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New Methods for Architecture Selection and Conceptual Design:

Space Systems, Policy, and Architecture Research Consortium (SSPARC) Program Overview

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For the LAI Plenary Meeting,

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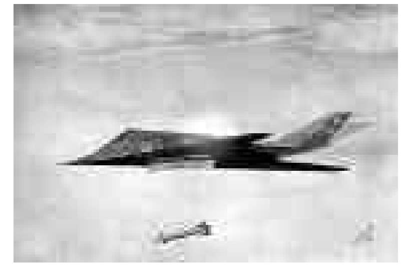
Space Systems, Policy, and Architecture Research Consortium
A joint venture of MIT, Stanford, Caltech & the Naval War College
for the NRO

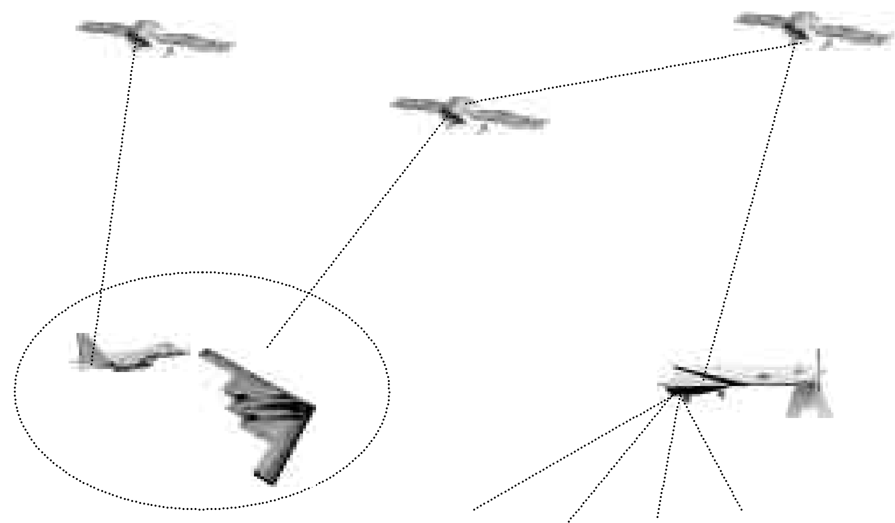
Aerospace Systems are Changing

From a focus on single vehicles to platforms…



To networks of platforms and…

More flexible challenges in their employment



Innovation in the industry is shifting from single vehicles to networks of capability

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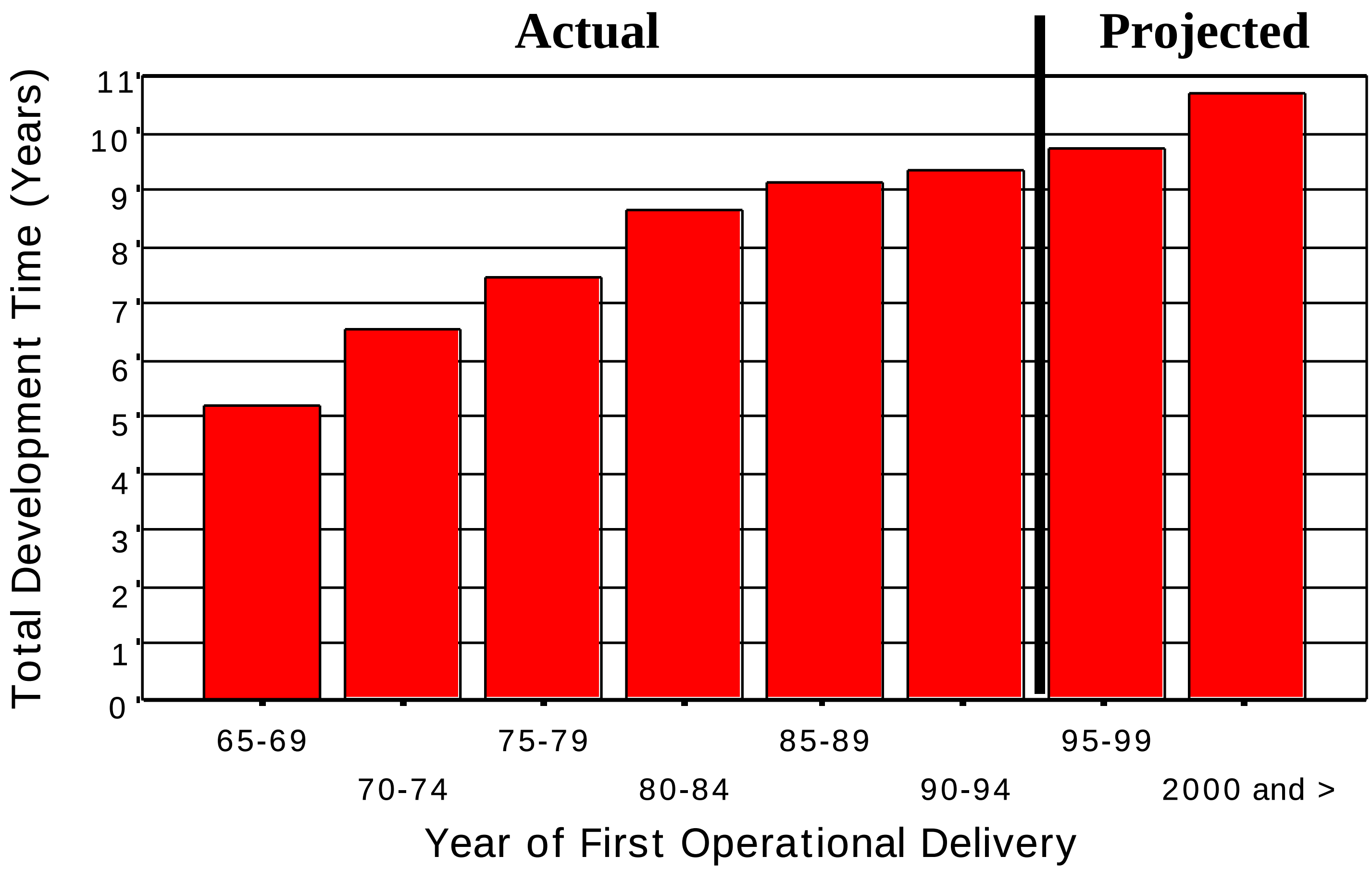
Product Development Time



Innovation, ability to react to change impeded by long lead times

All Major Defense Acquisitions Programs. Milestone 1 to First Operational Delivery Data from RAND Selected Acquisition Report Database. Current as of Dec 1994.

Problem: Current space system design and build practices

Long lead times and poor front-end processes lead to products that do not meet current needs

Flexibility, upgradability lacking

Difficult to evaluate proposed systems *as systems*

Difficult to evaluate new ideas

"Craft" design and manufacturing techniques

SSPARC Approach

- Consortium of MIT, CalTech, Stanford and the Naval Warfare College, working with government and industry
- Three-pronged approach to problem:
  - Develop advanced processes through design projects working on problems of interest to the customer
  - Research on emerging barriers/enablers/opportunities
  - Reduction to practice, diffusion and interaction with US industry

Unique structure for university research program

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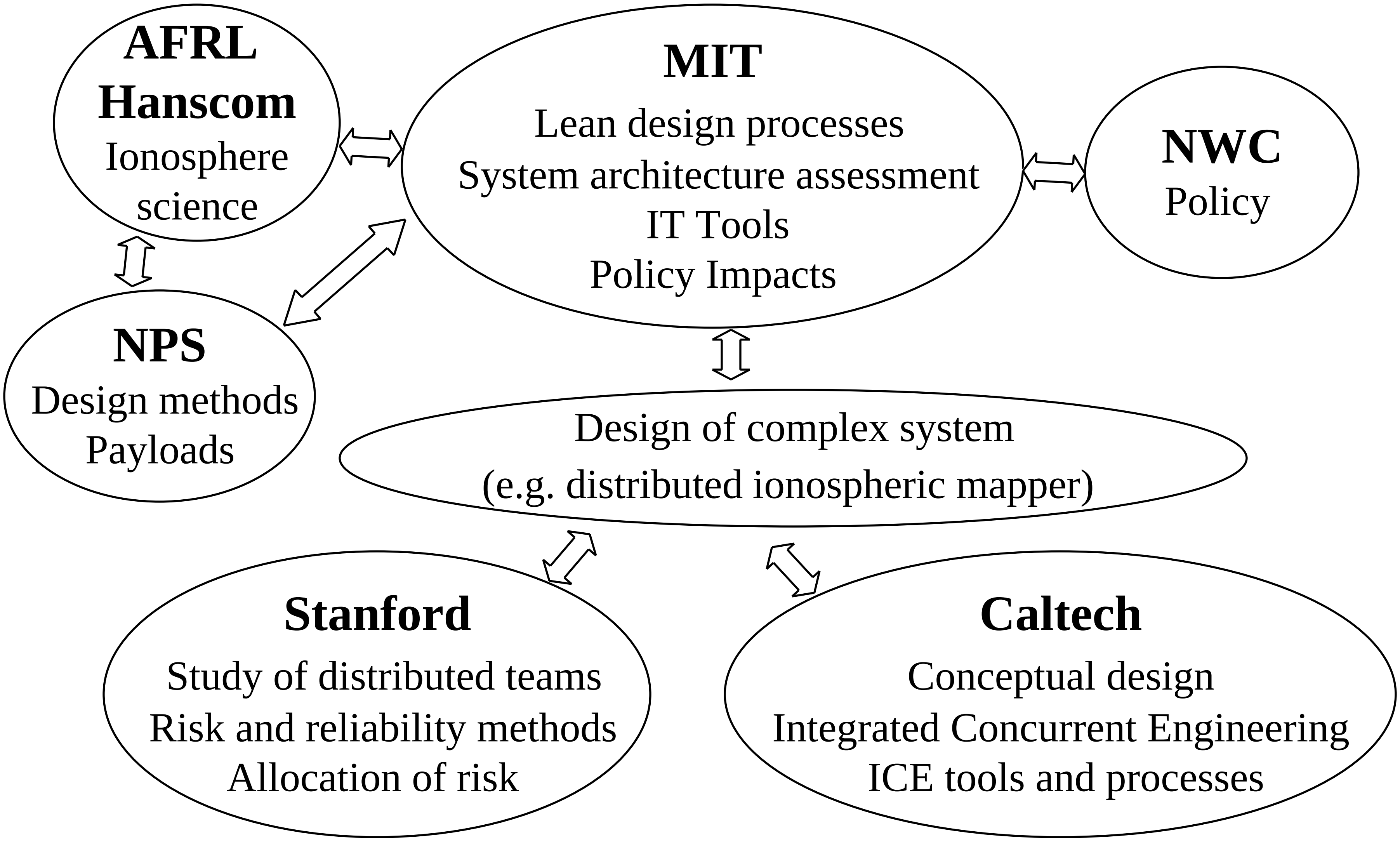
Design Project Collaboration Concept



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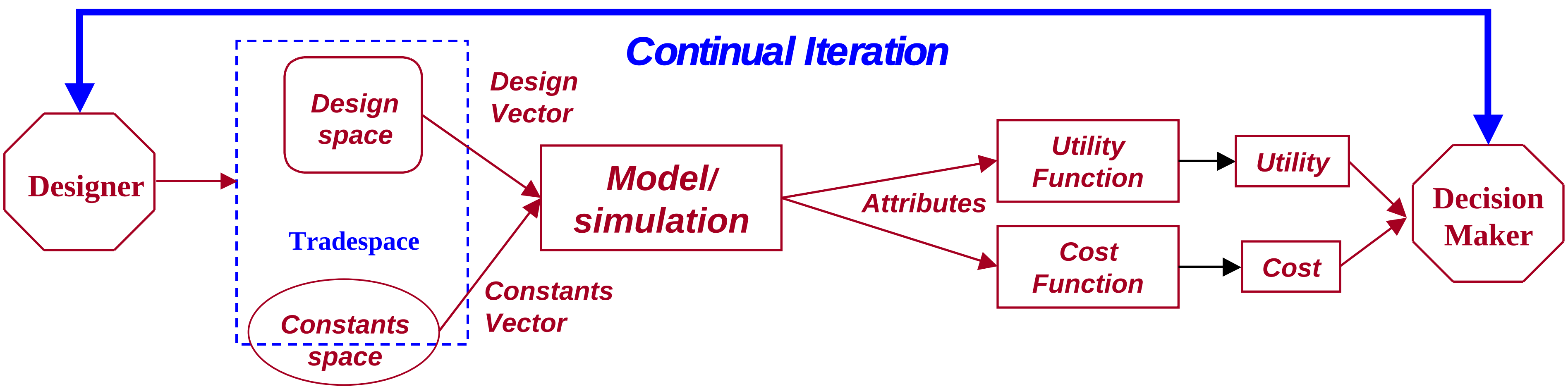
Architecture Study: Multi Attribute Tradespace Exploration (MATE)

- Lean methods and Multi-Attribute Utility (MAU) techniques used to understand and quantify user preferences
- Simulations used to evaluate many (typically thousands) possible architectures in terms of utility and cost
- Result is optimal architecture(s); Multidisciplinary Optimization (MDO) can help find them
- Allows understanding and exploration of design space

MATE Process Notional Flow Diagram



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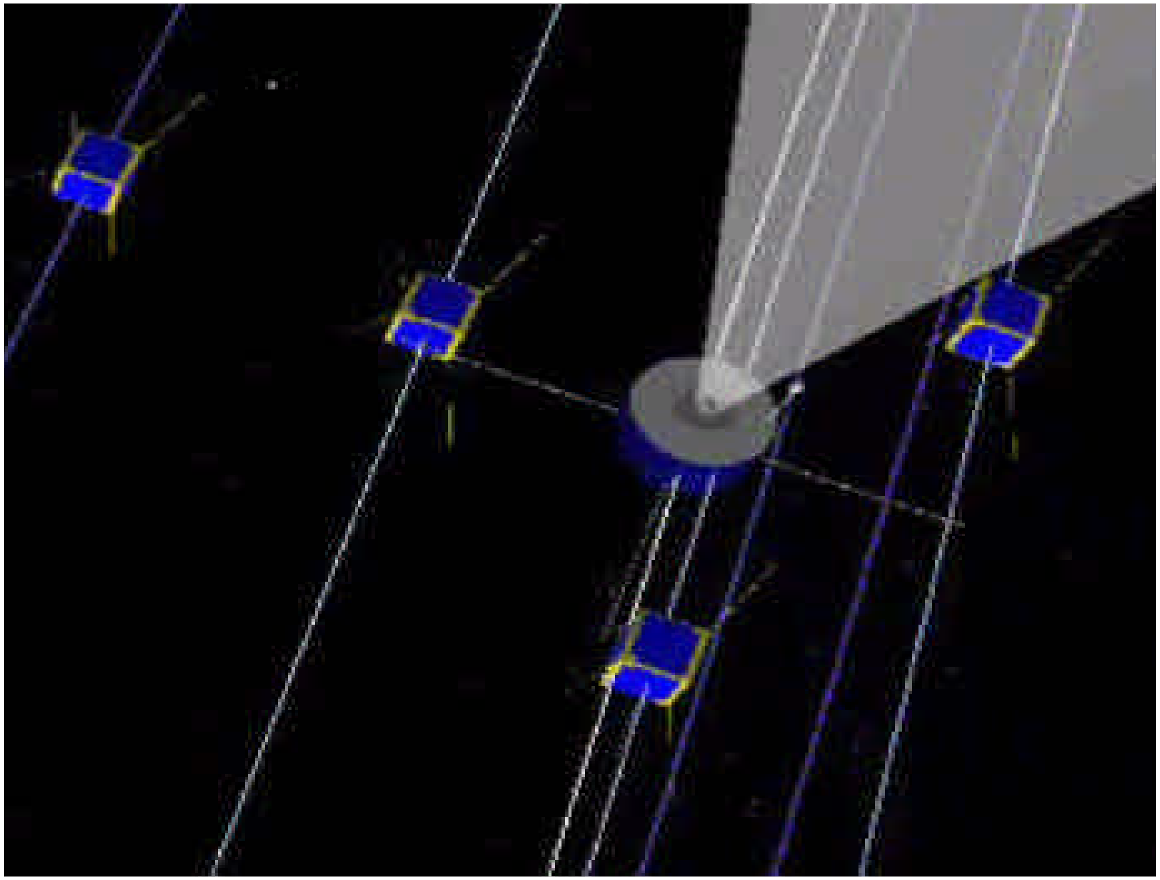
Example Architecture Result



Swarm architecture:

- Group of satellites in nearby orbits that work together to perform a function
- Orbits chosen so that satellites stay close together with minimal ΔV
- Spares for reliability
- Functions distributed between Mother (center) and daughters

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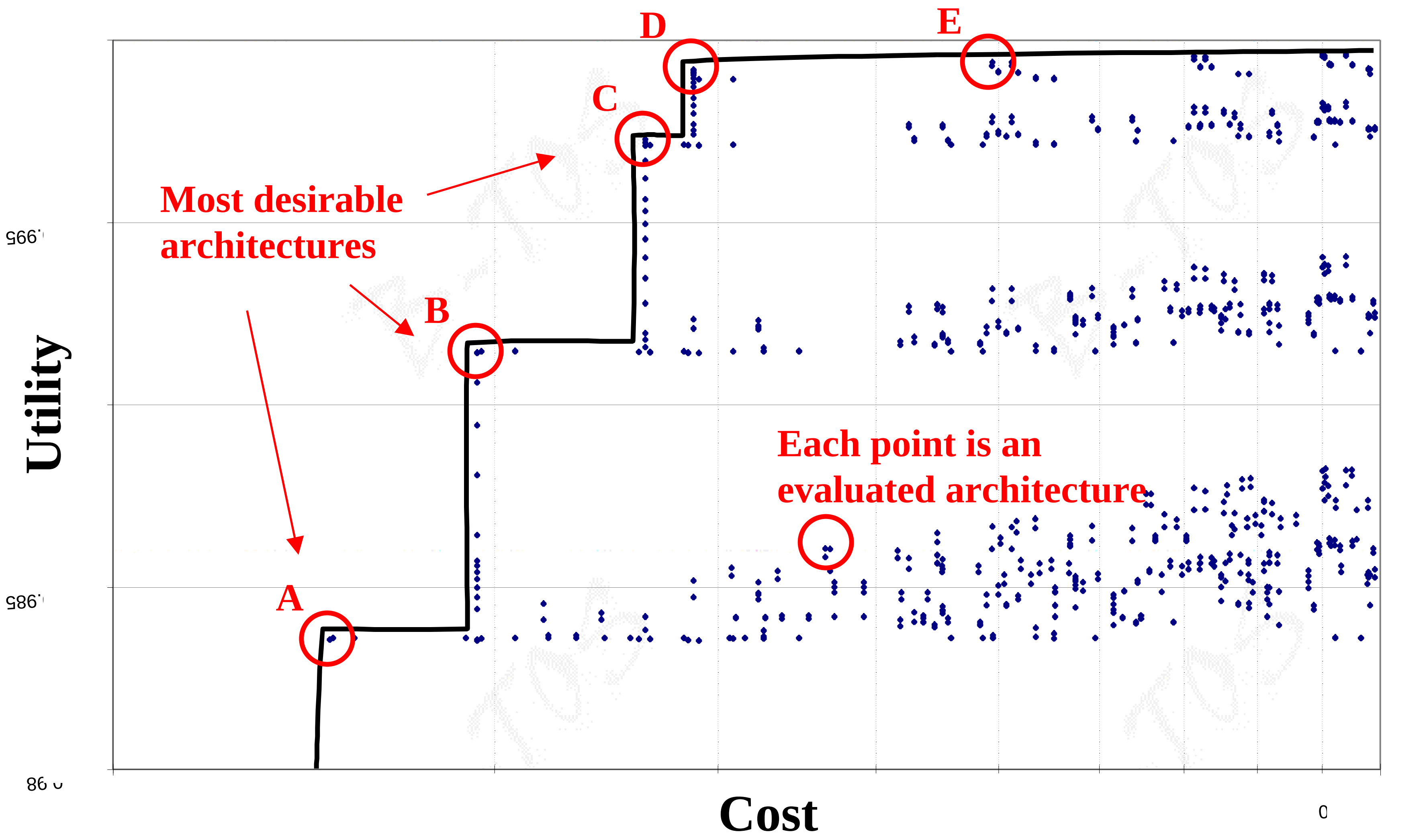
Example Architecture Tradespace



Examine "frontier" architectures in detail

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Architectural trades on the frontier

Architecture	A	B	C	D	E
Swarms/Plane	1	1	1	1	2
Satellites/Swarm	4	7	10	13	13
Swarm Radius (km)	0.18	1.5	8.75	50	50
Spatial Resolution (deg)	4.36	5.25	7.34	9.44	9.44
Revisit Time (min)	805	708	508	352	195
Latency (min)	3.40	3.69	4.36	5.04	5.04
Accuracy (deg)	0.15	0.018	0.0031	0.00054	0.00054
Inst. Global Coverage	0.29%	0.29%	1.15%	2.28%	4.55%
IOC Cost ($M)	90	119	174	191	347
Lifecycle Cost ($M)	148	194	263	287	494

Problem dominated by trade of accuracy vs. size (and cost) of swarm

Terrestrial Planet Finder: Taking Pictures

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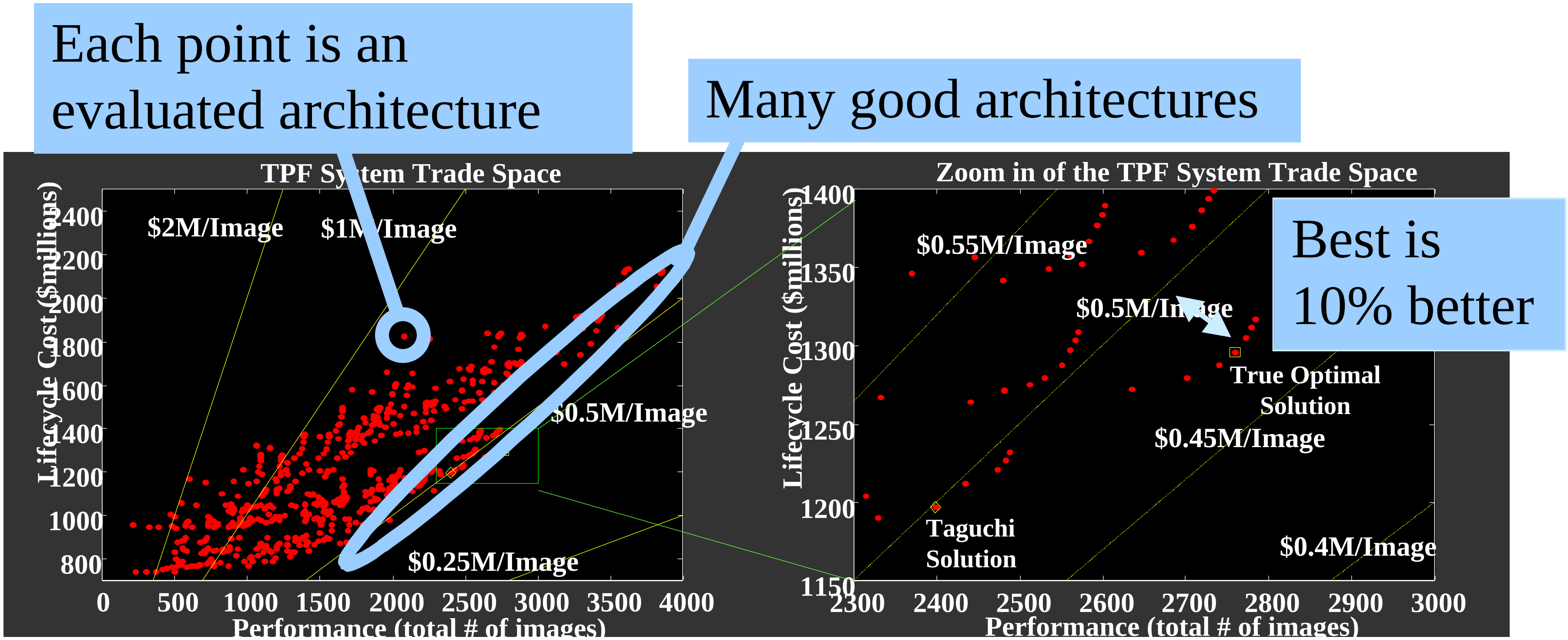
- Tool for mathematically modeling Distributed Satellite Systems as optimization problems: enables efficient search for best families of system architectures (i.e. most cost effective) within global trade space during Conceptual Design Phase
- Note that the $0.5M/Image line is near MANY architectures
- Mission viable: large funding range



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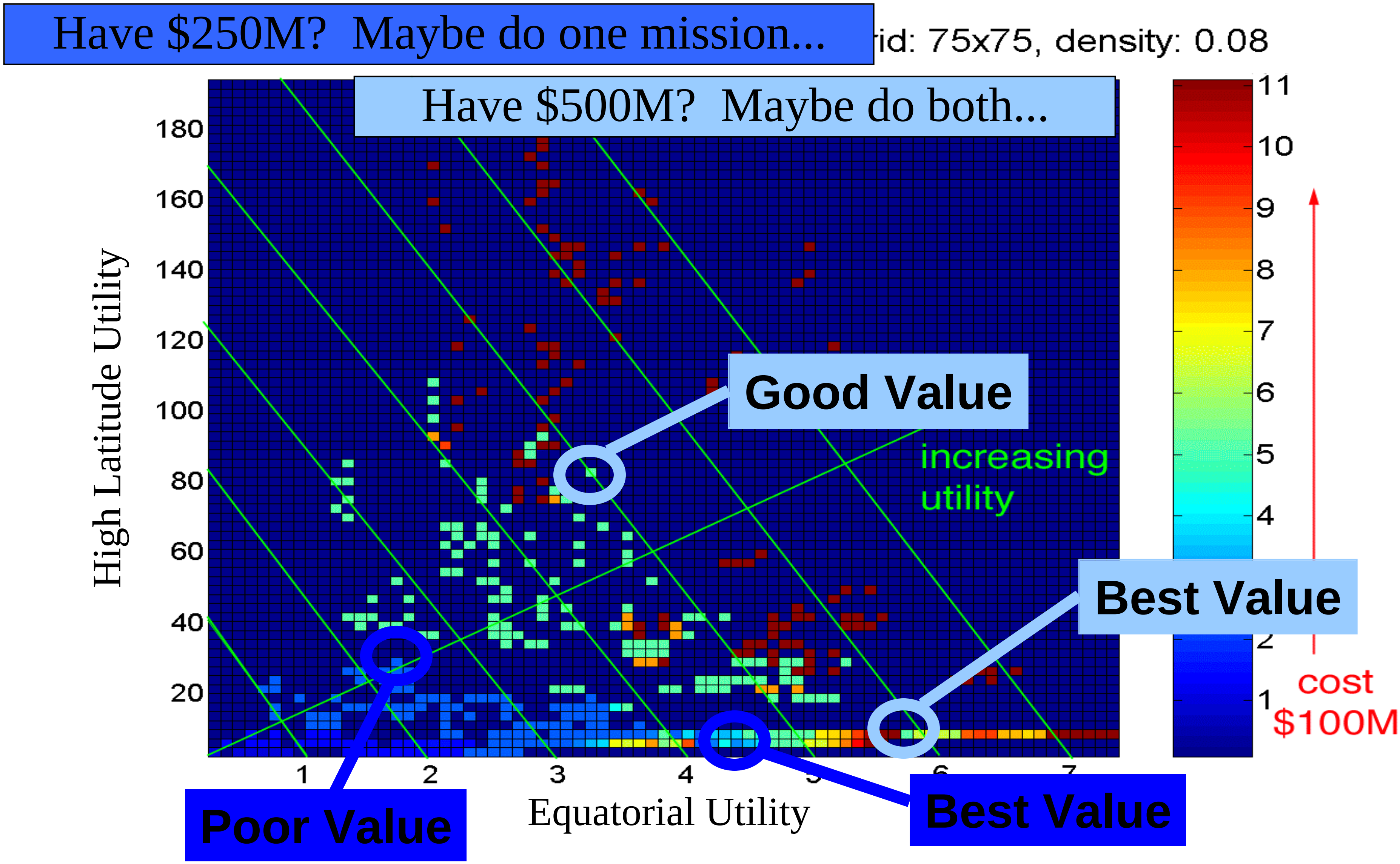
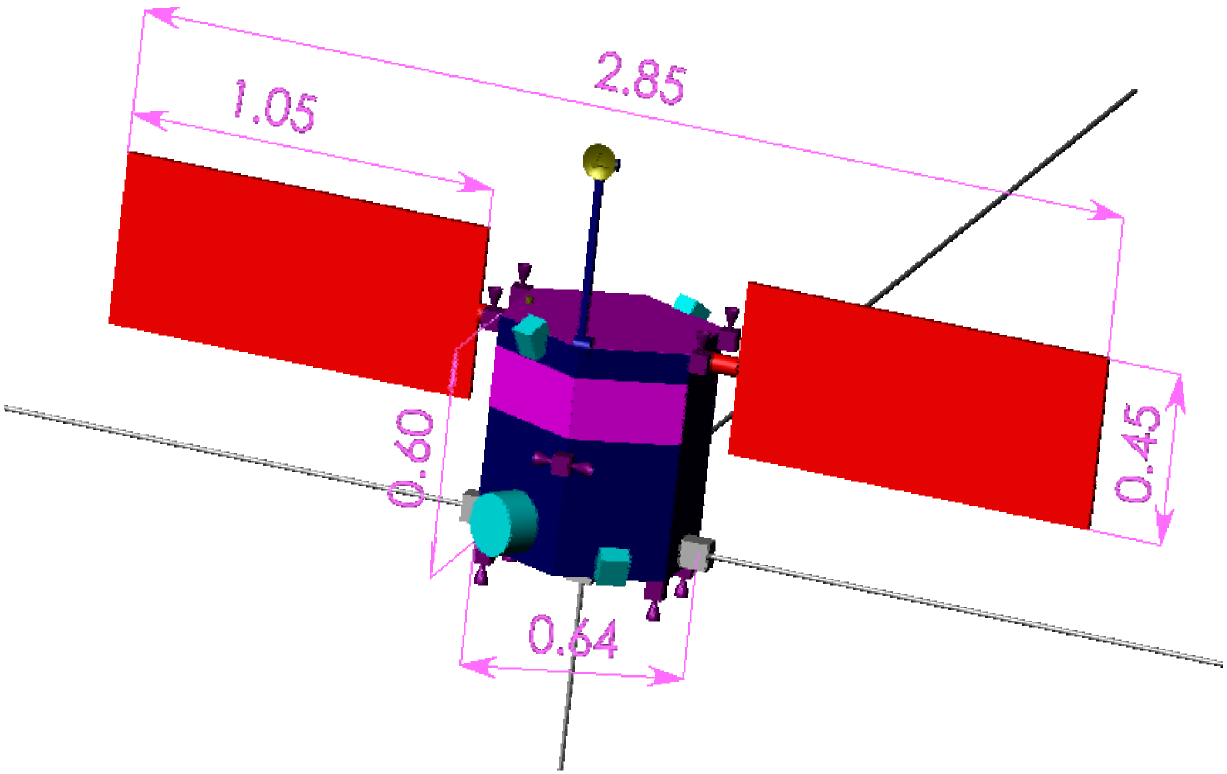
A-TOS: Two missions for in-situ sensors



Conceptual Design Studies: Integrated Concurrent Engineering (ICE)

- ICE techniques from CalTech and JPL
- Linked analytical tools with human experts in the loop
- Very rapid design iterations
- Result is conceptual design at more detailed level than seen in architecture studies
- Allows understanding and exploration of design alternatives
- A reality check on the architecture studies - can the vehicles called for be built, on budget, with available technologies?

Example Conceptual Design Result



Mother Satellite for Swarm shown earlier:

Main bus dimensions
- 0.64 m (length)
- 0.64 m (width)
- 0.60 m (height)

Payload
- two high-frequency (HF) whip 10 m antennas
- two HF whip 5 m antennas
- white box

Total mass (with contingency)
- 125.2 kg

Emerging Capability

- Reduced cycle time *from user preferences to conceptual design*
- Gets to the *right* system - considering
  - large design space - many (thousands) possibilities considered
  - needs of multiple customers
  - complex considerations such as risk, uncertainty, and policy
- Allows iterations on designs early - when they are still cheap

User Needs ⇨

⇨

⇨ **Robust Adaptable Designs**

Months, not Years

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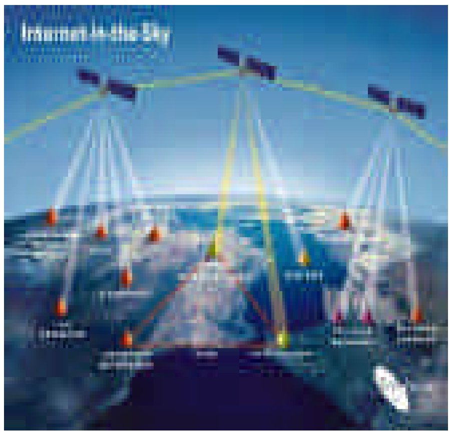
Research Achievements

- Approaches to risk and uncertainty
  - Coordinated, synergistic efforts at Stanford, MIT, CalTech
  - Allows *explicit* inclusion of *technical* risks in early design processes
- Understanding impacts of policy
  - Framework allows quantitative assessment of impacts
- Architecture and early design methods and tools
  - Allows rigorous assessment of system architectures very early in design
  - Original process plus addition of Multi-Attribute Utility (MAU), Multi-Disciplinary Optimization (MDO) tools
  - Integrated with Integrated Concurrent Engineering (ICE) and knowledge management tools

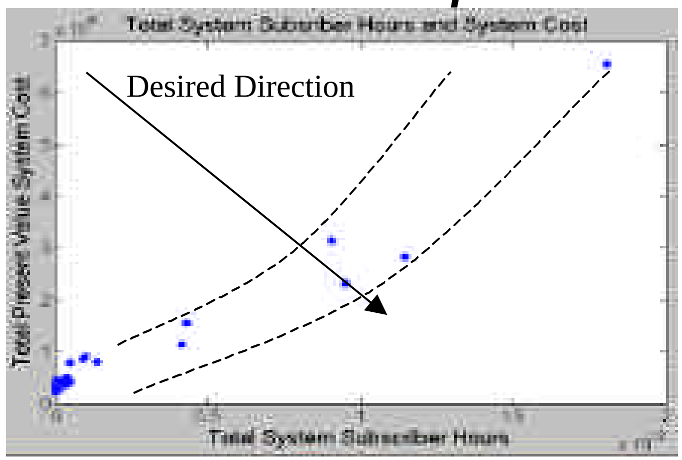
Formalizing Uncertainty/Value Tradeoffs

Broadband Communication Case Study

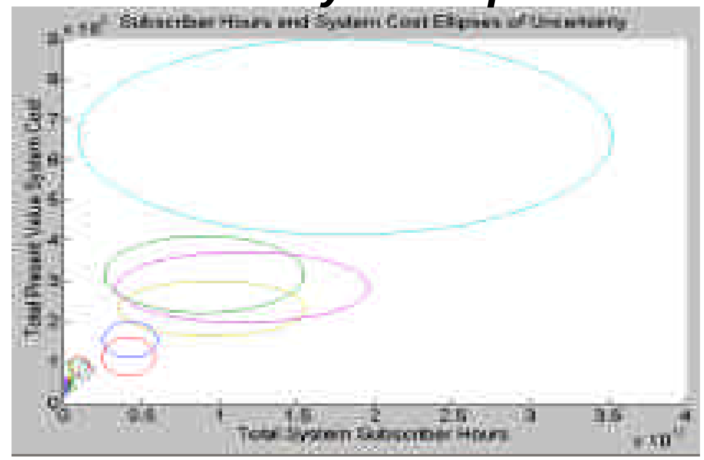


Design Vector
- *# of Satellites*
- *Altitude*
- *Inclination*
- *# of Planes*
- *Power*
- *Antenna Area*

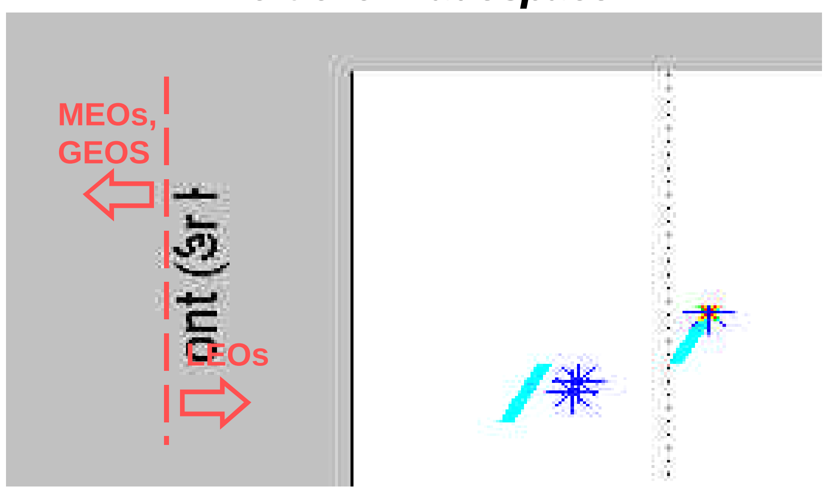
Traditional Tradespace



Uncertainty Tradespace



Portfolio Tradespace



Portfolio theory is used to suggest "optimal" investment strategies that **diversify exposure to risk** and maximize return

Potential to change RFP awards to push forward sets of solutions instead of point-designs

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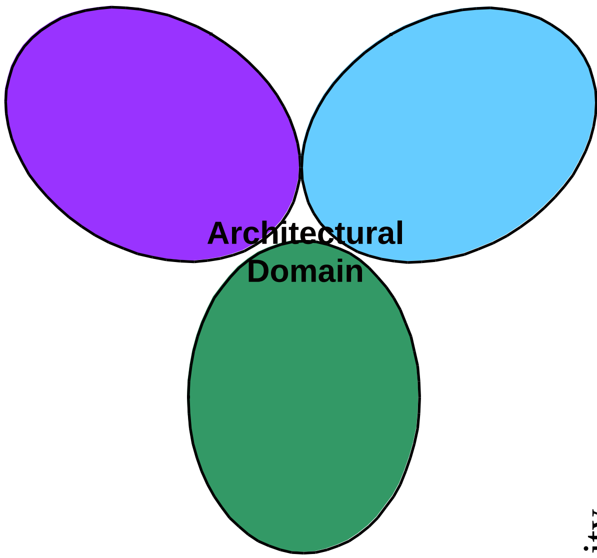
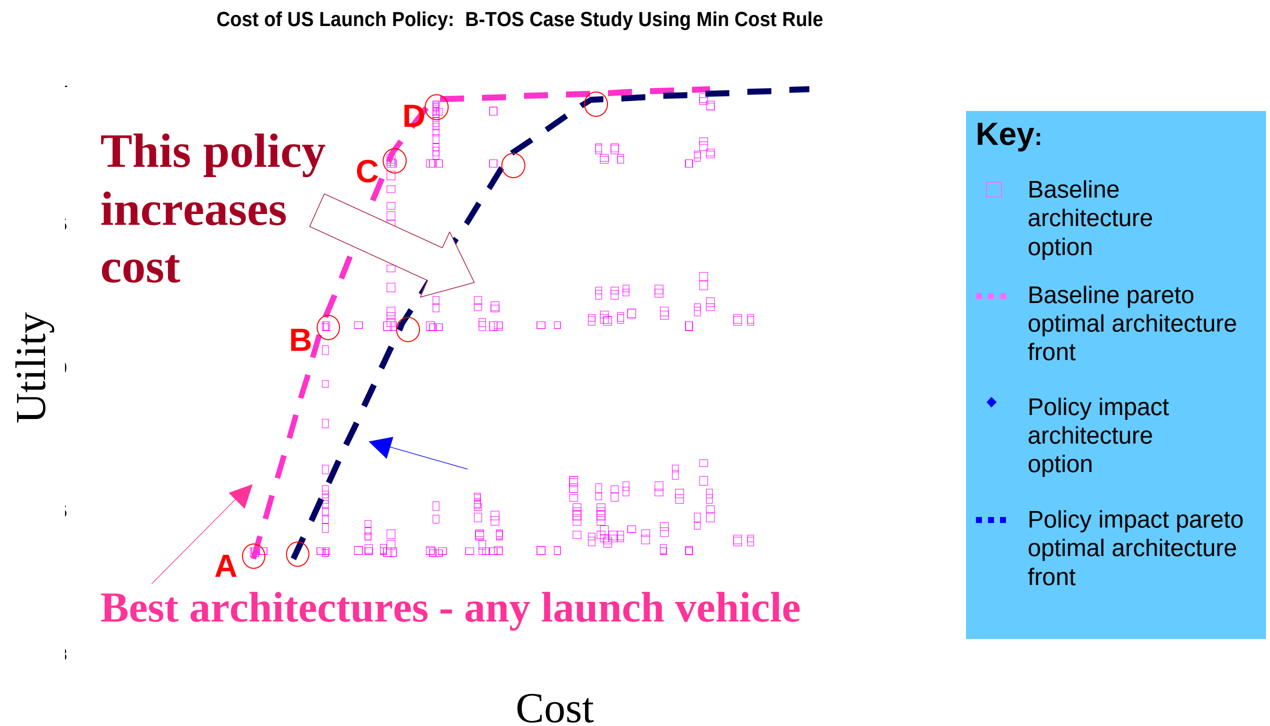
Policy Impact on System Architecture





Discussions with senior officials indicate most common policy intervention is budget adjustment

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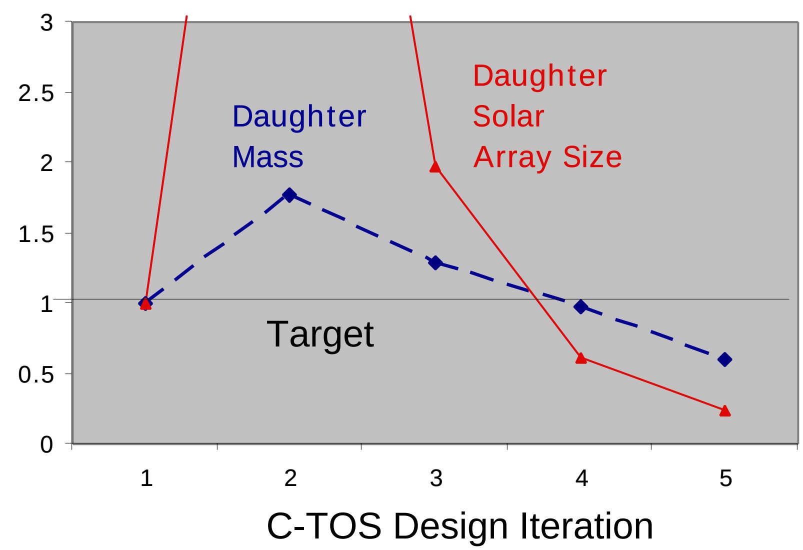
Design Evolution Capture

	ADACS	Arch & Payload	C&DH	Config	Cost	Mission Design	Power & Pyro	Prop	Risk	S&M	Systems	Telecom	Thermal Control
ADACS	n/a	6	26	142	8	0	22	28	18	82	56	0	32
Arch & Payload	15	n/a	12	74	7	9	26	4	28	38	61	2	8
C&DH	0	6	n/a	24	8	2	22	0	18	12	28	0	4
Configuration	12	0	0	n/a	0	0	0	0	0	10	22	0	6
Cost	0	0	0	0	n/a	0	0	0	0	0	74	0	0
Mission Design	12	0	0	12	6	n/a	8	8	22	102	59	4	11
Power & Pyro	20	20	30	44	12	20	n/a	20	18	44	80	22	50
Propulsion	40	4	10	86	6	8	22	n/a	18	42	58	8	18
Risk	0	4	0	0	0	0	0	0	n/a	0	4	0	0
S&M	50	0	10	4	12	0	22	0	51	n/a	38	0	8
Systems	2	0	6	4	22	4	22	6	22	6	n/a	6	2
Telecom	6	0	10	56	10	1	22	0	18	24	50	n/a	4
Thermal Control	0	0	12	26	8	0	22	0	18	16	14	0	n/a

- Semi-automated processes amenable to analysis (e.g. by DSM methods)
- Tool tracks values of parameters as they shift throughout the design process
- Enhanced understanding of design processes



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Conclusions

- New processes allow efficient quantitative assessment of system architectures given user needs
- Linked to state-of-the-art conceptual design processes that reality-check architectures and refine selected architectures to vehicle designs
- Research on critical issues of risk, uncertainty and policy impacts demonstrates the possibility of designing in robustness and/or adaptability early in design
- Understanding of design processes enhanced

Emerging capability to get from user needs to robust solutions quickly, *while considering full range of options*

Emerging Capability from SSPARC