Concurrent Engineering of Space Systems

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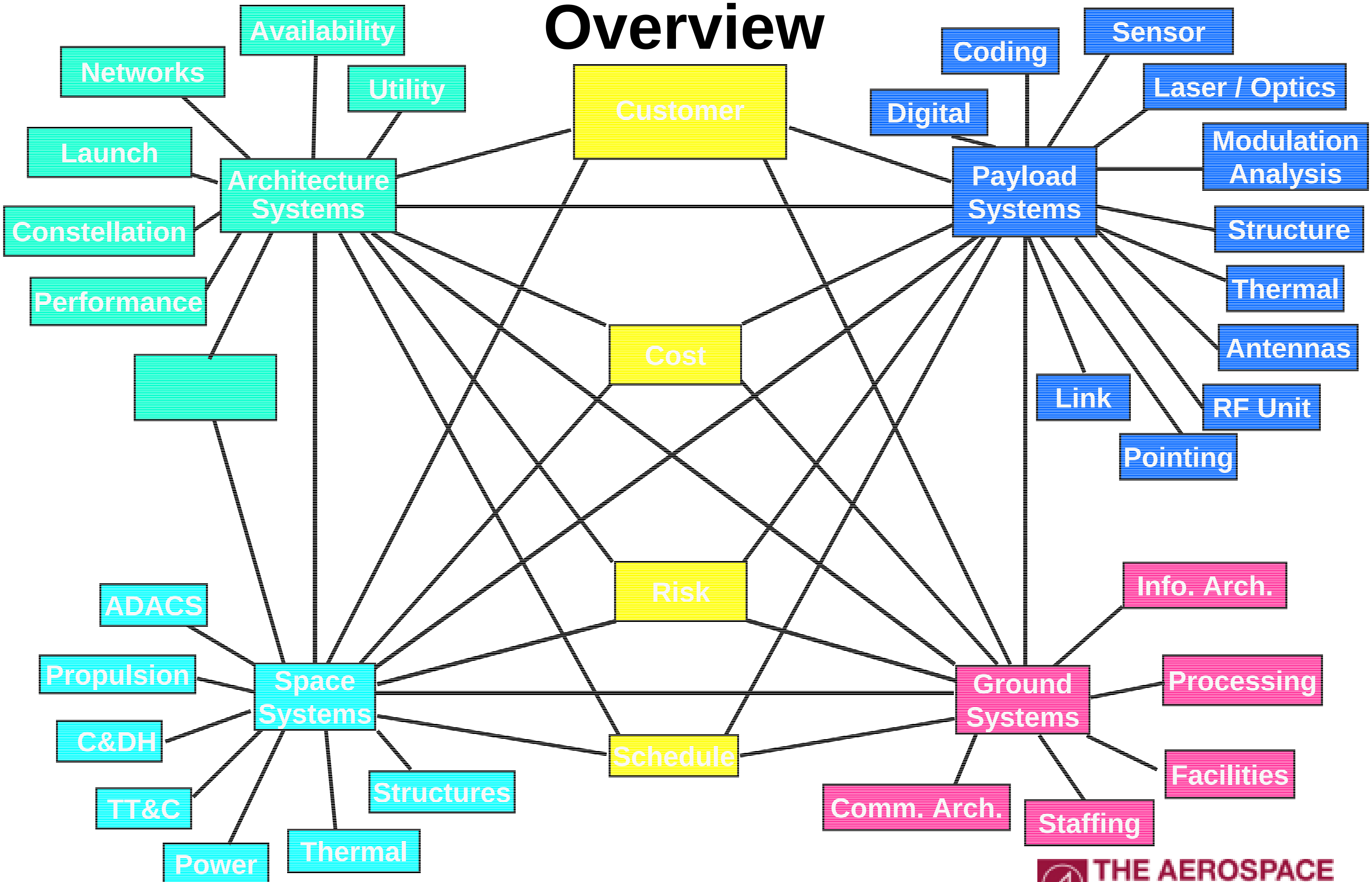
- Concurrent Engineering at The Aerospace Corporation
- Complex Product Development
- The Concept Design Center
- Risk Mitigation
- Results of Concurrent Engineering

Overview



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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

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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	Communications and Networking	Computers and Software	Vehicle Systems	Systems Engineering	Laboratory Operations
Micro-electronics	Communication Architectures	Computer Technology	Guidance/ Control	System Architecture	Electronics and Photonics
Power Systems	Network Systems	Information Science	Real-Time Simulation	Modeling Simulation	Mechanics
Sensor Engineering & Exploitation	Communication Systems Engineering	Software Engineering	Flight/Fluid Mechanics	Mission Performance	Materials
Optical Sensors	Spectrum Management	Software Verification	Thermal Control	Concept Design	Space Environment
Radar Systems	Digital Communication Implementation	Software Acquisition	Structural/ Dynamics Analysis	Cost Engineering	Mission Oriented Research
	Communication Electronics	Ground Systems	Test and Evaluation	Resource Allocation	Special Sensor Fabrication
	Antenna Systems	Operations Engineering	Risk Management	Operability Assessment	Remote Sensing Signatures
				Reliability & Failure Analysis	MEMS

A Matrix Organizational Structure Facilitates Concurrent Engineering

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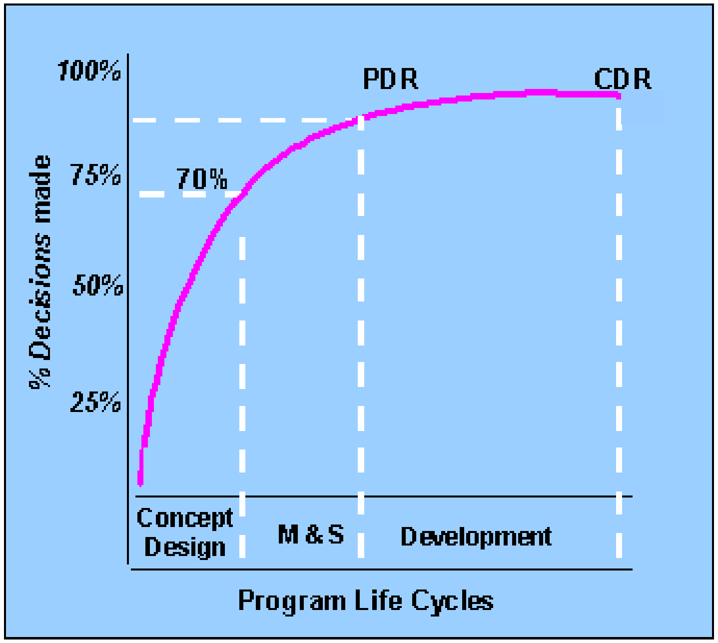
Complex Product Development

- **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]

[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.

Conceptual Design…

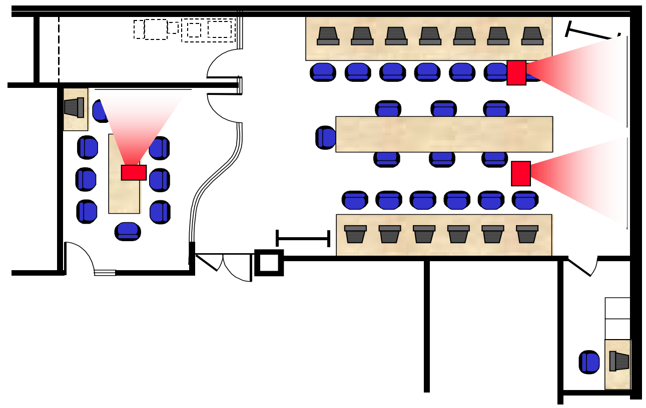
- Helps define requirements via performance, risk, & cost trades
- Identifies internal element coupling
- Examines impact of new technologies
- Assesses business cases/models
- Supports RFP generation, source selections, & independent assessments
- Helps determine block upgrade strategies

The Concept Design Center (CDC)

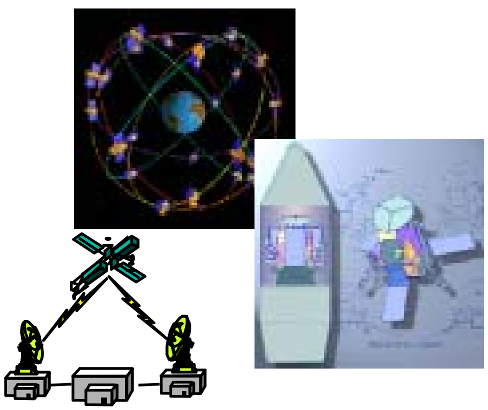
Aerospace's Primary Example of Successful Concurrent Engineering

Teams provide full breadth & depth of required expertise

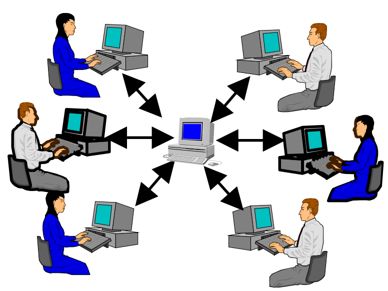
- Experience across many, many space programs
- Can include regional site experts as needed
- 26 avg. years of experience since bachelor degree*



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



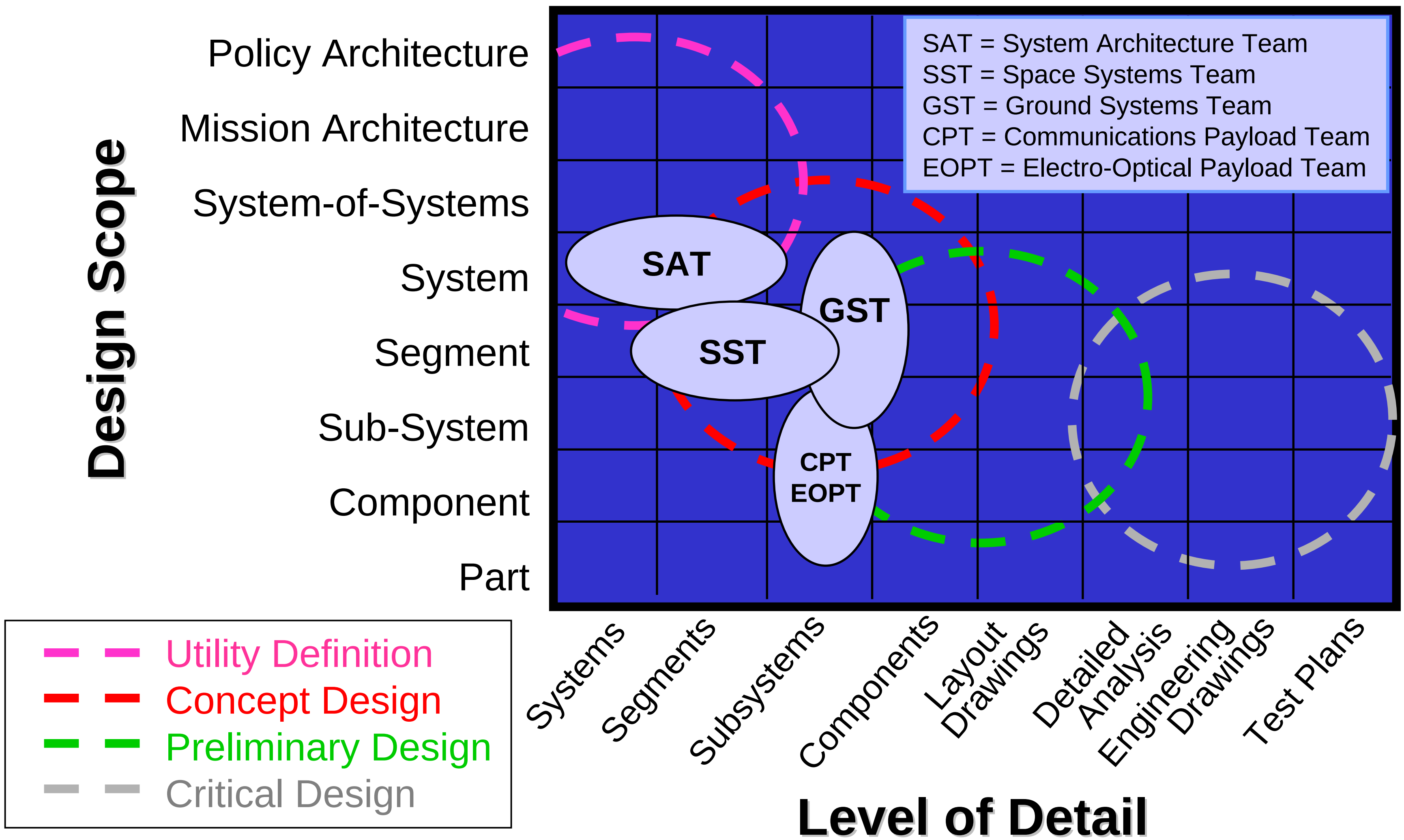
Process integrates team & design tools to produce quality results quickly



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

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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

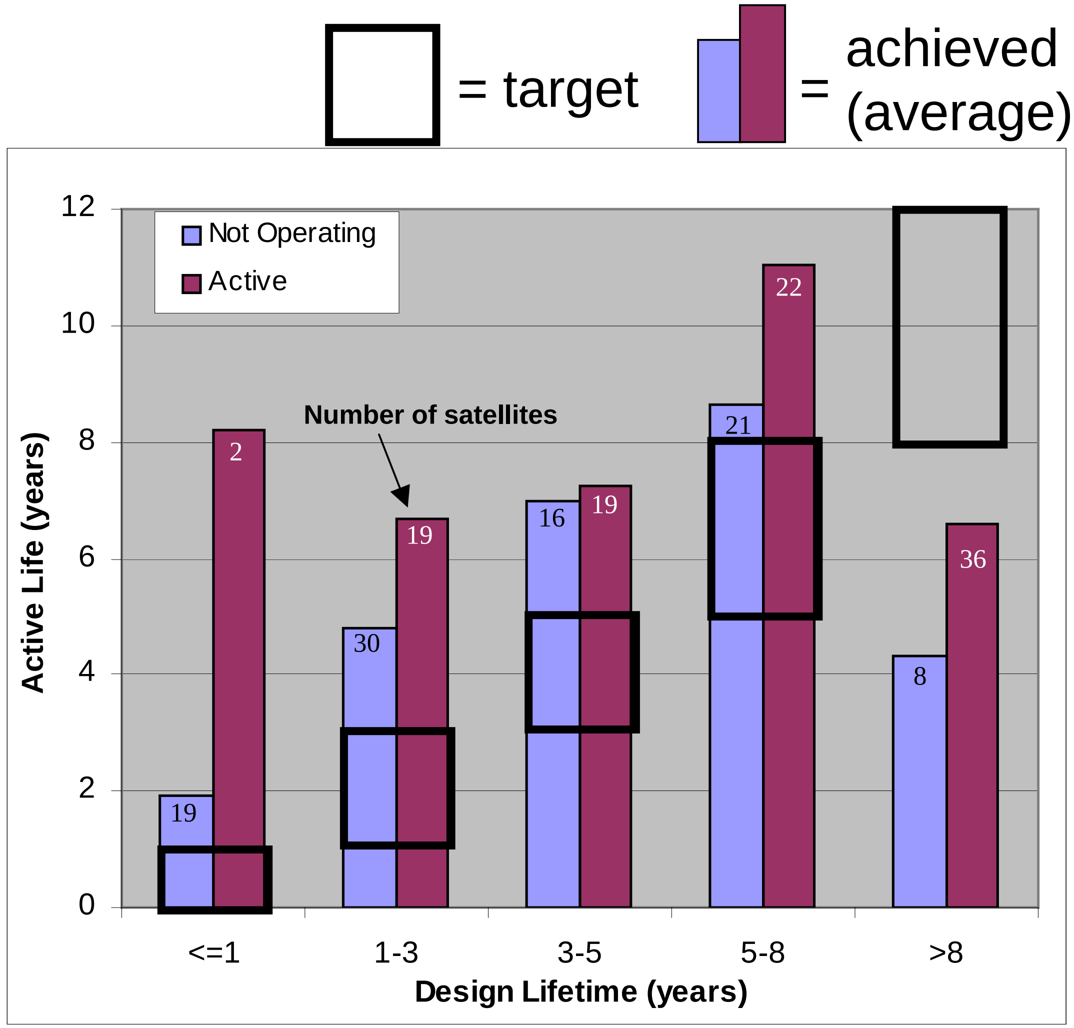
Find and fix defects early, by using broadly based teams versed in concurrent methodologies

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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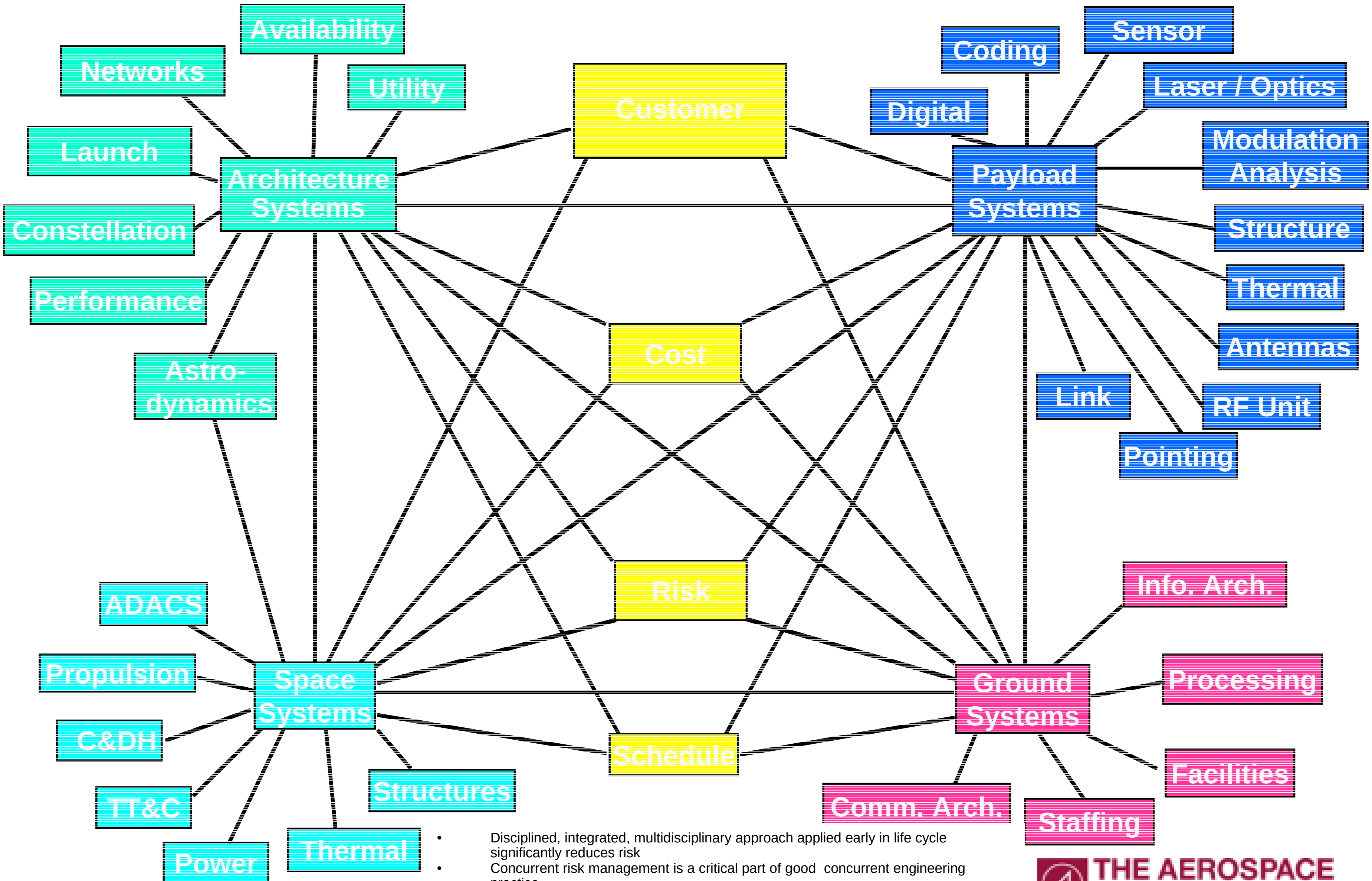
Conclusions



- 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

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Backup

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