Perspectives on NASA Mission Cost and Schedule Performance Trends

Presentation for the Future In-Space Operations (FISO) Colloquium

2 July 2008

Bob Bitten

Acknowledgments: Claude Freaner, Dave Bearden, Debra Emmons, Tom Coonce

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Typical Questions

- What is the magnitude of cost and schedule growth?
- How reliable are projects' estimates in the conceptual design stage?
- Why does cost growth occur?
- What is the relationship between cost, schedule and "complexity"?
- Are there any improvements that can be made in estimating the costs of future design concepts?

Forty NASA Robotic Science Missions Experienced 27% Cost and 22% Schedule Growth*

United States General Accounting Office
GAO
Report to the Chairman, Subcommittee on Investigations and Oversight, Committee on Science, Space, and Technology, House of Representatives

December 1992

NASA PROGRAM COSTS

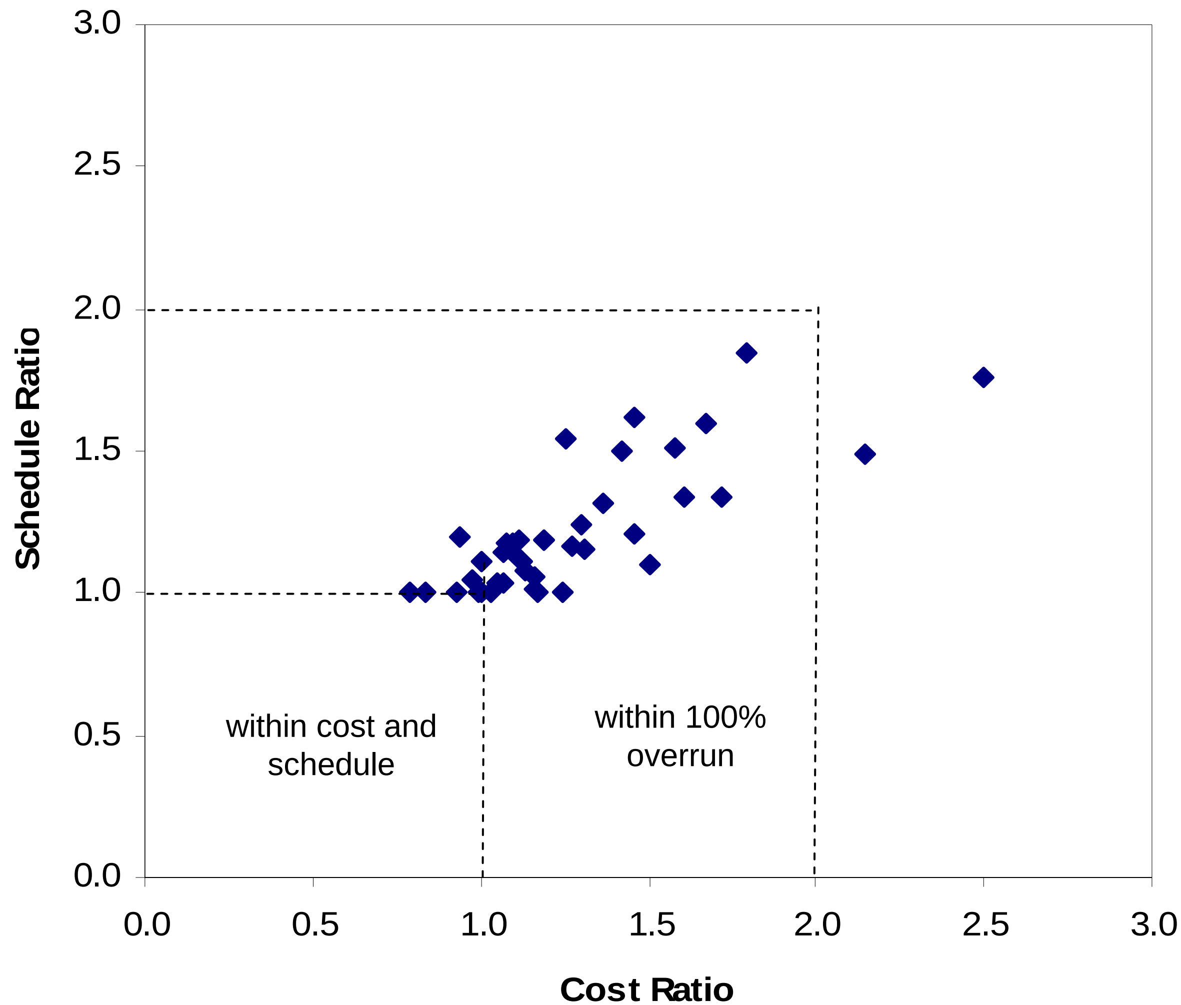
Space Missions Require Substantially More Funding Than Initially Estimated

United States General Accounting Office
GAO
Report to the Committee on Science, House of Representatives

May 2004

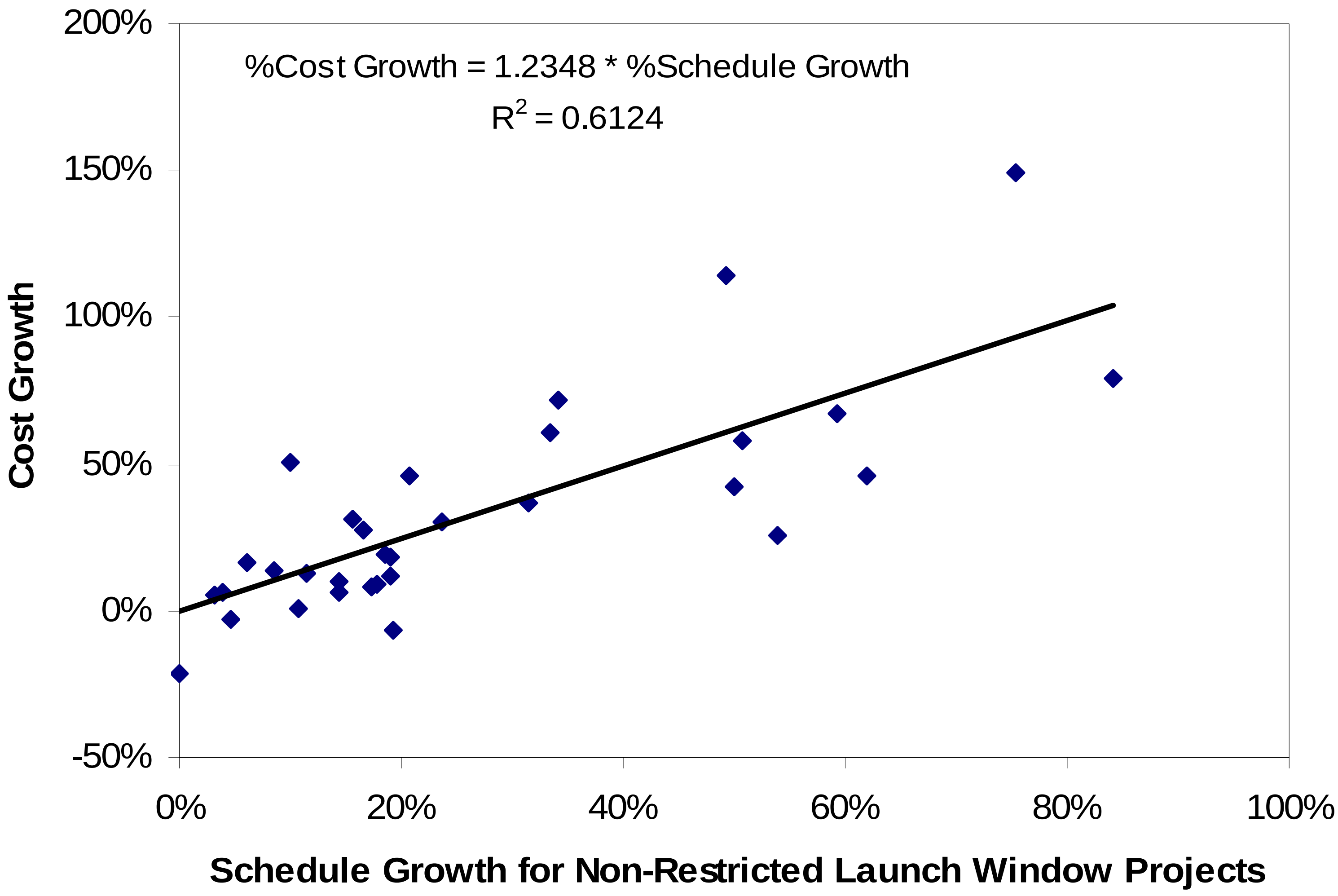
NASA

Lack of Disciplined Cost-Estimating Processes Hinders Effective Program Management



* “Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines”, Bitten R., Emmons D., Freaner C.

While Significant Variability is Evident, for Every 10% of Schedule Growth, there is a Corresponding 12% Increase in Cost*



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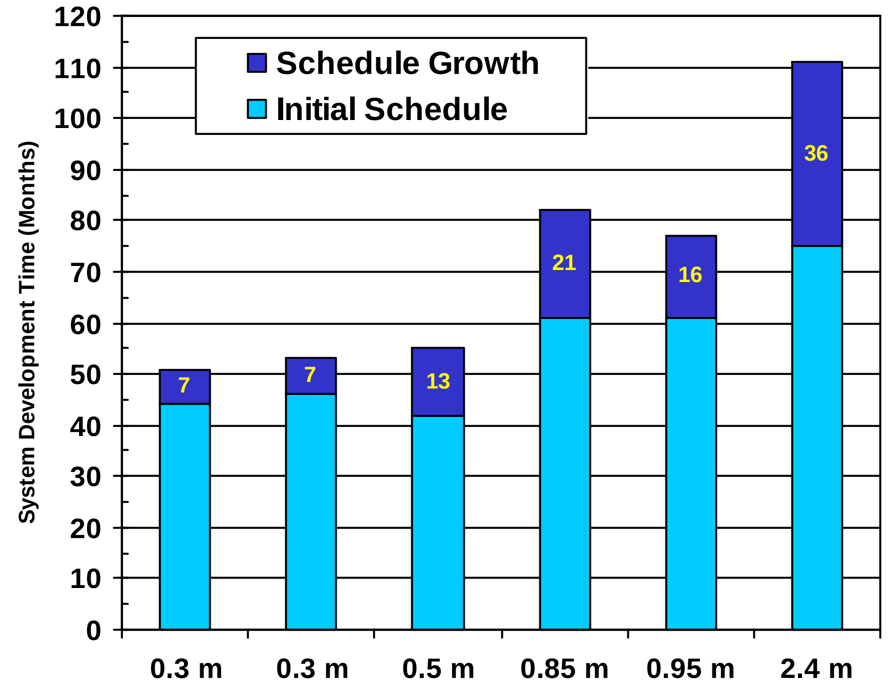
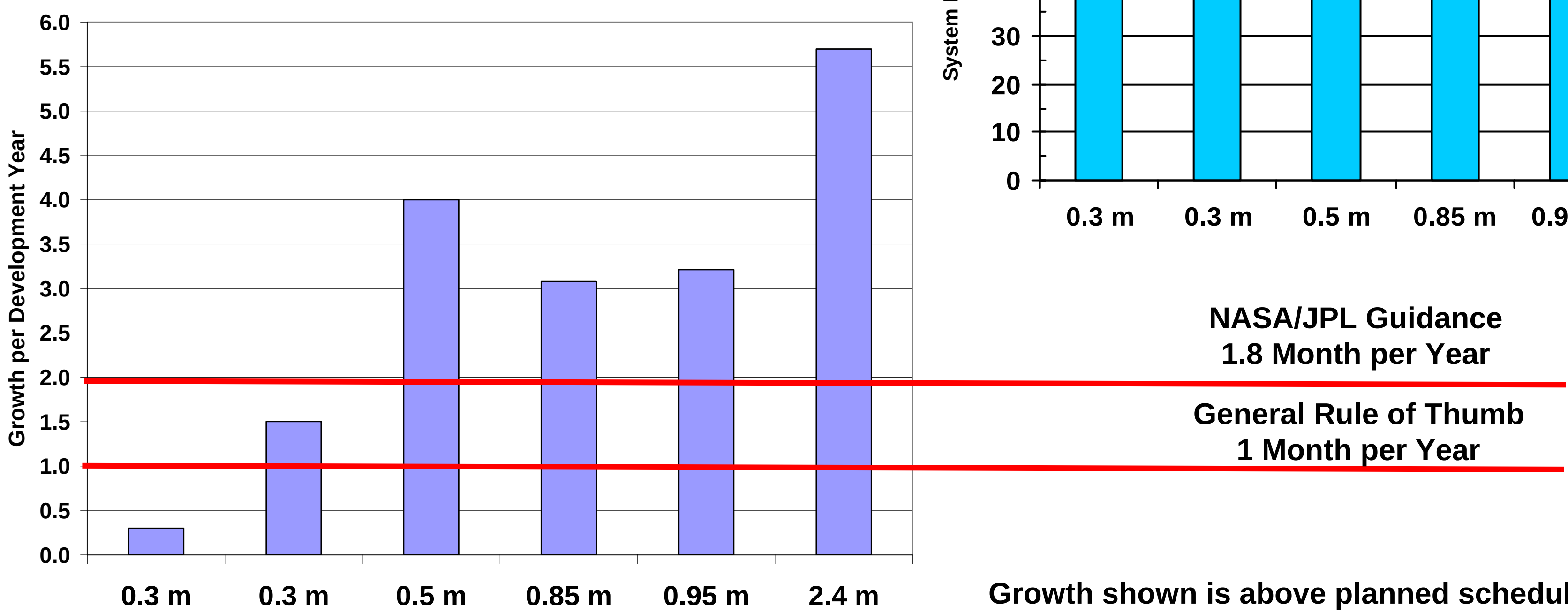
Comparison of Schedule Growth Data with Agency Guidelines: NASA Telescope Missions

Four of Six Telescope Missions Exceeded Common Schedule Reserve Guidelines





Growth shown is above planned schedule reserve

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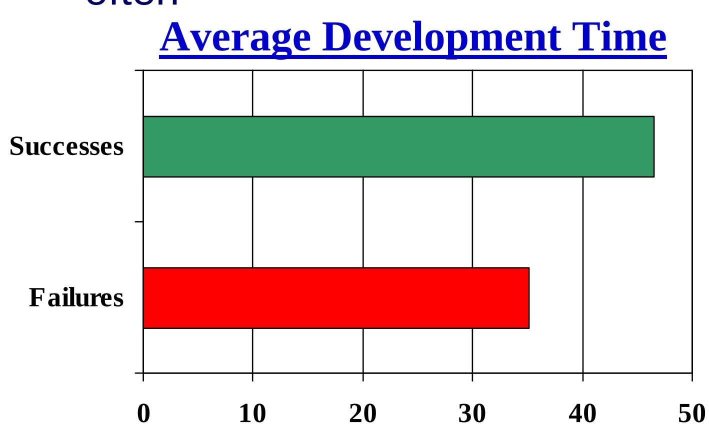
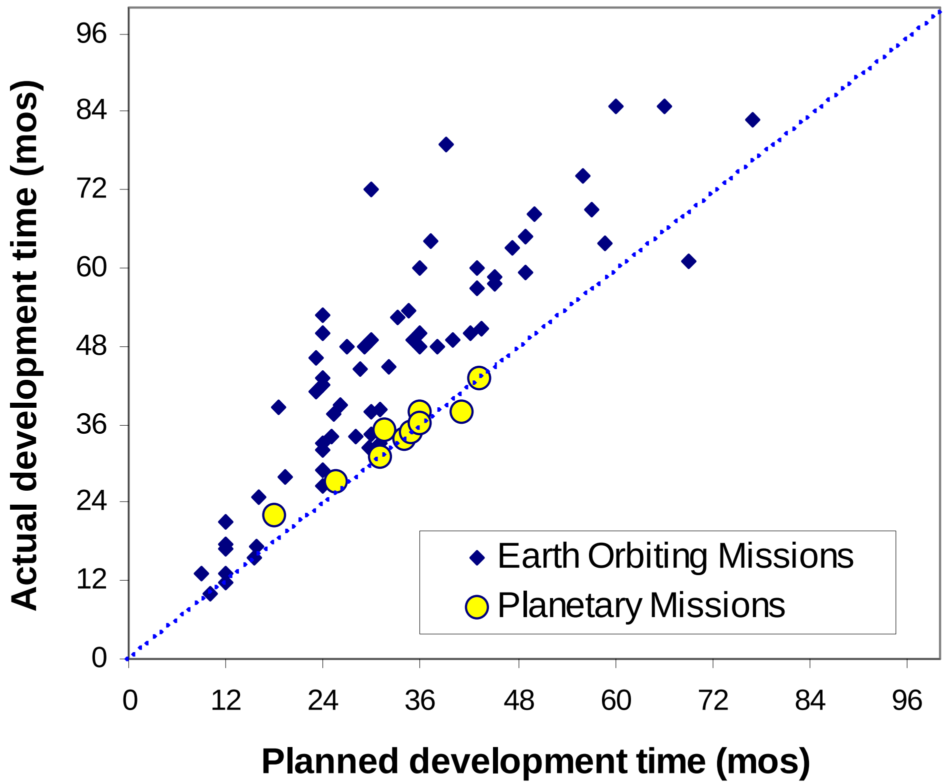
Comparison of Schedule Growth and Success for Planetary Missions vs. Earth-orbiting Missions*

- Development times for Planetary missions less than Earth-orbiting missions due to constrained launch windows
- Planetary missions experienced less schedule slip on average than earth-orbiting missions
- However, planetary missions failed or impaired twice as often

	Planetary	Earth-Orbiting
Sample Size	10	56
Schedule Growth	3.9%	38.3%

Outcome	Planetary	Earth-orbiting
% Successful	30%	84%
% Partial	40%	7%
% Catastrophic	30%	9%





* "The Effect of Schedule Constraints on the Success of Planetary Missions", Bitten R.E., Bearden D.A., Lao N.Y. and Park, T.H.

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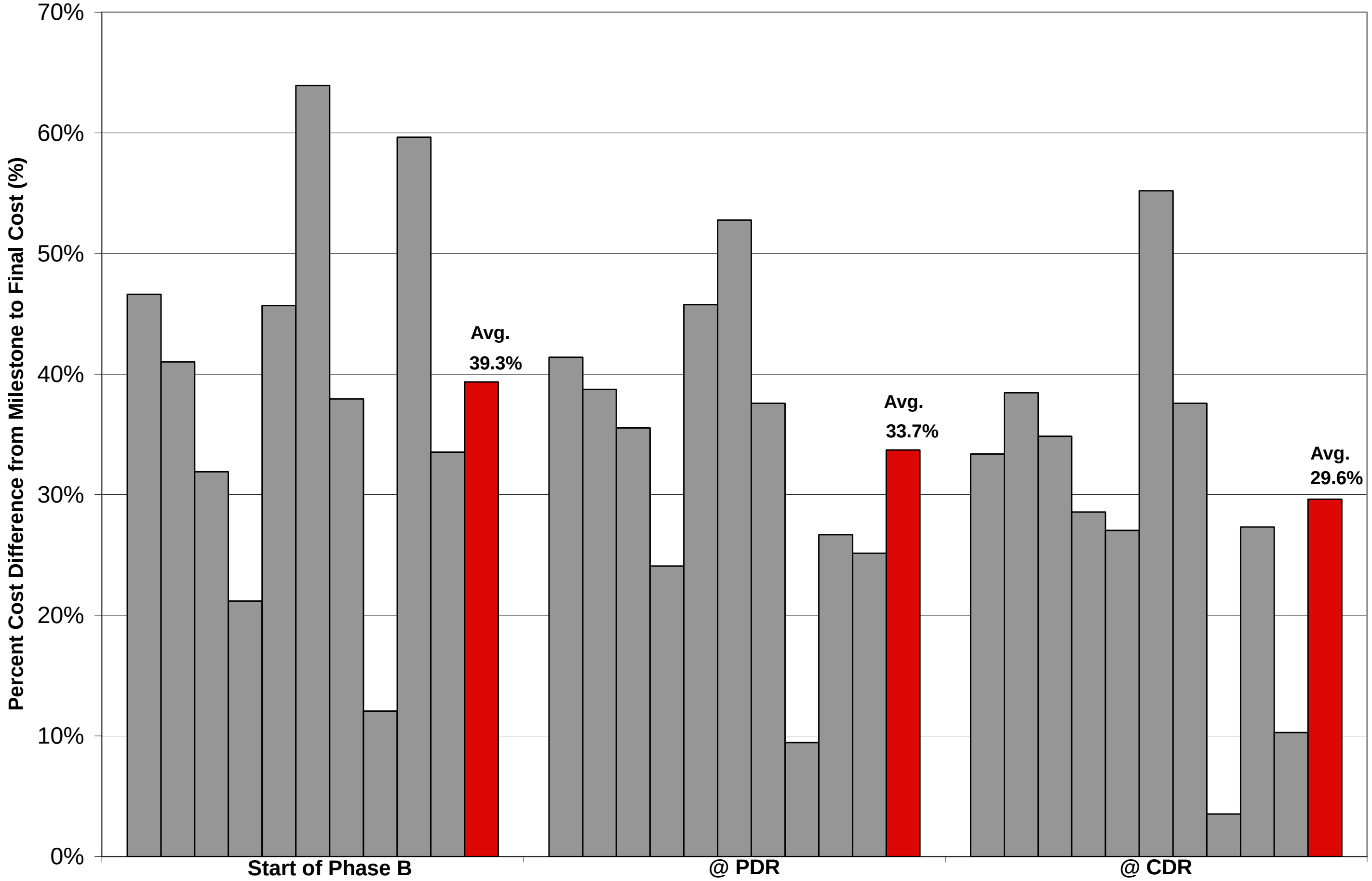
How Reliable are the Projects' Estimates at the Conceptual Design Stage and How Does Confidence Progress?



Ten Missions Demonstrate How Accuracy of Project Estimates Increases Over Time however Cost Growth, Over and Above Reserves, Still Occurs Deep into the Project Life Cycle

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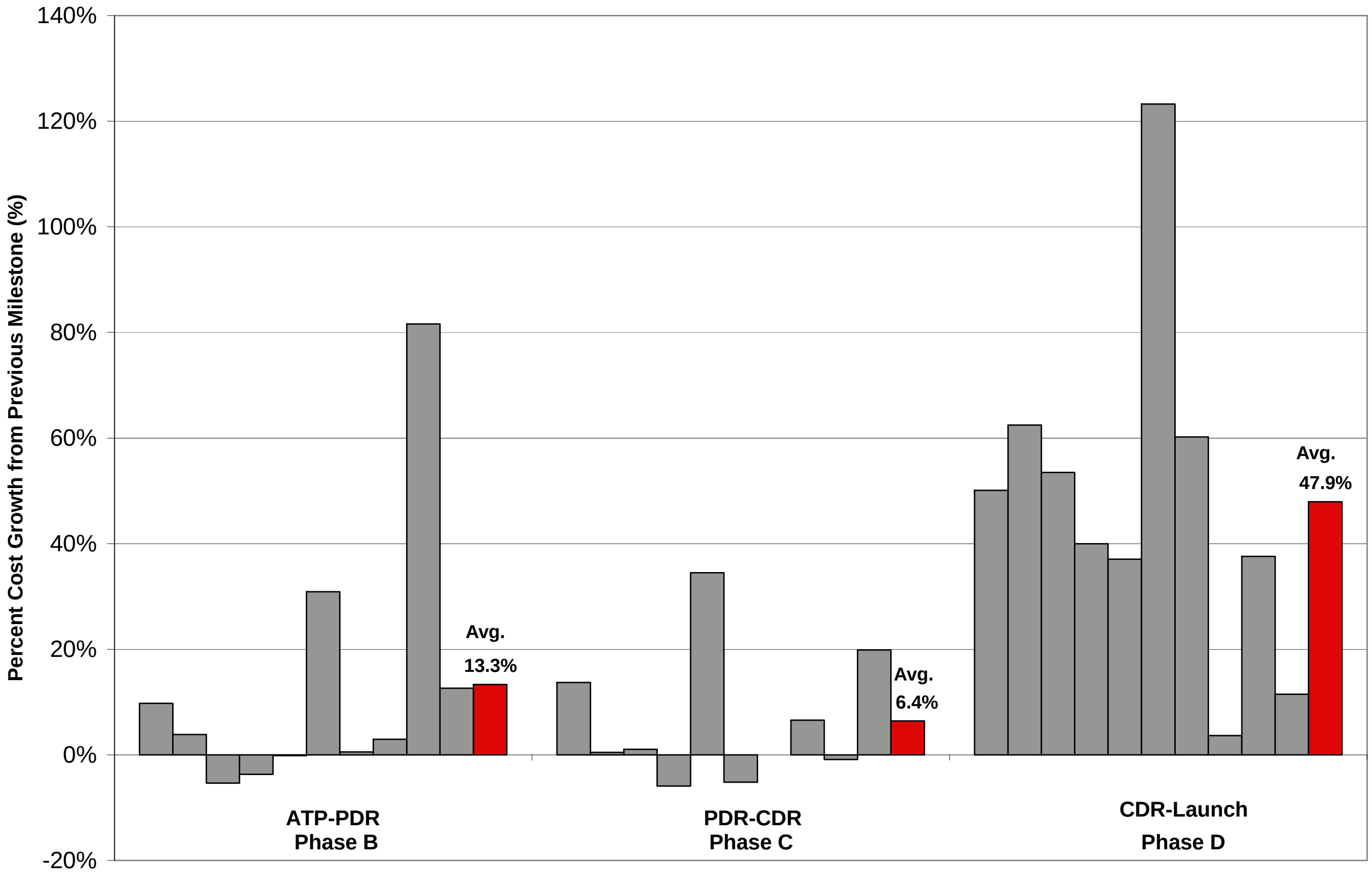
In What Phase Does Cost Growth Occur?



Greatest Growth Occurs During Integration and Test (Phase D) When Trying to Get Hardware & Software to Function as Designed

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Some of the Reasons

- Inadequate definition of technical and management aspects of a program prior to seeking approval

  (NASA's Project Management Study, 1980)

- Program and funding instability; difficulties in managing programs in an environment where funding must be approved annually and priorities change

  (Advisory Committee on the Future of the U.S. Space Program, 1990)

- Lack of emphasis on technological readiness and requirements on the front end of a program

  (NASA's Roles and Missions Report, 1991)

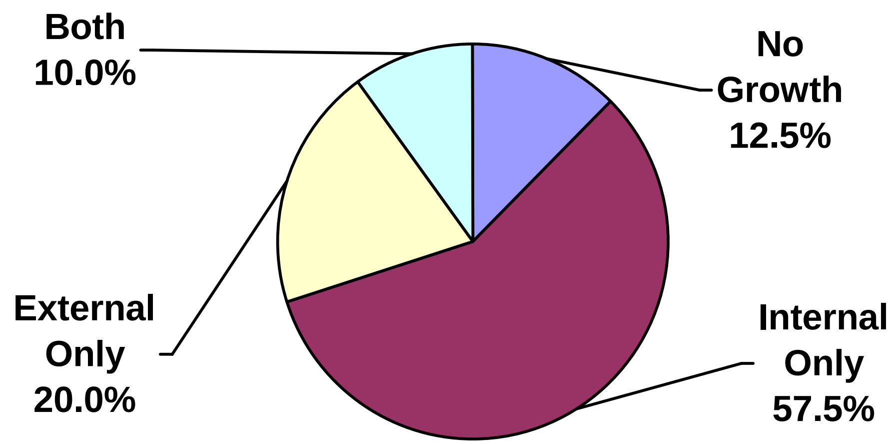
- Program redesign, Technical Complexity, Budget Constraints, Incomplete Estimates

  (GAO Report on NASA Program Costs, 1992)

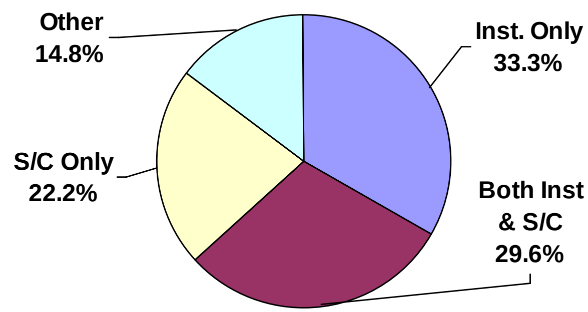
The Reasons for Growth - Study of 40 NASA Missions: Internal versus External Factors Driven-Growth*

- Internal Growth
  (within Project's control)
  - Technical
    - Spacecraft development difficulties
    - Instrument development difficulties
    - Test failures
    - Optimistic heritage assumptions
  - Programmatic
    - Contractor management issues
    - Inability to properly staff an activity

Distribution of Growth

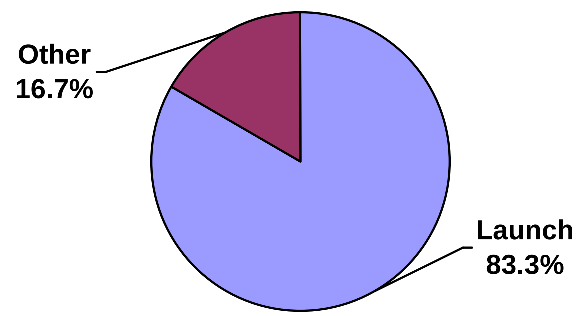


- External Growth
  (outside Project's control)
  - Launch vehicle delay
  - Project redesign
  - Requirements growth
  - Budget constraint
  - Labor strike
  - Natural disaster



Distribution of Internal Growth

Distribution of External Growth



* "Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines", Bitten R., Emmons D., Freaner C.

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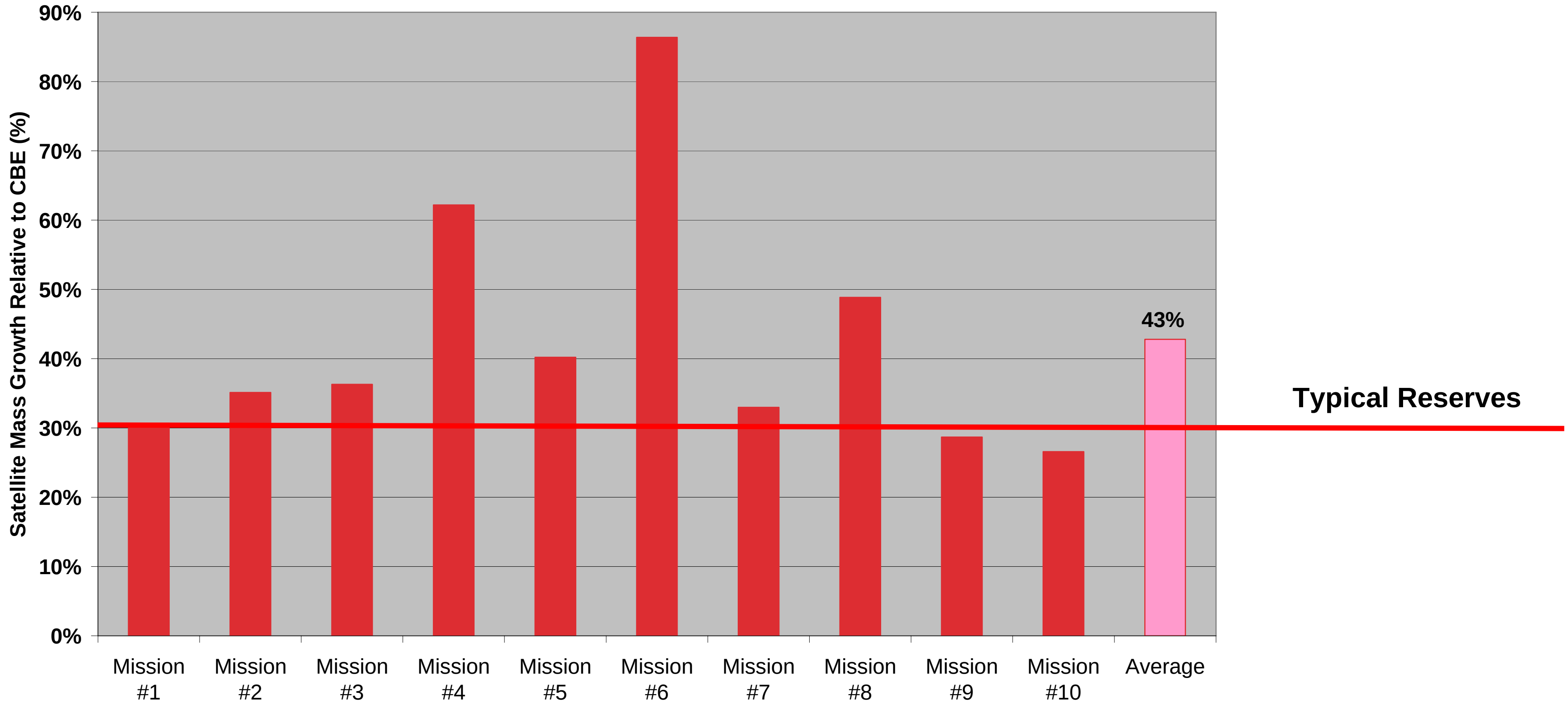
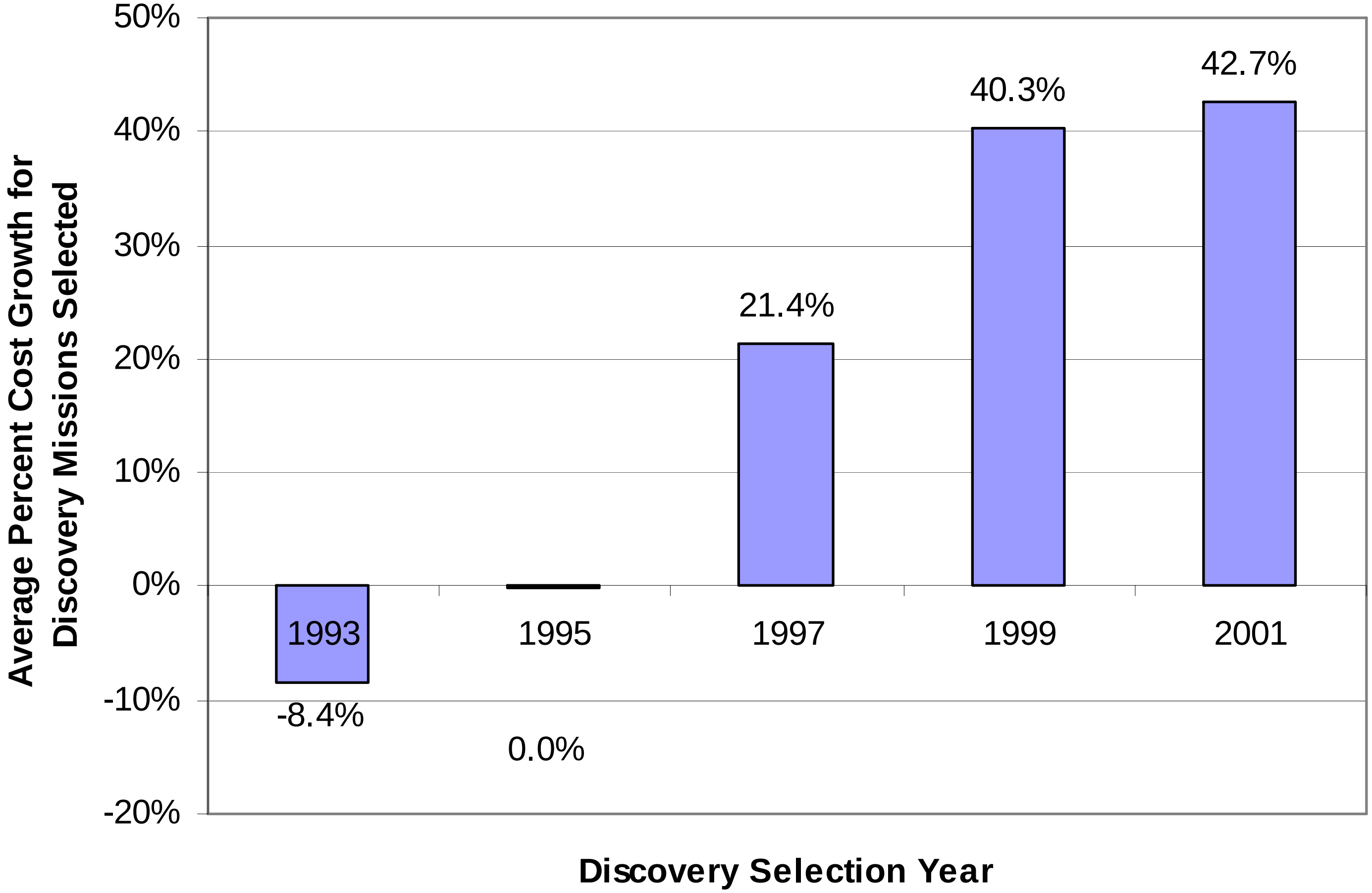
Mass Growth Exceeds Typical Guidance*

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



* "An Assessment of the Inherent Optimism in Early Conceptual Designs and its Effect on Cost and Schedule Growth", Freaner C., Bitten R., Bearden D., and Emmons D.

Assessing Relationships for Causality: Inherent Optimism in Initial Design & Estimates*



Progression of Average Cost Growth for Discovery Selections May be Indicative of Competitive Pressures Leading to More Aggressive Designs

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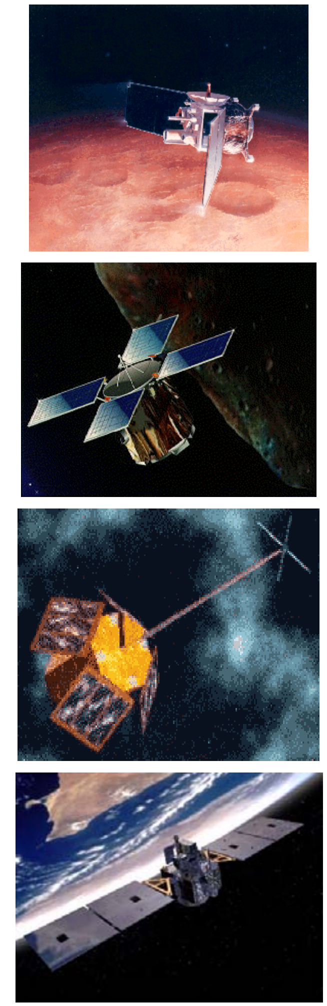
Hypothesis*

- ***Complexity Index*** could be derived using a broad set of parameters to arrive at a top-level representation of the system
- Correlation to spacecraft cost and/or development time based on actual program experience might be apparent
- Data assembled for most spacecraft launched during past two decades (1989 to present) including technical specifications, costs, development time, mass properties and operational status
- Complexity Index calculated based on performance, mass, power and technology choices for purposes of comparison
- Relationship between complexity and "failures" investigated compared with adequacy of cost and schedule resources
- Method to assess complexity at the system-level should allow more informed overall decisions to be made for new systems being conceived



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* "A Complexity-based Risk Assessment of Low-Cost Planetary Missions: When is a Mission Too Fast and Too Cheap?", Bearden, D.A.

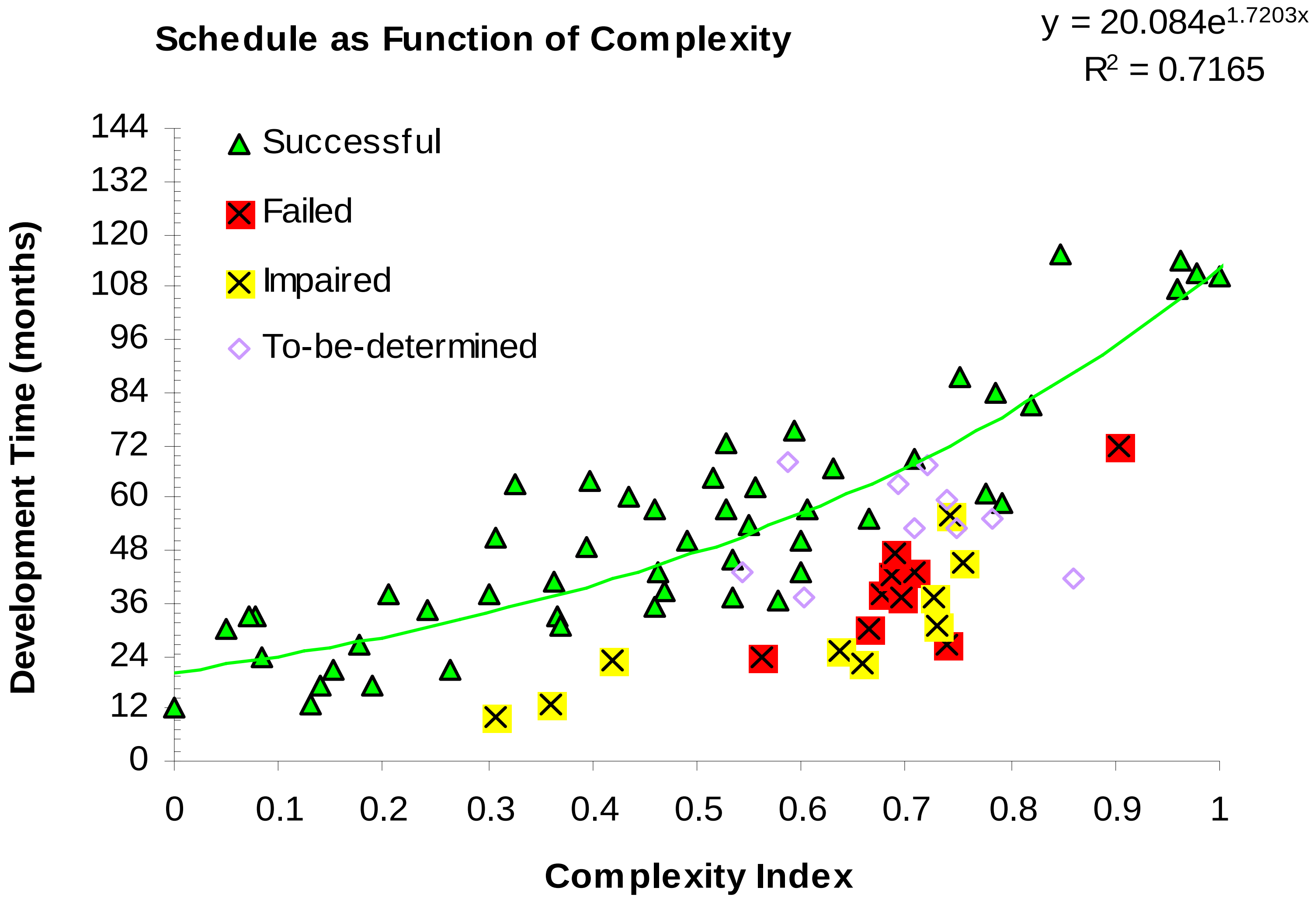
Complexity Index Example

Factor	Unit	Min	Mean	Max	Example	
Payload Mass	(kg)	0	265	6065	90	55%
Payload Orbit Average Power	(W)	0	166	1600	62	38%
Payload Peak Power	(W)	0	174	750	85	31%
Payload Data Rate (average)	(Kbps)	0	11678	304538	175	55%
Number of Instruments		1	4	18	3	43%
Aperture diameter	(cm)	3	67	240	60	58%
BOL Power	(W)	12	761	8000	1750	89%
EOL Power	(W)	3	653	6600	1651	92%
Solar Array Area	(m^2)	0	5	58	7.5	82%
Solar Cell Type/Power Source		Si	GaAs, GaAs-mult	GaAs-conc, RTG/R	GaAs-mult	75%
Battery Type		Lead-acid	NiCd, SNiCd	NiH2, Li-Ion	Li-Ion	100%
Battery Capacity	(A-hr)	1	36	516	266	98%
# Articulated Structures		0	1	6	2	87%
# Deployed Structures		0	2	9	3	81%
Pointing Accuracy	(deg)	0	2	35	0.0039	88%
Pointing Knowledge	(deg)	0	1	20	0.0036	80%
Platform Agility (slew rate)	(deg/sec)	0	1	5	0.62	80%
Pointing Stability (Jitter)	(urad/sec)	0	87	524	5.000	64%
Number of Thrusters+Tanks	(#)	0	6	26	18	86%
Propulsion Type		None, Cold-Gas	Mono, Biprop-(blow,pres)	OB+US, Ion	mono	40%
Max Uplink Data Rate	(kbps)	0	38	2000	2.0	27%
Transmitter Power (peak)	(W)	1	10	60	20	85%
Central Processor Power	(Mips)	0	58	1600	119	81%
Onboard Software Code	(KSLOC)	2	78	650	110	79%
Flight Software Reuse	(%)	0%	36%	90%	47%	44%
Data Storage Capacity	(Mbytes)	0	4186	136000	512.0	60%
Thermal Type		passive	heaters, semi-active	active, cryo	heaters	25%
Multi-Element System?		single-sc	CL, mult (aerobr, rend)	entry/landed/dock	mult	66%

Complexity Index **60%**

Normalized Complexity Index **79%**

When is a Mission Too Fast?*



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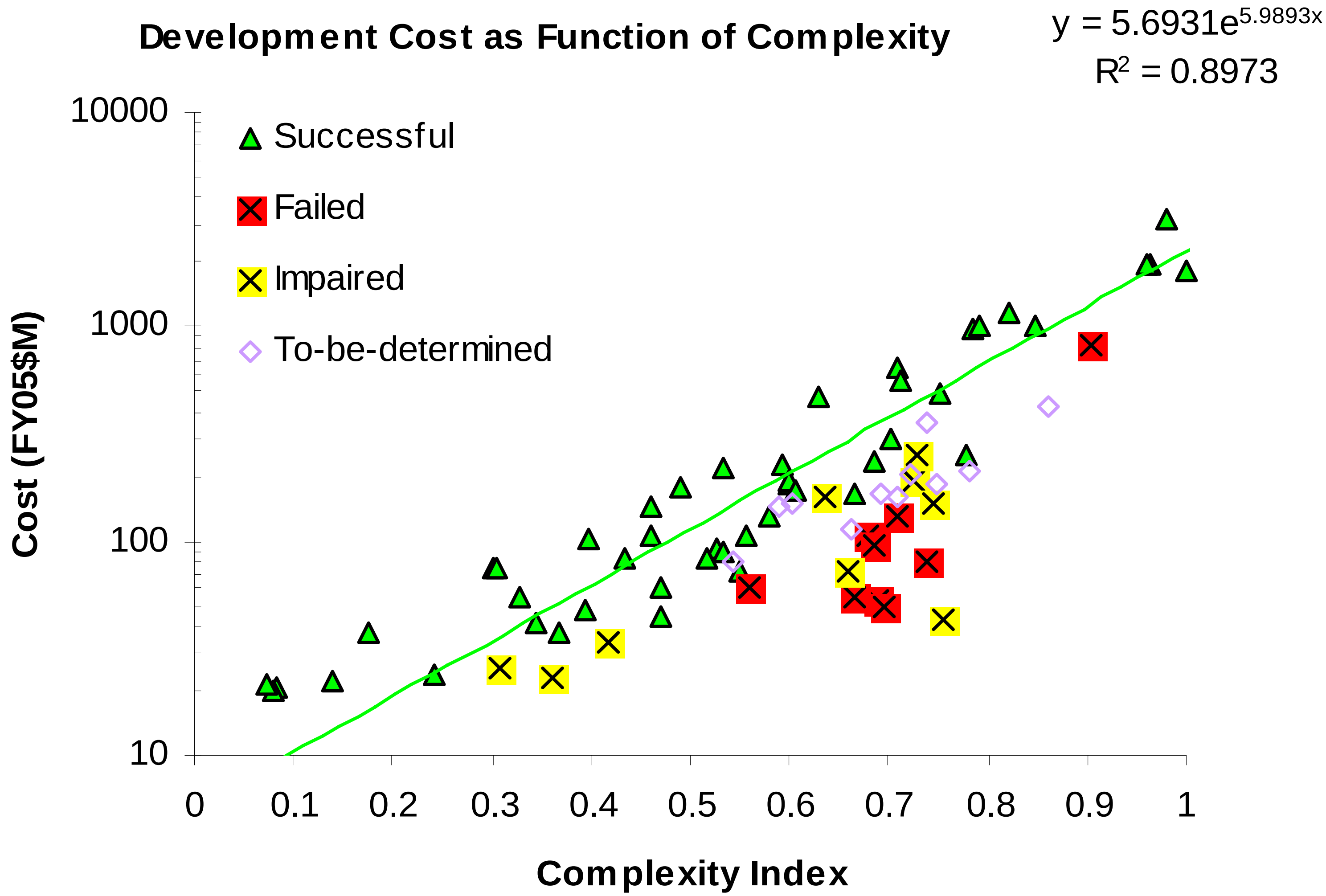
When is a Mission Too Cheap?*



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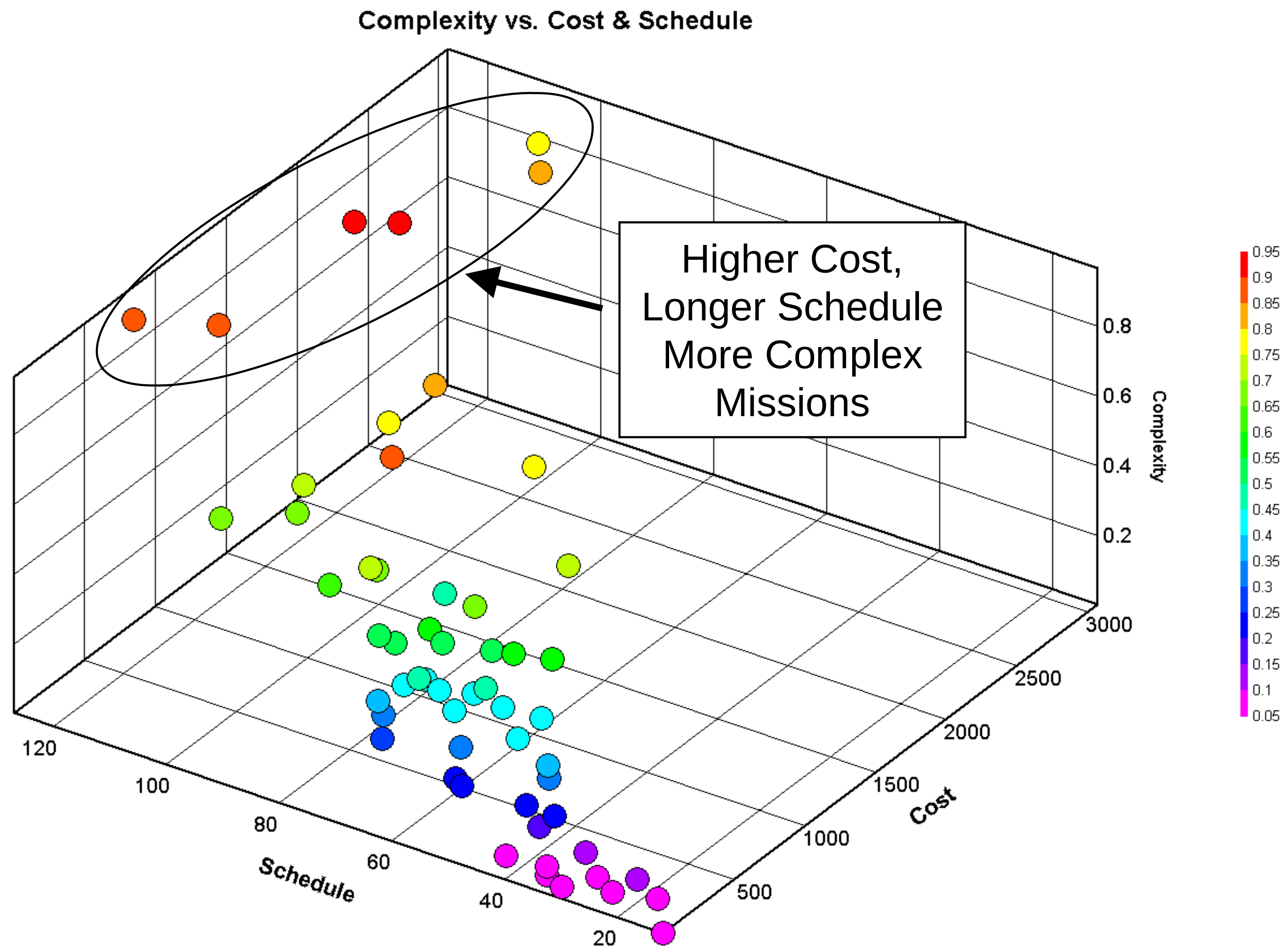
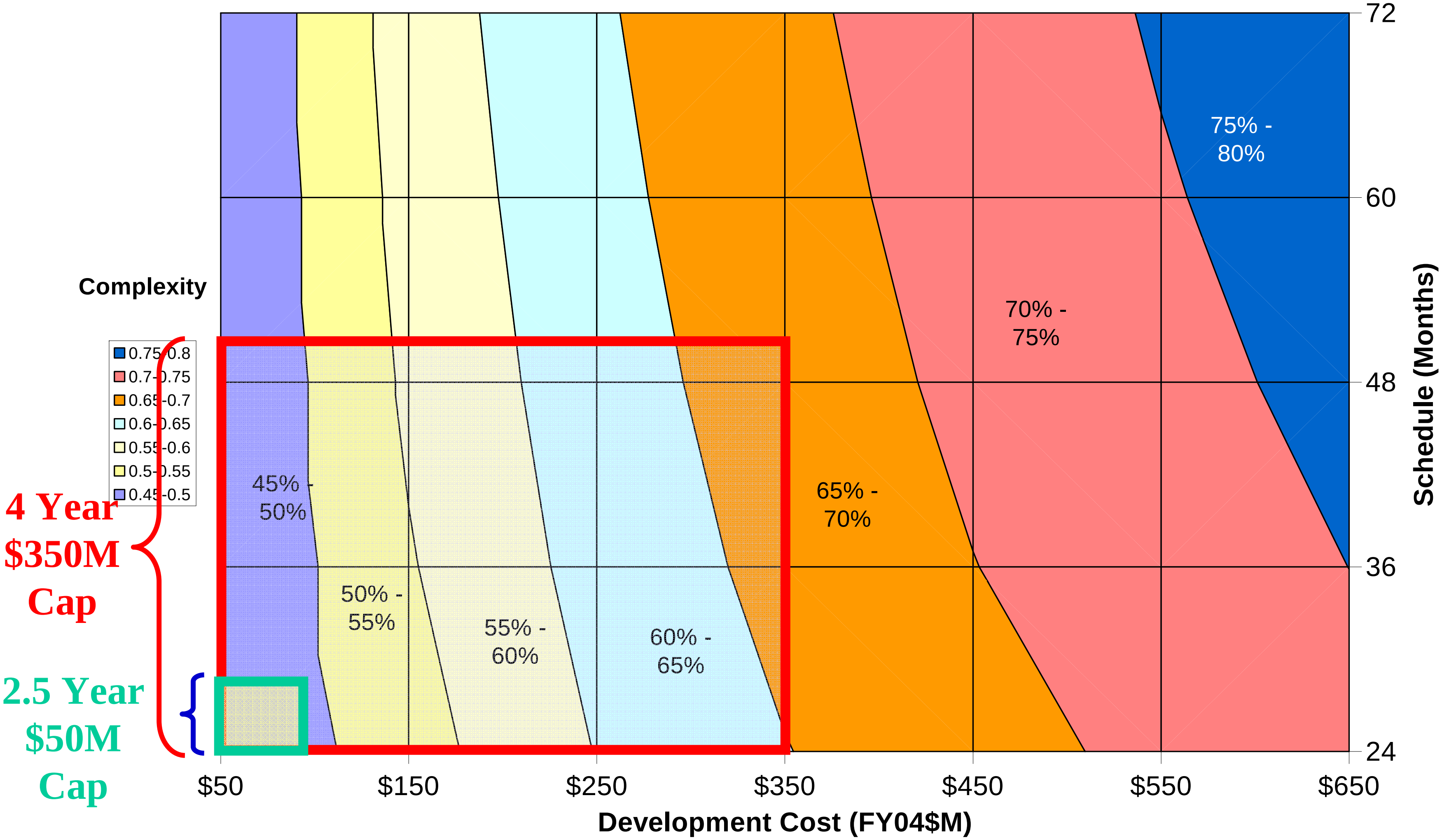
3-D Trade Space – Intuitive Result: Missions that have the greatest complexity, are highest cost and longest development*



* "A Quantitative Assessment of Complexity, Cost, And Schedule: Achieving A Balanced Approach For Program Success", Bitten R.E., Bearden D.A., Emmons D.L.

Complexity Bands vs. Cost and Schedule Help Proposers Define Scope of Mission to Fit Fixed Cost & Schedule*



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NASA's Report Card Following Mars '98 Failures

- Complexity of Failed Missions High in Both Catagories!
- Planetary Missions are "Fastest"
  - But fail more often than earth-orbiters
- NASA Earth-Orbiting Missions are "Cheapest"
  - But longer to develop than planetary
- Overall Success Record is About 3 out of 4 !

AW&ST 12 June 2000

SPACE TECHNOLOGY

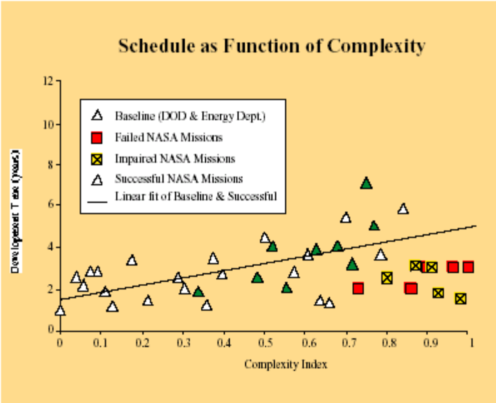
Aerospace Corp. Study Shows Limits of Faster-Better-Cheaper

MICHAEL A. DORNHEIM/LOS ANGELES

Failure of NASA's faster-better-cheaper (FBC) spacecraft may be predictable, according to an Aerospace Corp. examination of the last decade of FBC missions. Missions that crossed into an area of high complexity and low development time inevitably failed, the study found.

"When Is a Mission Too Fast and Too Cheap?" was the subtitle of the study, called "A Complexity-Based Risk Assessment of Low-Cost Planetary Missions," by David A. Bearden, director for Jet Propulsion Laboratory programs at The Aerospace Corp. (TAC). The Air Force think tank's work is the first and only quantitative examination of NASA's FBC successes and failures. NASA itself has not made such an examination, though the agency in mid-July commissioned an assessment of FBC best-practices by former Jet Propulsion Laboratory manager Anthony J. Spear, which was more anecdotal (**AW&ST** Mar. 20, p. 37).

"When do performance and technolo-



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	NASA Planetary	NASA Earth Orbiting	All NASA
Average Complexity of Failed/Impaired Missions	94%	91%	93%
Average Complexity of Successful Missions	70%	55%	58%
Overall Average Complexity	82%	60%	67%
Success Ratio: "Better"	50%	86%	74%
Average Development Time: "Faster" (mos)	41	46	44
Total Spacecraft Cost: "Cheaper" ($M)	132	75	98

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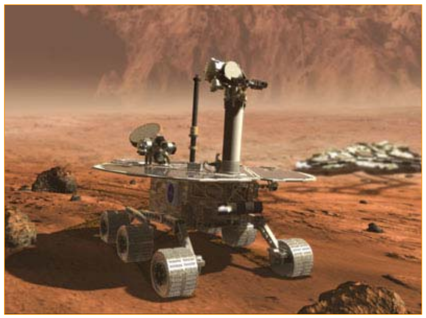
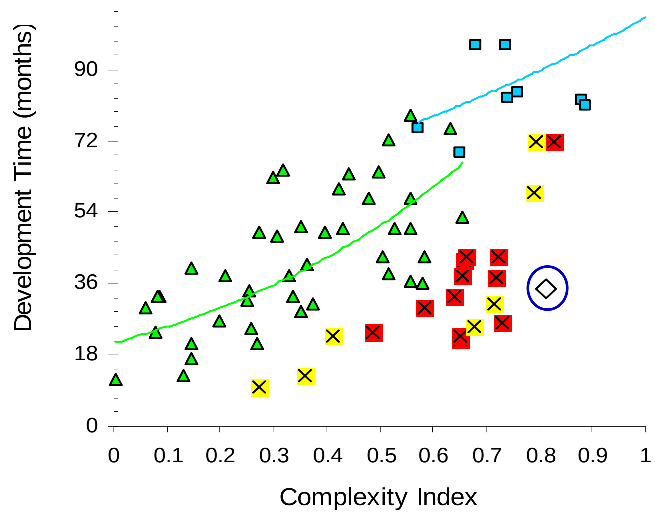
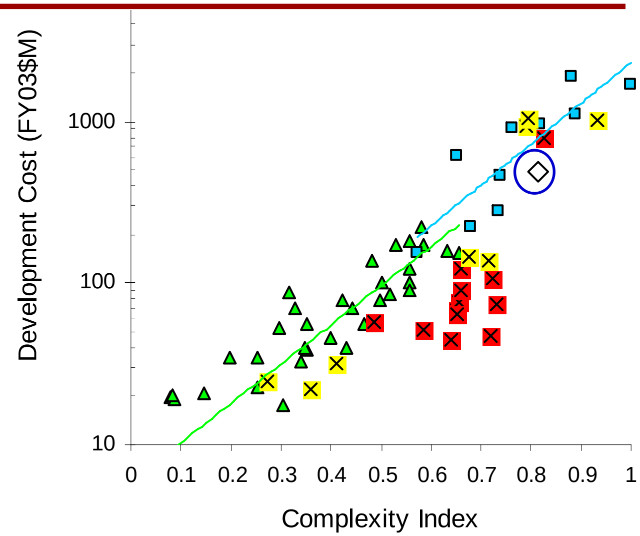
For a project that has fixed requirements and schedule, the inevitable outcome is that cost will grow if developmental problems occur







- Case Study: Mars Exploration Rover (MER)
  - 90-day surface lifetime; ~9-mos cruise
  - Launch Mass: 1050 kg (Delta II)
  - Mobile platform: 1000-m range
- Assessment found that:
  - 33-month development appeared inadequate
  - “Open Checkbook” and heritage offset shortfall
- Mitigations:
  - Focused on rapidly deploying staff to front load schedule (dual/triple shifts)
  - Developed extra hardware test-beds
- Cost grew from $299M to $420M

Can $$$ Buy Time?

Complex rovers were developed in a dangerously short period

MICHAEL A. DORNHEIM/PASADENA, CALIF.

AW&ST, 26 May 2003

The Mars Exploration Rovers are complex spacecraft developed under a tight schedule, a classic recipe for disaster. NASA is fully aware of this and unlike the agency's prior "Faster, Better, Cheaper" philosophy, is now willing to throw money at the problem. Today's tune might be called "Faster, Better" but not "Cheaper."

The shortage of time is apparent in a comparison made by The Aerospace Corp. This technique was reported by Aviation Week & Space Technology in 2000 and has been updated to include Mars Exploration Rovers (MERs) and other programs (AW&ST June 12, 2000, p. 47). The method assigns MER a Complexity Index of 0.81, on a scale where 1.0 is the most complex space-

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Example: Substantial Differences Exist between STEREO Science Definition Team (SDT) and Final Implemented Configuration*

	STEREO SDT	STEREO Final
Programmatics		
Schedule (months)	40	70
Launch Vehicle	Taurus	Delta II
Technical		
Mass (kg)		
Satellite (wet)	211	612
Spacecraft (dry)	134	414
Payload	69	133
Power (W)		
Satellite (Orbit Average)	152	515
Payload (Orbit Average)	58	108
Other		
Transponder Power (W)	20	60
Downlink Data Rate (kbps)	150	720
Data Storage (Gb)	1	8

SDT Configuration

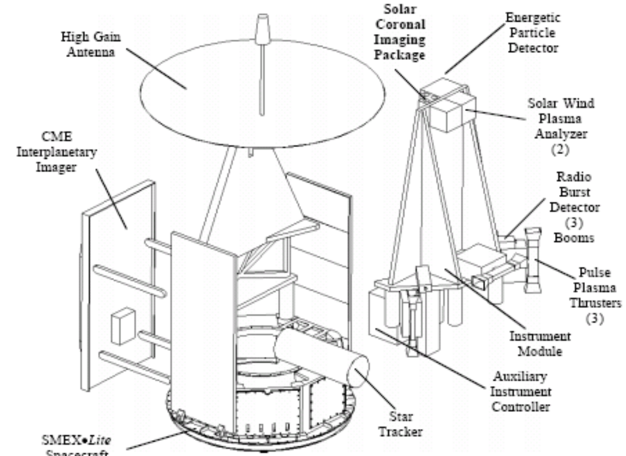
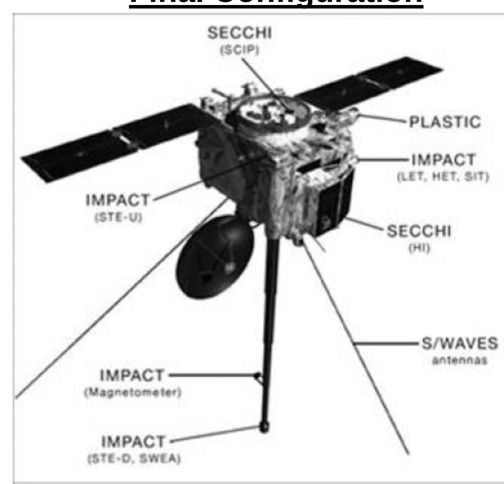


Figure 10. STEREO Configuration Details

Final Configuration



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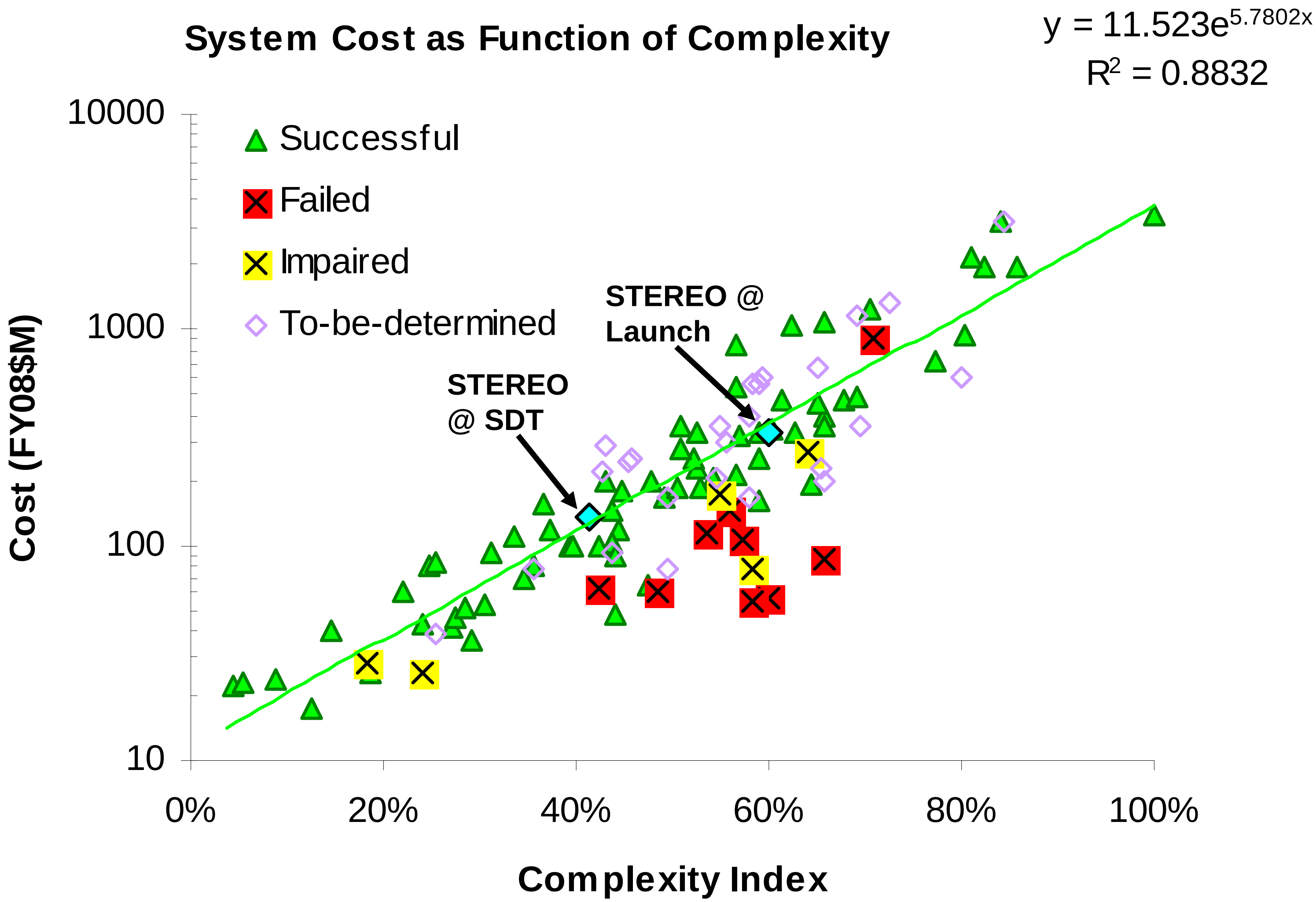
Effect of Increased Complexity on Flight System Cost: STEREO Complexity Increased from 40% to 60%*



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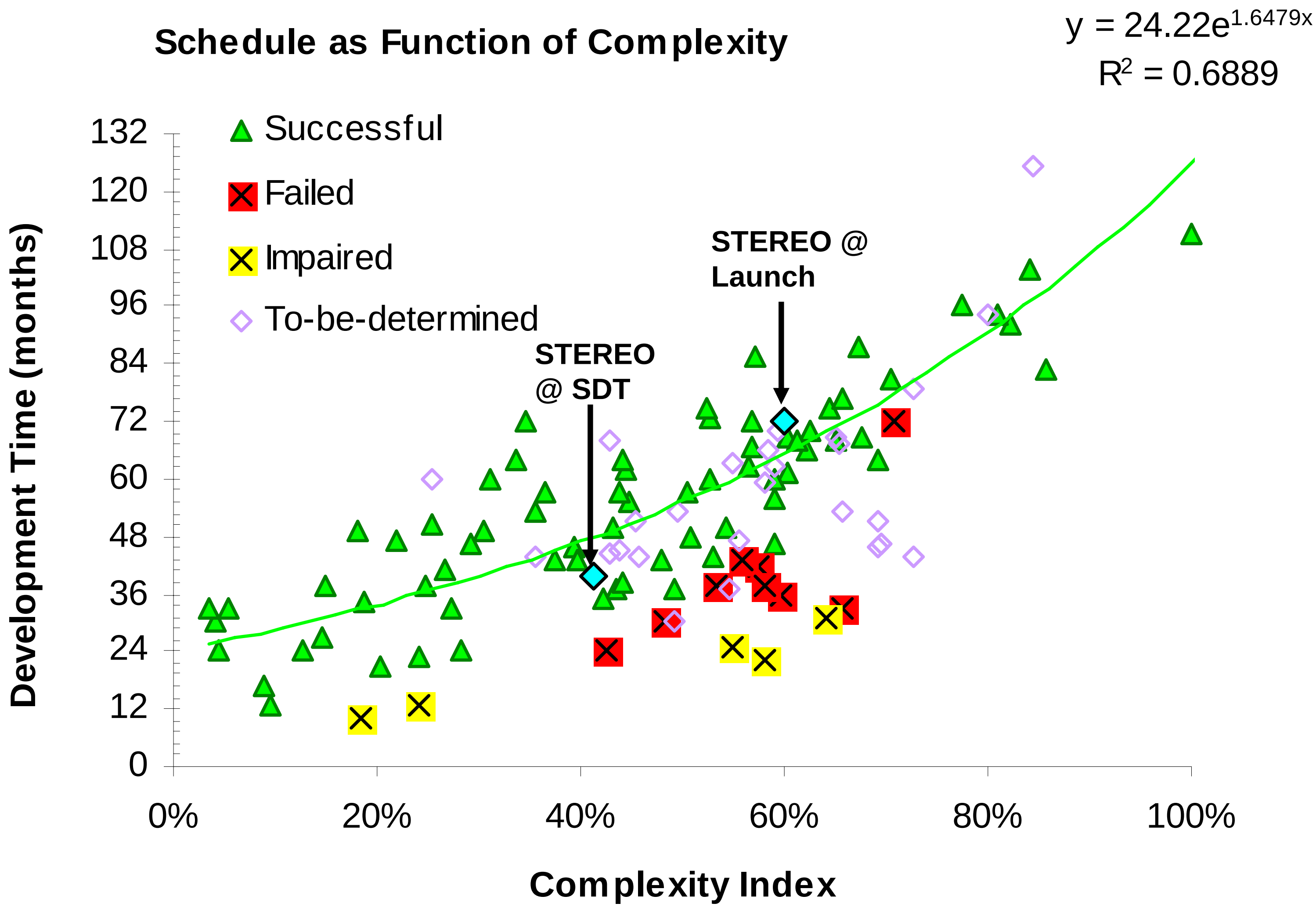
Effect of Increased Complexity on Development Time: STEREO Complexity Increased from 40% to 60%*



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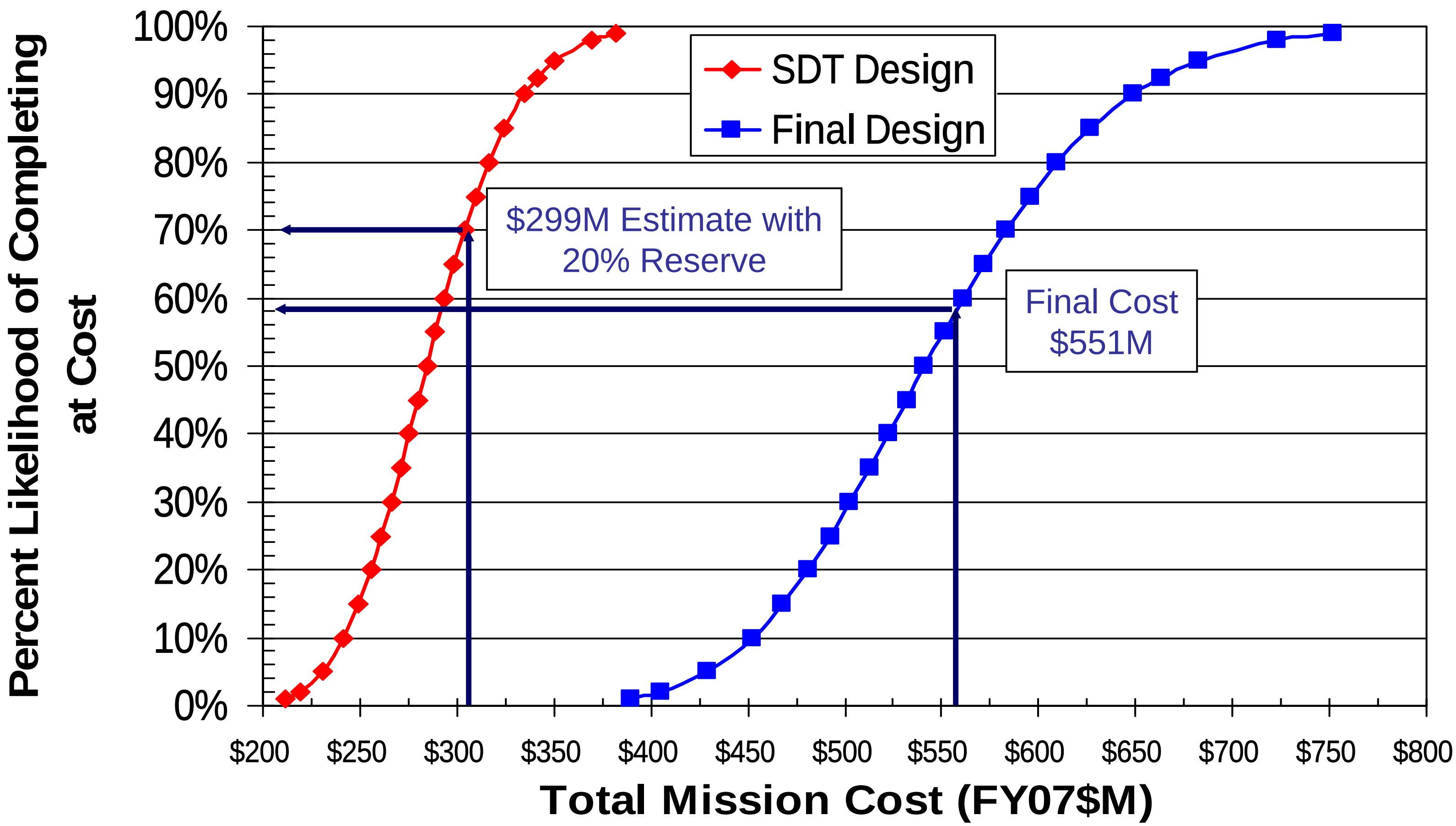
Typical Cost-risk Analyses Won't Capture Large Changes During Concept Evolution*



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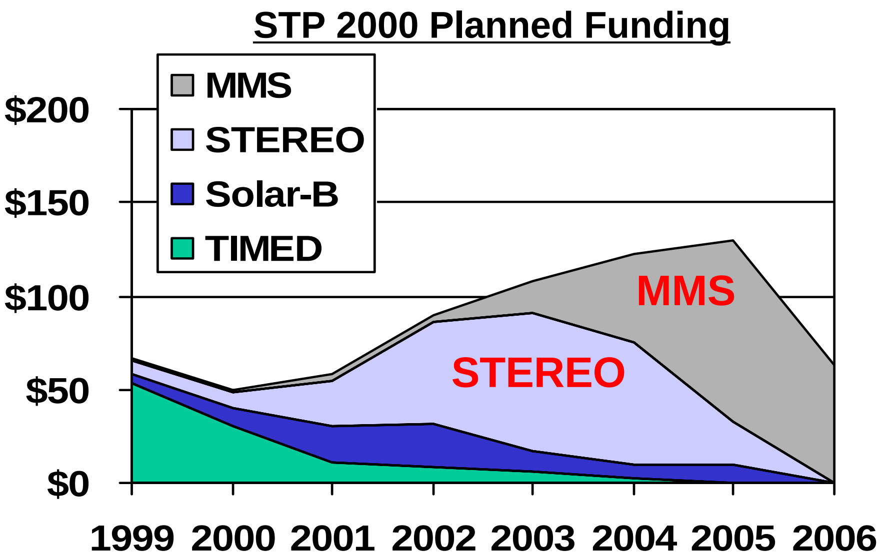
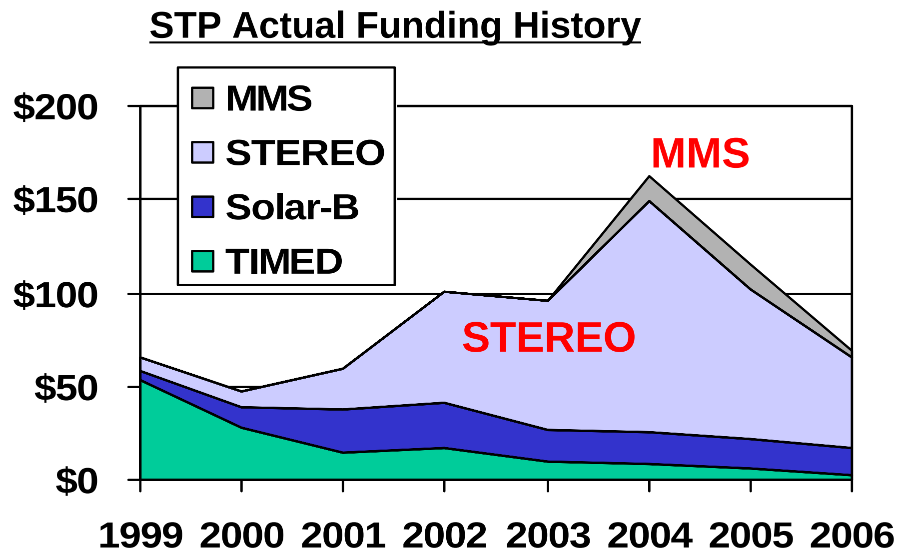
Inadequate Budget Planning for One Project Results in a Domino Effect for Other Projects in the Program Portfolio





Total Program Funding 1999-2006
- Planned = $689M
- Actual = $715M

Although the total program funding remained essentially the same over this time period, implementation of successive missions (e.g. MMS) was substantially affected

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Summary

- Methods exist to estimate cost and schedule at the conceptual phase albeit with some level of uncertainty
- The greatest growth manifests itself late in project during Integration & Test
- Data highlighted that the primary reason for cost and schedule growth is internal project technical and development issues often associated with instruments
- Initial project estimates may be unreliable due to design and technology immaturity and inherent optimism
- Success dependence on system complexity and adequacy of resources observed with identification of a “no-fly zone”
- Better technical and programmatic appraisal early in lifecycle is needed along with independent assessment of design and programmatic assumptions

References and Further Reading

1) Bearden, David A., “A Complexity-based Risk Assessment of Low-Cost Planetary Missions: When is a Mission Too Fast and Too Cheap?”, Fourth IAA International Conference on Low-Cost Planetary Missions, JHU/APL, Laurel, MD, 2-5 May, 2000.
2) Dornheim, Michael, "Aerospace Corp. Study Shows Limits of Faster-Better-Cheaper", *Aviation Week and Space Technology*, 12 June 2000.
3) Bearden, David A., "Small Satellite Costs", *Crosslink Magazine*, The Aerospace Corporation, Winter 2000-2001.
4) Dornheim, Michael, “Can $$$ Buy Time?", *Aviation Week and Space Technology*, 26 May 2003.
5) Bitten R.E., Bearden D.A., Lao N.Y. and Park, T.H., “The Effect of Schedule Constraints on the Success of Planetary Missions”, Fifth IAA International Conference on Low-Cost Planetary Missions, 24 September 2003.
6) Bearden, D.A., “Perspectives on NASA Robotic Mission Success with a Cost and Schedule-constrained Environment”, Aerospace Risk Symposium, Manhattan Beach, CA, August 2005
7) Bitten R.E., Bearden D.A., Emmons D.L., “A Quantitative Assessment of Complexity, Cost, And Schedule: Achieving A Balanced Approach For Program Success”, 6th IAA International Low Cost Planetary Conference, Japan, 11-13 October 2005.
8) Bitten R.E., “Determining When A Mission Is "Outside The Box": Guidelines For A Cost- Constrained Environment”, 6th IAA International Low Cost Planetary Conference, October 11-13, 2005.
9) Bitten R., Emmons D., Freaner C., “Using Historical NASA Cost and Schedule Growth to Set Future Program and Project Reserve Guidelines”, IEEE Aerospace Conference, Big Sky, Montana, March 3-10, 2007.
10) Emmons D., “A Quantitative Approach to Independent Schedule Estimates of Planetary & Earth-orbiting Missions”, 2008 ISPA-SCEA Joint International Conference, Netherlands, 12-14 May 2008.
11) Freaner C., Bitten R., Bearden D., and Emmons D., “An Assessment of the Inherent Optimism in Early Conceptual Designs and its Effect on Cost and Schedule Growth”, 2008 SSCAG/SCAF/EACE Joint International Conference, Noordwijk, The Netherlands, 15-16 May 2008.

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