Free Executive Summary

Review of NASA's Exploration Technology Development Program: An Interim Report

Committee to Review NASA's Exploration Technology Development Program, National Research Council

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Summary

NASA requested that a committee under the auspices of the National Research Council's Aeronautics and Space Engineering Board carry out an assessment of NASA's Exploration Technology Development Program (ETDP). Organizationally, this program functions under the direction of NASA's Exploration Systems Mission Directorate and is charged with developing new technologies that will enable NASA to conduct future human and robotic exploration missions, while reducing mission risk and cost. The Committee to Review NASA'S Exploration Technology Development Program has been tasked to examine how well the program is aligned with the stated objectives of the President's Vision for Space Exploration (VSE), to identify gaps in the program, and to assess the quality of the research. The full statement of task is given in Appendix A. The committee consists of 25 members and includes a cross section of senior executives, engineers, researchers, and other aerospace professionals drawn from industry, universities, and government agencies with expertise in virtually all the technical fields represented within the program.

On October 10-11, 2007, the committee held a general data-gathering meeting at which representatives from NASA headquarters briefed the members on the ETDP. The meeting was followed by site visits from subsets of the full committee to three NASA centers for detailed presentations on each of the 22 individual program projects. A lead specialist and at least two other committee members were selected to concentrate on each project; their reports have been discussed by all other members of the committee by e-mail and in three teleconferences. The results of the committee's study as of December 2007 are described in the present interim report. The committee's final report, described below, is planned for release in the summer of 2008.

Chapter 1 focuses on an assessment of the 22 individual projects that form the ETDP. The objectives and status of each project are summarized. Chapter 2 discusses cross-cutting issues, i.e., issues that transcend a given project and that became evident during the course of the committee's work.

Each of the 22 ETDP projects was evaluated on the basis of:

1. The quality of the research, taking into account the research team, facilities, and the plan to achieve the objectives.
2. The effectiveness with which the research is carried out and transitioned to the Exploration Program, including progress to date, apparent gaps in the program, and the likelihood that the required technology readiness level (TRL) will be reached. (The committee decided that simply noting gaps, as requested in the study task, was too narrow an objective and that "effectiveness," as defined here, was more appropriate and inclusive.)

3. The degree to which the research is aligned with the Vision for Space Exploration, specifically, the degree to which the program included exploration beyond the Moon.

In each of these three areas, the projects were rated using a flag whose color represents the committee's consensus view:

- Gold star. Quality unmatched in the world; on track to deliver or exceed expectations.
- Green flag. Appropriate capabilities and quality, accomplishment, and plan. No significant issues identified.
- Yellow flag. May contain risks to project/program. Close attention or remedial action may be warranted.
- Red flag. This area threatens the success of the project/program. Remedial action is required. (Not used to indicate the degree of alignment with the Vision for Space Exploration.)

A summary of the ratings is provided in Table S-1. A few topics were given two flag colors due to major distinctions between elements in the topic. Detailed observations on each project are presented in Chapter 1.

At the conclusion of the site visits, the committee came away with an appreciation of the enormity of the task faced by the NASA workforce engaged in the Exploration Technology Development Program, especially in light of the constraints imposed by a limited budget relative to the exploration goals, the timescale laid out for meeting the requirements of the Vision for Space Exploration, and the desire to fully employ the NASA workforce at all of its centers. In spite of these constraints, the committee was impressed with the intensity of the effort, the dedication and enthusiasm of the personnel to play a part in contributing to the VSE, the degree to which inter-NASA-center cooperation has developed, and the fact that all 10 NASA centers are engaged in the program.

Reflecting on its site visits, and its subsequent investigation and analysis, the committee cites the following specific issues that cut across individual project lines; they will receive further analysis by the committee in the next months, and related findings and recommendations will be provided in the committee's final report.

1. Some of the ETDP projects are carried out primarily within NASA centers. As a result, NASA is not taking advantage of expertise available in the university and industrial sectors that could support more rapid and higher-quality early research and development. The committee therefore concluded that the speed and efficiency with which NASA could move forward on these projects are being compromised.
2. The committee notes a general tendency toward an incremental approach to ETDP developments, with the bulk of ETDP funding going to incremental advances on existing technologies. The committee questions

whether this approach can allow NASA to successfully undertake and accomplish the innovative research goals of the VSE, especially as a lack of innovative R&D will discourage the entry of young researchers into the field and thus decrease the nation's ability to build the future workforce that will conduct the VSE.

3. Many of the technology development projects reviewed by the committee tended to focus on supporting near-term aspects of the VSE. Some were linked exclusively to Orion and Ares 1, and others to the lunar surface access module and lunar surface operations. The committee did not find evidence that the extensibility of technologies to the exploration of Mars is a routine consideration. A possible consequence is the development of technologies that will not be extensible to the full VSE, which was the criterion mandated by NASA for evaluation in this NRC review.

4. It was apparent that NASA is now funding much less research at low Technology Readiness Levels (TRLs) in-house and in the university community than in the past. The committee was not clear as to how, in the absence of low-TRL research, the technologies required over the next 10-30 years will be developed and made available for future programs, or how the future expertise required by both NASA and the contractor community will be generated. The significant reduction and/or termination of low-TRL research, and the concomitant lack of personnel to either conduct the research or apply it, will have major negative impacts on the ability of the United States to participate in future human exploration programs.

5. In a number of areas, mission-critical tests -- i.e., a system/subsystem model or prototype demonstration in an operational environment -- are not included in the program, usually as a result of a lack of time (scheduling) and/or funding to carry out necessary flight tests or to develop needed test facilities. Specific examples were identified in the following programs: 02 Ablative Thermal Protection System for CEV, 03 Lunar Dust Mitigation, 05 Cryogenic Fluid Management, 09 Integrated Systems for Health Management, 11 Intelligent Software Design, 12 Autonomous Landing and Hazardous Avoidance Technology, 19 In Situ Resource Utilization, 20 Fission Surface Power, and 22 Human Robotic Systems/Analogs. Not including these tests limits the TRL to which the technologies can be advanced and may increase mission risk. Although near term budgetary pressures are clear, the need for adequate testing is a recurrent theme in program failure reports and should be addressed.

These topics will be explored and commented on in more detail in the committee's final report.

The committee hopes that the observations made in this interim report will contribute to the ultimate success of the Exploration Technology Development Program.

TABLE S-1 Summary of the Committee's Ratings of NASA's ETDP Projects

Project Name	Quality	Effectiveness	Alignment
1 Structures, Materials, and Mechanisms	Yellow	Yellow	Yellow
2 Ablative Thermal Protection System	Yellow	Yellow	Yellow
3 Lunar Dust Mitigation	Green	Red	Yellow
4 Propulsion	Green	Green	Green
5 Cryo Fluid Management	Yellow	Yellow	Yellow
6 Energy Storage	Green, Yellow	Green, Yellow	Green
7 Thermal Control	Yellow	Green	Yellow
8 High Performance and Rad-hard Electronics	Yellow	Yellow	Green
9 Integrated Systems for Health Management	Green	Yellow	Green
10 Autonomy for Operations	Yellow	Yellow	Green
11 Intelligent Software Design	Green	Yellow	Green
12 Autonomous Landing and Hazard Avoidance	Gold star	Green	Green
13 Automated Rendezvous and Docking	Yellow	Yellow	Yellow
14 Exploration Life Support	Green	Yellow	Yellow
15 Advanced Environmental Monitoring and Control	Green, Red	Green, Red	Green
16 Fire Prevention, Detection and Suppression	Green	Yellow	Green
17 EVA Technologies	Yellow	Yellow	Yellow
18 ISS Research	Green	Yellow	Yellow
19 In-Situ Resource Utilization	Green	Red	Green
20 Fission Surface Power	Green	Yellow	Gold star
21 Supportability	Green	Yellow	Green
22 Human Robotic Systems/Analogs	Green	Yellow	Green
Totals			
Gold star	1	0	1
Green	13	5	12
Yellow	9	16	9
Red	1	3	0

Definition of colors:

- Gold star: Quality unmatched in the world; on track to deliver or exceed expectations
- Green flag: Appropriate capabilities and quality, accomplishment, and plan. No significant issues identified
- Yellow flag: May contain risks to project/program. Close attention or remedial action may be warranted
- Red flag: This area threatens the success of the project/program. Remedial action is required

Table S-1. A summary table of the committee's ratings of each ETDP project with regard to the project's quality, effectiveness in developing and transitioning, and Alignment with the Vision for Space Exploration.

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An Interim Report

Committee to Review NASA's Exploration Technology Development Program
Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

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Preface

In January 2004, President George W. Bush announced new goals for by issuing the Vision for Space Exploration (VSE). The fundamental goal of the VSE is to advance U.S. scientific, security, and economic interests through a robust space exploration program.[1] In support of this goal, the United States will:

- Implement a sustained and affordable human and robotic program to explore the solar system and beyond;
- Extend human presence across the solar system, starting with a human return to the Moon by the year 2020, in preparation for human exploration of Mars and other destinations;
- Develop the innovative technologies, knowledge, and infrastructures both to explore and to support decisions about the destinations for human exploration; and
- Promote international and commercial participation in exploration to further U.S. scientific, security, and economic interests.

Because exploratory voyages lead to an understanding of the unknown, the benefits of exploration cannot be precisely defined in advance, but the committee believes that

- Preparing for exploration accelerates the development of technologies important for our economy and national security,
- Inspiring young people to seek careers in science and engineering is critical to our future competitiveness, and
- Discovering new knowledge about the universe will stimulate human thought and creativity in the sciences and the humanities.

The human exploration aspect of the NASA initiative to fulfill the VSE is entrusted under the current NASA organization to the Exploration Systems Mission Directorate (ESMD). To meet its objectives, ESMD must develop the enabling technologies for its missions of exploration. NASA's Exploration Technology Development Program (ETDP) is part of the Advanced Capabilities Theme of ESMD, as shown in Figure P-1. ETDP develops new technologies that will enable NASA to conduct future human and robotic exploration missions, while reducing mission risk and cost. At present, the primary customers of the ETDP are the designers of flight systems in the Constellation

[1] Executive Office of the President and National Aeronautics and Space Administration. 2004. Vision for Space Exploration. National Aeronautics and Space Administration, Washington, DC. Available at http://www.nasa.gov/mission_pages/exploration/main/index.html [Accessed 3/27/2008].

program, which is developing the Orion, Altair, and Ares crew launch vehicle.

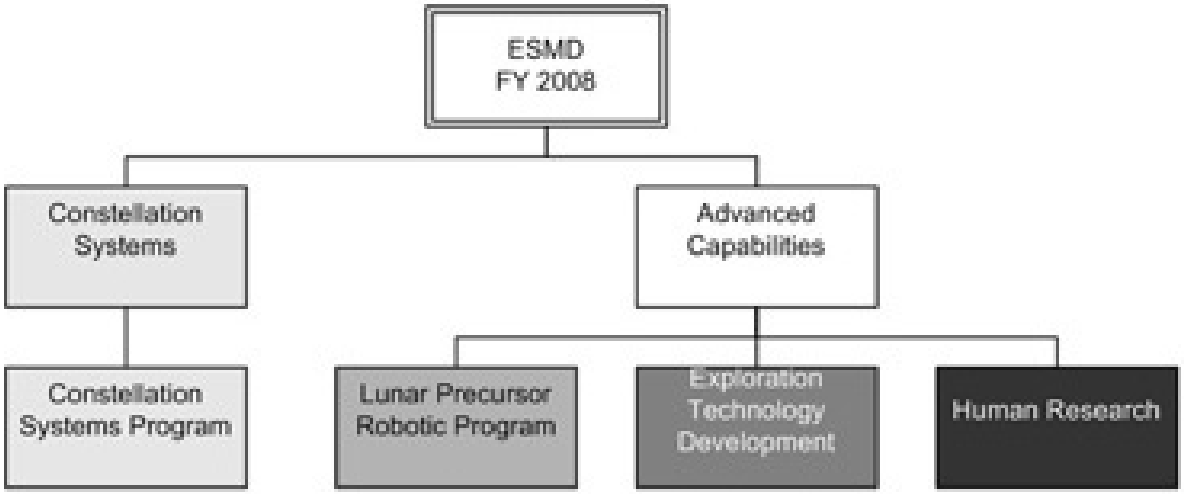

Figure P-1 An organization chart of NASA's Exploration Systems Mission Directorate (ESMD). The Exploration Technology Development Program is a part of the Advanced Capabilities Theme.

ETDP has initiated 22 technology projects to meet the requirements that flow down from the Constellation program and whose assessment is the object of this report. The projects are:

01. Structures/ Mechanisms/Materials
02. Ablative Thermal Protection System for CEV
03. Lunar Dust Mitigation
04. Propulsion (PCAD)
05. Cryogenic Fluid Management
06. Energy Storage
07. Thermal Control
08. High Performance & Radiation Hardened Electronics- RHESE
09. Integrated System Health Management
10. Autonomy for Operations
11. Intelligent Software Design
12. Autonomous Landing and Hazard Avoidance
13. Automated Rendezvous and Docking (AR&D) Sensors
14. Exploration Life Support
15. Advanced Environmental Monitoring and Control
16. Fire Prevention, Detection, and Suppression
17. EVA Technologies

18. ISS Research
19. In-Situ Resource Utilization
20. Fission Surface Power
21. Supportability
22. Human Robotic Systems/Analogs

In the House report (H. Rept. 107-520) that accompanied the House-passed version of the Science, State, Justice and Commerce FY2007 appropriations bill (H.R. 5672), NASA was directed to "enter into an arrangement with the National Research Council (NRC) for an independent assessment of NASA's restructured Exploration Technology Development Program (ETDP) to determine how well the program is aligned with the stated objectives of the Vision for Space Exploration (VSE), identify any gaps, and assess the quality of the research." Although that bill did not become law, NASA nonetheless asked the NRC to make this assessment.

A statement of task was developed by NASA and the NRC (see Appendix A), and a committee was formed by the NRC's Aeronautics and Space Engineering Board to carry out this task.

The Committee to Review NASA's Exploration Technology Development Program (ETDP) was assembled and approved by the NRC Governing Board on September 28, 2007. The committee consists of 25 members (see Appendix B) and includes a cross section of senior executives, engineers, researchers, and other aerospace professionals drawn from industry, universities, and government agencies with expertise in all of the fields which comprise the ETDP.

The committee held its first meeting on October 10-11, 2007, in Washington, D.C. The meeting included a series of presentations by NASA personnel that provided an overview of the administrative and technical background for ETDP. A set of questions to be used in the assessment process was agreed upon by the committee and sent to NASA for distribution to the centers included in the site visits to provide the centers with a clear and concise idea of the issues that the subgroups of the committee were charged to assess. (See Appendix C for a copy of the questions.)

A subset of the committee met at the Jet Propulsion Laboratory in Pasadena, California, on November 8-9, 2007, for specialized presentations and a tour of the laboratory. A second subset met at the Johnson Space Center in Houston, Texas, on November 27-30, and a third subset visited the Glenn Research Center in Cleveland, Ohio, on December 11-12. A lead specialist and at least two other committee members were selected to concentrate on each project. Their reports and preliminary ratings were discussed by all other members of the committee using e-mail and in teleconferences organized on January 8, 11 and 16 to ensure consistency in the ratings given to each project which formed the basis of this committee's interim report. With a few exceptions, this review covers information made available to the committee through December 2007.

The full committee met for a second time on February 5-6, 2008, in Irvine, California, to continue its data-gathering activity, obtain clarification on selected areas of the ETDP technologies, and examine in detail cross-cutting issues that emerged as a result of the overall study process.

Chapter 1 of the interim report focuses on an assessment of each of the 22 individual projects that form the ETDP. The objectives and status of each project are summarized. Ratings are assigned for the quality of the research, the effectiveness with which the research is carried out and transitioned to the Exploration program, and the degree to which the research is aligned with the VSE.

Where sufficient background information was available at the time of the preparation of this interim report, cross-cutting issues -- i.e., issues that the committee believes pervade many projects – were identified, and these are summarized in Chapter 2.

The committee's final report will consider the ETDP in a more holistic sense; it will take a top-down approach relative to the bottom-up approach of this report with findings at a programmatic level and recommendations for increasing effectiveness. The final report will also discuss areas of study that the committee believes NASA might include within its future plans.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the Report Review Committee of the National Research Council (NRC). The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Steven J. Battel, Battel Engineering
Tom Bauer, Microcosm Space Mission Engineering
Robert L. Crippen, Thiokol Propulsion (retired)
Guy Fogelman, Federation of American Societies for Experimental Biology
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Joe Oefelein, Sandia National Laboratories
Richard Robbins, Robbins Group, LLC
David Van Wie, Johns Hopkins University Applied Physics Laboratory
Dianne Wiley, Boeing Company

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by **Maxine Savitz, Honeywell Incorporated (retired)**. Appointed by the NRC, she was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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