Multi-Mission Strategic Technology Prioritization Study


"Systematic Technology Prioritization For New Space Missions"

Humphrey’s Half Moon Inn, San Diego, CA

Jet Propulsion Laboratory
California Institute of Technology
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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)

- **Inner Solar System**
  - Venus Surface (1-site land)
  - Venus Surface (Multi-site-land)
  - Comet Sample Return

- **Earth Observation**
  - Biomass**

- **Earth’s Moon**
  - OASIS*
  - Lunar Sample Return
  - Remote Lunar Survey**
  - Lunar Precursor Resource Survey

- **Mars**
  - Mars Science Lab
  - Mars Scout Line
  - Mars Astrobiology Lab
  - Mars Sample Return

- **Outer Solar System**
  - Titan Surface
  - Europa Lander

➢ 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)

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

- 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)

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

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

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

This is an early draft for April 19th, 2004. Please do not distribute.
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
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

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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 and characterization of system risks and their relationships.
- Improve design techniques and tools for analysis and tracking of risk through the lifecycle.
- Improve breadth and accuracy of risk assessment methods.
- Combine disparate data, models, and tools into a risk management capability.

**Challenges**
- Risks not well understood or not 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 led 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**

<table>
<thead>
<tr>
<th>Attribute Definition</th>
<th>Best Case</th>
<th>Worst Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility of risk data</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Potential to reduce design risks</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Risk model enhancement</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>End-to-end risk integration</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Accessibility of risk data**: Easy to use DB spans multiple mission/projects with risk events categorized for search. DB may be limited to specific category or series of missions. 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**: 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. Technology helps identify risk data for Phase A/K; Large potential cost benefits if used. Provides a screen that limits potential risks from passing CDR.

- **Risk model enhancement**: Technology provides new approach for addressing design risk life-cycle or part of life-cycle not previously addressed (e.g., mgmt, org, risks). Technology either provides new, more effective approach for risk analysis or fills missing gap in temporal or breadth of risk analyses (but not both). Technology does not address missing gap in design life-cycle.

- **End-to-end risk integration**: Technology provides synergistic integration with other tools and databases fully compatible with emerging design environments (temporal and breadth). Risk technology allows interaction with common databases but cannot be integrated with other stand-alone applications. 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*

<table>
<thead>
<tr>
<th>Technology</th>
<th>Level</th>
<th>Metric</th>
<th>Unit</th>
<th>Polarity</th>
<th>SOA</th>
<th>Low</th>
<th>ML</th>
<th>High</th>
<th>$M</th>
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</thead>
<tbody>
<tr>
<td>ECS</td>
<td>1</td>
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<td></td>
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<tr>
<td>SRRM</td>
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<tr>
<td>RISK Methods &amp; Tools</td>
<td>4</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accessibility of Historical Risk Event Data</td>
<td>0-10</td>
<td>+</td>
<td>4</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential to Understand and Reduce Design Risks and Optimize Resources to Retire Risk</td>
<td>0-10</td>
<td>+</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk Model Enhancement (Potential for Better Model Credibility)</td>
<td>0-10</td>
<td>+</td>
<td>2</td>
<td>9</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-to-end Risk Integration for Breadth of Domain</td>
<td>0-10</td>
<td>+</td>
<td>2</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Extent of Needs Covered</td>
<td>0.1</td>
<td>+</td>
<td>0.5</td>
<td>0.7</td>
<td>0.8</td>
<td>0</td>
<td>9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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

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

High funding

Medium funding

Low funding

Combined est. Mission Success % and Tech Area investment Suggestion

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