SSPARC

Space Systems Architecture
Lecture 3
Introduction to
Tradespace Exploration

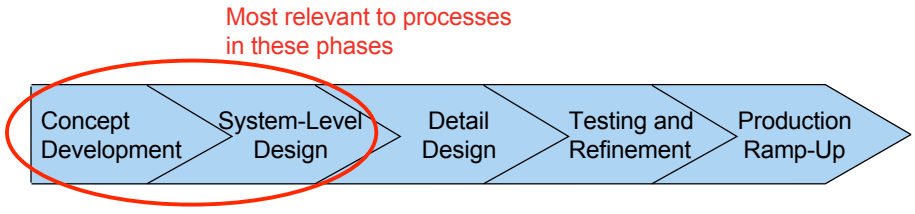
Hugh McManus
Metis Design

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

SSPARC

Tradespace Exploration

- A process for understanding complex solutions to complex problems
- Allows informed "upfront" decisions and planning



Phases of Product Development

From Ulrich & Eppinger, ***Product Design and Development***, 1995

SSPARC

Architecture Trade Space Exploration

A process for understanding complex solutions to complex problems

- Model-based high-level assessment of system capability
- Ideally, *many* architectures assessed
- Avoids optimized *point solutions* that will not support evolution in environment or user needs
- Provides a basis to explore technical and policy *uncertainties*
- Provides a way to assess the value of *potential* capabilities

Allows informed “upfront” decisions and planning

SSPARC

Integrated Concurrent Engineering

A process creating preliminary designs very fast

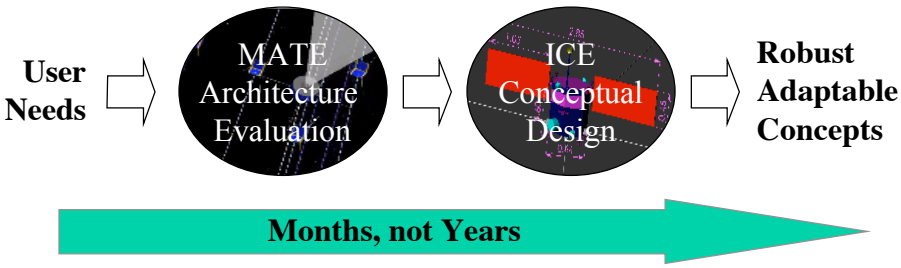
- State-of-the-art rapid preliminary design method
- Design tools linked both electronically and by co-located humans
- Design sessions iterate/converge designs in hours
- Requires ready tools, well poised requirements

Allows rapid reality check on chosen architectures
Aids transition to detailed design

SSPARC

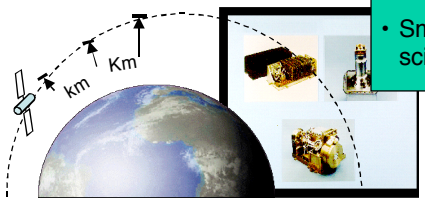
Emerging Capability

- Linked method for progressing from vague user needs to conceptual/preliminary design very quickly
- MANY architectures, several/many designs considered
- Understanding the trades allows selection of robust and adaptable concepts, consideration of policy, risk.

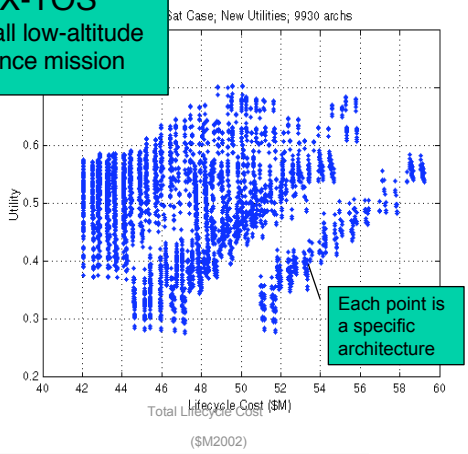


SSPARC

What is an Architecture Trade Space?



X-TOS
- Small low-altitude science mission



DESIGN VARIABLES: The architectural trade parameters

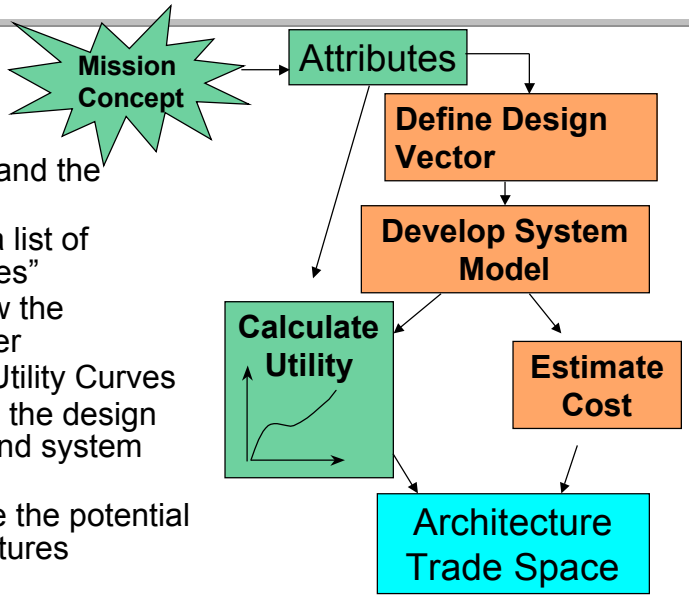
- Orbital Parameters
  - Apogee altitude (km) 150-1100
  - Perigee altitude (km) 150-1100
  - Orbit inclination 0, 30, 60, 90
- Physical Spacecraft Parameters
  - Antenna gain
  - communication architecture
  - propulsion type
  - power type
  - delta_v

Assessment of the utility and cost of a large space of possible system architectures

SSPARC

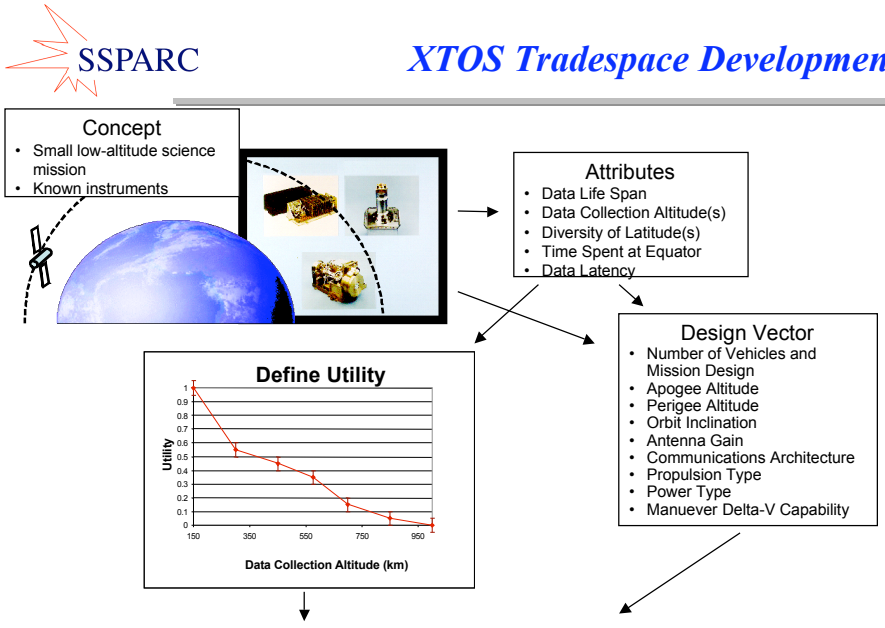
Developing A Trade Space

- Understand the Mission
- Create a list of "Attributes"
- Interview the Customer
- Create Utility Curves
- Develop the design vector and system model
- Evaluate the potential Architectures



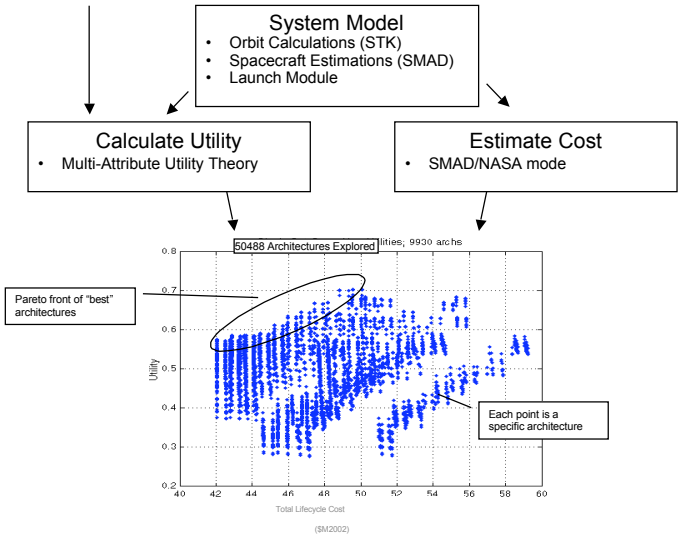
SSPARC

XTOS Tradespace Development



SSPARC

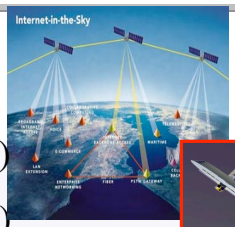
Continued

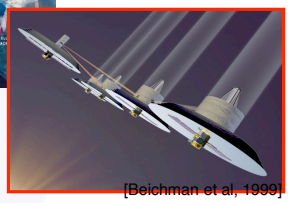


SSPARC

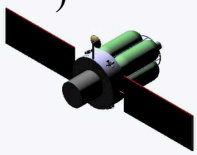
Understanding What Systems Do

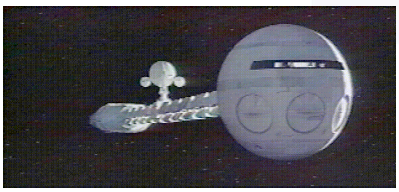
- Transmit Information
- Collect Information
- Move Mass (inc. People)
- Others (Space Station…)

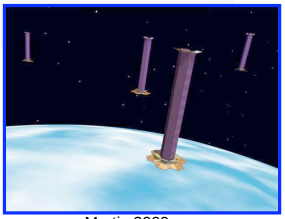




[Beichman et al, 1999]





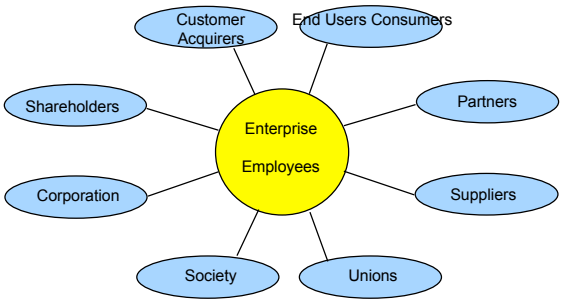


Martin 2000

SSPARC

Understanding who cares - Stakeholders

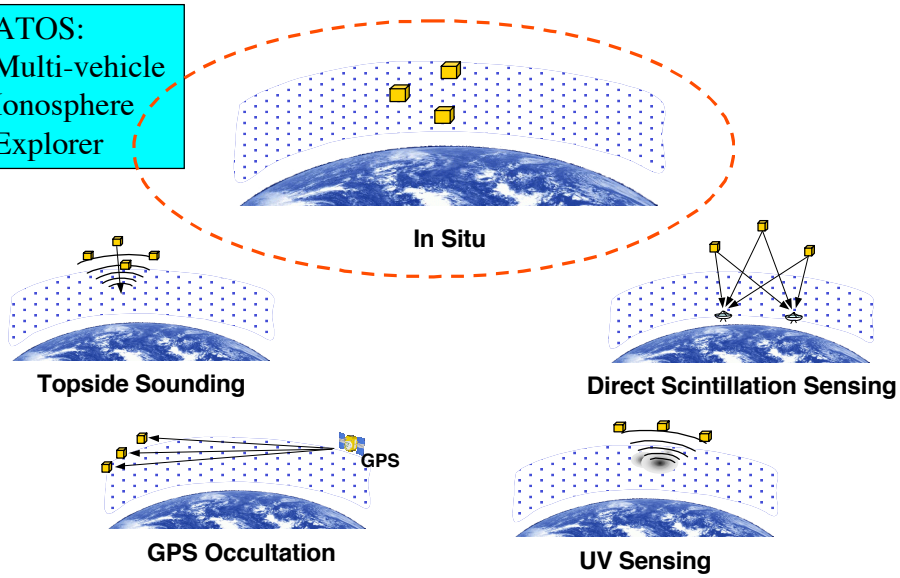
- Many interested parties in a complex system
- Each "customer" has a set of needs
- They are different, and can be contradictory



SSPARC

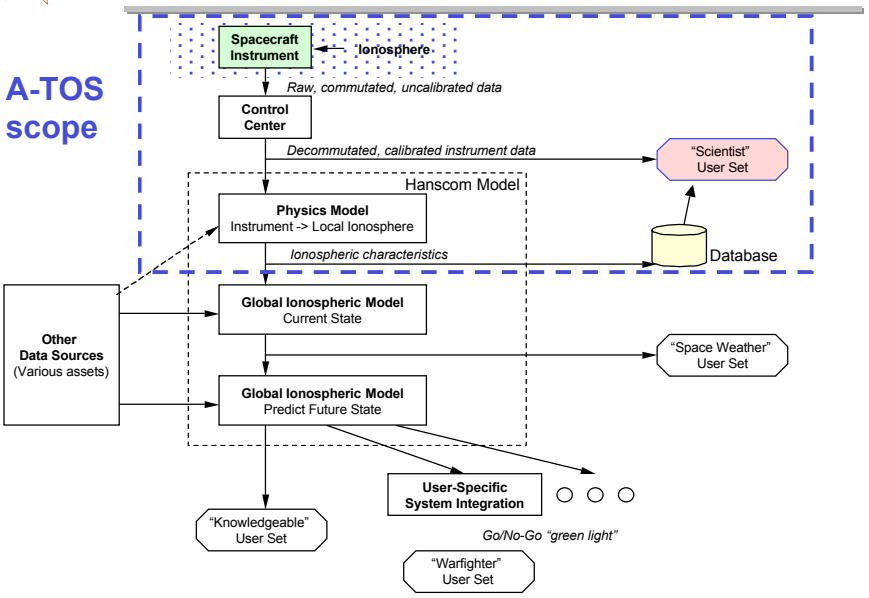
Concept Selection: Bounding

ATOS:
Multi-vehicle
Ionosphere
Explorer



SSPARC

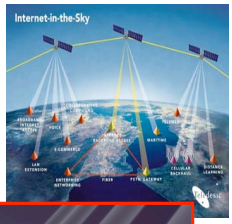
Scoping



SSPARC

Attributes

- "what the decision makers need to consider"
- (and/or what the user truly cares about)
- Examples: Billable minutes = GINA metrics
- TPF Pictures = camera performance metrics
- Rescue/move satellites = mass moving, grappling capability, timeliness
  - Could have sub-cartoons for above



[Beichman et al, 1999]

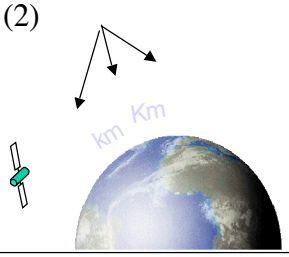
SSPARC

XTOS Attributes

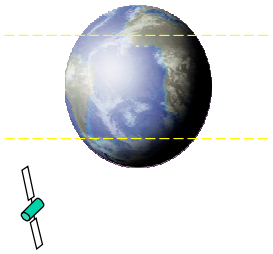
1) Data Life Span
2) Data Altitude
3) Maximum Latitude
4) Time Spent at Equator
5) Data Latency

(1)

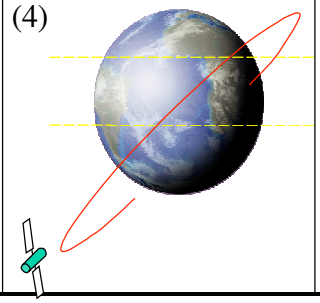
(2)



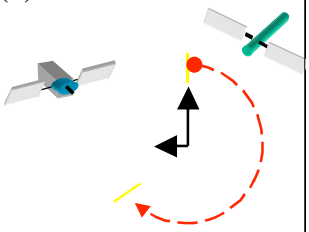
(3)



(4)



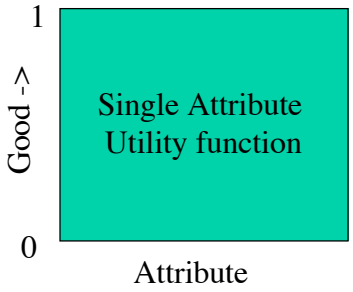
(5)

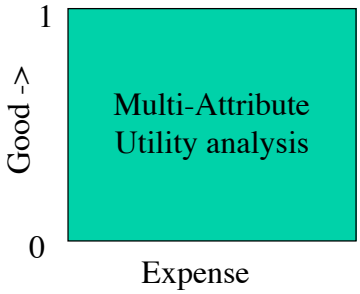


SSPARC

Utilities

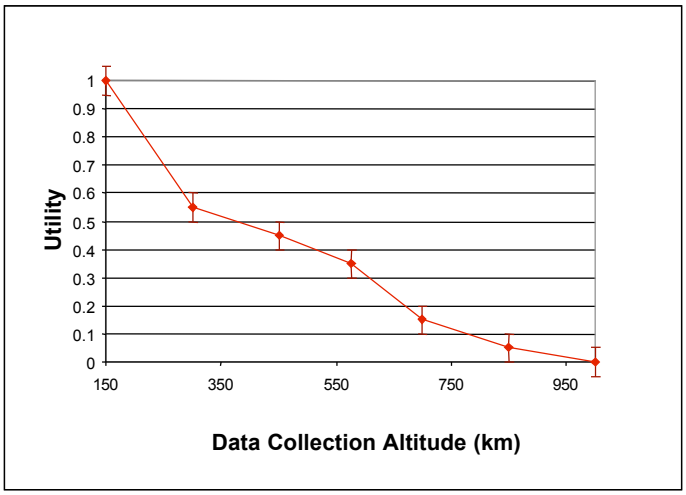
- "What the attributes are WORTH to the decision makers"
- Single Attribute utility maps attribute to utility
- Multi-attribute utility maps an architecture (as expressed by its attributes) to utility





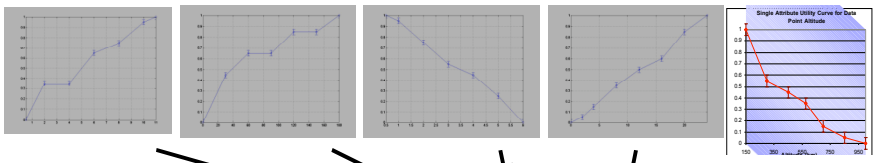
SSPARC

Single Attribute Utilities

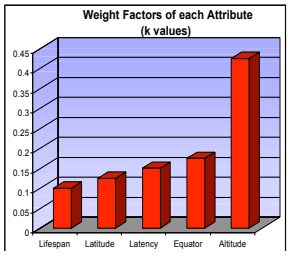


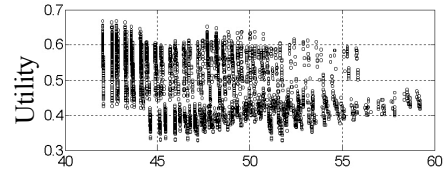
SSPARC

Multi-Attribute Utility



$$KU(\underline{X})+1=\prod_{i=1}^{N}\left(Kk_iU(X_i)+1\right)$$





Total Lifecycle Cost ($M 2002)

SSPARC

XTOS Design Vector

- "Parameters of the Trade Space"

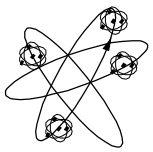
Variable:	First Order Effect:
Orbital Parameters:	
•Apogee altitude (200 to 2000 km)	Lifetime, Altitude
•Perigee altitude (150 to 350 km)	Lifetime, Altitude
•Orbit inclination (0 to 90 degrees)	Lifetime, Altitude
	Latitude Range
	Time at Equator
Physical Spacecraft Parameters:	
•Antenna gain (low/high)	Latency
•Comm Architechture (TDRSS/AFSCN)	Latency
•Propulsion type (Hall / Chemical)	Lifetime
•Power type (fuel / solar)	Lifetime
•Total ΔV capability (200 to 1000 m/s)	Lifetime

SSPARC

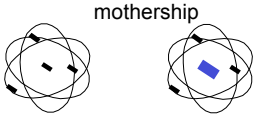
ATOS design Vector

- Geometry of the Multi-vehicle Swarm

Swarm Orbit Parameters

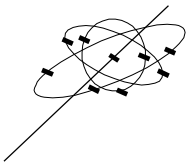


Mothership/ no mothership



Number of spacecraft in swarm

Geometry of swarm



SSPARC

Scoping-QFDs

Attributes	Perigee	Apogee	Delta-V	Propulsion	Inclination	Comm System	Ant. Gain	Rower system	Mission Scenario	Total Impact
Design Vars										
Data Lifespan	9	9	9	6	0	0	0	6	9	48
Sample Altitude	9	9	0	0	0	0	0	0	9	27
Diversity of Latitudes	0	0	0	0	9	0	0	0	9	18
Time at Equator	0	6	0	0	9	0	0	0	9	24
Latency	3	3	0	0	3	9	9	6	3	36
Total	21	27	9	6	21	9	9	12	39	
Cost	9	9	3	6	6	3	6	6	9	
Total w/Cost	30	36	12	12	27	12	15	18	48	

Identify key interactions for modeling

Sums identify attributes and Design Variables that are likely to be (or not be) distinguishers

SSPARC

Scoping-Iteration/evolution

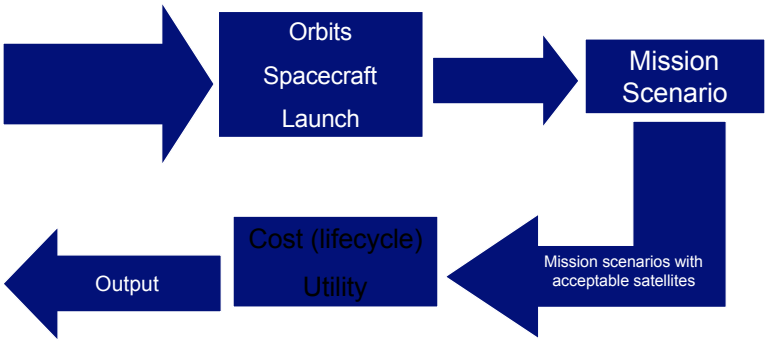
TABLE II. EVOLUTION OF DESIGN VECTOR

First Cut	After GINA exercise	After utility characterization and module progress	Schedule Crunch
10/20/00	10/31/00	1/15/01	1/21/01
Swarm type	Concept type	Swarm perigee altitude	Swarm perigee altitude
# sats/swarm	# sats/swarm	Swarm apogee altitude	Swarm apogee altitude
# swarms	# swarms per plane	# sats/swarm	# sats/swarm
Swarm orbit	# orbital planes	# subplanes/swarm	# subplanes/swarm
Intra-swarm orbit	Swarm altitude	# suborbits/subplane	# suborbits/subplane
Instrument type	Swarm orientation	Yaw angle of subplanes	Yaw angle of subplanes
# instruments/sat	Swarm geometry	Max sat separation	Max sat separation
TT&C scheme	Separation within swarm	Mothership (yes/no)	
Ground station	Mothership (yes/no)		
Mission lifetime			
Processing scheme			
Position control scheme			
Latitude of interest			

SSPARC

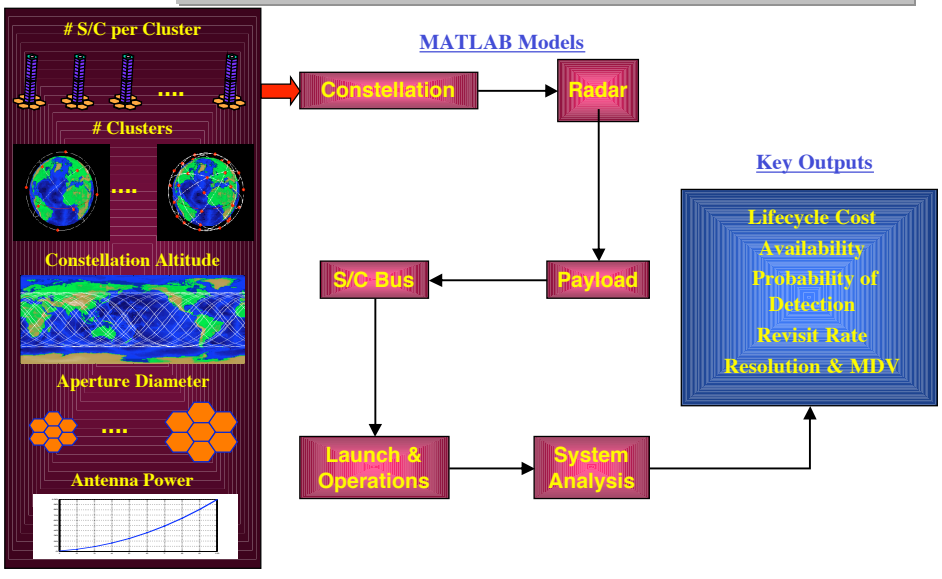
Mapping Design Vector to Attributes and Utilities - Simulation Models

XTOS Simulation Software Flow Chart



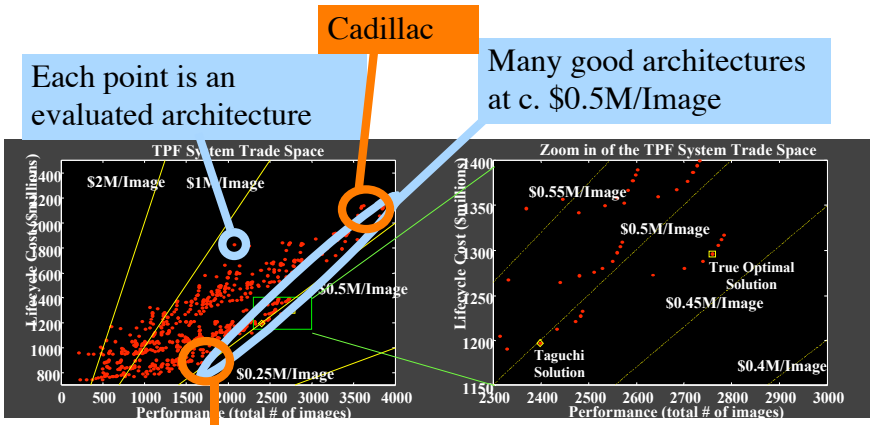
SSPARC

Techsat Models



SSPARC

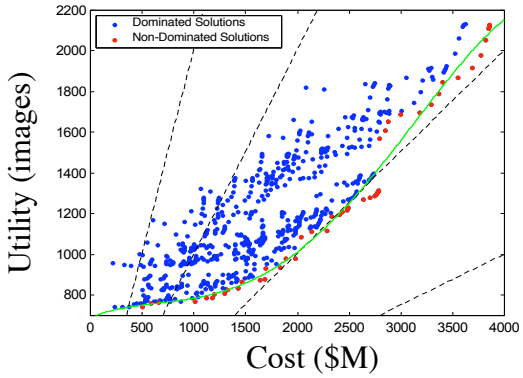
Exploring the Tradespace



SSPARC

The Pareto Front

- Set of "best" solutions
- "Dominated" solutions are more expensive or less capable

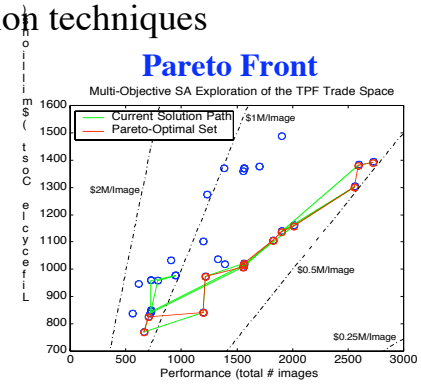


SSPARC

Optimization

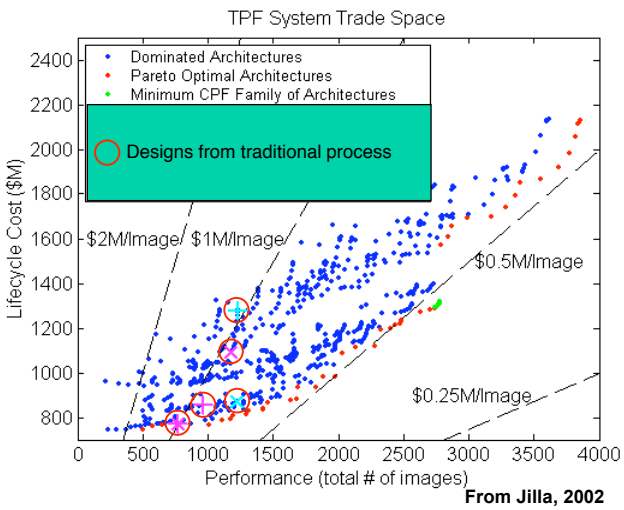
- Can look for the Pareto front using advanced optimization techniques

Pareto Front



SSPARC

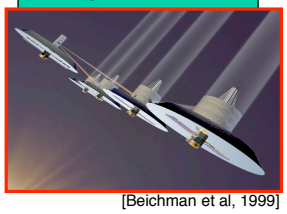
Using the Trade Space to Evaluate Point Designs



From Jilla, 2002

TPF

- Terrestrial Planet Finder - a large astronomy system
- Design space: Apertures separated or connected, 2-D/3-D, sizes, orbits
- Images vs. cost



[Beichman et al, 1999]