challenges**
  - Separating technology maturity issues from engineering challenges dificult
  - Inherent optimism difficult to recognize and manage
  - Access to space challenge was very difficult– both technically and programmatically
  - Bias that small missions have small problems ever present
- **Successful development due to many factors**
  - Successful and robust risk management very useful
  - Additional time prior to “real” CDR was necessary
  - Fabrication of three units required more time than anticipated
- **Cohesive team throughout life was critical**
  - Majority of key team members present for entire mission
  - Understanding of technologies as well as spacecraft critical for successful mission
  - Mission well poised for success

All Three Spacecraft in I&T