NASA Technology Roadmap Interim Report

Aeronautics and Space Engineering Board
National Research Council of the National Academies
September 2011

Agenda

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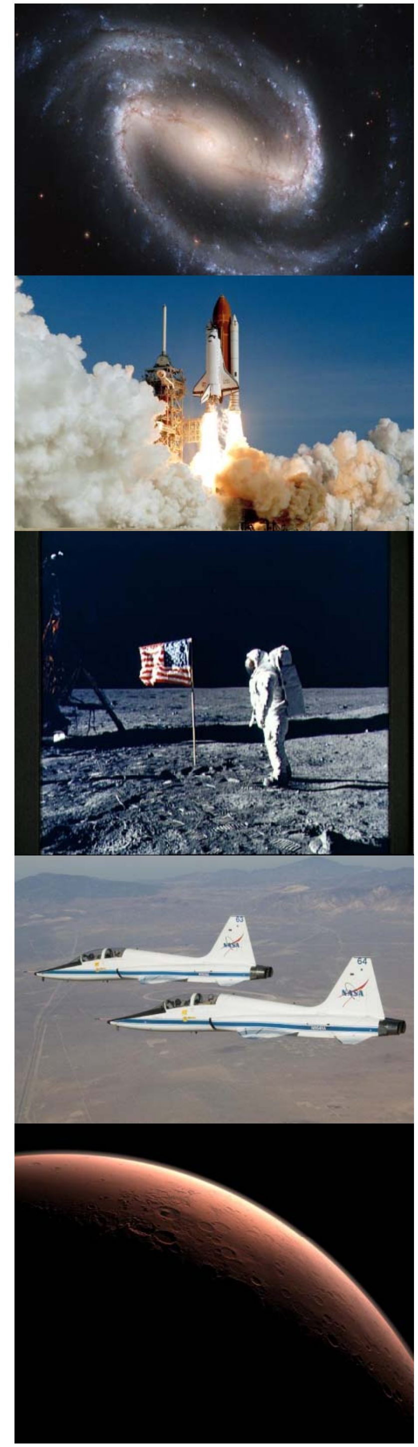

Statement of Task

- The NRC will appoint a steering committee and up to seven panels to solicit external inputs to and evaluate the 14 draft technology roadmaps that NASA has developed as a point of departure. The study committee will also provide recommendations that identify and prioritize key technologies. The scope of the technologies to be considered includes those that address the needs of NASA's exploration systems, Earth and space science, and space operations mission areas, as well as those that contribute to critical national and commercial needs in space technology. (This study will not consider aeronautics technologies except to the extent that they are needed to achieve NASA and national needs in space; guidance on the development of core aeronautics technologies is already available in the National Aeronautics Research and Development Plan.)

Statement of Task (continued)

- The steering committee and panels will prepare two reports, as follows;
  - The steering committee will establish a set of criteria to enable prioritization of technologies within each and among all of the technology areas that the NASA technology roadmaps should satisfy.
  - Each panel will conduct a workshop focused on one or more roadmaps, as assigned, to solicit feedback and commentary from industry and academia on the 14 draft roadmaps provided by NASA at the initiation of the study. Other means of community engagement may be employed including submission of community white papers.
  - Based on the results of the community input and its own deliberations, the steering committee will prepare a brief interim report that addresses high-level issues associated with the roadmaps, such as the advisability of modifying the number or technical focus of the draft NASA roadmaps.

Statement of Task (continued)

- Each panel will meet individually to:
  - Suggest improvements to the roadmaps in areas such as:
    - the identification of technology gaps,
    - the identification of technologies not covered in the draft roadmaps,
    - development and schedule changes of the technologies covered,
    - a sense of the value (such as potential to reduce mass and/or volume, number of missions it could support, new science enabled, facility to operate, terrestrial benefit) for key technologies,
    - the risk, or reasonableness, of the technology line items in the NASA technology roadmaps, and
    - the prioritization of the technologies within each roadmap by groups such as high, medium, or low priority; this prioritization should be accomplished, in part, via application of relevant criteria described above and in a uniform manner across panels.
  - Prepare a written summary of the above for the steering committee

Statement of Task (continued)

- The steering committee will subsequently develop a comprehensive final report that
  - Summarizes findings and recommendations for each of the 14 roadmaps
  - Integrates the outputs from the workshops and panels to identify key common threads and issues
  - Prioritizes, by group, the highest priority technologies from all 14 roadmaps

Committee Membership

Steering Committee

Raymond S. Colladay, Chair

John D. Anderson, Jr.
James B. Armor, Jr.
Edward F. Crawley
Ravi B. Deo
Walt Faulconer
Phillip D. Hattis
Tamara E. Jernigan
John C. Karas
John M. Klineberg
Ivett A. Leyva
Lester L. Lyles
H. Jay Melosh
Daniel R. Mulville
Dava J. Newman
Richard R. Paul
Liselotte J. Schioler
Gerald Schubert

Panel One: TA01,02,03,13
John R. Rogacki, Chair
Douglas M. Allen
Henry W. Brandhorst, Jr.
David E. Crow
Alec D. Gallimore
Mark W. Henley
Anthony K. Hyder
Ivett A. Leyva (L)
Paulo Lozano
Joyce A. McDevitt
Rogers M. Myers
Lawrence J. Ross
Raymond J. Sedwick
George F. Sowers

Panel Two: TA04,05
Stephen P. Gorevan, Chair
Julie A. Adams
Edward J. Groth, III
Phillip D. Hattis (L)
Jonathan P. How
James W. Lowrie
David P. Miller
Jonathan Salton
Donna L. Shirley
George W. Swenson, Jr.

Panel Three: TA08,11
James L. Burch, Chair
Philip E. Ardanuy
Webster Cash
John A. Hackwell
Robert J. Hanisch
David Y. Kusnierkiewicz
Joel R. Primack
Gerald Schubert (L)
Daniel A. Schwartz
Alan M. Title
Daniel Winterhalter
Carl Wunsch

Panel Four: TA06,07
Bonnie J. Dunbar, Chair
David L. Akin
Dallas G. Bienhoff
Robert L. Curbeam, Jr.
Gregory J. Harbaugh
Tamara E. Jernigan (L)
Daniel R. Masys
Eric E. Rice
Ronald E. Turner

Panel Five: TA10,12,14
Mool C. Gupta, Chair
Gregory R. Bogart
Donald M. Curry
John R. Howell
George A. Lesieutre
Liselotte J. Schioler (L)
Robert E. Skelton
George W. Sutton

Panel Six: TA09
Todd J. Mosher, Chair
John D. Anderson, Jr. (L)
Tye M. Brady
Basil Hasaan
Stephen Ruffin
Robert J. Sinclair
Byron D. Tapley
Beth E. Wahl
Gerald D. Wahlberg

L: Liaison Member

Technology Roadmap Organization

Panel 1: Propulsion and Power

TA01: Launch Propulsion Systems
TA02: In-Space Propulsion Systems
TA03: Space Power and Energy Storage Systems
TA13: Ground and Launch Systems Processing

Panel 2: Robotics, Communications, and Navigation

TA04: Robotics, Tele-Robotics, and Autonomous Systems
TA05: Communication and Navigation Systems

Panel 3: Instruments and Computing

TA08: Scientific Instruments, Observatories, and Sensor Systems
TA11: Modeling, Simulation, Information Technology, and Data Processing

Panel 4: Human Health and Surface Exploration

TA06: Human Health, Life Support and Habitation Systems
TA07: Human Exploration Destination Systems

Panel 5: Materials

TA10: Nanotechnology
TA12: TA12 Materials, Structures, Mechanical Systems, and Manufacturing
TA14: Thermal Management Systems

Panel 6: Entry, Descent and Landing

TA09: Entry, Descent and Landing Systems

Study Schedule

Committees Approved	January 2011
First Meetings – Panels	January 2011
First Meeting – S.C.	January 25-27, 2011
Second Meetings – Panels	March/April 2011
Second Meeting – S.C.	May 18-20, 2011
Third Meetings – Panels	May/June 2011
Fourth Meetings – Panels	June/July 2011
Interim Report to Review	June 15, 2011
Third Meeting – S.C.	August 9-11, 2011
Interim Report to NASA	August 25, 2011
Fourth Meeting – S.C.	September 20-22, 2011
Final Report to Review	November 5, 2011
Final Report to NASA	January 24, 2012

Public Input

- Each technology roadmap was the subject of a public workshop, where the technology panels engaged with invited speakers, guests, and members of the public in a dialogue on the technology areas and their value to NASA.
- Community input was solicited from a public website, where 144 individuals completed 244 public input forms on the technologies that appear in the draft roadmaps. The individuals providing these inputs included 91 personnel from NASA, 6 from other government organizations, 26 from industry, 16 from academia, and 5 from other organizations or no organization at all.

Public Input (continued)

- The data included in the public input forms can be found online at:
  http://www8.nationalacademies.org/asebsurvey/tabs/publicview.aspx

- In addition, 87 sets of general comments were received via e-mail from 7 individuals who completed the public input forms and 68 individuals who did not. These individuals included 47 personnel from NASA, 1 from another government agency, 7 from industry, 4 from academia, 5 from other organizations, and 11 whose organization is unknown.

Interim Report

» Observations

NASA Technology Roadmaps and NASA's Technology Base

- Success in executing future NASA space missions will depend on advanced technology developments that should already be underway.
- NASA's technology base is largely depleted
- Currently available technology is insufficient to accomplish many intended space missions in Earth orbit and to the Moon, Mars, and beyond.
- Future U.S. leadership in space requires a foundation of sustained technology advances

NASA Technology Roadmaps and NASA's Technology Base (continued)

- A robust space technology base is urgently needed to:
  - assure the future of U.S. leadership in space
  - enhance technology readiness of new missions and mitigate technological risks
  - improve the quality of cost estimates and thereby contribute to better overall mission cost management

- Technology roadmaps that lay out the time sequencing and interdependencies of high-priority advanced space technology R&D over the next 5 to 30 years will enhance the effectiveness of efforts to reinvigorate the technology base

General Management Practices

- **Program Stability**
  - Stability is important in the short term to avoid disrupting individual programs and in the long term to ensure that other federal agencies, industry, academia, and foreign organizations recognize NASA as a reliable partner.
- **Evolutionary Improvements and Intermediate Goals**
  - Pursuing evolutionary improvements and setting intermediate goals . . . lead to time-phased applications, promote sustainable facilities and workforce within industry, and improve NASA's ability to manage its resources and provide effective oversight.
- **Focus and Flexibility**
  - Balance is needed between support of focused technological approaches and support of technologies that accommodate a wide range of destination and schedule options.

*NASA recognizes the importance of these practices and the steering committee understands that some involve issues, such as facility capability and workforce needs, that are not directly OCT's responsibility.

General Management Practices (continued)

- **Flight Testing and Demonstration**
  - Flight opportunities to test and demonstrate the performance of new technologies under realistic flight conditions are necessary for many of the technologies in the roadmaps.

- **Facilities**
  - Facility issues are of concern for some key technologies covered by the draft NASA roadmaps.
  - Recognized as largely outside the scope and responsibility of OCT

- **Cooperative Development of Technology**
  - Roadmaps would be more valuable and actionable if they provided more detail about how various goals may be accomplished through partnerships with outside organizations.

Integrated Approach to Technology Development

Precision Landing Systems

- Precision landing and assured hazard avoidance capabilities do not yet exist, and as a result, several missions have come very close to failure during the landing process.
- Advances in GN&C, propulsion, autonomous system, sensor, and EDL technologies—as well as related engineering development—are necessary to reduce navigational uncertainty.

Guidance, Navigation and Control

- An integrated approach to GN&C is required because one roadmap (TA05) is focused on communications and navigation systems, while guidance and control show up separately in at least two other roadmaps on robotics, telerobotics, and autonomous systems (TA04) and entry, descent, and landing (TA09).

Integrated Approach to Technology Development (continued)

Launch from Locations other than Earth

- Advances are needed in technologies related to TA02 In-Space Propulsion Technologies, TA04 Robotics, Telerobotics & Autonomous Systems, TA07 Human Exploration Destination Systems, TA12 Materials, Structures, Mechanical Systems & Manu., and TA13 Ground & Launch Systems Processing.

Radiation Protection

- An integrated approach is needed to meet . . . challenges associated with space radiation: TA02 In-Space Propulsion Technologies, TA03 Space Power & Energy Storage, TA06 Human Health, Life Support & Habitation Systems, TA08 Science Instruments, Observatories and Sensor Systems, TA10 Nanotechnology, and TA12 Materials, Structures, Mechanical Systems & Manufacturing.

Additional Observations

- **Human Factors and Knowledge Integration**
  - Developers of space technology could more easily access and understand relevant human factors considerations if
    - Consolidated crew comments (on human factors, stowage, psychology, exercise, and so on) from the Apollo, Skylab, Shuttle, and Shuttle Spacelab/Spacehab programs were integrated into an existing electronic ISS data base
    - NASA Standard 3001 and the Apollo-ISS crew data bases were made accessible to all U.S. developers of exploration technology
  - Also worthwhile to integrate human factors requirements and experience into the roadmap TA04 for human-robot compatible designs, TA06 Human Health, Life Support & Habitation Systems, and TA07 Human Exploration Destination Systems.

Interim Report

- Roadmap Gaps and Structure

Crosscutting Gap: Commercial Space

- Identify how the commercial space sector could benefit from advanced technology
- Develop pre-competitive technology relevant to the needs of the commercial space sector, in much the same way that NASA supports pre-competitive technology development in support of the aeronautics industry.
- Transfer advanced technologies to U.S. industry to help satisfy the needs of the commercial space sector as well as NASA's own mission needs.

Crosscutting Gap: Avionics

It is appropriate for NASA to support the development of avionics technologies that are uniquely driven by NASA mission requirements. These technologies would contribute to the following capabilities:

- High computation rates and high data throughput for avionics components that are intrinsically radiation hard.
- Fault-tolerant processing. Processor faults can lead to mission failure. Technology advancements in fault tolerant processing would improve future vehicle safety and mission reliability.
- Fully coordinated, reliable, and successful operation of complex, highly integrated avionics systems. The complexity and density of avionics systems for some future space vehicles will press the state of the art.

Crosscutting Gap: Space Weather Beyond Radiation Effects

The technology roadmaps as a whole do not adequately address the broader impacts of space weather:

- Spacecraft charging and discharging from plasma effects
- Single event effects (SEE) in electronics
- Thermal and material degradation from exposure to UV and atomic oxygen
- Communication and navigation disruption from x-rays and geomagnetic storms
- Enhanced orbital drag from atmospheric heating

Revised Technology Area Breakdown Structure

TABS Includes 3 Levels

Level 1: Technology area
(Example: TA01 Launch Propulsion Systems)

Level 2: Technology subarea
(Example: 1.1 Solid Rocket Propulsion Systems)

Level 3: Technology
(Example: 1.1.1 Propellants)

Revised Technology Area Breakdown Structure

- The steering committee and the panels modified the TABS for some of the technology areas, primarily for the purpose of filling technology gaps within a particular roadmap. The revised TABS forms the basis of the committee's evaluation and prioritization, which will be reported against that structure in the final report.

Changes to TABS:
TA02 In-Space Propulsion Technologies

Four technologies have been deleted:

2.4.1: Engine Health Monitoring and Safety
2.4.3: Materials and Manufacturing Safety
2.4.4: Heat Rejection
2.4.5: Power

None of these technologies fall under the scope of TA02, and Roadmap TA02 is not suggesting that any of them should be developed as part of TA02.

Changes to TABS:
TA03 Space Power and Energy Storage

Two new technologies have been added:

3.2.4: Electric and Magnetic Field Storage

3.2.5: Thermal Storage

Changes to TABS: TA04 Robotics, Tele-Robotics, & Autonomous Systems

- In order for this roadmap to describe and provide supporting text for each of the level 3 technologies (like the other roadmaps), it would need to be largely rewritten.
- The breakdown structure in the existing TA04 roadmap (Fig 2) does not correlate to any of the roadmap's supporting text below level 2.
- A new set of level 3 technologies was developed . . . consistent both with the relevant panel's understanding of applicable TA04 technology needs and with the intent of much of the existing roadmap text.

Changes to TABS: TA04 Robotics, Tele-Robotics, & Autonomous Systems

- Some new level 3 technologies address important technology gaps within the existing TA04 roadmap:
  - 4.1.6 Multi-Sensor Data Fusion
  - 4.1.7 Mobile Feature Tracking and Discrimination
  - 4.2.1 Extreme Terrain Mobility
  - 4.2.2 Below Surface Mobility
  - 4.3.3 Modeling of Contact Dynamics
  - 4.3.4 Mobile Manipulation
  - 4.4.4 Intent Recognition and Reaction
  - 4.4.7 Safety, Trust and Interfacing of Robotic/Human Proximity Operations
  - 4.5.3 Autonomous Guidance and Control
  - 4.5.5 Adjustable Autonomy
- The other new level 3 technologies reorder, restate, or regroup the entries from the original TABS.

Changes to TABS:
TA05 Communication and Navigation

- 5.4.1 Timekeeping and 5.4.2 Time Distribution have been merged to form 5.4.1 Timekeeping and Time Distribution.
- 5.6.7 Reconfigurable Large Apertures have been renamed Reconfigurable Large Apertures Using Nanosat Constellations.

TA06 Human Health, Life Support, & Habitation Systems

- 6.5.4 Space Weather Prediction has been renamed Radiation Prediction.

Changes to TABS: TA07 Human Exploration Destination Systems

Renamed Technologies:

- 7.1.3 Consumables Production; now ISRU Products/Production
- 7.2.1 Logistics System; now Autonomous Logistics

Added Technologies:

- 7.2.4 Food Production, Processing & Preservation
- 7.4.3 Smart Habitats
- 7.5.5 Integrated Flight Operations Systems
- 7.5.6 Integrated Risk Assessment Tools

Deleted Technologies:

- 7.5.2 Environmental Protection
- 7.5.3 Remote Mission Operations
- 7.5.4 Planetary Safety
- 7.6.1 Modeling, Simulations, & Destination Characterization

Changes to TABS:
TA08 Science Instruments, Observatories & Sensor Systems

Renamed Technologies:

- 8.1.3 Optical Components and 8.2.1 Mirror Systems were merged and renamed 8.1.3 Optical Systems
- 8.3.1 Particles: Charged & Neutral and 8.3.2 Fields and Waves were merged to form 8.3.1 Particles, Fields and Waves: Charged and Neutral Particles, Magnetic and Electric Fields

Added Technologies:

- 8.1.7 Space Atomic Interferometry
- 8.2.4 High Contrast Imaging and Spectroscopy Technologies
- 8.2.5 Wireless Spacecraft Technologies

Changes to TABS:
TA09 Entry, Descent & Landing Systems

- 9.1.5 Instrumentation and Health Monitoring has been moved to technology subarea 9.4 Vehicle System Technology and redesignated 9.4.6.
- Modeling & Simulation for Entry (9.1.6), Descent (9.2.5), and Landing (9.3.6) have been combined into a new level three technology (9.4.5 Modeling and Simulation) in technology subarea 9.4, Vehicle Systems Technology.
- GN&C sensors (9.2.4) and large body GN&C (9.3.4) have been combined into a new level 3 technology (9.4.7, GN&C Sensors & Systems)
- 9.4.1 Architecture Studies was deleted.

Changes to TABS:
TA10 Nanotechnology

- The steering committee made no changes to the structure of this roadmap, although the technologies in NASA's draft roadmap reflected seven changes relative to the TABS.

TA11 Modeling, Simulation, Information Technology & Processing

- 11.2.4 Science and Engineering Modeling has been split in two:
  - 11.2.4a Science Modeling & Simulation
  - 11.2.4b Aerospace Engineering Modeling & Simulation

Looking Ahead

The final report for this study, which will be issued early in 2012, will provide specific guidance on how the effectiveness of the technology development program managed by NASA's Office of the Chief Technologist can be enhanced in the face of scarce resources by focusing on the highest priority technologies.