Concurrent Engineering of Space Systems

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Overview

- Concurrent Engineering at The Aerospace Corporation
- Complex Product Development
- The Concept Design Center
- Risk Mitigation
- Results of Concurrent Engineering

Concurrent Engineering: A Definition

- **Concurrent Engineering:** "A design team working together to improve efficiencies in product development"
  - Faster development cycles
  - Better quality products
  - Lower total cost

  Sounds like faster, better, cheaper…
  …but there is an unstated assumption here which makes the process work…

- **Example of successful Concurrent Engineering**
  - NASA Apollo 13 Anomaly: from lunar module to lifeboat
    - Time critical integrated design solutions developed within hours

- **Examples that Concurrent Engineering could improve:**
  - Urban planning – avoiding traffic congestion
    - Design, build, and maintain continually evolving network that functions well for all its users – better transport of goods and people, fewer disruptions/delays
  - Emergency response – to tsunami, hurricane, earthquake, etc.
    - Pre-planned coordination of relief, recovery, and rebuilding efforts; timely placement of people, equipment, and donated goods

The Aerospace Corporation

- A California nonprofit corporation that operates a Federally Funded Research and Development Center (FFRDC) sponsored by the United States Air Force

- Space Stewardship Accountabilities:
  - Provide highly knowledgeable technical staff, available throughout the engineering development cycle
  - Apply broad technical expertise to assess and solve complex, multidisciplinary technical issues

Dedicated to Space Mission Success
Supports All Phases of Program Acquisition

An Engineering Matrix Organization

Customer

- SYSTEMS PLANNING AND ENGINEERING
- SPACE PROGRAMS
- SPACE SUPPORT
- LAUNCH PROGRAMS
- ELECTRONIC PROGRAMS
- IMAGERY PROGRAMS
- ADVANCED TECHNOLOGY
- PLANNING & COMMUNICATIONS
- CIVIL & COMMERCIAL

ENGINEERING AND TECHNOLOGY GROUP

Electronics and Sensors

- Micro-electronics
- Power Systems
- Sensor Engineering & Exploitation
- Optical Sensors
- Radar Systems

Communications and Networking

- Communication Architectures
- Network Systems
- Communication Systems Engineering
- Spectrum Management
- Digital Communication Implementation
- Communication Electronics
- Antenna Systems

Computers and Software

- Computer Technology
- Information Science
- Software Engineering
- Software Verification
- Software Acquisition
- Ground Systems
- Operations Engineering

Vehicle Systems

- Guidance/ Control
- Real-Time Simulation
- Flight/Fluid Mechanics
- Thermal Control
- Structural/ Dynamics Analysis
- Test and Evaluation
- Risk Management

Systems Engineering

- System Architecture
- Modeling Simulation
- Mission Performance
- Concept Design
- Cost Engineering
- Resource Allocation
- Operability Assessment
- Reliability & Failure Analysis

Laboratory Operations

- Electronics and Photonics
- Mechanics
- Materials
- Space Environment
- Mission Oriented Research
- Special Sensor Fabrication
- Remote Sensing Signatures
- MEMS

A Matrix Organizational Structure Facilitates Concurrent Engineering

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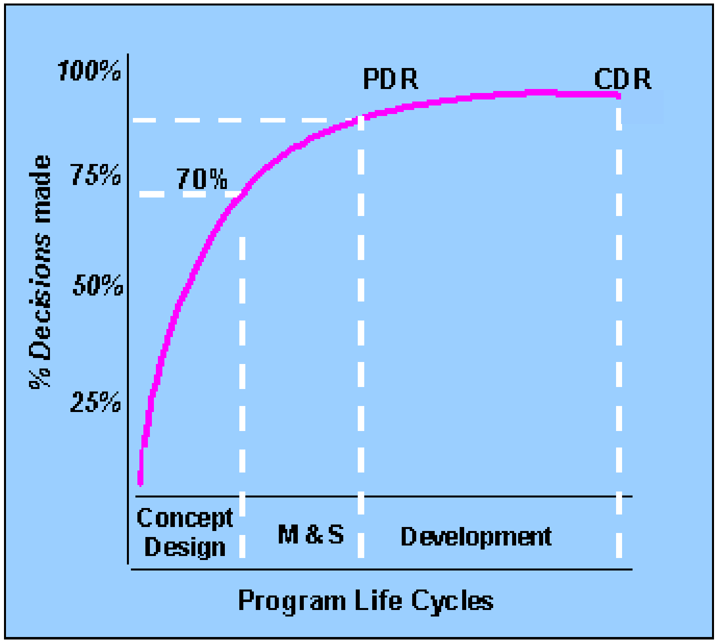
Complex Product Development

- **Space systems are some of the most complex products ever devised**
  - Drive for cutting edge performance
  - Integration of diverse subsystem technologies
  - Need for high quality materials, manufacturing procedures, workforce
  - Long design and procurement cycles
  - Severe consequences of failure
- **Successful products start with good designs**
- **Most projects use some combination of design methodologies**
  - Top down: start with a vision
  - Bottom up: start with some pieces
  - Sequential: develop the pieces, then integrate
  - Concurrent: plan to integrate the pieces
- **Concurrent design, as part of a complete concurrent engineering approach, is vital to success**

Conceptual Design & Program Life Cycle



70% Of All Decisions Affecting Life Cycle Costs Are Made During the Concept Definition Phase[1,2]

Conceptual Design…

- Helps define requirements via performance, risk, & cost trades
- Identifies internal element coupling
- Examines impact of new technologies
- Assesses business cases/models
- Supports RFP generation, source selections, & independent assessments
- Helps determine block upgrade strategies

[1] Wade, D.I. and C.S. Welch. 1996. "Spacecraft Manufacturing Implications for Volume Production Satellites." Paper No. IAF-96-U.4.08, presented at the 47th International Astronautical Congress, Beijing, China.

[2] "The Affordable Acquisition Approach Study (A3 Study), Part II, Final Briefing," Headquarters Air Force Systems Command, Andrews AFB, MD, 1983.

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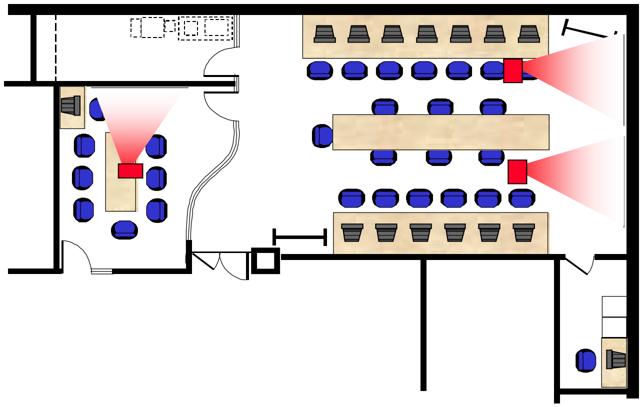
The Concept Design Center (CDC)

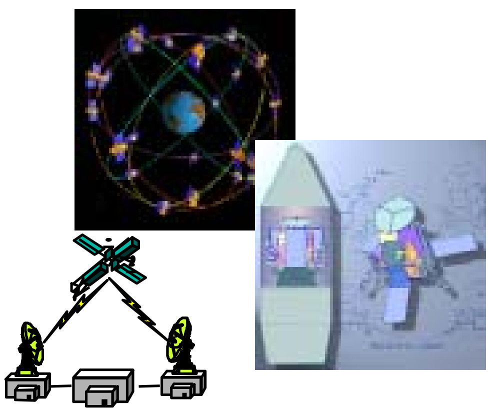
Aerospace's Primary Example of Successful Concurrent Engineering

Teams provide full breadth & depth of required expertise

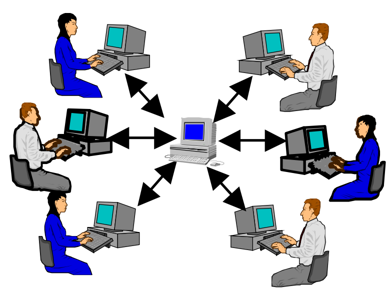
- Experience across many, many space programs
- Can include regional site experts as needed
- 26 avg. years of experience since bachelor degree*



Facilities enable the customer to interact efficiently with a team of experts



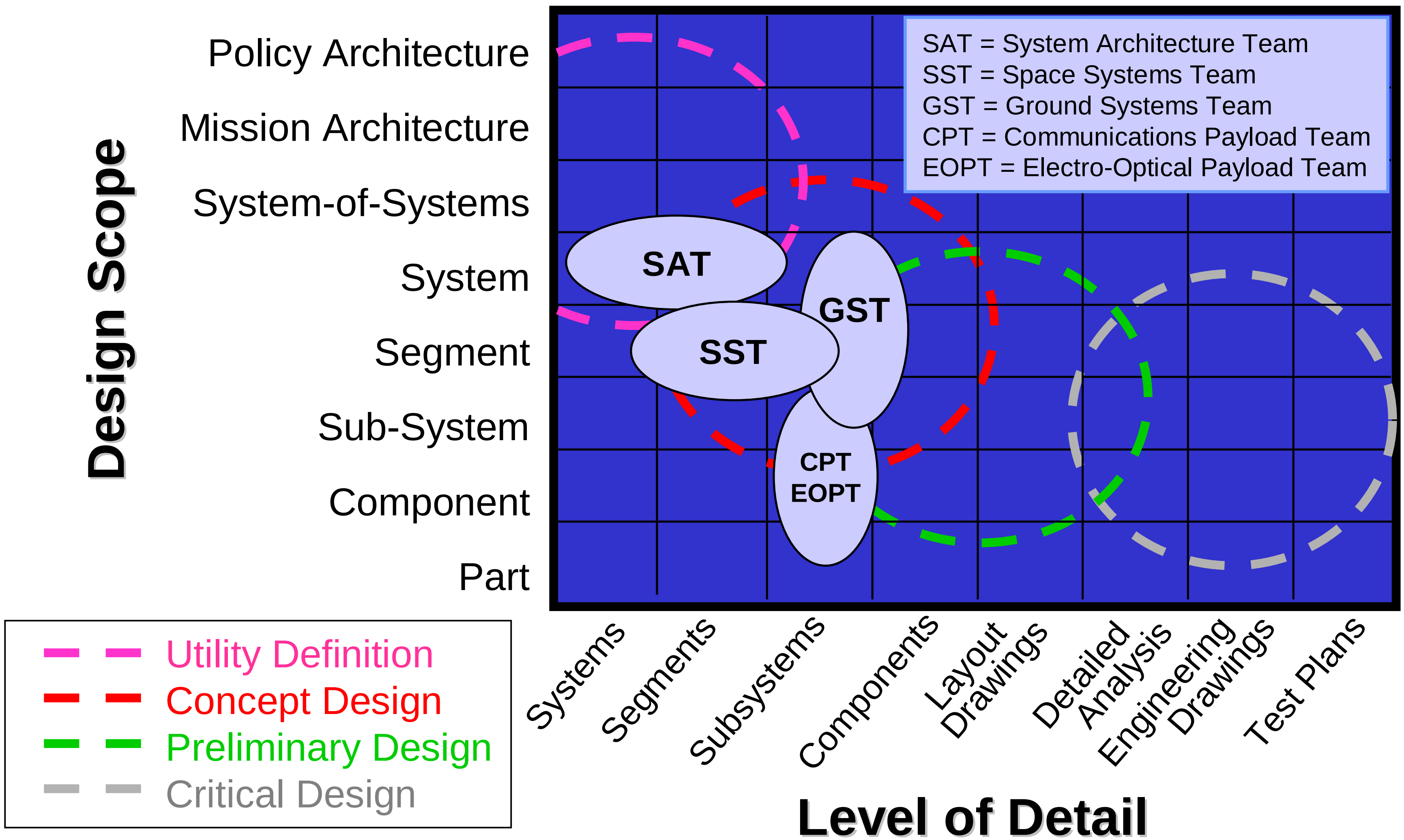
Process integrates team & design tools to produce quality results quickly



Process Results	
Time to perform a study	↓
Cost of a study	↓
Trade space exploration	↑
Consistency	↑

* Based on Aerospace MTS population

CDC Teams vs Design Cycles



CDC teams address transition into preliminary design

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Concept Design Center - Evolution & History

Time	Facility	Tools	Teams (# of Studies)					Studies	Funding Trend	
			SST	SAT	EOPT	GST	CPT	per Year	Customer	Corporate
1990	Ad Hoc	Early CEM								
1991										
1992		Linked CEM								
1993										
1994										
1995										
1996										
1997	CDC Created		6					6		
1998			10	2	2			14		
1999			10	2	1			13		
2000			8	1	0	2		14		
2001	CDC Moved		10	1	1	2		16		
2002			16	3	3	2		24		
2003		IDEA	18	6	2	8		34		
2004			17	1	1	1		20		
2005	CDC Upgraded		25	0	2	3		30		
2006			24	8	0	3	1	36		
2007	From anywhere to anywhere		13	2	0	3	0	19 YTD		
Future										

Early Years: No formal tracking

SST = Space Systems Team
SAT = Space Architecture Team
EOPT = Electro-Optical Payload Team
GST = Ground Systems Team
CPT = Communications Payload Team
CEM = Concurrent Engineering Methodology
IDEA = Integrated Data Exchange Architecture

Investments in Concurrent Design Tools have resulted in greater productivity, lower cost to design

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Types of Success in the CDC

- **Design Validation**
  - CDC design validated contractor design very close to what will fly
- **Requirements Validation**
  - Rapid exploration of configurations provided better insight into system needs; requirements rewritten to be unambiguous and verifiable
- **“Path Pruning”**
  - Killing off unfeasible ideas early, saving program cost that would be needed to explore or develop them
- **Launch Cost Reduction**
  - Careful orbit selection to optimize SV duty cycle and power sizing reduced the initial estimated SV mass, allowing spacecraft to fly on smaller launch vehicle
- **Technical Improvements**
  - Optimized constellations and replenishment strategies to save costs
  - Developed alternate SV transfer orbit designs, increasing available SV mass for payloads or propellant
- **Team Building**
  - Accelerated customer education – early-on, program personnel are still learning about their system-to-be, and will carry early knowledge and decisions with them
  - Sharpen skills for other activities such as source selection or cost estimation

Concurrent design provides customers with timely, integrated, lower risk solutions

The Unstated Assumption: Risk Management

Risk is multidimensional and must also be managed concurrently

- Four variables in project management:
  - Schedule
  - Performance
  - Cost
  - **Risk**
- Need to define risk rigorously and cap it at an acceptable level
- If you cap the other three variables, risk grows

General Methods to Reduce Risk

- Plan out the effort among stakeholders
- Leave time to fail early in the program
- ✓ Nail down requirements
- ✓ Perform scenario planning
- ✓ Ensure technology is or will be available
- ✓ Have margins for schedule, cost, performance, resources
- ✓ Use models, prototypes, and simulations
- Have alternative sources
- Perform non-stakeholder reviews
- Improve production models
- Implement continuous customer feedback cycles

✓ Defined concurrently during Conceptual Design

Concurrent Engineering and Risk Mitigation Strategies

- ✓ **Know what the risks are**
  - Consistent and complete risk identification
- ✓ **Implement executable plans and off-ramps**
  - Early review of risks, and handling plans
  - Preserve margin for unknowns
  - Limit risk exposure
- **Track aggregate risk & keep risk constant or decreasing**
  - Continuous monitoring & review against milestone targets
  - Take off-ramps or modify requirements as necessary
  - Independent reviews of program risk level
  - Actively allocate resources
- **Integrate with other engineering areas**
  - Reliability
  - Safety
  - Parts, Materials and Processes
  - Mated to WBS to show program hot spots

✓ **Risk management strategies are further developed and defined during conceptual design activities**

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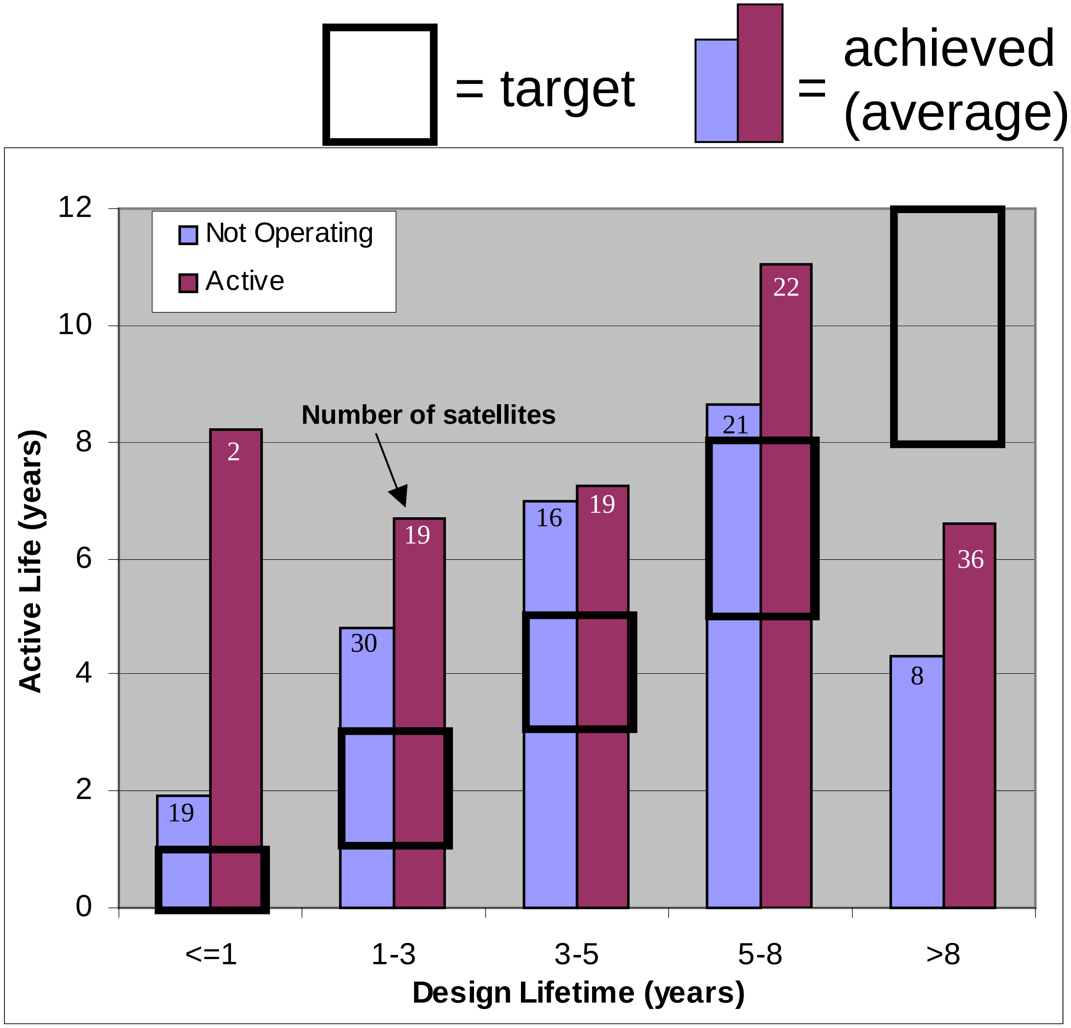
Key Ways Aerospace Manages Risk

- **Develop disciplined mindset early in program development**
  – Aerospace standardized Mission Assurance Framework captures program risk management "To Do's" from historical baselines
  – Include entire Customer/Aerospace/Industry team
  – Significant success demonstrated on EELV program
  – Don't "catch up later"
- **Establish environment that encourages problem reporting**
  – Weekly Watchlist shared across programs, where possible
  – Broad dissemination of Problem/Failure Reports
  – Formal lessons learned management
- **Manage risk at a sufficiently senior level**
  – Lower levels trading mission success for cost and schedule increases risk
  – Perform "What If" scenarios – don't stop at the "obvious" quick fix
- **Government/Industry team manages risk incrementally**
  – Robust mission assurance tailored to program phase
  – Use "buildup" process in design and test to identify and manage risk

Find and fix defects early, by using broadly based teams versed in concurrent methodologies

Results: Actual vs. Design Lifetime

- Analysis of U.S. civil and military satellites
  - 2005 Aerospace internal study
  - Using our Space Systems Engineering Database
- On average, most satellites live well beyond their original design life
- Satellites with >8 year design life launched too recently to accurately assess



Good concurrent engineering practices contribute to enhanced mission success

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Conclusions

- Disciplined, integrated, multidisciplinary approach applied early in life cycle significantly reduces risk
- Concurrent risk management is a critical part of good concurrent engineering practice
- Concurrent engineering facilities, tools, and teams are an investment that pay back in reduced program costs and increased system life

Backup

Selected CDC References

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- **"A Systems Engineering Tool for Small Satellite Design",** A.McInnes, D.Harps, J.Lang, C.Swenson, 15th Annual AIAA/USU Conference on Small Satellites, Logan, Utah, August 13-16, 2001.
- **"Concurrent Design at Aerospace",** P.Smith, A.Dawdy, T.Trafton, R.Novak, S.Presley, Crosslink, Winter 2000/2001.
- **"Scope vs. Detail: The Teams of the Concept Design Center",** J.Aguilar, A.Dawdy, 2000 IEEE Aerospace Conference Proceedings, March 18-25, 2000.
- **"The Aerospace Corporation's Concept Design Center",** J.Aguilar, A.Dawdy, G.Law, Proceedings of the 8th Annual International Symposium of the International Council on Systems Engineering, July 26-30, 1998.