- **Chuck Weisbin**

Multi-Mission Strategic Technology Prioritization Study

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"Systematic Technology Prioritization For New Space Missions"
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Jet Propulsion Laboratory
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- **S. Prusha for assisting in selection of ECS technologies to analyze; M. Feather for providing information about correlations of tasks and needs**

Study Staff & Roles

- **JPL**
  - J. Derleth, Mission & Technology Portfolio Optimization
  - A. Elfes, ECS Data & Analysis
  - B. Kennedy, ECT Data & Analysis
  - R. Manvi, Tech Life Cycle & Risk Management Model
  - K. Shelton, Mission & Technology Data Base
  - J. H. Smith, Integrated Risk Analysis
  - G. Rodriguez, System Analysis
- **GSFC staff** (M. Steiner, J. Azzolini, J. Mapar, C. Stromgren)

Study Objectives

- **Perform a pilot study of sufficient breadth which demonstrates in an auditable fashion how advanced space technology development can best impact future NASA missions**
  - Include wide spectrum of missions & technologies
  - Can add new missions & technologies easily
  - Optimize technology portfolios
  - Lead to rapidly prototyped example
- **Show an approach to deal effectively with inter-program analysis trades**
- **Explore the limits of these approaches and tools in terms of what can be realistically achieved (scope, detail, schedule, etc.)**

Technology Portfolio Optimization Approach

- **Collect performance data for many individual technologies; each data input is viewed as a statistical sample representing an expert assessment**
- **Group the technological data into a tree-like hierarchical model to predict "integrated" system, mission, and multi-mission impact of individual technologies**
- **Search computationally for technology portfolios with optimal science return, risk and cost impact**
- **Investigate sensitivity of the optimal portfolio to changes in available budget levels**

Major Study Challenges

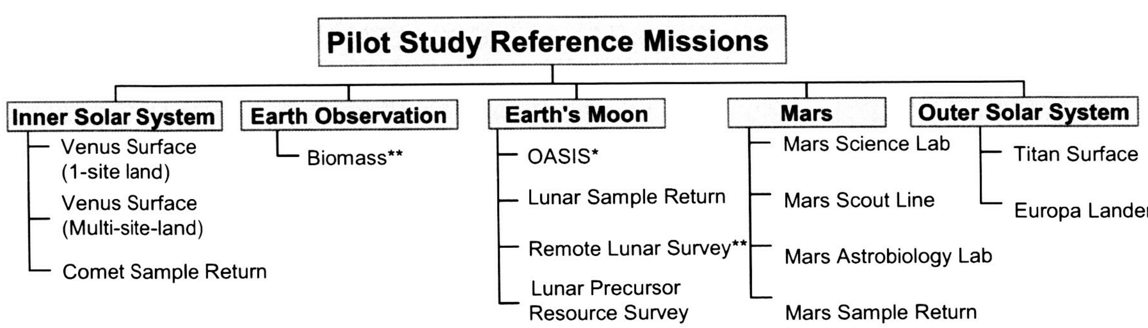
- **Reference Missions: assess mission value; characterize capability requirements**
- **Technology Projections: characterize performance; manage widely dispersed and non-uniform data**
- **Uncertainty: incorporate & manage widespread uncertainty**
- **ROI Measures: formulate suitable value function for portfolio analysis**
- **Layers of Abstraction: choose and maintain appropriate level of analytical abstraction**
- **Technological Boundaries: boundaries of technology domains not clearly marked**
- **Many Scales: large differences in cost and performance scales for different technologies**
- **Performance Parameters: not fully understood for some technologies**
- .....

Implementation Approach

- **Iterative in three phases (keep eye on big picture early, and continuously)**
  - Phase 1 minimalist multi-mission set; ECT/ECS technologies
  - Phase 2 more extensive set of missions & technologies (June 04)
  - Phase 3 completion of full study (December 04)
- **Maintain high degree of connectivity**
  - Space Architect
  - Revolutionary Mission Concepts
  - Advanced Space Technology Programs
  - Enterprises
  - Centers
  - Etc.

Pilot Study Reference Missions

(Organized by Science-Site Location)



- ➢Initial reference mission set as of April 15, 2004
- ➢More missions and enabling technologies will be added throughout the period of performance of the study

* OASIS is a near Earth transportation infrastructure that enables access to the Moon. It consists of: a Hybrid Propellant Module, a Chemical Propulsion Module, a Solar Electric Propulsion Module, and a Crew Transport Vehicle.

** GSFC contribution to this study focuses on these missions

Reference Missions & Major Challenges
(Minimalist Mission Set for PHASE I)

Reference Mission Classes (not listed in order of priority)	Major Challenges
Earth's Moon: Orbital Aggregation and Space Infrastructure Systems (OASIS); Lunar Remote Survey; Lunar Surface Missions; etc.	Deep Space Robotic Rendezvous & Docking; Long Term Cryogenic Fuel Storage in Space (>2 years); Long Life Ion Engines(>15 K-hours)
Mars Surface: (e.g. Mars Science Laboratory; Astrobiology Field Lab; Mars Sample Return; etc.)	Long-Range, Long-Life Mobility (10's of kilometers, >600 sols); Substantive Sample Collection and Return (>1kg, 0<depth<100m subsurface)
Earth Observation: Biomass	Lidar/Radar Instrument Systems; Multi-Spectral Scanner; Sensor Webs & Data Fusion
Outer Solar System: Titan Surface; Europa Lander	Extreme Environments; Sub-Surface Ice Mobility
Inner Solar System: Venus surface; comet sample return	Extreme Environments (460C temp; 90 bar pressure; sulfuric acid clouds at 50 km)

- **Technologies to be evaluated will include:**
  - Technological products in several discipline fields (aimed at operational flight system implementation (e.g. advanced materials, structures, etc.)
  - Risk assessment tools and infrastructure to allow for risk quantification, and risk mitigation during an entire mission life-cycle, but that do not necessarily appear in the flight system implementation (e.g. risk management methods)

Enabling Technologies for Which Data Has Been Collected to Date

- **Extreme Temp & Pressure Components, Thermal Control, Pressure-Vessel-Encapsulated Electronics (Venus)**
- **Electric & Chemical Propulsion; Reaction Control; Multifunction Structures; Fuel Storage & Control; Syntactic Foams, Formation Flying (OASIS)**
- **Entry Descent & Landing; Surface,Aerial,Subsurface Mobility; Manipulation, Drilling, Sampling (Mars, Titan, Comet, Lunar Surface)**
- **In-Space Inspection, Maintenance, Assembly (OASIS, Large Observatory Platform, Gateway, Space Solar Power)**
- **Risk Methods, Tools and Workstation; Mishap Anomaly Data Base; Complex Systems Research; Risk Characterization & Visualization; etc. (All Reference Missions)**

Enabling Technology Areas

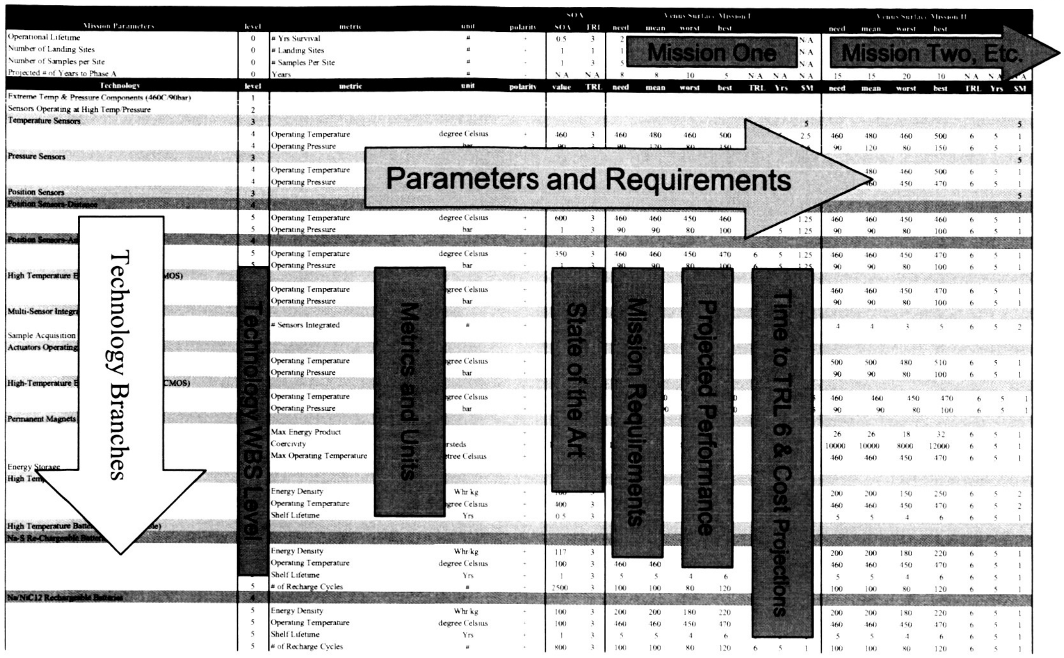
(for which data has been collected to date)

Enabling Technology Areas	Missions
Electric & Chemical Propulsion; Reaction Control; Multifunction Structures; Fuel Storage & Control; Syntactic Foams, Formation Flying; In-Space Robotic Inspection, Maintenance, Assembly	OASIS
Entry Descent & Landing; Surface, Aerial,Subsurface Mobility; Manipulation, Drilling, Sampling	Mars, Earth's Moon, Titan, Comet
Risk Methods, Tools & Workstation; Mishap Anomaly Data Base; Complex Systems Research; Risk Characterization & Visualization; etc.	All
Extreme Temp & Pressure Components, Thermal Control, Pressure-Vessel-Encapsulated Electronics	Venus, Titan, Europa

Technology Areas are Decomposed into Many Sub-Areas & Performance Parameters

A Few Typical Technology Areas	A Few Typical Technology Sub-Areas	A Few Typical Performance Parameters
Multi-Function Structures	Modular, Distributed Structures, Deployable Structures, etc.	Contract/Extend (cm), Power per Mass (W/kg), etc.
Fuel Storage & Control	On Orbit Cryogenic Fuel Transfer, Tank Pressure Control, Fuel Storage, etc.	Flow Rate (kg/min), Pressure (kPa), Time (yrs), etc.
Subsurface Ice Mobility	Range, Radiation Dose, Payload Capacity, Ambient Pressure, etc.	Distance (km, mRads), Mass (kg), Pressure (atm), etc.
Extreme Temperature & Pressure Components	High Temperature Electronics, Permanent Magnets, Energy Storage, etc.	Temperature (Celsius), Pressure (Bars), Energy Density (Whr/l) etc.
Risk Methods, Tools & Workstation	Model Based Risk Analysis, Mission Risk Profiling Capability, etc.	Accessibility, applicability to multiple mission phases, risk mitigation coverage

Mission & Technology Data Base



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Mission & Technology Data Base

-- Current Size Summary --

- **Size of Mission & Technology Capability Data Base (as of April 15, 2004)**
  - 13 missions covering wide spectrum of NASA strategic plans
  - 23 technology areas (structures, energetics, extreme environments, surface mobility, etc.)
  - 86 technology sub-areas (batteries, payload capacity, thermal control, etc.)
  - 167 technological performance parameters (power density, operating temperature, etc.)
- **Remarks About Data Base**
  - Current data set is more detailed in some areas than in others
  - More technologies & detail will be collected in subsequent phases
  - Our analysis methods can handle data sets with non-uniform detail

This is an early draft for April 15th, 2004. Please do not distribute.

Risk Related Requirements

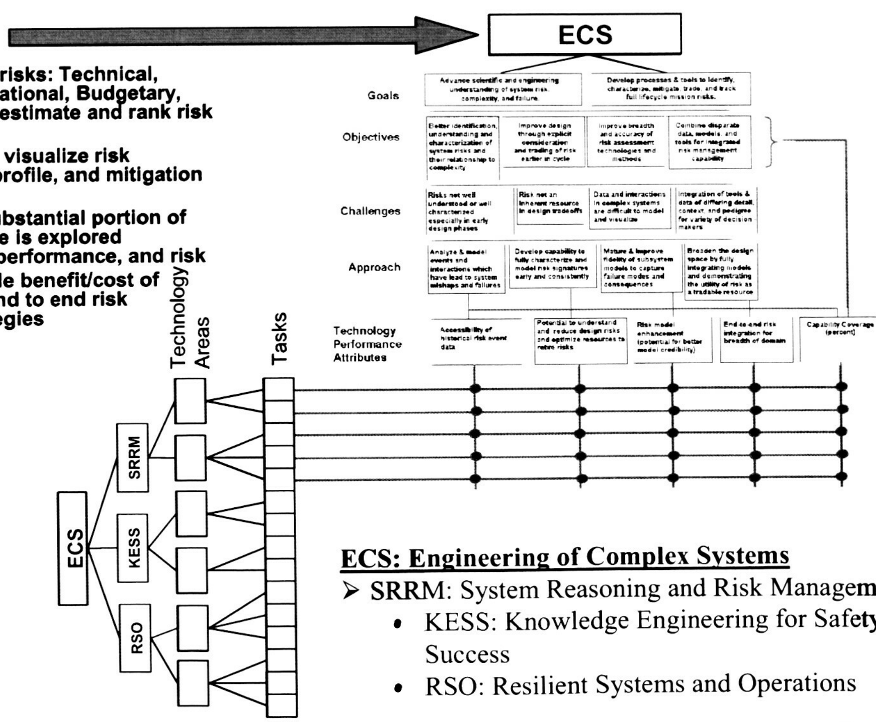
(from Point of View of a Project Manager)

- **Risk Management Must:**
  - Delineate major risks: Technical, Human, Organizational, Budgetary, and Schedules ;estimate and rank risk levels
  - Provide ways to visualize risk elements, time profile, and mitigation strategies
  - Assure that the systems and trade analysis includes cost, performance, and risk
  - Provide auditable benefit/cost of implementing begin-to-end risk mitigation strategies

Connecting Risk Technologies to Requirements

Requirements:

- ❑ **Delineate major risks: Technical, Human, Organizational, Budgetary, and Schedules; estimate and rank risk levels**
- ❑ **Provide ways to visualize risk elements, time profile, and mitigation strategies**
- ❑ **Assure that a substantial portion of the design space is explored including cost, performance, and risk**
- ❑ **Provide auditable benefit/cost of implementing end to end risk mitigation strategies**



ECS: Engineering of Complex Systems

- SRRM: System Reasoning and Risk Management
  - KESS: Knowledge Engineering for Safety and Success
  - RSO: Resilient Systems and Operations

System Reasoning and Risk Management (SRRM) Project Executive Summary

Goals

- Advance scientific and engineering understanding of system risk, complexity, and failure.
- Develop processes & tools to identify, characterize, mitigate, trade, and track full lifecycle mission risks.

Objectives

- Better identification, understanding and characterization of system risks and their relationship to complexity
- Improve design through explicit consideration and trading of risk earlier in cycle
- Improve breadth and accuracy of risk assessment technologies and methods
- Combine disparate data, models, and tools for integrated risk management capability

Challenges

- Risks not well understood or well characterized, especially in early design phases
- Risk not an inherent resource in design tradeoffs
- Data and interactions in complex systems are difficult to model and visualize
- Integration of tools & data of differing detail, context, and pedigree for variety of decision - makers

Approach

- Analyze & model events and interactions which have lead to system mishaps and failures
- Develop capability to fully characterize and model risk signatures early and consistently
- Mature & improve fidelity of subsystem models to capture failure modes and consequences
- Broaden the design space by fully integrating models and demonstrating the utility of risk as a tradable resource

Technology Performance Attributes

- Accessibility of historical risk event data
- Potential to understand and reduce design risks and optimize resources to retire risks
- Risk model enhancement (potential for better model credibility)
- End-to-end risk integration for breadth of domain
- Degree of Alignment (Effectiveness in percent)

Attribute Definitions

Attribute	Scale	Definition
Accessibility of risk data	Best Case 10	Easy to use DB spans multiple mission/projects with risk events categorized for search.
	5	DB may be limited to specific category or series of missions.
	Worst Case 0	Supporting data/verifications are anecdotal (narrative) format without categories of risk events for easy search. May require further processing to another format.
Potential to reduce design risks	Best Case 10	Technology helps to identify and reduce risks during early phases of project (Phase A/B) with potential to dramatically reduce overall project costs by reducing rework.
	5	Technology helps identify/reduce mission risks for Phase C/D; Large potential cost benefits if used. Provides a screen that limits potential risks from passing CDR.
	Worst Case 0	Technology helps identify technology development or subsystem risks, but may or may not influence overall system risk.
Risk model enhancement	Best Case 10	Technology provides new approach for addressing design risk life-cycle or part of life-cycle not previously addressed (e.g., mgmt, org. risks)
	5	Technology either provides new, more effective approach for risk analysis or fills missing gap in temporal or breadth of risk analyses (but not both)
	Worst Case 0	Technology does not address missing gap in design life-cycle.
End-to-end risk integration	Best Case 10	Technology provides synergistic integration with other tools and databases fully compatible with emerging design environments (temporal and breadth).
	5	Risk technology allows interaction with common databases but cannot be integrated with other stand-alone applications.
	Worst Case 0	Technology is stand-alone; focused, narrow; little breadth or temporal range, databases are separated with little or no connectivity. Integration difficult.

All SRRM Technology Areas Are Included for the Pilot Study

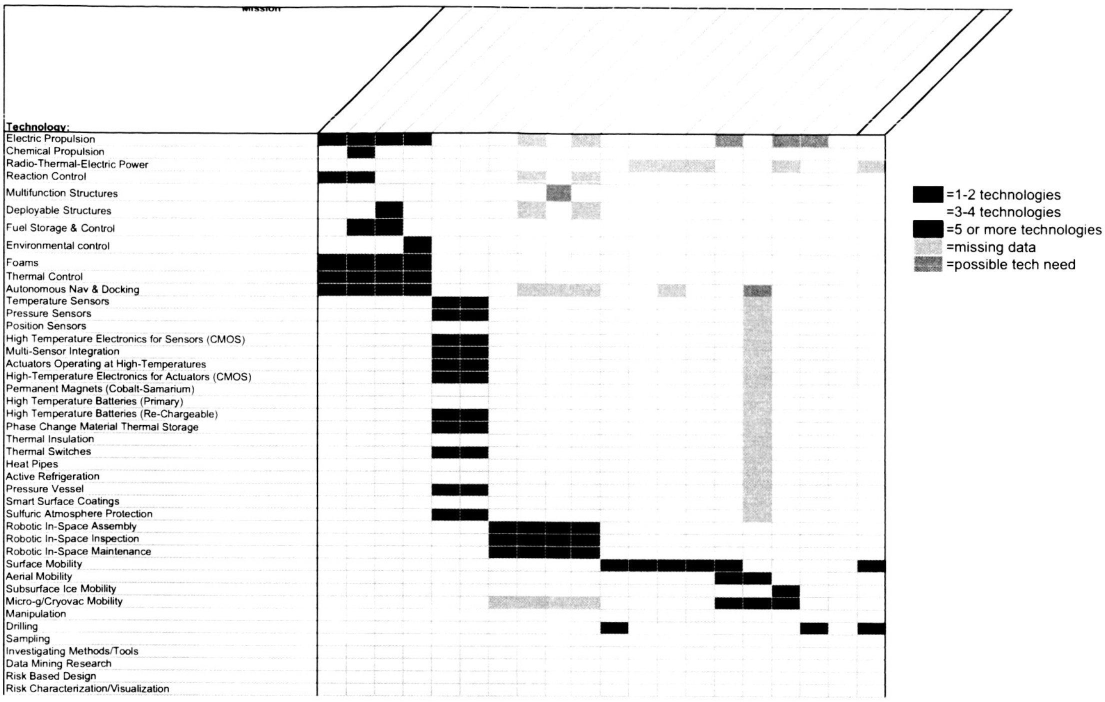
1. Risk Methods/Tools (RMT)
2. Risk Workstation (RWS)
3. Mishap/Anomaly Database (MAIS)
4. Model-Based Hazard Analysis (MBHA)
5. System Complex Research (SCR)
6. Risk Characterization/Visualization (RCV)
7. Risk-Based Design (RBDO)
8. Data Mining Research (DMR)
9. Investigation Methods/Tools (IMT)

Typical SRRM Technology Area Data*

Technology	Level	Metric	Unit	Polarity	SOA	Low	ML	High	$M
		How performance is measured	What unit performance is measured in	+ = Better if performance is higher - = Better if performance is lower	Current state-of-the-art for similar technologies	Technologist's estimate of low, most likely, and high values of what will be provided to the mission			How much the technologist needs to achieve TRL 6 in $M
ECS	1								
SRRM	2								
RISK Methods & Tools	4	Accessibility of Historical Risk Event Data	0-10	+	4	7	8	9	2
		Potential to Understand and Reduce Design Risks and Optimize Resources to Retire Risk	0-10	+	1	7	8	9	
		Risk Model Enhancement (Potential for Better Model Credibility)	0-10	+	2	9	10	10	
		End-to-end Risk Integration for Breadth of Domain	0-10	+	2	8	9	10	
		Extent of Needs Covered	0-1	+	0.5	0.7	0.8	0.9	

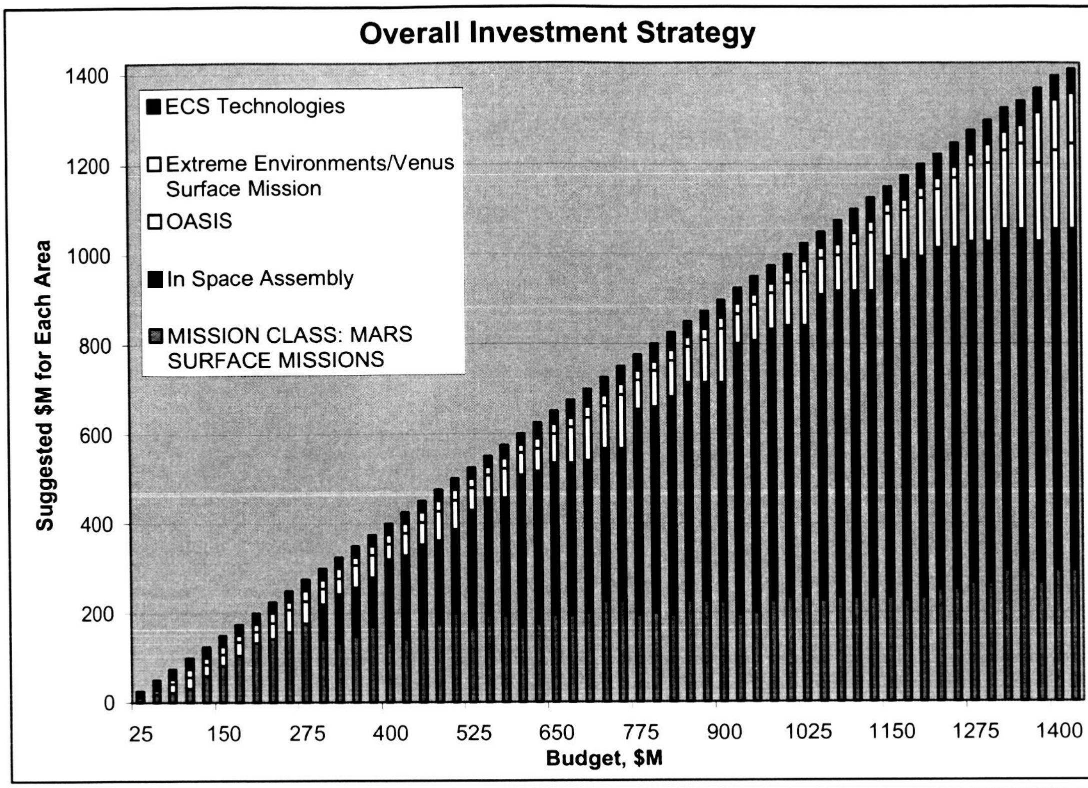
*SRRM data cast in same format used for all other technologies (shown in slide 14)

Mission-Technology Complexity Map

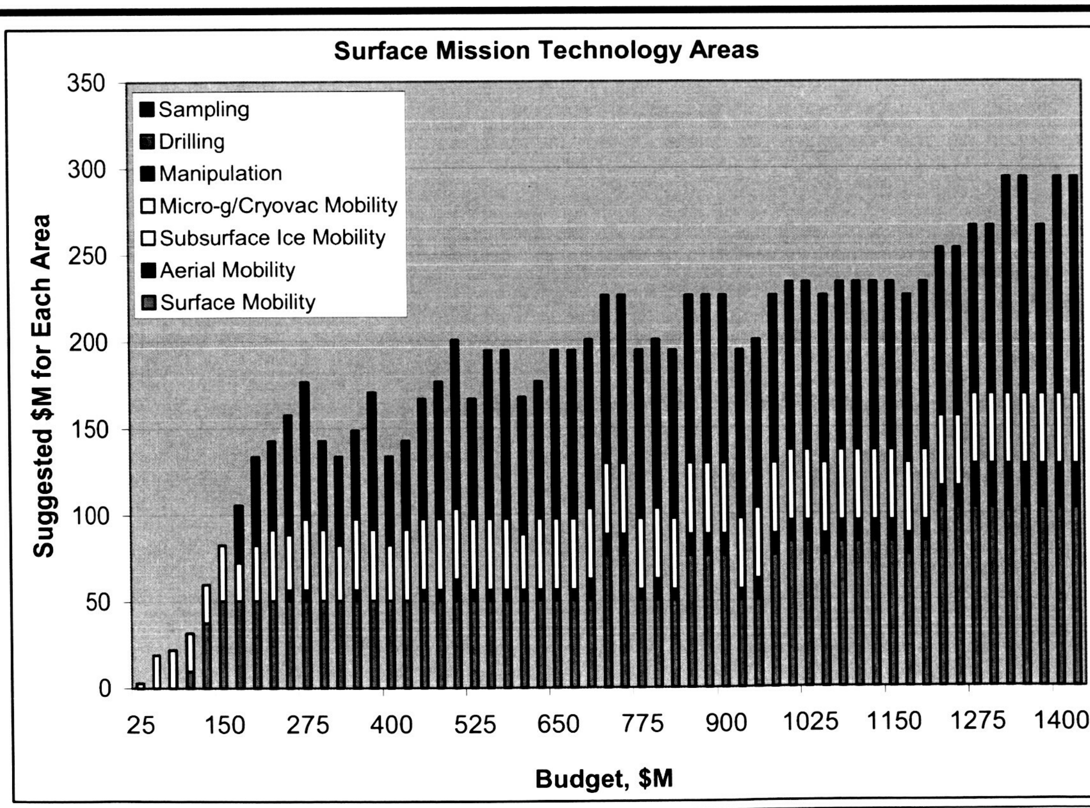


Analysis Options Used to Get Typical Results in Slides 25-30

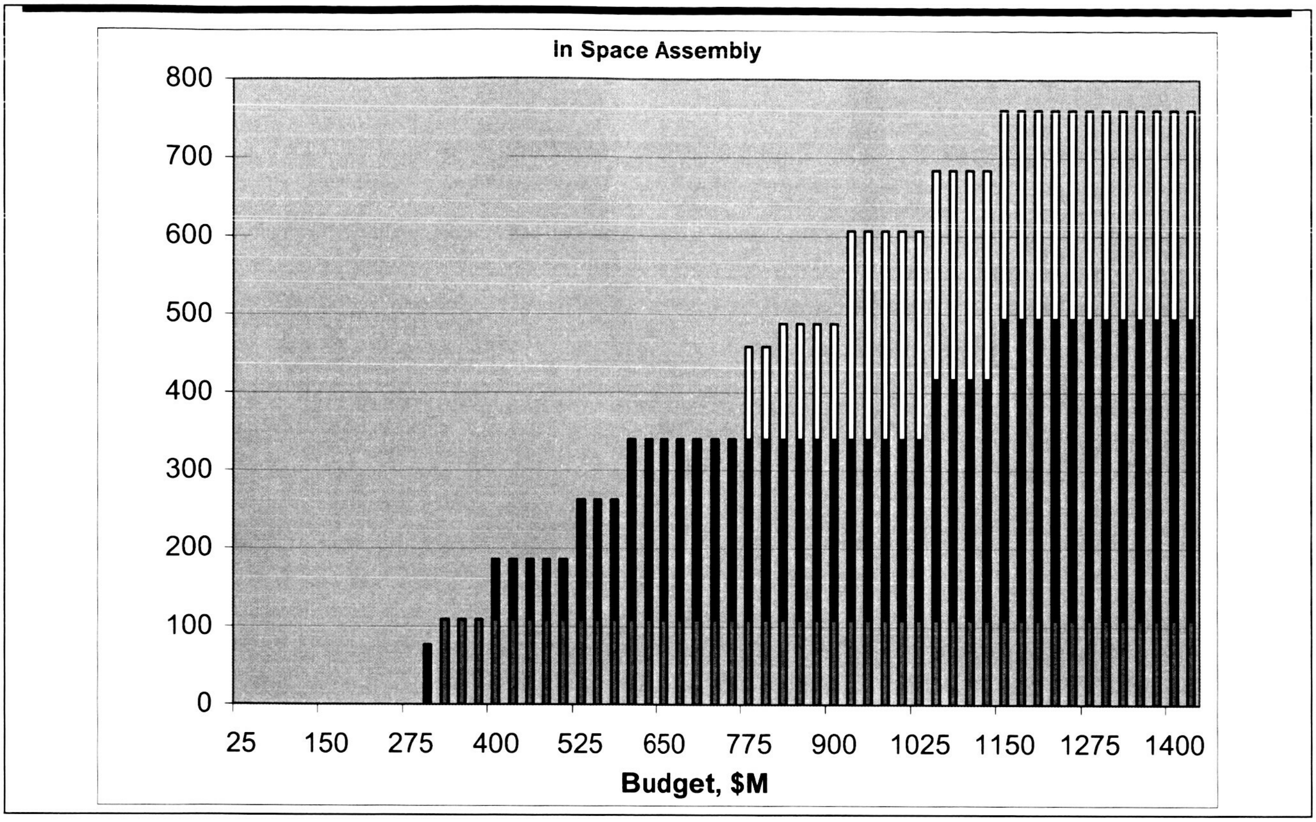
Analysis Options Used	Other Options Available
Uniform science-return value for all missions	Can assign non-uniform science return value (user prescribed)
Uniform value for all technologies at the same hierarchical level; "democratic" hierarchy	Can prescribe general technology organizations; based for example on mission and system decomposition
Technology correlations and co-dependencies set to zero	Can explicitly include correlation & co-dependency parameters when available
Risk estimates based only on performance uncertainty	Can include cost, schedule and other risk factors
Identical development time (~10 yrs) for all technologies	Can vary technology development time as a model parameter
TRL data not included in technology projections	Can analyze TRL data within existing analysis framework



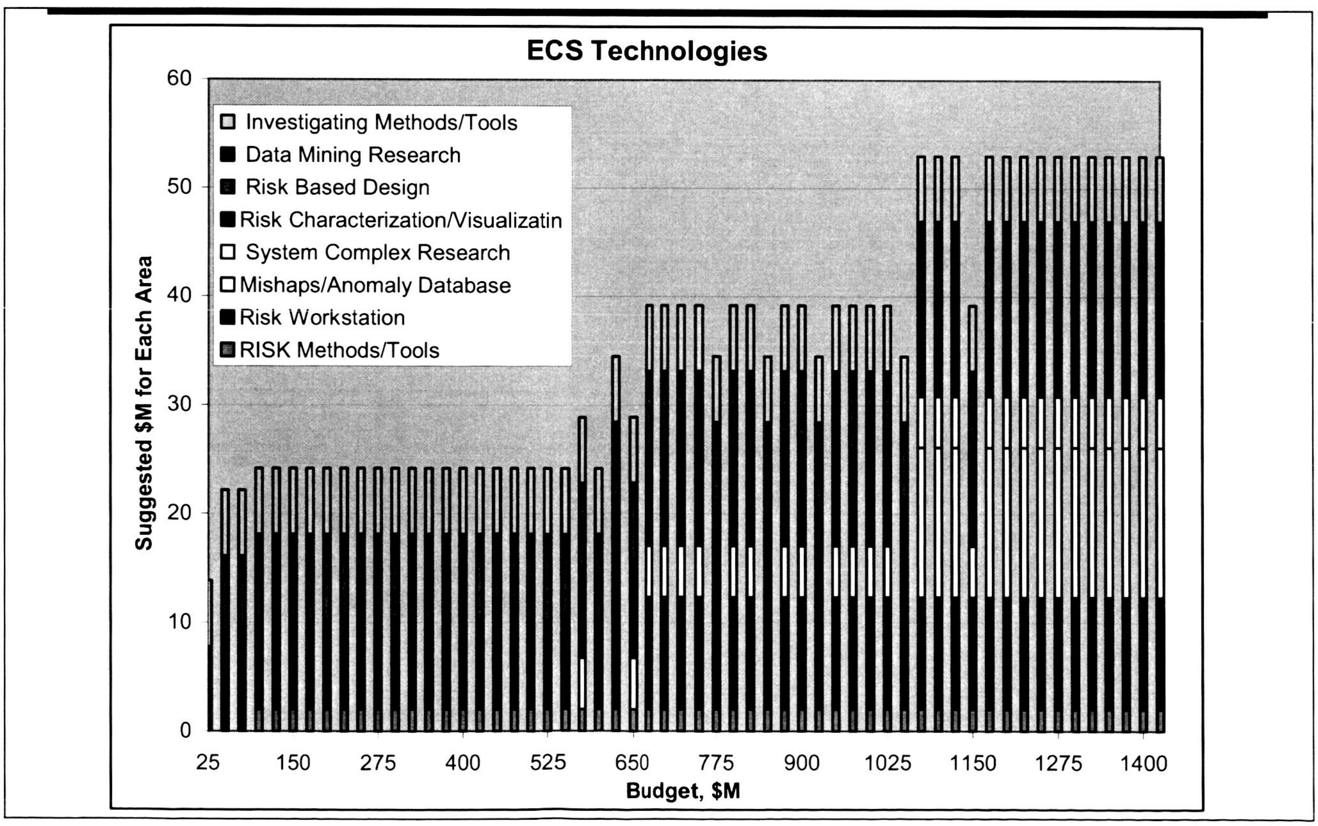
Overall Investment Strategy
ECS Technologies
Extreme Environments/Venus Surface Mission
OASIS
In Space Assembly
MISSION CLASS: MARS SURFACE MISSIONS
Suggested $M for Each Area
0
200
400
600
800
1000
1200
1400
25
150
275
400
525
650
775
900
1025
1150
1275
1400
Budget, $M



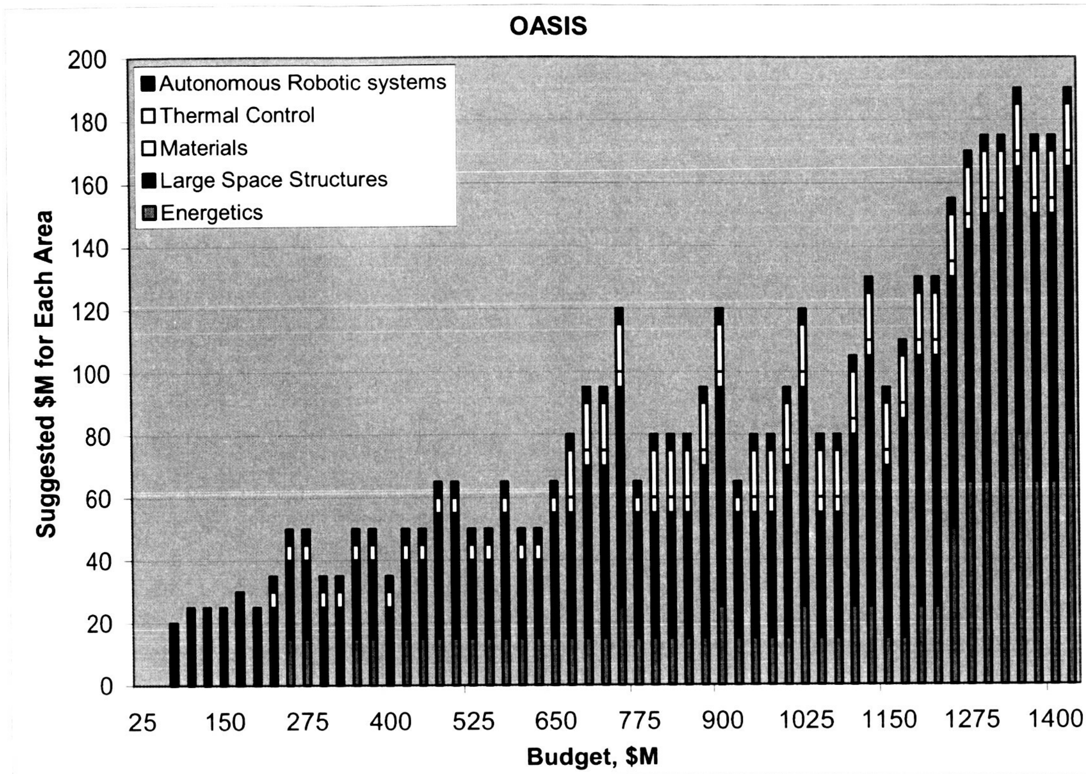
Surface Mission Technology Areas
Sampling
Drilling
Manipulation
Micro-g/Cryovac Mobility
Subsurface Ice Mobility
Aerial Mobility
Surface Mobility
Suggested $M for Each Area
0
50
100
150
200
250
300
350
25
150
275
400
525
650
775
900
1025
1150
1275
1400
Budget, $M

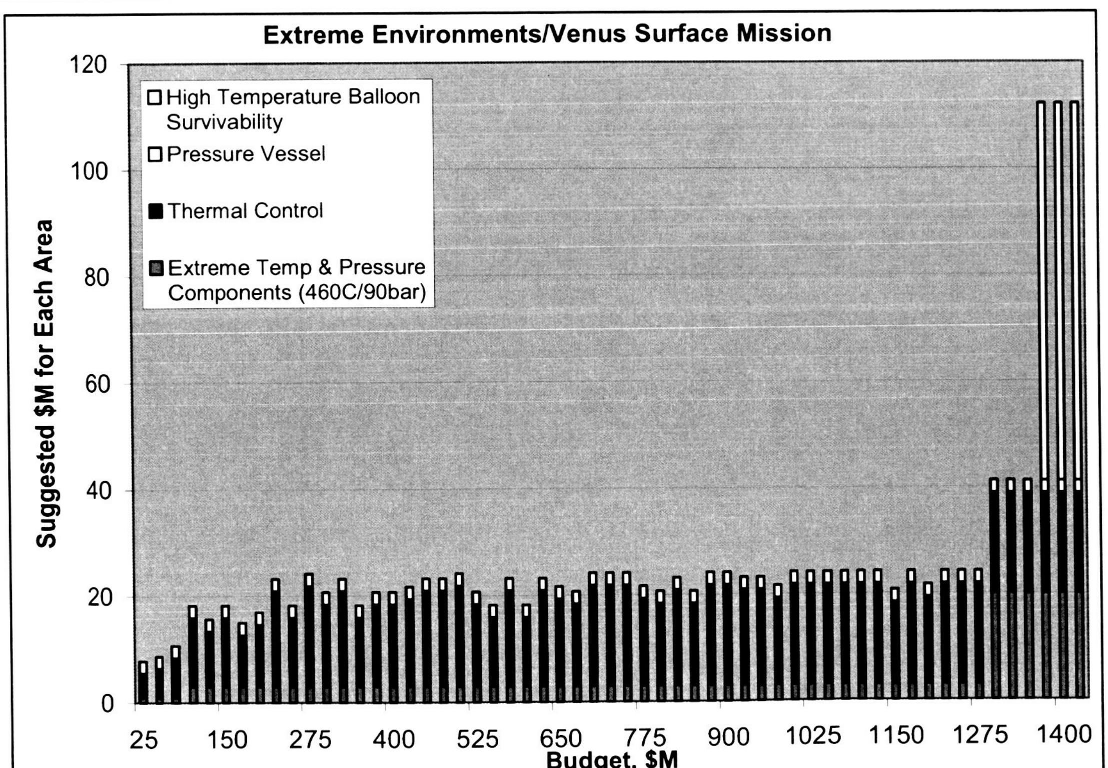


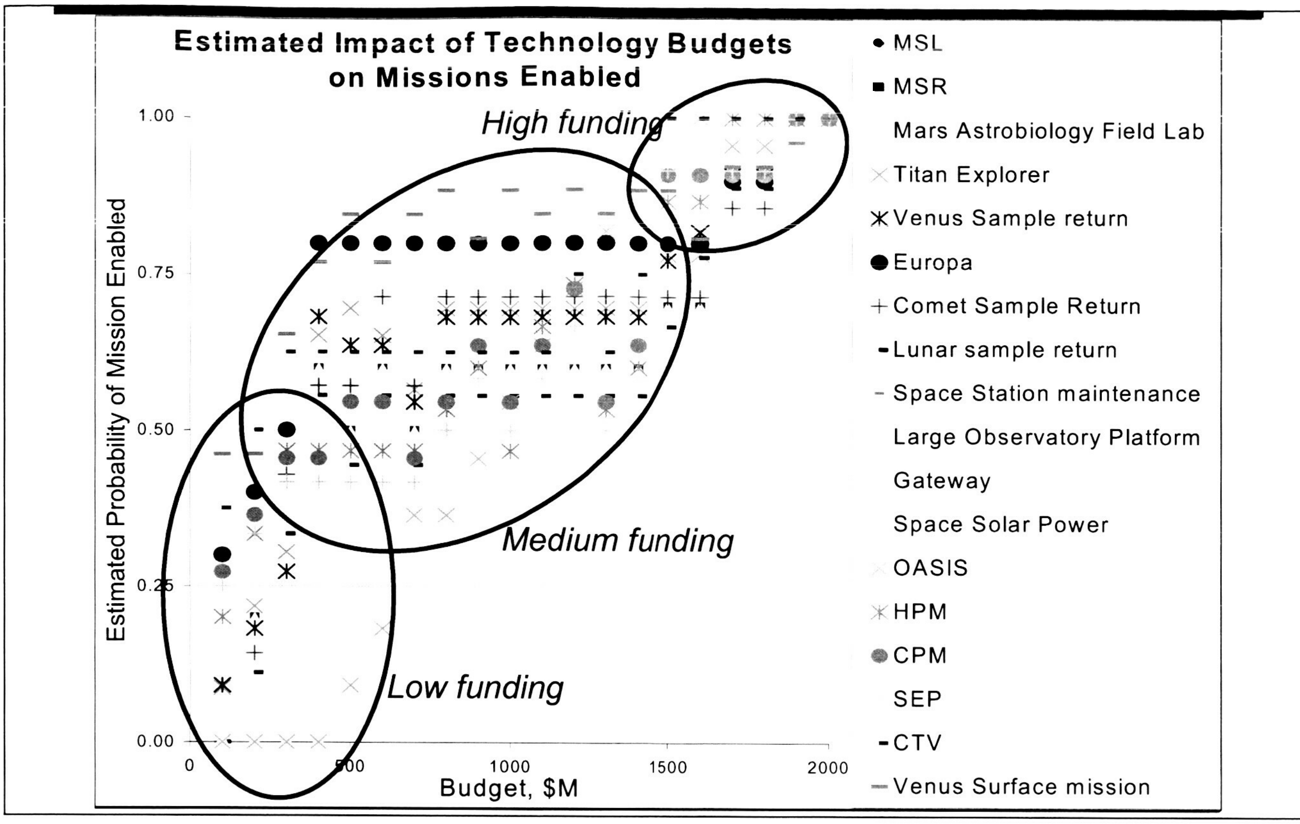
In Space Assembly
800
700
600
500
400
300
200
100
0
25 150 275 400 525 650 775 900 1025 1150 1275 1400
Budget, $M



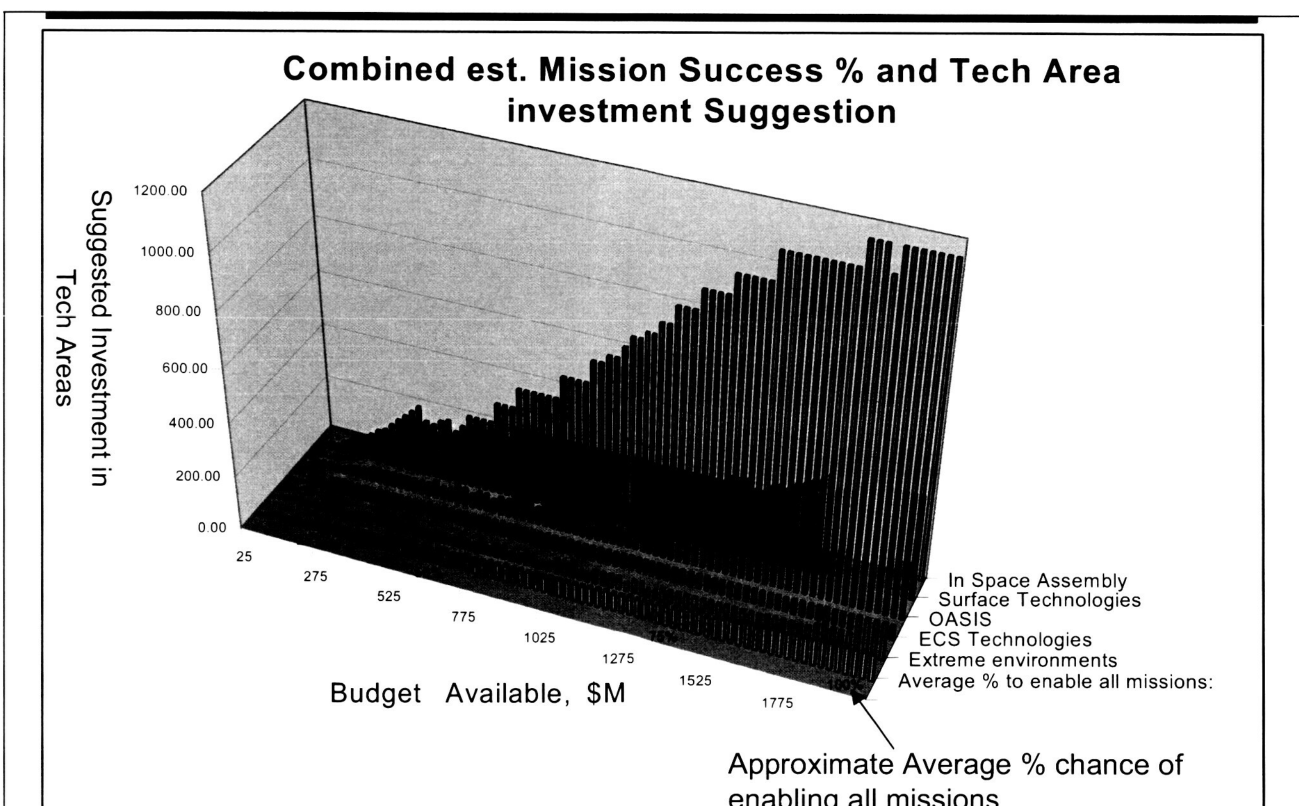
ECS Technologies
Investigating Methods/Tools
Data Mining Research
Risk Based Design
Risk Characterization/Visualizatin
System Complex Research
Mishaps/Anomaly Database
Risk Workstation
RISK Methods/Tools
Suggested $M for Each Area
60
50
40
30
20
10
0
25 150 275 400 525 650 775 900 1025 1150 1275 1400
Budget, $M


OASIS
Autonomous Robotic systems
Thermal Control
Materials
Large Space Structures
Energetics
Suggested $M for Each Area
0
20
40
60
80
100
120
140
160
180
200
25
150
275
400
525
650
775
900
1025
1150
1275
1400
Budget, $M


Extreme Environments/Venus Surface Mission
High Temperature Balloon Survivability
Pressure Vessel
Thermal Control
Extreme Temp & Pressure Components (460C/90bar)
Suggested $M for Each Area
0
20
40
60
80
100
120
25
150
275
400
525
650
775
900
1025
1150
1275
1400
Budget, $M



Estimated Impact of Technology Budgets on Missions Enabled
High funding
Medium funding
Low funding
Estimated Probability of Mission Enabled
1.00
0.75
0.50
0.25
0.00
0
500
1000
1500
2000
Budget, $M
MSL
MSR
Mars Astrobiology Field Lab
Titan Explorer
Venus Sample return
Europa
Comet Sample Return
Lunar sample return
Space Station maintenance
Large Observatory Platform
Gateway
Space Solar Power
OASIS
HPM
CPM
SEP
CTV
Venus Surface mission



Combined est. Mission Success % and Tech Area investment Suggestion
Suggested Investment in Tech Areas
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
25
275
525
775
1025
1275
1525
1775
Budget Available, $M
In Space Assembly
Surface Technologies
OASIS
ECS Technologies
Extreme environments
Average % to enable all missions:
Approximate Average % chance of enabling all missions

Concluding Remarks

- **Study Results to Date (January-March, 2004)**
  - Initial data base for 13 missions and 167 technology performance parameters in 23 technical areas, representing Code T,S,M,Y enterprises
  - Rapidly prototyped analysis capability to evaluate impact of technological investment on science and exploration return
- **Work Remaining (April-December, 2004)**
  - Expand data base to include more enabling missions and technologies (e.g. modular distributed structures, etc.)
  - Conduct more in-depth analysis of the representation and fidelity of the existing data set, and a more detailed treatment of the consistency and integration across program elements
  - Calibrate data base and analysis with extensive WHAT-IF computational