A Process For Technology Prioritization In A Competitive Environment

In Space Propulsion Technology Project
NASA Marshall Space Flight Center
Karen Stephens & Melody Herrmann/NASA MSFC
Brand Griffin/Gray Research Inc.
42nd AIAA Joint Propulsion Conference
July 9 - 12, 2006
In-Space Propulsion Technology (ISPT) Project

Solar Electric

Solar Sails

Advanced Chemical

Aerocapture

Emerging
ISPT Focuses On Mid-TRL
Propulsion System Development and Integration

Flight Validation and Mission Implementation:
(Solar Electric Propulsion example)

NSTAR (Deep Space 1)

Dawn (In Development)

In-Space Propulsion Technologies

Advanced Chemical
Aerocapture
Solar Electric
Solar Sail

Research (not part of ISPT)

National Aeronautics and Space Administration
Mission Driven Technology Planning Activity

Objective:
Identify the current, most likely “need date” for each technology and create ISPT technology area development schedules based on this “mission pull”

Base schedules on:
• Launch date of first flight opportunity (pacing mission)
• Historic average for spacecraft program implementation phases

Ground Rules:
• All technologies require flight validation (except NSTAR Heritage or commercial EP)
• Minimum 4 years between successful flight validation and pacing mission

Schedule Driven by Launch Date

<table>
<thead>
<tr>
<th>ISTP Tech Development</th>
<th>Phase B</th>
<th>Phase C/D</th>
<th>Historic Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRL 6+</td>
<td>Launch</td>
<td>Flight Validation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Four years</td>
<td>Launch Pacing Mission</td>
<td></td>
</tr>
</tbody>
</table>

Historic Average:

- ESA Science Missions
- NMP (JPL)
- NASA, Level II Program Office
Mission Driven Technology Planning

Why was this activity undertaken?

- Content for upcoming NASA/ISPT NRA (2006 ROSES) was needed. Technology teams needed to formulate acquisition strategy for coming years' requirements. ISPT program management needed to prioritize acquisitions.

- Early planning for POP06 was underway.

- ISPT examining agency mission priorities and ISPT technology progress relative to evolving mission needs. Planning activity would enhance future reprioritization if budget fluctuations required it.

- Majority of ISPT technologies were maturing beyond the “tech push” (TRL 1-3) to “mission pull” (TRL 4-6) phase. Need for the program to orient to “1st mission” for product-focused forward progress.

ISPT needed to identify the “pacing mission” for each technology to determine optimal funding for each of the technology areas within the expected program budget.
ISPT Systems Analysis Technology Area for Independent Assessment

Charter of ISPT Systems Analysis:

- Provide quantified inputs to ISPT Technology Project management to support investment decisions through parametric studies to show benefits of in-space propulsion technologies compared to state-of-the-art for destinations approved by the Science Mission Directorate (SMD).

- Drive out technology development challenges by conducting concept definition studies in sufficient detail to identify potential problem areas that help define and focus technology investments.

- Develop systems analysis tools to promote common methods for reproducible results within each community.

Systems analysis provides a non-biased assessment for critical data used in determining funding priorities and program direction.
Systems Analysis
Studies, Trades & Improved Tools to Guide Investments

- Consistent LT Trajectories
- SOA algorithms/methods
- Multi-year, Inter-agency team

- Ion & Hall Engine Performance Sensitivity Studies
- Ion Propulsion Trades for Scout, Discovery & New Frontiers Missions Generating a Reference DRM
- Standard Architecture for Gridded Ion: System Definition & Requirements
- Aerocapture Mars System Study
- Multipass Aerocapture at Multiple Destinations
- Solar Sail Heliostorm Mission Study
- Solar Sail Reqs Definition for Adv Sails & Booms
- MXER Tether Analysis, Systems Planning & Tools

- Advanced Propellant & Engine Comparison Studies
- Advanced Chemical Propulsion System Model (ACPS)
- Aerocapture Probabilistic Risk Assessment
- Technology Infusion Studies
- Direct Trajectory Optimization Model
- Round Trip Mission Analysis Model
Central Question

- How should funding be allocated in a product focused technology development program?
  - Squeaky wheel gets the grease
  - Last up at bat
  - Best track record
  - Manager's pet project
  - None of the Above!

- Need a priority-driven process for sequencing technology development and allocating funding.
Process for Activity

- Assemble independent team for assessment & oversight
- Identify current agency mission priorities and mission definition
- Assess missions for ISPT technology applicability
- Identify potential "pacing mission" for all ISPT technologies
- Determine corresponding "need date" for each ISPT technology

Iterative Process

ISPT Management Input

Technology Team Response

Assessment Team Guidance

National Aeronautics and Space Administration
CRAI/APIO effort determined most applicable missions for ISPT technologies (2004)

Low Power EP Mission Technology Metrics for APIO

Drafts of both the SSE and SSSC Roadmaps provided the most recent mission priorities for SMD (2005)

STEAM effort assessed ISPT technologies for 52 candidate missions (2002 & 2003)
## SSE Mission Pull

<table>
<thead>
<tr>
<th>Source</th>
<th>Class</th>
<th>Mission Title</th>
<th>Launch Date</th>
<th>Solar Electric</th>
<th>Aerocapture</th>
<th>Sails</th>
<th>Adv Chem</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSE</td>
<td>NF</td>
<td>Pluto-Kuiper Belt Explorer</td>
<td>2006</td>
<td>NSTAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>NF</td>
<td>Lunar South Pole Aitken Basin</td>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>NF</td>
<td>Jupiter Polar Orbiter with Probes</td>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>NF</td>
<td>Venus In-Situ Explorer</td>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>NF</td>
<td>Comet Surface (Nucleus) Sample Return (CSSR)</td>
<td>2013</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>F</td>
<td>Europa Geophysical Observer</td>
<td>2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>F</td>
<td>Titan Explorer</td>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>F</td>
<td>Neptune System Mission</td>
<td>2025</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>F</td>
<td>Comet Cryo Nucleus Sample Return</td>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>F</td>
<td>Venus Sample Return</td>
<td>2020</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>F</td>
<td>Europa Astrobiology Lander</td>
<td>2025</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>Dis-</td>
<td>Near Earth Asteroid SR</td>
<td>every 2 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>Dis-</td>
<td>Comet Rendezvous</td>
<td>every 2 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSE</td>
<td>Dis-</td>
<td>Vesta-Ceres Rendezvous</td>
<td>every 2 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Venus Orbiter</td>
<td>every 2 years</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### ISP Technology

<table>
<thead>
<tr>
<th>Solar Electric</th>
<th>Aerocapture</th>
<th>Sails</th>
<th>Adv Chem</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSTAR</td>
<td>Blunt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NEXT</td>
<td>LB</td>
<td>~ 15 g</td>
<td></td>
</tr>
<tr>
<td>Hall</td>
<td>Inflat</td>
<td>5 - 15 g</td>
<td>&lt; 5 g</td>
</tr>
<tr>
<td>Lox-Hydrazine</td>
<td>Pump Fed</td>
<td></td>
<td>Mass Reductn</td>
</tr>
</tbody>
</table>

- **Applicable, studied**
- **Likely Applicable, needs study**

National Aeronautics and Space Administration
## SSSC Mission Pull

<table>
<thead>
<tr>
<th>Source</th>
<th>Class</th>
<th>Mission Title</th>
<th>Launch Date</th>
<th>ISP Technology</th>
<th>Adv Chem</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Solar Electric</td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Magnetospheric Multi-Scale</td>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Heliostorm</td>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>L1 Solar-Climate Explorer (L1SCE)</td>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Geospace Electrodynamic Connections (GEC)</td>
<td>2017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Inner Heliosphere Sentinels (IHS)</td>
<td>2017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>L1-Earth-Sun</td>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>L1-Missions</td>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Solar Orbiter (Phase 2??)</td>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Solar Probe</td>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>DOPPLER</td>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Aeronomy and Dynamics at Mars (ADAM)</td>
<td>2022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Solar Polar Imager</td>
<td>2024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Inner Magnetospheric Constellation (IMC)</td>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Interstellar Probe</td>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Io Electrodynamics</td>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>JPO</td>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Mars Atmospheric Reconnaissance Survey (MARS)</td>
<td>2027</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>MTRAP</td>
<td>2033</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Reconnection and Microscale (RAM)</td>
<td>2033</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSSC</td>
<td></td>
<td>Solar Connection Observatory ... (SCOPE)</td>
<td>2035</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **SSSC Mission Pull**
- **ISP Technology**
  - Solar Electric
  - Aerocapture
  - Sails
  - Adv Chem
- **Launch Date**
- **Applicable, studied**
- **Likely Applicable, needs study**
## Likely Announcement Opportunities

<table>
<thead>
<tr>
<th>History</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST4 Cancelled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST5 Selected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST6 Selected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST8 AO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST9 AO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Frontiers JUNO AO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Discovery AO</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Calendar Year

<table>
<thead>
<tr>
<th>Year</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **New Frontier** (3 years)
- **Discovery** (2 years)
- **New Millennium** (1 year)
- **ISPT** (1 year)

---

National Aeronautics and Space Administration
NASA Development/Procurement

Hardware and Software for entire spacecraft

Pre Phase A

MISSION FEASIBILITY
• Goals and Objectives
• Concept/Design Evaluation Criteria
• Mission Concepts
• Life Cycle Cost Estimates
• Feasibility Assessment

Phase A

MISSION DEFINITION
• Mission Need Statement
• Functional Mission Concept
• Science Requirements
• Trade and Analysis Results
• Technology Development Plan

Phase B

SYSTEM DEFINITION/PRELIM DESIGN
• Systems Engineering Mgt Plan
• Risk Mgt Plan
• Configuration Mgt
• Science Payloads
• Verification Requirements
• Concept of Operations
• Trades and Analysis

Phase C/D

DESIGN DEVELOPMENT
• Lower level Design Specs
• Refine Requirements Doc
• Refine Verification Doc
• Interface Doc
• Mfg Plan
• End-to-end systems design
• Integrated Logistics Support

National Aeronautics and Space Administration
Schedule Logic

Technology Development

Pre Phase A

Competitive

Phase A

Program Implementation

Development to TRL 6+

Single Prime Contractor

Phase B

Launch
(Pacing Mission)

Phase C/D

4 yrs* (<$450m)

5 yrs** (>=$450m)

** Average of available data for NASA & ESA missions

National Aeronautics and Space Administration
Pacing Mission Selection

Similar Development Paths with flight validation and major mission pull

Solar Sail Propulsion
• Flight validation required
• 2016 Heliostorm is pacing mission (optimistic schedule)

Aerocapture Technology
• Flight validation required
• 2020 Titan Explorer is pacing mission for blunt body
• 2025 Neptune System Mission is pacing mission for lifting body

Technologies will be used as soon as developed

Plan to Announcement of Opportunity (Discovery Class ~ every 2 yrs.)

Solar Electric Propulsion
• 2007 Discovery AO for NSTAR with Near Earth Asteroid pacing mission
• 2007 Discovery AO for NEXT with CSSR pacing mission
• 2007 Discovery AO for Hall with Comet Rendezvous pacing mission

Advanced Chemical Propulsion
• 2007 Discovery AO, 2011 Jupiter Orbiter with Probes for High Temperature Rocket
• 2007 Discovery AO, 2013 CSSR for LOX-Hydrazine
• 2007 Discovery AO, 2020 Comet Cryo Nucleus SR for pump fed
Pacing Mission Technologies 2/2

NFAO NF AO NF AO NF AO NF AO NF AO NF AO NF AO

Electric Prop
- NSTAR
- NEXT
- HALL

Advanced Chem
- High Temp Rocket
- LOX-Hydrazine
- Pump Fed

TAM development schedule
National Aeronautics and Space Administration
Follow-on Activities

- Each Technology Area used the identified technology "need date" to back out a development schedule.
  - In some cases, the need date was either not technically or programmatically possible. A later opportunity would become the pacing mission for technology development.

- A pacing mission that was in the near future served to increase the priority for funding. A pacing mission that was much later decreased funding priority.

- After initial programmatic priorities and budgets were set, Technology Areas updated development flows and corresponding project schedules. The funding negotiation was an iterative process.

- The outcome was a much vetted and thoroughly scrubbed program spending plan that was presented to SMD Management as a technology development plan for FY06 and out years.

- FY06 Mid year (and beyond) budget reductions disallowed total implementation of the development plan produced.
  - The process, resulting priorities and technology development plans allowed for timely restructuring of the budget/content for ISPT after the budget reductions
  - Program remains focused on high-priority product deliveries that will stay as aligned to customer priorities as possible