Fostering Visions for the Future: A Review of the NASA Institute for Advanced Concepts

Committee to Review the NASA Institute for Advanced Concepts; National Research Council

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Advisers to the Nation on Science, Engineering, and Medicine

Fostering Visions for the Future

A Review of the NASA Institute of Advanced Concepts

Committee to Review the NASA Institute for Advanced Concepts
Aeronautics and Space Engineering Board
Division on Engineering and Physical Sciences

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[1] Major General Bolden became NASA administrator on July 17, 2009, after writing and review of this report was completed.

Preface

The NASA Institute for Advanced Concepts (NIAC) was established in 1998 to provide an independent, open forum for the external analysis and definition of revolutionary space and aeronautics advanced concepts to complement the advanced concepts activities conducted within the NASA enterprises. Funded at approximately $4 million per year, NIAC received a total of $36.2 million in NASA funding during the 9 years of its existence; it was terminated by NASA in 2007.

In the report that accompanied the Commerce, Justice, Science, and Related Agencies fiscal year 2008 appropriations bill passed by the U.S. House of Representatives,[1] the NASA administrator was directed to

> Enter into an arrangement with the National Research Council [NRC] to evaluate NIAC's effectiveness in meeting its mission, including a review of the grants made by the Institute, their results, and the likelihood that they will contribute to the Institute's stated goals; evaluate the method by which grantees are selected and recommend changes, if needed; and make recommendations as to whether the Institute should continue to be funded by the federal government and, if so, what changes, if any, should be made to its mission, goals, operations, or other matters.

To carry out the review of NIAC, an ad hoc committee of 12 experts in advanced space and aeronautical concepts was established under the auspices of the NRC's Aeronautics and Space Engineering Board. The members of the Committee to Review the NASA Institute for Advanced Concepts were chosen for their experience with aspects of scientific innovation and creativity, from across a number of institutions and agencies, including the Defense Advanced Research Projects Agency (DARPA), NASA, the SETI Institute, industry, and academia. The committee membership is shown in Appendix B. The committee heard testimony from the NIAC director, NASA leadership involved in the creation and management of NIAC, a cross section of NIAC grantees, and leaders of other advanced technology organizations, including DARPA. A list of presenters is shown in Appendix C.

The committee's first meeting was held in Washington, D.C., on December 8-9, 2008, and was devoted largely to gathering data on the history, organization, and accomplishments of NIAC; discussing the data; and forming subgroups to examine specific issues. The objectives of the committee's second meeting, held on February 19-20, 2009, at the Arnold and Mabel Beckman Center in Irvine, California, were to gather additional data from presentations made by former NIAC grantees and by persons from within and outside NASA that were experienced in the infusion of advanced concepts into mission-oriented programs and to formulate the committee's findings and recommendations.

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[1] U.S. House of Representatives, *Commerce, Justice, Science, and Related Agencies Appropriations Act, 2008*, H.R. 3093, available at http://thomas.loc.gov/.

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:

Wanda Austin, The Aerospace Corporation,
Paul Bevilaqua, Lockheed Martin Aeronautics Co.,
John Howell, University of Texas, Austin,
John Reppy, Cornell University (emeritus),
George Sutton, SPARTA, Inc., and
Gerald Walberg, Walberg Aerospace (retired).

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 Martha Haynes, Cornell University. 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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Acronyms

ASMCS	Astrophysics Strategic Missions Concept Studies
BHI	Black Hole Imager
DARPA	Defense Advanced Research Projects Agency
ESMD	Exploration Systems Mission Directorate
ETDP	Exploration Technology Development Program
GSFC	Goddard Space Flight Center
IPP	Innovative Partnership Program
M2P2	Mini-Magnetospheric Plasma Propulsion
MAXIM	Micro-Arcsecond X-ray Imaging Mission
MSFC	Marshall Space Flight Center
NIAC	NASA Institute for Advanced Concepts
NIAC2	a successor entity to NIAC, as referred to in this report
NRC	National Research Council
NSFP	NIAC Student Fellows Prize
SBIR	Small Business Innovation Research
SMD	Science Missions Directorate
STTR	Small Business Technology Transfer Research
TRL	technology readiness level
USRA	Universities Space Research Association

Summary

> NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth.[1]

The NASA Institute for Advanced Concepts (NIAC) was formed in 1998 to provide an independent source of advanced aeronautical and space concepts that could dramatically impact how NASA develops and conducts its missions. Until August 2007, NIAC provided an independent open forum, a high-level point of entry to NASA for an external community of innovators, and an external capability for analysis and definition of advanced aeronautics and space concepts to complement the advanced concept activities conducted within NASA. Throughout its 9-year existence, NIAC inspired an atmosphere for innovation that stretched the imagination and encouraged creativity.

Utilizing an open, Web-based environment to conduct solicitations, perform peer review, administer grant awards, and publicize its activities, this small program succeeded in fostering a community of external innovators to investigate advanced concepts that might have a significant impact on future NASA missions in a 10- to 40-year time frame. Funded at approximately $4 million per year, NIAC received a total of $36.2 million in NASA funding, more than 75 percent of which was used directly for grants. NIAC received more than 1,300 proposals and awarded 168 grants, for a total of $27.3 million. There were 126 Phase I grants awarded for 6 months of initial study. Upon successful completion of Phase I and based on the continued promise of the advanced concept, 42 Phase II grants were awarded by NIAC for 2 years of additional concept maturation.

Many NIAC grantees went on to receive additional funding for continued development of their concepts from NASA, other government agencies, or private industry. In addition to developing revolutionary advanced concepts, NIAC increased public interest in science and engineering and provided motivation to the nation's youth to study technical subjects. NIAC was featured in more than 40 general-interest publications—attracting mainstream media coverage for the agency and receiving more than 226,000 Google hits to its Web site.

Box S-1 Objectives of This Study

1. Evaluate NIAC's effectiveness in meeting its mission, including a review of the grants made by the Institute, their results, and the likelihood that they will contribute to the Institute's stated goals.
2. Evaluate the method by which grantees were selected and recommend changes, if needed.
3. Make recommendations on whether NIAC or a successor entity should be funded by the federal government and, if so, what changes, if any, should be made to NIAC's original mission, goals, operations, or other matters.
4. Make recommendations as to how the federal government in general and NASA in particular should solicit and infuse advanced concepts into its future systems.

NOTE: The full statement of Task is given in Appendix A

Originally conceived as reporting to the NASA's chief technologist so that infusion across all NASA enterprises could be assured, NIAC operated in an environment of frequent NASA organizational changes. In 2004, NASA management of NIAC was transferred to the Exploration Systems Mission Directorate, where it was not well aligned with its sponsor's near-term mission

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[1] National Aeronautics and Space Administration, *NASA Strategic Plan: 1998 Policy Directive (NPD)-1000.1*, Washington, D.C., 1998. Available at: http://www.hq.nasa.gov/office/nsp/.

objectives. NIAC was terminated in 2007.

In 2008, Congress directed the National Research Council (NRC) to conduct a review of the effectiveness of NIAC and to make recommendations concerning the importance of such a program to NASA and to the nation as a whole, including the proper role of NASA and the federal government in fostering scientific innovation and creativity and in developing advanced concepts for future systems. This report of the NRC Committee to Review the NASA Institute for Advanced Concepts is organized according to the four objectives set in the statement of task (see Box S-1 and Appendix A). The findings in response to objectives 1 and 2 form the basis for the recommendations made by the committee in response to objectives 3 and 4. The complete findings and recommendations of this study are listed in the second section of this summary, and several key findings and recommendations are discussed immediately below.

As described in more detail in Chapter 1, the committee found the NIAC program to be effective in achieving its mission and accomplishing its stated goals. At present, there is no NASA organization responsible for solicitation, evaluation, and maturation of advanced concepts (defined as those at technology readiness level [TRL] 1 or 2; see Appendix H) or responsible for subsequent infusion of worthy candidate concepts into NASA planning and development activities. Testimony from several sectors confirmed that NASA and the nation must maintain a mechanism to investigate visionary, far-reaching advanced concepts in order to achieve NASA's mission. **The committee recommends that NASA should reestablish a NIAC-like entity, referred to in this report as NIAC2, to seek out visionary, far-reaching, advanced concepts with the potential of significant benefit to accomplishing NASA's charter and to begin the process of maturing these advanced concepts for infusion into NASA's missions.**[2]

When it was formed, NIAC was managed by a high-level agency executive concerned with the objectives and needs of all NASA enterprises and missions. The committee found that NIAC was most successful as a program with cross-cutting applicability to NASA's enterprises and missions. When it was transferred to a mission-specific directorate, NIAC lost its alignment with sponsor objectives and priorities. **To allow for sustained implementation of NIAC2 infusion objectives, the committee recommends that NIAC2 should report to the Office of the Administrator, be outside mission directorates, and be chartered to address NASA-wide mission and technology needs. To increase NIAC2's relevance, NASA mission directorates should contribute thematic areas for consideration. The committee also recommends that a NIAC2 organization should be funded and administered separately from NASA development programs, mission directorates, and institutional constraints. Future NIAC2 proposal opportunities should continue to be managed and peer-reviewed outside the agency.**

While NIAC's Internet-based technical review and management processes were found to be effective and should be continued in NIAC2, the committee found a few policies that may have hastened NIAC's demise. Key among these was (1) the complete focus on revolutionary advanced concepts and (2) the exclusion of NASA personnel from participation in NIAC awards or research teams. NIAC's focus on *revolutionary* advanced concepts with a time horizon of 10 to 40 years in the future often put its projects too far out of alignment with the nearer-term horizons of the NASA mission directorates, thereby diminishing the potential for infusion into NASA mission plans. **The committee recommends that NIAC2 should expand its scope to include concepts that are scientifically and/or technically innovative and have the potential to provide major benefit to a future NASA mission in 10 years and beyond.** NIAC was formed to provide an independent, open forum for the external analysis and definition of space and aeronautics advanced concepts to complement the advanced concepts activities conducted within NASA; hence, NIAC solicitations were closed to NASA participants. NIAC was formed at a time when there was adequate funding for development of novel, long-term ideas internal to NASA. As internal funding for advanced concepts and technology diminished or became more focused

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[2] The full text of the findings and recommendations discussed in this summary is provided in "List of Findings and Recommendations" below this summary.

on flight-system development and operations, the cultural disconnect between the development activities internal and external to the agency grew, and transitioning of NIAC concepts to the NASA mission directorates became more difficult. **The committee recommends that future NIAC2 proposal opportunities be open to principal investigators or teams both internal and external to NASA.**

One important NIAC performance metric to assess was achievement of 5 to 10 percent infusion of NIAC-developed Phase II concepts into NASA's long-term plans. One way to gauge such infusion is to look at the receipt of post-NIAC funding from NASA for the continued development of a NIAC-funded advanced concept. **The committee found that 14 NIAC Phase I and Phase II projects, which were awarded $7 million by NIAC, received an additional $23.8 million in funding from a wide range of organizations, demonstrating the significance of the nation's investment in NIAC's advanced concepts. NIAC matured 12 of the 42 Phase II advanced concepts (29 percent), as measured by receipt of post-NIAC funding; 9 of them (21 percent) received post-NIAC funding from NASA itself.**

Over the long term, the ultimate criterion for NIAC success is the number of funded projects that eventually make their way into the relevant NASA mission directorate decadal survey, strategic plan, or mission stream. **The committee also found that three NIAC Phase II efforts (7 percent of the Phase II awards) appear to have impacted NASA's long-term plans, and two of these efforts have either already been incorporated or are currently under consideration by the NRC Astronomy and Astrophysics Decadal Survey as future NASA missions.** Considering the 40-year planning horizon of NIAC activities coupled with the 9-year existence of NIAC, the committee believes it is likely that the number of NIAC Phase II projects considered for NASA missions will continue to increase over time.

In addition, the committee received much testimony that the potential for receipt of a NIAC Phase III award is needed to aid the transition of the most highly promising projects. **Therefore, the committee recommends that future NIAC2 proposal opportunities include the potential selection of a small number of Phase III "proof of concept" awards for up to $5 million each for 4 years to demonstrate and resolve fundamental feasibility issues, and such awards should be selected jointly by NIAC2 and NASA management.**

A persistent NIAC challenge was the lack of a NASA interface to receive the hand-off of promising projects. To improve the manner in which advanced concepts are infused into its future systems, the committee recommends that NASA consider reestablishing an aeronautics and space systems technology development enterprise. Its purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies. NASA's consideration should include implications for the agency's strategic plan, organizations, resource distributions, field center foci, and mission selection process. Increased participation of NASA field center personnel, beyond review and management functions, should also significantly enhance advanced concept maturation and infusion into NASA mission planning. **In particular, the committee recommends identification of center technical champions and provision for the technical participation of NASA field center personnel in NIAC2 efforts. Participation of NASA personnel can be expected to increase as NIAC2 projects mature.**

LIST OF FINDINGS AND RECOMMENDATIONS

Given below is a complete list of the committee's findings and recommendations, in the order in which they appear in the report.

Findings

Finding 1.1: NIAC's approach to implementing its functions successfully met NASA-defined objectives, resulted in a cost-effective and timely execution of advanced concept studies, afforded an opportunity for external input of new ideas to the agency, and subsequently provided broad public exposure of NASA programs.

Finding 1.2: The utilization of an Internet-based management environment enabled broad public scrutiny of NIAC-funded concepts and brought a high degree of efficiency to the proposal submission and review process.

Finding 1.3: NIAC was successful in encouraging and supporting a wide community of innovators from diverse disciplines and institutions. Through establishment of its NIAC Fellows program, conferences, and awards, NIAC developed a community of innovators. NIAC was successful in its mission of developing a large community of innovative advanced concepts, as evidenced by receipt of 1,309 proposals in its 9-year lifetime. The 126 NIAC Phase I studies were led by a total of 109 distinct principal investigators, each of which led a research team of 3-10 personnel, often across multiple organizations.

Finding 1.4: The majority of NIAC-supported efforts were highly innovative. Many pushed the limits of applied physics. Overall, the efforts supported produced results commensurate with the risks involved.

Finding 1.5: NIAC was successful in providing widespread positive publicity for NASA, as evidenced by TV and media coverage and Internet interest.

Finding 1.6: Considerable anecdotal evidence suggests that, through establishment of the NIAC student undergraduate Fellows program and media coverage of its activities, NIAC motivated young people to pursue studies in engineering and science.

Finding 1.7: NIAC-funded projects were distributed well across the NASA exploration systems, science, and space operations directorates. Although the NIAC solicitation was open across all NASA enterprises, a low number of aeronautics proposals were submitted. As such, NIAC made a relatively limited number of aeronautics awards.

Finding 1.8: Throughout its 9-year existence, NASA invested $36.2 million in NIAC advanced concept studies. Fourteen NIAC Phase I and Phase II projects, which were awarded $7 million by NIAC, received an additional $23.8 million in funding from a wide range of organizations, demonstrating the significance of the nation’s investment in NIAC’s advanced concepts. NIAC successfully matured 12 of the 42 Phase II advanced concepts (29 percent), as measured by receipt of post-NIAC funding; 9 of them (21 percent) received post-NIAC funding from NASA itself. In addition, 3 NIAC Phase II efforts (7 percent of the Phase II awards) appear to have impacted NASA’s long-term plans, and 2 of these efforts have either already been incorporated or are currently under consideration by the NRC Astronomy and Astrophysics Decadal Survey as future NASA missions.

Finding 1.9: By design, the maturity of NIAC Phase II products was such that a substantial additional infusion of resources was needed before these advanced concepts could be deemed technically viable for implementation as part of a future NASA mission or flight program. This technology readiness immaturity created infusion difficulties for the NIAC program and innovators.

Finding 1.10: NIAC produced studies that were of relevance to the aerospace sector at large, including other government agencies and aerospace industries, as evidenced by the fact that 19 percent of the Phase II advanced concepts received additional funding from other government agencies and industry. In addition, three new small business entities were created based on NIAC-spinoff technology.

Finding 1.11: Partnerships and cost sharing were not required in NIAC’s statement of work. However, a number of projects were partially supported by the grantees’ organizations, thus leveraging the impact of the NIAC grant.

Finding 2.1: The process for selecting NIAC grantees was well documented, was disciplined, met the charter of NIAC, and was generally commensurate with practices of other federal funding agencies.

Finding 2.2: The process for selecting NIAC grantees led to a variety of involved organizations, principally from universities and small businesses.

Finding 4.1: NASA is now an agency oriented toward flight-system development and operations. Priorities have thus diminished within NASA for long-range research and development efforts. At present, there is no NASA organization responsible for solicitation and evaluation of advanced concepts (defined as those at technology readiness level 1 or 2) and subsequent infusion of worthy candidates into NASA planning and development activities.

Finding 4.2: Any expectations of a NIAC2 will depend on the management approach provided by the agency. Management with senior, NASA-wide perspectives and resources outside the near-term focus of the NASA mission directorates should, based on successful Innovative Partnership Program experiences, materially increase the probability for sustained value from a NIAC2 program.

Recommendations

Recommendation 3.1: NASA should reestablish a NIAC-like entity, referred to in this report as NIAC2, to seek out visionary, far-reaching, advanced concepts with the potential of significant benefit to accomplishing NASA's charter and to begin the process of maturing these advanced concepts for infusion into NASA's missions.

Recommendation 3.2: NIAC2 should employ the streamlined, Internet-based, technical review and management processes developed by the original NIAC. These approaches met NASA-defined objectives, resulted in a cost-effective and timely implementation of advanced concept studies, afforded an opportunity for external input of new ideas to the agency, and provided broad exposure for NASA of advanced program concepts.

Recommendation 3.3: A NIAC2 organization should be funded and administered separately from NASA development programs, mission directorates, and institutional constraints.

Recommendation 3.4: NIAC2 proposal opportunities should be managed and peer-reviewed outside the agency.

Recommendation 3.5:

(a) The key selection requirement for NIAC2 proposal opportunities should be that the concept is scientifically and/or technically innovative and has the potential to provide major benefit to a future NASA mission.

(b) Over the long term, the ultimate criterion for NIAC2 success is the number of funded projects that eventually make their way into the relevant NASA mission directorate decadal survey, strategic plan, or mission stream. Because most NIAC2 projects will bear fruit only over the long term, in addition to the annual performance and feedback reviews, a major review of NIAC2 grants should occur every 5 years to ensure continuous infusion opportunities into NASA missions and planning.

(c) NIAC2 proposal opportunities should be open to principal investigators or teams both internal and external to NASA.

(d) NIAC2 proposal opportunities should be defined as follows: Phase I, up to $100,000 each for 1 year; Phase II, up to $500,000 each for 2 years.

(e) NIAC2 proposal opportunities should include the potential selection of a small number of Phase III "proof-of-concept" awards for up to $5 million each for 4 years to demonstrate and resolve fundamental feasibility issues, and such awards should be selected jointly by NIAC2 and NASA management.

(f) NASA, through NIAC2, should allow awardees to retain rights to data and associated intellectual property developed under NIAC2 awards. NIAC2 should also be proactive in coaching the awardees in protection of intellectual property.

(g) Efforts should be made to disseminate announcements and solicitations to the widest possible audience in order to reach the largest possible number of researchers, including those from small disadvantaged businesses and minority institutions.

(h) Efforts should be made to encourage the widest possible demographics of reviewers, including gender, age, and ethnicity, while ensuring that breadth of experience and technical competence are paramount considerations in reviewer selection.

Recommendation 4.1: To improve the manner in which advanced concepts are infused into its future systems, the committee recommends that NASA consider reestablishing an aeronautics and space systems technology development enterprise. Its purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies. NASA’s consideration should include implications for the agency’s strategic plan, organizations, resource distributions, field center foci, and mission selection process.

Recommendation 4.2: To allow for successful, sustained implementation of NIAC2 infusion objectives, NIAC2 should report directly to the Office of the Administrator, be outside mission directorates, and be chartered to address NASA-wide mission and technology needs. It is worth noting that this organizational structure was in place during the formation and initial operation of NIAC. To increase NIAC2’s relevance, NASA mission directorates should contribute thematic areas for consideration. The Innovative Partnership Program (IPP) offers characteristics compatible with effective and healthy, long- and short-term advanced concepts projects. The agency should consider adding a new element to the existing IPP to house the (internal management of) NIAC2, with its focus on technology readiness level 1 and 2 and higher concept studies.

Recommendation 4.3: Identification of center technical champions and provision for technical participation of NASA field center personnel in NIAC2 efforts—participation that can be expected to increase as NIAC2 projects mature—is recommended. Increased participation of NASA field center personnel, beyond review and management functions, may significantly enhance advanced concept maturation and infusion into NASA mission planning. As appropriate, Phase II and Phase III NIAC2 projects should include realistic transition plans to the appropriate NASA enterprises.

Background and Significance

> *NASA Institute for Advanced Concepts (NIAC) Mission Statement:*
>
> NIAC was formed for the explicit purpose of being an independent source of revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its mission. . . . NIAC provides an independent, open forum for the external analysis and definition of space and aeronautics advanced concepts to complement the advanced concepts activities conducted within NASA. The NIAC has advanced concepts as its sole focus. It focuses on revolutionary concepts—specifically systems and architectures—that can have a major impact on missions of the NASA Enterprises in the time frame of 10 to 40 years in the future. It generates ideas for how the current NASA Agenda can be done better; it expands our vision of future possibilities.[1]

"The NASA Institute of Advanced Concepts (NIAC) was established in 1998 to inspire and explore innovative aerospace systems and architectures."[2] This virtual institute, using a peer review process, sought out aerospace and space science concepts, specifically systems or architectures aimed 10 to 40 years in the future that could have a major impact on future missions of the NASA enterprises. NASA funding for NIAC ended in 2007.

In 2008, Congress directed the National Research Council to review the performance of NIAC. Operating under the auspices of the Aeronautics and Space Engineering Board, the Committee to Review the NASA Institute for Advanced Concepts was asked to evaluate how well NIAC had developed revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its mission (see Appendix A for the full statement of task). The committee's review is intended to guide NASA by assessing NIAC's processes and results and to shape future efforts in this area.

Committee Objectives

1. Evaluate NIAC's effectiveness in meeting its mission, including a review of the grants made by the Institute, their results, and the likelihood that they will contribute to the Institute's stated goals.
2. Evaluate the method by which grantees were selected and recommend changes, if needed.
3. Make recommendations on whether NIAC or a successor entity should be funded by the federal government and, if so, what changes, if any, should be made to NIAC's original mission, goals, operations, or other matters.
4. Make recommendations as to how the federal government in general and NASA in particular should solicit and infuse advanced concepts into its future systems.

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[1] See http://www.niac.usra.edu/institute/mission.html.

[2] NASA Institute of Advanced Concepts, *Long-Term Success of NIAC-Funded Concepts,* Short Report, Atlanta Ga., June 8, 2007, p.1.

IMPORTANCE OF ADVANCED CONCEPT DEVELOPMENT

Historically, the first technical challenge to the space community was to launch a satellite into orbit, regardless of its mass or payload. Quickly the challenge became to use satellites for observation, and unexpected findings like the Van Allen belts emerged, one after another. The crewed space programs presented further challenges—meeting safety and reliability requirements and addressing life support issues. Grand adventures in space science, astronomy, Earth observations, and life and materials sciences followed as the United States, largely through NASA, achieved world leadership in space science and technology.

In the 1980s, under the pressure of limited budgets, NASA retreated from its exciting, risk-taking, high-technology culture. At present, its big programs, all very costly, relate either to continued low-Earth-orbit human spaceflight with little cutting-edge technology involved, or to the planned return of humans to the Moon in a manner that looks remarkably like the Apollo program with an infusion of existing 21st-century technology. Today, NASA's investment in advanced concepts and long-term technological solutions to its strategic goals is minimal.

Through NASA, the United States would be well served by investing at least a small fraction of the agency's budget in support of advanced concepts—concepts so difficult to achieve that their chance of individual success within a decade is less than 10 percent, yet projects so innovative that their success could serve as game-changers for entirely new aeronautics and space endeavors. The importance of high-value basic and applied research is now as great as ever. Major breakthroughs are needed to address society's energy, health, transportation, and environmental challenges. While NASA investments alone will not solve these grand challenges, NASA does have a unique ability to motivate and attract many of the country's best minds into educational programs and careers in engineering and science. If NASA does not support advanced concept activities, no other U.S. source of funding is likely to fill the gap—not the National Science Foundation, and not the Defense Advanced Research Projects Agency. Although it is not possible to predict which advanced concepts will produce world-shaking results, it is certainly true that in the absence of research on such concepts, the United States will *not* make revolutionary technological advances in aeronautics and space. This line of thought led to the establishment of NIAC.

BRIEF HISTORY OF THE NASA INSTITUTE FOR ADVANCED CONCEPTS

Operation of NIAC began on February 10, 1998, when a contract was awarded to the Universities Space Research Association (USRA) by NASA's Office of the Chief Technologist. ANSER Corporation (an operating unit of Analytic Services, Inc.), through a subcontract from USRA/NIAC, provided program support, technical support, and information technology support for NIAC's operation. Funded at $4 million per year—approximately 0.02 percent of NASA's budget—NIAC was established to provide an independent, open forum for the external analysis and definition of space and aeronautics advanced concepts to complement the advanced concepts activities conducted within the NASA enterprises. NIAC's purpose was to develop advanced concepts, visions, and architectures to *inform* technology development that NASA would invest in later. The concepts studied by NIAC in this role were more speculative than those funded by the better-known Small Business Innovation Research and Small Business Technology Transfer Research programs, which followed well-defined paths to technical maturity. NIAC selected the concepts for support, independent of NASA, through an external review process by respected technical experts.

Sponsorship for NIAC followed a difficult path over its 9-year existence, due to NASA's history of frequent reorganization. NIAC was originally created within NASA's Code R organization as a cross-cutting program that supported all the NASA directorates. In fact, the NIAC operating charter called for NASA review and concurrence on all concepts selected for funding, and NASA's NIAC Concurrence Review Panel consisted of members from all the directorates.

NIAC was transferred in 2004 to the new Exploration Systems Mission Directorate (ESMD)—a mission-specific organization focused largely on developing the transportation elements to achieve the Vision for Space Exploration.[3] From 2005 to its termination in 2007, NIAC received $4.3 million per year through the Exploration Technology Development Program (ETDP). In fiscal year 2007, NIAC was terminated as part of a general elimination of a majority of ESMD elements that were not directly aligned with the near-term objectives of the Vision for Space Exploration. Over the course of its 9-year existence, NIAC received a total of $36.2 million and funded 126 Phase I (6 months, up to $75,000) and 42 Phase II (2 years, up to $500,000) studies, for a total of $27.3 million for a wide range of universities and businesses.

How effectively NIAC met its mission of identifying and nurturing such concepts, and how the federal government can foster continuing and future innovation through the development of advanced concepts, are discussed in the chapters that follow.

NIAC's Programmatic History

February 1998—NIAC created in Office of Aerospace Technology (Code R); intended to inform strategic visions for all NASA enterprises.

October 2001—NIAC funded by Enabling Concepts Technologies Program (Code R) as a low-technology-readiness-level (TRL) crosscutting technology program.

January 2004—NIAC funded by Exploration Systems Research and Technology Program (ESR&T) (ESMD); broadly competed technology program focused on exploration.

November 2005—Exploration Systems Architecture Study; ESR&T restructured to form the Exploration Technology Development Program (ETDP).

December 2005—NIAC funded by ETDP (ESMD); mission-focused mid-TRL technology program.

August 2007—NIAC contract terminated.

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[3] Executive Office of the President, *A Renewed Spirit of Discovery, the President' s Vision for U.S. Space Exploration,* Washington, D.C., January 2004.

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Effectiveness of NIAC

Committee to Review the NASA Institute for Advanced Concepts Statement of Task, Objective 1—

Evaluate NIAC's effectiveness in meeting its mission, including a review of the grants made by the Institute, their results, and the likelihood that they will contribute to the Institute's stated goals.

The NASA Institute of Advanced Concepts (NIAC) was formed for the explicit purpose of being an independent source of advanced aeronautical and space concepts that could dramatically impact how NASA develops and conducts its mission. The NASA statement of work that funded NIAC (reprinted in Appendix D) outlined a broad set of goals and objectives, which included:

- Implementing a procedure to select and fund innovative, technically competent, revolutionary advanced concepts that could benefit NASA in its mission,
- Sustaining public interest in revolutionary concepts of alternative aerospace futures,
- Providing a positive inspiration to the nation's youth to study technical subjects so that they can conceive of their exciting role in the future and persevere in making their vision a reality,
- Achieving a balanced distribution of effort and resources between NASA enterprises,
- Enabling 5 to 10 percent infusion of NIAC-developed advanced concepts into NASA's long-term plans, and
- Utilizing an Internet-based management environment to enable broad public scrutiny of NIAC-funded concepts.

In evaluating NIAC's effectiveness in meeting its mission, the Committee to Review the NASA Institute for Advanced Concepts mapped NIAC's accomplishments to each of the above goals and objectives. The results address the following questions posed in the committee's statement of task:

- To what extent were the NIAC-sponsored advanced concept studies innovative and technically competent?
- How effective was NIAC in infusing advanced concepts into NASA's strategic vision, future mission plans, and technology development programs?
- How relevant were these studies to the aerospace sector at large?
- How well did NIAC leverage potential partnerships or cost-sharing arrangements?

NIAC'S APPROACH TO IMPLEMENTATION

To assess the overall impact of NIAC's research efforts on future NASA missions, the fundamental approach to producing these results was evaluated by the committee. The committee focused on the method used by NIAC in soliciting projects, making awards, and evaluating and measuring the progress of the funded concepts. Central to this approach was NIAC's need to establish a rapid process for soliciting and reviewing the proposals, along with choosing a cadre of technically qualified reviewers.

A key starting point for a discussion of the degree of innovation and technical competence of the NIAC-sponsored studies is to focus on the definition of the term "advanced concept," as given in NASA's statement of work for NIAC:

> The term "advanced concepts" has many meanings. Establishing the meaning and scope of the kind of "advanced concepts" to be solicited by the NIAC is fundamental in meeting the goals of this SOW. The following are a number of tests that the contractor shall apply to a specific concept to determine if it meets the requirements and intent of this SOW. Generally, the NIAC is seeking advanced concepts that could come into fruition in the 10-40 year timeframe.
>
> A. The concepts shall be revolutionary rather than evolutionary. **Evolutionary** means the next progressive step in development and/or a similar type of research to the research currently being conducted. **Revolutionary** often includes a new paradigm. It entails a leap ahead in technological advances and is generally a totally new way of doing something. The advanced concept may have been explored before, but in order for another exploration of the advanced concept to be revolutionary, it must be a new approach. This difference is illustrated in the following example: An improved rocket that would enhance human's ability to explore space would be evolutionary. A totally different and new type of transportation into space would be revolutionary and might include a space tether, a space elevator, or a mini-magnetospheric plasma propulsion system, three concepts previously studied under past NIAC funded studies.
>
> B. The concepts shall be consistent with the National Space Policy and the NASA Strategic Plan (see http://www.hq.nasa.gov/office/codez/new/policy/pddnstc8.htm and http://www.hq.nasa.gov/office/codez/plans.html).
>
> C. The concepts shall have a "new" aspect. They shall not repeat or duplicate concepts previously studied or currently being studied by NASA unless they have a new approach as stated in 4.A. above.
>
> D. The concepts shall involve major systems and architectures and potentially have a major impact on how future Enterprise missions are accomplished. **Systems** include the physical embodiment of the overall plan to accomplish a goal and/or a suite of equipment, software and operations methods capable of accomplishing an operational objective. **Architectures** include an overall plan to accomplish a goal and/or a suite of physical embodiments of the overall plan and their operational methods of meeting an overall mission or program objective.
>
> E. The concepts shall not solely be a specific advanced technology or new design approach such as a new solar cell or a new spectrometer. The concepts must be put into a mission application context.
>
> F. The concepts shall expand the number of approaches or choices rather than increase the depth of analysis of known concepts.
>
> G. An advanced concept shall include both a technical description (the physics, chemistry and technology) as well as the quantification of potential benefits.[1]

This definition was used throughout the 9-year life of NIAC, and a total of 1,309 proposals for Phase I funding (which focused on a concept) were received. Thus, the NIAC definition of the term "advanced concepts" was successful in attracting a wide range of proposals. These proposals were submitted online and given a preliminary screening by the NIAC staff and then were passed along to an external review team. The reviewer pool consisted of nearly 200 skilled professionals. The proposals were examined and given a preliminary evaluation using an all-electronic approach to initial evaluation, which was unique at the time. The preliminary evaluation was followed by a meeting of senior reviewers who selected the final proposals for recommendation. NIAC award criteria are presented in Box 1-1.

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[1] Statement of work for the NASA Institute for Advanced Concepts, Attachment A of Contract NAS5-03110, Amendment of Solicitation/Modification No. 7, issued by NASA for the Universities Space Research Association, dated July 11, 2003, pp. 2-3; reprinted in Appendix D.

BOX 1-1 NASA Institute of Advanced Concepts Award Criteria

Phase I

- **6 months**
- **$50,000 to $75,000**
- **Technical proposal limit: 12 pages**
- **Electronic PDF submission only**

Is the concept revolutionary rather than evolutionary?

To what extent does the proposed activity suggest and explore creative and original concepts?

Is the concept for an architecture or system, and have the benefits been qualified in the context of a future NASA mission?

Is the concept substantiated with a description of applicable scientific and technical disciplines necessary for development?

Phase II

- **Up to 24 months**
- **Up to $400,000**
- **Technical proposal limit: 25 pages**
- **Electronic PDF submission only**

Does the proposal continue the development of a revolutionary architecture or system in the context of a future NASA mission? Is the proposed work likely to provide a sound basis for a future mission or program?

Is the concept substantiated with a description of applicable scientific and technical disciplines necessary for development?

Has a pathway for development of a technology roadmap been adequately described? Are all of the enabling technologies identified?

Are the programmatic benefits and cost versus performance of the proposed concept adequately described and understood? Does the proposal show the relationship between the concept's complexity and its benefits, cost, and performance?

NIAC recommendations were presented to NASA Headquarters for review of any conflicts with ongoing programs. If no conflicts were identified, the recommendations were generally accepted, and awards were made to the proposers to the limit of funding available. NIAC's process ensured that there was an unbiased, rapid review of the proposals, followed by approval and funding. From receipt of proposals to award, the process usually took 8 to 12 weeks. In general, the evaluation and award of Phase II projects (which focused on a continuation of the development of an architecture or system) took a few weeks longer. In addition, unsuccessful proposers were given a debriefing and encouraged to remedy the shortcomings of their proposal and resubmit at the next opportunity. The awards were announced publicly and placed on the NIAC Web site for all to follow. The reports and annual meetings were all open to the public.

Although the proposal themes in general were distributed among all the NASA enterprises, a few of the proposals addressed advances in aeronautics. The committee notes that aeronautics vehicles and the air traffic control system are also in need of innovative advances and are certainly an important part of the NASA mission.

Finding 1.1: NIAC's approach to implementing its functions successfully met NASA-defined objectives, resulted in a cost-effective and timely execution of advanced concept studies, afforded an opportunity for external input of new ideas to the agency, and subsequently provided broad public exposure of NASA programs.

Finding 1.2: The utilization of an Internet-based management environment enabled broad public scrutiny of NIAC-funded concepts and brought a high degree of efficiency to the proposal submission and review process.

INNOVATION AND TECHNICAL COMPETENCE OF NIAC-SPONSORED STUDIES

For the purpose of this report, the committee defines innovation as the unique connection of disparate ideas into a new concept. An innovator takes the knowledge of today and produces the concepts of tomorrow. An innovator, seeing what others see, develops a novel product by thinking differently about the problem.

Of the 1,309 proposals received over the 9-year history of NIAC, 1,066 were evaluated (243 proposals were not evaluated due to the closure of NIAC in 2007). Of these, 126 were funded as Phase I studies. The 126 NIAC Phase I studies were led by a total of 109 distinct principal investigators, each of which led a research team of 3 to 10 personnel, often across multiple organizations. Recipients of NIAC awards were designated "NIAC Fellows." Only investigators who had a Phase I contract could propose a Phase II effort. Subsequently, 126 Phase II proposals were received and 42 were awarded. As in any advanced concept effort, some Phase I projects did not deliver the potential anticipated, or they encountered insurmountable technical obstacles and were not renewed in Phase II. Due to the short time duration of the Phase I efforts, some of the concepts could not be sufficiently advanced to merit award of a Phase II effort. For an activity with a long-term horizon, this is to be expected. As a result of the NIAC annual meetings, new ideas were created and submitted. This open process also led to new ideas that might not have surfaced without such meetings. Insofar as innovation is concerned, a review of all the NIAC-supported efforts shows that most of these efforts were innovative, and, in some cases, pushed the bounds of knowledge (see Appendix E).

Overall, the creativity and expertise of the investigators brought new approaches into NASA's technology "tool box." A study of the published results of NIAC-sponsored studies by this committee confirms a high degree of innovation in many of them.

Finding 1.3: NIAC was successful in encouraging and supporting a wide community of innovators from diverse disciplines and institutions. Through establishment of its NIAC Fellows program, conferences, and awards, NIAC developed a community of innovators. NIAC was successful in its mission of developing a large community of innovative advanced concepts, as evidenced by receipt of 1,309 proposals in its 9-year lifetime. The 126 NIAC Phase I studies were led by a total of 109 distinct principal investigators, each of which led a research team of 3 to 10 personnel, often across multiple organizations.

In regard to NIAC research efforts, technical competence must be viewed through the program guidelines of "revolutionary systems and architectures" and "innovative concepts" as defined by NASA in the NIAC statement of work (see Appendix D). The external review process eliminated those proposals that were poorly formulated or violated the laws of physics. The awarded proposals were competently addressed and final reports were filed. The committee further notes that in all the annual reviews of NIAC carried out by NASA, NIAC was rated "excellent" in all categories, including technical competence and innovation. A detailed commentary on the technical competence of each NIAC research effort is beyond the scope of the committee's charge; however, summaries of the funded studies can be seen on the NIAC Web site.[2] In addition, the technical competence and advances made by three NIAC Phase II investigations are highlighted in Appendix F.

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[2] See http://www.niac.usra.edu.

Finding 1.4: The majority of NIAC-supported efforts were highly innovative. Many pushed the limits of applied physics. Overall, the efforts supported produced results commensurate with the risks involved.

NIAC'S ROLE IN CREATING PUBLIC VISIBILITY

NIAC fostered an open review of its advanced concepts by a combination of open access to reports and briefings on the NIAC Web site, a NIAC Annual Meeting and the NIAC Fellows Meeting. NIAC Fellows were required to present the results of their research at annual meetings open to the public. The purpose of these meetings was to offer an opportunity for the currently funded NIAC Fellows and NIAC Student Fellows to present the results of their concept development efforts and to encourage dialogue among all attendees. In addition, TV and news coverage was solicited, and the resulting articles and visibility brought positive attention to NASA and its advanced concepts.

NIAC and NIAC-sponsored advanced concepts received international recognition in the popular and technical press. NIAC Fellows were highly visible in technical society meetings with numerous presentations and published technical papers. In addition to attracting proposals from the established technical community, NIAC started a special program to encourage undergraduate students to use their creativity to stretch well beyond typical undergraduate course work. The NIAC Student Fellows Prize (NSFP) was initiated in 2005 to attract these students and facilitate the development of their advanced aerospace concepts.

The NIAC Fellows were encouraged to independently publicize their work, leading to substantial public visibility. The NIAC Web site contains all the reports of the studies and the annual meetings for anyone to access and use as appropriate. Over its 9-year life, the NIAC Web site received 226,000 Google hits. From 2006 to 2007 alone, there were about 86 interviews, articles in popular magazines and the press, TV or radio coverage, and public appearances at noteworthy meetings by many of the awardees. Complete information on all the outreach and public relations activities carried out by NIAC as part of its commitment to the NIAC statement of work may be found in the NIAC annual reports.[3]

Finding 1.5: NIAC was successful in providing widespread positive publicity for NASA, as evidenced by TV and media coverage and Internet interest.

Finding 1.6: Considerable anecdotal evidence suggests that, through establishment of the NIAC student undergraduate Fellows program and media coverage of its activities, NIAC encouraged young people to pursue studies in engineering and science.

INFUSING ADVANCED CONCEPTS INTO NASA'S STRATEGIC VISION, FUTURE MISSION PLANS, AND TECHNOLOGY DEVELOPMENT PROGRAMS

A significant goal for NIAC was a "balanced distribution of effort and resources between NASA enterprises, a record of 5 to 10 percent infusion of NIAC-developed advanced concepts into NASA's long-term plans."[4]

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[3] Information on NIAC outreach and public relations activities can be found in the NIAC annual reports, published yearly from 1999 to 2006 (NASA, Washington, D.C., available at http://www.niac.usra.edu). See the following sections for each given year: 1999, pp. 7-9; 2000, pp. 15-18; 2001, pp. 8-11; 2002, pp. 7-10; 2003, App. A and B; 2004, App. A and B; 2005, App. C and D; 2006, App. E and F; 2007, App. E and F.

[4] Statement of work for the NASA Institute for Advanced Concepts, Attachment A of Contract NAS5-03110, Amendment of Solicitation/Modification No. 7, issued by NASA for the Universities Space Research Association, dated July 11, 2003, Section 3; reprinted in Appendix D.

All NIAC awards listed in Appendix E of this report were categorized by the committee according to NASA directorate (aeronautics research, exploration systems, science, and space operations) based on information from the final reports for each project. The categorization is somewhat subjective, given that some projects could possibly fit into other directorates due to the interdisciplinary nature of the activities. While a relatively low percentage of aeronautics projects were awarded, the committee found that the NIAC proposal solicitation was open across all NASA enterprises. Balance in NIAC awards across all NASA enterprises was also assessed in a 2003 National Research Council (NRC) report,[5] which observed that NIAC was making efforts to solicit proposals across all NASA enterprises.

Finding 1.7: NIAC-funded projects were distributed well across the NASA exploration systems, science, and space operations directorates. Although the NIAC solicitation was open across all NASA enterprises, a low number of aeronautics proposals were submitted. As such, NIAC made a relatively limited number of aeronautics awards.

Over the 9 years of its existence, NIAC supported a total of 126 Phase I studies and 42 Phase II efforts for a total of 168 awards. At least two Phase I projects and 12 Phase II projects attracted external funding from both NASA and other sources, as shown in Table 1-1. These 14 projects received approximately $7 million in funding from NIAC and attracted at least $23.8 million in funding from NASA, other agencies, or the private sector. Some projects have become classified and others are receiving trickle funds from aerospace sources; therefore, the total external funding may be higher. About 29 percent (12 out of 42) of the Phase II efforts achieved additional funding. Nine of these Phase II efforts (21 percent of the 42) received additional funding from NASA. When all sources of funding are considered, approximately 8 percent of the Phase I and Phase II efforts received additional funding. These numbers show significant interest from both NASA and the aerospace community, including DARPA and other government agencies. An in-depth explanation of the content of all 42 NIAC research efforts can be found on the NIAC Web site.[6]

Although a significant percentage of NIAC-sponsored Phase II advanced concepts received additional funding from NASA or other sources following the conclusion of their NIAC-funded efforts, infusion into NASA's long-term plans is difficult to assess quantitatively because of the changing nature of NASA's long-term planning process and the long-term development horizon of NIAC-funded activities. Considering the 40-year planning horizon of NIAC-funded activities, coupled with the 9-year existence of NIAC, the committee believes it is likely that the number of Phase II projects considered for NASA missions will continue to increase over time. For this review, the committee identified three NIAC-sponsored activities (approximately 7 percent of Phase II awards) that appear to have had an impact on NASA's long-term plans. The committee considers this measure of success for the Phase II projects to be the most meaningful and consistent with the NIAC charter, based on the NIAC statement of work (see Appendix D).[7]

1. *Mini-Magnetospheric Plasma Propulsion* (Robert Winglee and J. Slough, University of Washington). Funded in 1998 as a Phase I effort, the Mini-Magnetospheric Plasma Propulsion (M2P2) system was proposed as a revolutionary means for spacecraft propulsion that efficiently utilized the energy from space plasmas to accelerate payloads to much higher speeds than can be attained by present chemical-oxidizing propulsion systems. As part of the NIAC Phase II effort funded in 1999, Winglee and his team developed and tested several laboratory-scale models to improve understanding of the proposed magnetic-inflation process and to confirm theoretical models of the effect. Their tests demonstrated that plasma

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[5] National Research Council, *Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Pioneering Revolutionary Technology Program*, The National Academies Press, Washington, D.C., 2003.

[6] See http://www.niac.usra.edu.

[7] Additional discussion of these three projects appears in Appendix F.

TABLE 1-1 Return on NIAC Investment as Measured by Additional Funding

	External Funds Received ($ million)	
Project	From NASA	From Other Sources
Phase I Studies		
Swarm Array Space Telescope	0	0.345
Propagating Magnetic Wave Plasma Accelerator	0	0.100
Phase II Studies		
The Space Elevator	2.5	6.0
Moon and Mars Orbiting Spinning Tether Transport	2.1	1.3
Global Environmental Micro Sensors	0.05	2.75
The New Worlds Observer	1.5	2.1
Micro-Arcsecond X-ray Imaging Mission	1.0	0
Electromagnetic Formation Flying	0.65	1.0
Global Constellation of Stratospheric Scientific Platforms	0.65	0
Mini-magnetospheric Plasma Propulsion	0.90	0
Lorentz-Actuated Orbits: Electrodynamic Propulsion without a Tether	0	0.550
The BioSuit™	0.146	0
Scalable Flat-Panel Nano-particle MEMS/NEMS Propulsion	0	0.100
Very Large Optics for the Study of Extrasolar Terrestrial Planets	0	0.075

NOTE: MEMS/NEMS, micro/nano electro mechanical systems.
SOURCES: NASA Institute for Advanced Concepts, *9th Annual and Final Report*, Atlanta, Ga., 2007; references following Table E-1, Appendix E of this report; and NASA Institute for Advanced Concepts, *Long-term Success of NIAC-Funded Concept,* Short Report, Atlanta, Ga., June 8, 2007.

confinement by the M2P2 followed classical linear scaling up to the point that wall effects became important and the tests demonstrated plasma inflation. This finding was instrumental in leading to NASA evaluation and testing at NASA Marshall Space Flight Center (MSFC) in an 18 ft x 32 ft vertical vacuum chamber. These experiments were able to quantify the performance of the prototype through comparative studies of the laboratory test results with the simulation results and provided strong evidence that the high thrust levels (1-3 N) reported in the original description should be achievable for low energy input (~500 kW) and low propellant consumption (<1 kg/day). Further testing to measure the thrust levels attainable by the prototype, however, did not confirm measurable thrust. In the 2001 to 2002 time frame, the M2P2 concept was considered a viable, emerging technology by the NASA Decadal Planning Team and the NASA Exploration Team. Through peer review, the M2P2 effort was deemed highly innovative and technically competent. In 2002, a review panel that included plasma experts concluded there were additional unresolved technical issues that centered around magnet field strengths, mass, and power requirements. While partially addressed by the M2P2 team,[8] this work came to a stop due to changing priorities within the agency.

2. *Micro-Arcsecond X-ray Imaging Mission* (Webster Cash, University of Colorado, Boulder). In 1999, a NIAC Phase I grant was awarded to Webster Cash for a proposal entitled "X-Ray Interferometry: Ultimate Astronomical Imaging." The concept was for an array of grazing-incidence x-ray mirrors on free-flying spacecraft, coordinated to focus the x rays on a set of beam-combining and detector spacecraft. The Phase I work validated the basic concept. Initial tests of a prototype x-ray interferometer were performed with additional NASA support at MSFC and demonstrated a significant improvement over the best previous results. In 2000, Cash's x-ray interferometry proposal was selected by NIAC for Phase II funding. He and his colleagues published their test results in a September 2000

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[8] R.M. Winglee, P. Euripides, T. Ziemba, J. Slough, and L. Giersch, Simulation of Mini-Magnetospheric Plasma Production (M2P2) interacting with an external plasma wind, AIAA Paper No. 2003-5224, July 2003.

issue of *Nature*.[9] Also that year NASA incorporated this concept into its strategic plans. Dubbed MAXIM, the concept appeared in the NRC decadal survey of astronomy and astrophysics released in 2000,[10] which identified x-ray interferometry for $60 million in funding over the following 10 years. Cash has selected as a long-range goal to image the event horizon of a black hole. While the technical implementation remains extremely challenging, the fact that the laboratory demonstration of this capability was published in *Nature* testifies to the significance of this accomplishment. NASA has continued support to further define and develop high-resolution x-ray imaging missions, and Cash's interferometry concept has remained among the leading contenders. The MAXIM Pathfinder mission was the subject of a NASA Goddard Space Flight Center (GSFC) Integrated Mission Design Center study in 2002. In 2004 MAXIM received a $1 million 3-year grant from NASA's Astronomy and Physics Research and Analysis Program to further develop the optics for this concept. Today, the technology of x-ray interferometry that was the subject of the initial NIAC study is the first of three competing methods that NASA is pursuing under its Black Hole Imager mission.

3. *New Worlds Observer* (Webster Cash, University of Colorado, Boulder). In 2004, Webster Cash led a successful proposal for a NIAC Phase I project, the New Worlds Imager, to study a variety of pinhole camera and occulting mask designs to enable imaging of planetary systems around other stars. In May 2005, NIAC selected Cash's proposal for a Phase II grant. During Phase II, Cash and his collaborators demonstrated suppression performance (reduction of starlight intensity) $<10^{-7}$ in a laboratory test of a miniature occulter. Both a publication in *Nature* in July 2006[11] and the laboratory demonstration testify to the significance and technical competence of the basic concept and the research supported by NIAC. With the completion of the NIAC Phase II study, NASA provided significant additional support for Cash's occulter concept, and it is now one of the competitive concepts for the Terrestrial Planet Finder program. In addition, both Ball Aerospace Corporation and Northrop Grumman Corporation have made internal investments to further develop the concept in conjunction with Cash and his team. In February 2008, NASA announced that a team led by Cash was awarded $1 million for the New Worlds Observer as one of its Astrophysics Strategic Missions Concept Studies (ASMCS). That study has been completed and the results will be used to prepare the New Worlds Observer mission concept for the NRC's Astronomy and Astrophysics Decadal Survey, Astro2010.

Other studies have had unexpected spin-offs into the medical community, including the work on a revolutionary spacesuit, the BioSuit™, and on hopping microbots. For example, the initial NIAC-funded efforts on the BioSuit™ have spawned research into using this technology to improve the locomotion capability of children with cerebral palsy. A number of athletic efficiency applications are also under study. The materials used in the hopping microbots are being developed for use in surgical procedures that rely on real-time use of magnetic resonance imaging instruments for positioning.

Finding 1.8: Throughout its 9-year existence, NASA invested $36.2 million in NIAC advanced concept studies. Fourteen NIAC Phase I and Phase II projects, which were awarded $7 million by NIAC, received an additional $23.8 million in funding from a wide range of organizations, demonstrating the significance of the nation's investment in NIAC's advanced concepts. NIAC successfully matured 12 of the 42 Phase II advanced concepts (29 percent), as measured by receipt of post-NIAC funding; 9 of them (21 percent) received post-NIAC funding from NASA itself. In addition, 3 NIAC Phase II efforts (7 percent of the Phase II awards) appear to have impacted NASA's long-term plans, and 2 of these efforts have either already been incorporated or are

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[9] W. Cash, A. Shipley, S. Osterman, and M. Joy, Laboratory detection of x-ray fringes with a grazing-incidence interferometer, *Nature* 407:160-162, 2000, doi:10.1038/35025009Letter.

[10] National Research Council, *Astronomy and Astrophysics in the New Millennium,* National Academy Press, Washington, D.C., 2001.

[11] W. Cash, Detection of Earth-like planets around nearby stars using a petal-shaped occulter, *Nature* 442:51-53, 2006, doi:10.1038/nature04930.

currently under consideration by the National Research Council Astronomy and Astrophysics Decadal Survey as a future NASA missions.

One of the weaknesses of the NIAC program was the lack of sufficient funding to mature the selected concepts to the point that a NASA program could take substantial interest. By design, NIAC concepts completing Phase II were certainly not at a technology readiness level that allowed adoption by a NASA flight program. This technology-readiness disconnect between the external innovators and NASA program personnel made infusion of NIAC concepts into future agency missions or strategic plans exceedingly difficult.

Finding 1.9: By design, the maturity of NIAC Phase II products was such that a substantial additional infusion of resources was needed before these advanced concepts could be deemed technically viable for implementation as part of a future NASA mission or flight program. This technology readiness immaturity created infusion difficulties for the NIAC program and innovators.

RELEVANCE TO THE AEROSPACE SECTOR AT LARGE

NIAC-funded efforts attracted funding from a wide range of government and private sources. The provision of additional funding from private industry is a clear indicator of how the work is relevant to long-range industry plans. Of the $23.8 million cited in Table 1-1, the private sector has provided about $9.6 million to further develop selected NIAC efforts. Other government agencies have contributed about $4.7 million and NASA has provided nearly $9.5 million (with approximately $1.3 million of the NASA total coming in the form of Small Business Innovation Research [SBIR] and Small Business Technology Transfer Research [STTR] programs). Specifically, these sources included DARPA; the National Reconnaissance Office; the U.S. Air Force; NASA centers, including GSFC and Kennedy Space Center; and aerospace companies such as Northrop Grumman and ENSCO, Inc. In addition, a few NIAC efforts have contributed to the launch of a new business division (e.g., Manobianco) and two entirely new businesses (e.g., Space Elevator: Black Line Ascension and Liftport).

Finding 1.10: NIAC produced studies that were of relevance to the aerospace sector at large, including other government agencies and aerospace industries, as evidenced by the fact that 19 percent of the Phase II advanced concepts received additional funding from other government agencies and industry. In addition, three new small business entities were created based on NIAC-spinoff technology.

PARTNERSHIPS AND COST SHARING

NIAC’s statement of work (see Appendix D) from NASA did not require NIAC investigators to develop partnerships or encourage cost-sharing support; it was understood that each project would be funded entirely by NIAC. However, during interviews with six grantees, the committee noted that all of them stated that their projects were partially supported by their organizations. This unexpected outcome was likely due to the enthusiasm that the grantees had for their projects. Unfortunately, because cost-sharing information was not tabulated in the NIAC records, the committee could not quantify the breadth or depth of the cost-sharing support across the NIAC research portfolio.

Finding 1.11: Partnerships and cost sharing were not required in NIAC’s statement of work. However, a number of projects were partially supported by the grantees’ organizations, thus leveraging the impact of the NIAC grant.

In summary, NIAC was, of itself, an innovative organizational concept that filled a void in NASA for long-term, innovative concepts. NIAC was successful in attracting a large number of proposals and funded about 10 percent of them for Phase I efforts. Thirty-three percent of the Phase I awards were extended into Phase II. It is likely that, given NASA's budget pressures and near-term mission focus, none of these concepts would have been supported by NASA's mission directorates. Thus, NIAC provided a vehicle for creativity that inspired new ideas and concepts, stimulated a group of innovative researchers, developed about 1 percent of all new ideas submitted to the point that they could secure additional funding, and allowed a few of these ideas to affect NASA's long-term planning process (potentially leading to future NASA or other agency mission impacts).

In addition, due to the open nature of NIAC, its Web site, and its annual meetings, substantial publicity was afforded to NASA. Some of these efforts, like the Space Elevator project, have spawned widespread interest and annual competitions that were not heretofore envisioned. Through media coverage and the establishment of the NIAC Student Fellows program for undergraduate students, NIAC motivated young people to pursue engineering and science programs and begin a potential career in aeronautics and space. Perhaps out of these seedling efforts, a new cadre of innovators will arise to continue this advancement in aeronautics and space technology.

2

Grantee Selection Process

Committee to Review the NASA Institute for Advanced Concepts Statement of Task, Objective 2—

Evaluate the method by which grantees were selected and recommend changes, if needed.

The NASA Institute of Advanced Concepts (NIAC) devoted considerable effort to the selection of grants in order to make the process fair and effective. Critical to the success of this selection process was whether the projects were chosen on solid grounds using appropriate selection procedures, whether the grantees had the credentials and capabilities to undertake the work, and whether the activities had breadth in their scope.

PEER REVIEW PROCESS

A general outline of the proposal selection process, based on peer review, is shown in Figure 2-1. The peer review process was created by the NIAC staff, with advice from the NIAC Science Council, whose members included accomplished technical leaders as well as researchers in emerging technical areas, in order to ensure a fair and objective process. The reviewers were asked to rank proposals with respect to the basic elements of the NIAC project philosophy:

1. Revolutionary and new concepts; not duplicative of concepts previously studied by NASA;
2. An inspiration for a great leap in performance or capabilities of aerospace endeavors, achievable within the NIAC time frame of 10-40 years in the future; and
3. Largely independent of existing technology or a unique combination of systems and technologies.

The selection process was also based on the specifics associated with each award phase. For Phase I awards, the reviewers analyzed each proposal with respect to the following specific questions:

1. How well have the benefits been qualified in the context of a future aeronautics and/or space mission appropriate to the NASA charter and responsibilities?
2. How well is the concept described in a system or architecture context?
3. Is the concept revolutionary rather than evolutionary? To what extent does the proposed activity suggest and explore creative and original concepts that may initiate a revolutionary paradigm change?
4. Is the concept substantiated with a description of applicable scientific and technical disciplines necessary for development?
5. How well conceived and organized is the study work plan, and does the team have appropriate key personnel and proven experience?

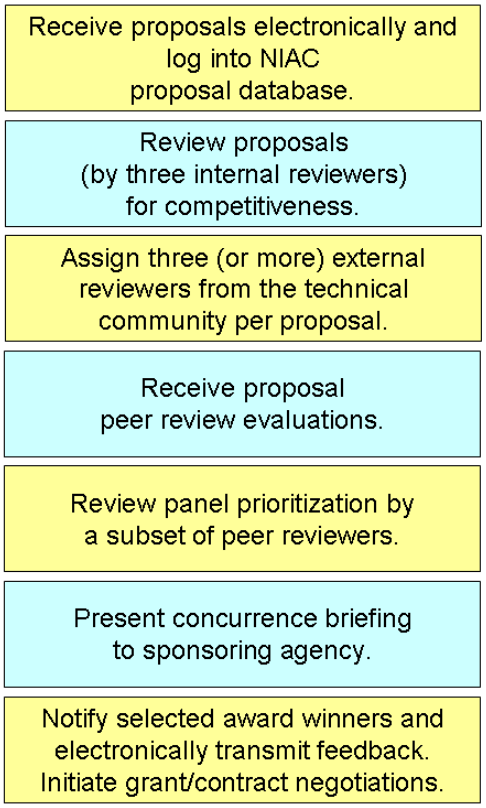

FIGURE 2-1 Selection process from receipt of proposals to notification of winners. SOURCE: Modified from NASA Institute for Advanced Concepts, *5th Annual Report* (2002-2003) Atlanta, Ga., July 2003, p. 24.

For Phase II awards, the reviewers analyzed each proposal with respect to the following specific questions:

1. Does the proposal continue the development of a revolutionary architecture or system in the context of a future NASA mission? Is the proposed work likely to provide a sound basis for NASA to consider the concept for a future mission or program?
2. Is the concept substantiated with a description of applicable scientific and technical disciplines necessary for development?
3. Has a pathway for development of a technology roadmap been adequately described? Are all of the appropriate enabling technologies identified?
4. Are the programmatic benefits and cost versus performance of the proposed concept adequately described and understood? Does the proposal show the relationship between the concept's complexity and its benefits, cost, and performance?

Reviewers were given forms to evaluate concepts using a numerical rating from 0 (worst) to 9 (best) for all these specific components, as well as written strengths and weaknesses for each of the components. In addition, the reviewers provided an overall opinion as to the viability of the proposal for NIAC funding.

BOX 2-1 Reasons for Rejection During Internal Review

- The concept is evolutionary, rather than revolutionary.
- The proposal is duplicative of concepts previously studied by NASA.
- The proposal does not describe an architecture or system.
- The concept was not placed into a NASA aeronautics and/or space mission context.
- The concept is inadequately substantiated with a description of the scientific principles that underpin it.
- The concept uses existing technology or a combination of systems and technologies without introducing a significantly unique or innovative concept.
- The concept continues the development of technologies that by their very nature are narrowly focused on the development and performance of subsystems or components.
- The concept incrementally extends the performance of an aerospace system or previously studied concept, or develops a new specialized instrument or high-performance material.
- The concept emphasizes an incremental system development, technology demonstration, or other supporting development program that is closely linked to an existing NASA program or mission and would be a near-term progression of the existing program or mission.
- The concept is based solely on technically unsubstantiated science fiction.
- A program, workshop plan, or literature search is proposed as a way to solve a problem or attain a goal with no specifically described architecture or system.
- The proposal solely describes research experiments on fundamental processes or theoretical derivations with no connection to an overall architecture or system.

Virtually all the reviews followed the process that was outlined in NIAC's first annual report:

> A group of forty-four reviewers took part in the peer review of the 119 proposals submitted in response to CP98-01. These peer reviewers represented a cross-section of senior research executives in private industry, senior research faculty in universities, specialized researchers in both industry and universities, and aerospace consultants. Peer reviewers for CP98-02 were drawn from a similar community of scientists and engineers.
>
> For CP98-01 each proposal received at least three peer reviews. Each reviewer was asked to evaluate the proposal according to the criteria stated in the Call-for-Proposals. Forms were created to help guide the reviewer through the process of assigning a numerical ranking and providing written comments.
>
> Each reviewer was required to sign a non-disclosure and no-conflict-of-interest agreement. A small monetary compensation was offered to each reviewer. Depending on the capabilities of each reviewer, the proposals and all required forms were transmitted to the reviewer over the Internet, by diskette or by paper copy. Each reviewer was given approximately thirty days to review the proposals and return the completed evaluation forms.
>
> The ANSER Corporation provided valuable assistance to the peer review process through a search of its archives, knowledge bases and additional resources. These information databases were used to provide additional background on prior and ongoing advanced concept research efforts sponsored by NASA and non-NASA sources.[1]

The review process began with an initial internal evaluation of proposals for competitiveness. This internal review was conducted by the NIAC senior technical staff (director, associate director, and senior science advisor), selected Universities Space Research Association (USRA) technical staff, and consultants, as needed. See Box 2-1 for a list of reasons for rejection during internal review.

To help ensure that a proposed concept did not duplicate previously studied concepts, NIAC accessed the NASA Technology Inventory Database and other public NASA databases to search for related NASA-funded projects.

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[1] NASA Institute of Advanced Concepts, *Annual Report* (1st; 1998-1999), Atlanta Ga., 1999, p. 10.

For the proposals that were selected for full review, external reviewers were assigned by NIAC senior technical staff based on the known qualifications of the reviewers in the database. Additional reviewers were recruited, as needed. After peer review, the proposals were generally ranked by a review panel into three categories based on the submitted ad hoc reviews: "reject," "support if funds are available," and "consider with a fourth review." The third option was used when the three reviewers had divergent opinions. The proposals were then ranked from top to bottom and a cut line was placed at the point where the funds were exhausted. Proposals on both sides of the margin were discussed again until a final ranking was established.

With this process completed, the documentation was taken to NASA Headquarters to obtain concurrence. The NIAC director was required to present the research grant selections to the NASA chief technologist and representatives of the NASA strategic enterprises before any awards were announced. Technical concurrence by NASA ensured consistency with NASA's charter, strategy, and budget limits before any grants were announced or issued.

Overall, the review process was efficient, effective, and in keeping with practices used by other federal funding agencies.

Finding 2.1: The process for selecting NIAC grantees was well documented, was disciplined, met the charter of NIAC, and was generally commensurate with the practices of other federal funding agencies.

Just as important as the award selection process was the selection of reviewers. NIAC strove to incorporate a wide spectrum of reviewers across education level, technical specialty, and organizational demographics. According to NIAC's 2004 annual report:

> The NIAC leadership has developed an efficient and proven method for identifying and selecting the most qualified and appropriate external review panel members to evaluate proposals submitted to the Institute. Over the last five years, NIAC has continuously recruited experts across a broad cross-section of technical expertise and a total of one hundred seventy eight individuals have been used, thus far, for peer review. In order to ensure a continuous refreshment of the available expertise representing newly emerging technologies within the scientific community, the NIAC leadership continually recruits additional reviewers for each new peer review cycle. NIAC peer reviewers recruited by USRA include senior research executives in private industry, senior research faculty in universities, specialized researchers in both industry and universities, and aerospace consultants.
>
> For identifying prospective peer reviewers, several resources are used in combination. Because Phase I proposals are necessarily less technically specific and will be judged more for the validity of the concept itself, evaluation of these proposals requires experts regarded as "big picture" people (i.e., individuals whose careers have exposed them to a variety of technical disciplines and an understanding of complex systems employing many different technologies). An example of this type of individual might be a vice president of a major aerospace corporation. Phase II proposals, however, which offer far more technical detail, will typically require a more specific group of evaluators.
>
> One significant resource that the Institute employed successfully was the personal knowledge of the NIAC Director, Associate Director, and Senior Science Advisor of many qualified experts in a wide variety of fields related to NIAC. Some of these experts had a prior association with NIAC, some served previously as NIAC reviewers, and some participated in Grand Challenges/Visions workshops. Others may have been suggested by NIAC Science Council members. An additional resource of qualified peer reviewers could be found in the authors of publications cited in the proposals to be reviewed. These researchers often represented the forefront of knowledge in a specific emerging technology directly relevant to the proposed study.[2]

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[2] NASA Institute for Advanced Concepts, *Annual Report* (6th; 2003-2004), Atlanta, Ga., 2004, p. 21.

BOX 2-2 Demographics for NIAC Peer Reviewers in 2003

Affiliation	
University	71
For-profit industry	30
Not-for-profit industry	21
Government laboratory	19
Consultant	22

Level of Experience	
Less than 10 years	2
10 to 20 years	31
20 to 30 years	40
More than 30 years	90

Highest Academic Achievement	
B.S.	19
M.S.	24
Ph.D./M.D.	130

Technical Specialist[1]	
Science	
Physics	47
Biological sciences	29
Chemistry	5
Physical sciences	22
Engineering	
Propulsion	39
Power	26
Design	18
Systems analysis	52
Computing/information technology	6
Biotechnology	5
Materials/structures	9

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[1] These numbers do not add up to 163 because many of the reviewers preferred to describe their area of technical specialty and experience in a more multidisciplinary manner.

All of these mechanisms for finding reviewers were commensurate with general practices at the National Science Foundation and other federal funding agencies. The total number of reviewers as of 2003 was 163. This number grew slightly for the subsequent years of NIAC activity. While information after 2003 is not available, it is likely that the demographics of the additional reviewers were similar to those presented in Box 2-2. As noted, there was a good distribution of reviewers from university, industry, laboratories, and other categories, as well as a good distribution of technical specialties. The level of experience of the reviewers was heavily weighted toward persons that have been in the field for a few decades—excluding, to a very large extent, beginning investigators. There was no evidence of an effort to achieve a balance of gender and ethnicity in the pool of reviewers, and statistics were thus not collected by NIAC.

DIVERSITY OF GRANTEES

Over the 9 years of NIAC's existence, a total of 1,066 Phase I proposals and 129 Phase II proposals were received at NIAC and evaluated for possible funding. The total number of evaluated submissions and awards for the entire life of NIAC can be visualized in Figure 2-2. The majority of submissions were from small businesses.

Especially in the early years of NIAC, a significant number of principal investigators submitted multiple proposals, even within the same solicitation. There may have been a lack of dissemination of the solicitations within a broader community. This is understandable in the early years of the program, when the news of this new source of funding was not widely available.

From what can be ascertained, dissemination of the NIAC solicitations was accomplished via a number of different paths, possibly enough to counteract the small number of submitters in the early years of NIAC.

Notices were sent to the NIAC email distribution list, generated from responses by individuals who signed up on the NIAC Web site to receive the call; announcements on professional society Web sites or newsletters (e.g., American Institute for Aeronautics and Astronautics, American Astronautical Society, the American Astronomical Society and the American Society of Gravitational and Space Biology); announcements on the USRA and NIAC Web sites; Web links from NASA mission directorate Web pages; Web link from the NASA coordinator's Web page; announcements to a distribution list for historically black colleges and universities, minority institutions, and small disadvantaged businesses, provided by NASA; distribution of announcements to an Earth-sciences list provided by NASA Goddard Space Flight Center; and announcements distributed at technical society meetings. Distribution of the NIAC Student Fellows Prize (NSFP) announcement also occurred through the Space Grant College Directors and the USRA Council of Institutions.

From the 1,066 evaluated submissions, a total of 126 Phase I grants were awarded by NIAC, as listed in Appendix E. This represents a success rate of 11.8 percent, which is comparable to other federal funding agencies. Figure 2-2 illustrates the total number of awards by category for the life of NIAC.

Phase II solicitations were limited to NIAC fellows (investigators that had received a Phase I award). A total of 129 proposals were submitted during the life of NIAC. Following the same trend as in the Phase I submissions and awards, the majority of grants were awarded to small businesses and universities (Figure 2-2). From the 129 submissions, a total of 42 Phase II awards were approved by NIAC. This represents a success rate of 32.6 percent. Figure 2-2 illustrates the total number of Phase II awards by category for the life of NIAC.

Finding 2.2: The process for selecting NIAC grantees led to a variety of involved organizations, principally from universities and small businesses.

In summary, the committee found the methods by which NIAC grantees were selected to be generally effective, efficient, and appropriate to the objectives of the NIAC program, including the advertisement of the solicitations, the selection of reviewers, the screening of proposals, and the use of electronic processes to streamline the overall evaluation.

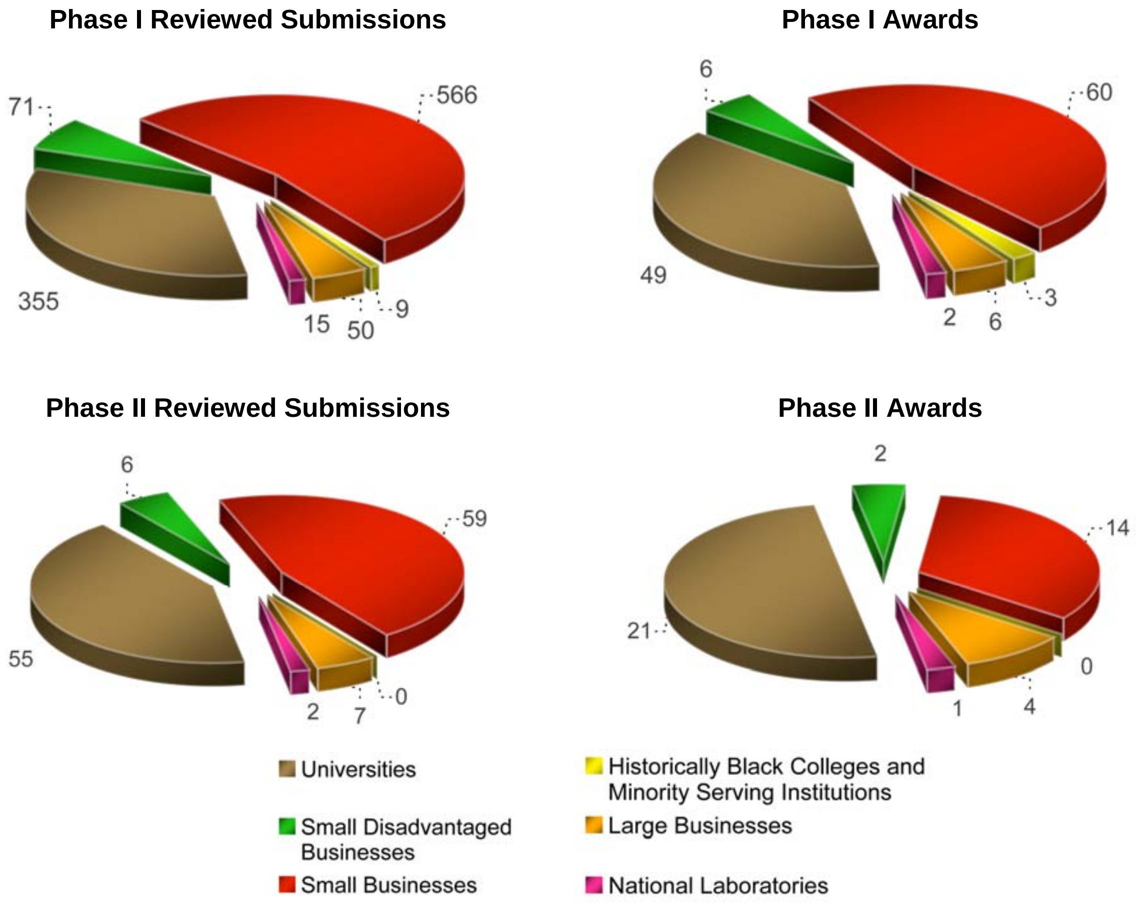

FIGURE 2-2 Reviewed submissions and awards over the life of NIAC.

3

A Successor to NIAC

Committee to Review the NASA Institute for Advanced Concepts Statement of Task, Objective 3—

Make recommendations on whether NIAC or a successor entity should be funded by the federal government and, if so, what changes, if any, should be made to NIAC's original mission, goals, operations, or other matters.

As discussed in Chapters 1 and 2, the NASA Institute for Advanced Concepts (NIAC) was both effective and efficient in meeting the objectives established for it by NASA. A recommendation as to whether or not NIAC or a successor entity should be funded also depends on factors external to NIAC. These include:

1. NASA's need to identify innovative concepts with significant benefits for advanced systems and missions,
2. Alternative methods used by NASA to establish and develop future mission concepts, and
3. Potential funding levels for a successor entity.

This chapter concludes with specific recommendations on changes that should be considered to maximize the effectiveness of a successor entity to NIAC, referred to in this report as NIAC2.

SHOULD THE FEDERAL GOVERNMENT FUND A NIAC-LIKE ENTITY?

Recommendation 3.1: NASA should reestablish a NIAC-like entity, referred to in this report as NIAC2, to seek out visionary, far-reaching, advanced concepts with the potential of significant benefit to accomplishing NASA's charter and to begin the process of maturing these advanced concepts for infusion into NASA's missions.

This recommendation is based on a combination of factors identified by the committee:

- NASA needs to have a viable, long-term plan for new missions and systems in order to meet its obligations to the public.
- NASA needs appropriate, open methods to ensure that it has access to the best new mission and system concepts from any source, not only those developed within NASA.
- NASA needs effective and efficient processes to assess new ideas for its future systems and missions and to develop the most promising of those ideas to a level suitable for its plans.
- NASA needs to continue to develop and expand its reputation for international leadership in aeronautics and space research and to inspire the public with bold missions of exploration.

One of NASA's roles is to inspire the public with a spirit of discovery and exploration, and NASA is at its best when it accomplishes this through significant scientific and technical achievement in aeronautics and space. By fostering the identification and development of innovative advanced concepts, and by its actions to advertise the results of its projects to the public at large, NIAC served NASA well in support of this inspirational role.

A NIAC-like entity could facilitate the introduction of valuable products—intellectual and material—into NASA. It could broaden the population that can contribute creative ideas and concepts to NASA, a breadth that has generated significant new ideas. These aspects of the success of the previous NIAC form a compelling set of reasons to reinstate an organization with this charter.

ALTERNATIVES TO NIAC

The committee discussed and evaluated current approaches of the Defense Advanced Research Projects Agency (DARPA) and NASA to develop advanced concepts or advanced technology development. The committee found no program similar to NIAC in fostering low technology-readiness-level (TRL 1-2) advanced concepts with such a long time horizon to fruition.

The most frequently referenced model of success for advanced concept development is DARPA. As the central research and development organization for the U.S. Department of Defense, DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming national security. DARPA is not tied to a particular operational mission. DARPA's approach is to imagine what capabilities a *future* military commander might need and to accelerate those capabilities into being through technology demonstrations.

DARPA's charter, culture, and business model are unique, with some features that could benefit a NIAC2 organization (Box 3-1). Chief among these are the ability to rapidly award and terminate projects; funding of high-risk, high-reward research and development projects that span basic, fundamental scientific investigations to full-scale prototypes of military systems; the intentionally short tenures of expert, entrepreneurial program managers, which ensures the presence of transition champions for successful projects; limited overhead and the absence of laboratories and facilities to prevent institutionalization; and a multitiered technology transition strategy with identified technology transition liaisons. Appendix G provides a more comprehensive description of DARPA.

BOX 3-1 Key Features of DARPA

- DARPA's only charter is radical innovation.
- DARPA is not tied to a particular operational mission
- DARPA looks beyond today's known needs and requirements.
- DARPA budget typically accounts for about 25 percent of DOD'S S&T budget.
- Projects range from fundamental scientific investigations to full scale prototypes
- Long time horizon from an idea's conception to its use by the U.S. military
- Program managers hired for only 4 to 6 years
- Very limited overhead and no laboratories or facilities prevent institutionalization.
- Organizational flexibility and ability to change direction quickly
- Multi-tier Technology Transition process with identified technology transition liaisons.
- Ensure transition of prototypes by negotiating a memorandum of agreement (MOA) with the Service adopting the system

NOTE: For additional information, see Appendix G.

In discussing the termination of NIAC, NASA management explained that advanced concept development is continuing in programs within the mission directorates. However, these activities are prioritized at varying levels across the mission directorates. For instance, NASA is studying advanced concepts for lunar and Mars exploration in the Exploration Technology Development Program (ETDP) within the Exploration Systems Mission Directorate (ESMD). The first human return to the Moon is planned for approximately 2020, while plans for human Mars exploration extend beyond 2030. However, a recent National Research Council (NRC) study of the ETDP found a focus on high-TRL technology and a lack of advanced concept development and low-TRL research.[1]

The concept development approach used by NASA's Science Mission Directorate (SMD) was singled out by some presenters to the committee as a potential agency model because it regularly employs a number of established processes for identifying new mission and system concepts to be incorporated into its advanced plans. The scientific objectives of the SMD are developed to implement the priorities defined by the NRC in its decadal surveys and other reports, which represent the broad consensus of the scientific community. In addition, each area of the SMD engages the scientific community to develop a series of roadmaps of its future science program.[2] The final roadmaps, together with the NASA Strategic Plan, the SMD Science Plan, and other planning documents, are used by NASA as guidance in soliciting and selecting proposals for concept and technology development. Thus, within SMD there is an established process that is regularly employed and that involves the scientific community in (1) setting research goals, (2) identifying future missions, and (3) supporting concept and technology development (primarily in the area of sensors) directed at those goals and missions.

Other programs to solicit new mission concepts and technologies are established by NASA from time to time in response to its needs. Within SMD, these include the "Astrophysics Strategic Mission Concept Studies," which are currently underway with a total of $12.7 million to fund 19 12-month investigations; and the "Vision Missions" advanced studies program of 2004 to 2006. While both of these ad hoc study projects and the roadmap process replicate some of the functions of NIAC, they lack the continuity, breadth, and focus on advanced missions that NIAC provided.

RECOMMENDED ORGANIZATION AND IMPLEMENTATION FOR NIAC

Recommendation 3.2: NIAC2 should employ the streamlined, Internet-based, technical review and management processes developed by the original NIAC. These approaches met NASA-defined objectives, resulted in a cost-effective and timely implementation of advanced concept studies, afforded an opportunity for external input of new ideas to the agency, and provided broad exposure for NASA of advanced program concepts.

As noted in Chapters 1 and 2, the committee found that the processes used by NIAC to select proposals for funding were efficient and effective. The committee also found that the majority of NIAC-supported efforts were highly innovative and creative.

The committee believes that the processes employed by NIAC to select proposals for award helped to ensure their success. These processes included the kind of technical peer review used by the scientific establishment for prior review of archival publications and used by NASA in the review of proposals for scientific investigations. The breadth of involvement of the larger technical community that results from the peer review process helps to ensure that the best ideas are identified from a wide range of possibilities. Also, these processes helped NIAC to avoid "stovepipes" and organizational inbreeding that can occur in a more restricted, less open organization. The above recommendation is not intended to exclude NASA employees from serving as peer reviewers; specifically, the NIAC2 recommended by the committee should not artificially restrict the pool of qualified peer reviewers according to whether or not they are employed by NASA.

The committee was impressed at the efficiency and effectiveness of the proposal peer review process developed and deployed by the original NIAC, which took advantage of electronic documents and communications and achieved uniformity of results through a set of templates and related forms used by the reviewers. These Internet-based review and management processes led to significant efficiencies,

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[1] National Research Council, *A Constrained Space Exploration Technology Program: A Review of NASA's Exploration Technology Development Program*, The National Academies Press, Washington, D.C., 2008.

[2] For an example, see http://sec.gsfc.nasa.gov/sec_roadmap.htm.

resulting in more than 75 percent of program funding going directly to grants. In addition to the costs associated with maintaining a staff of, typically, six personnel, the remaining funding went for activities called for in the NIAC statement of work to "sustain public interest in revolutionary concepts of alternative aerospace" and "provide a positive motivation to the nation's youth to study technical subjects,"[3] including workshops focused on emerging technical areas; participation by NIAC employees in national technical meetings; representation on technical committees and boards; and presentations of seminars at universities, K-12 schools, and other organizations. NIAC's activities to foster a community of innovators were successful. NIAC's public outreach was an important component of its value to NASA. These processes should be a baseline for NIAC2, subject to continued development and refinement as electronic communications capabilities increase. At approximately $4 million per year, the amount of funding allocated to NIAC for Phase I and Phase II grants was appropriate.

Recommendation 3.3: A NIAC2 organization should be funded and administered separately from the NASA development programs, mission directorates, and institutional constraints.

NASA is responsible for the management and execution of programs that represent a significant investment of public funds and that are of high importance and value to the reputation of the United States. The resulting management focus and attention on ensuring the success of these missions is essential, and has led to NASA's reputation as an agency oriented toward flight-system development and operations. However, for NASA to remain at the forefront of aeronautics and space exploration and research, this focus on execution of the mission must not be such as to exclude appropriate long-term planning for future programs.

NIAC was terminated after it had been transferred to the ESMD and at a time when the ESMD was focused on developing initial plans for the Vision for Space Exploration. In the context of this part of the NASA organization, and in the context of the focus required to develop the Vision for Space Exploration, the mission of NIAC seemed less relevant. Some of the most successful NIAC-funded projects, for example, the New Worlds Observer, could not be valued within the narrower context of the ESMD, especially while that organization was focused on developing a new human exploration transportation architecture. According to sources, NIAC was terminated because its focus was on far-term mission concepts that were not closely aligned with the lunar exploration architecture, and because NIAC had limited success in infusing advanced concepts into NASA's strategic plans.

Recognizing this relevance problem, the committee considered whether or not each NASA directorate should have its own NIAC-like entity. One potential advantage of such an arrangement is that each "sub-NIAC" could focus on the advanced system and mission needs of its associated directorate, which likely would help each such organization to be more relevant to the directorate and would facilitate the infusion of results obtained. In the opinion of the committee, the efficiencies resulting from having a single organization solicit and manage advanced concepts for NASA as a whole were more compelling. Improving NIAC's relevance to NASA and facilitating the infusion of NIAC concepts needs to be addressed by other methods, as discussed below.

Providing funding and administration for NIAC2 outside of the mission directorates will take advantage of the efficiencies of a single organization with common processes for soliciting and developing advanced concepts, while protecting it to work on concepts 10 years and beyond, despite the immediate management, financial, and technical pressures of the missions being executed in any individual directorate.

Recommendation 3.4: NIAC2 proposal opportunities should be managed and peer-reviewed outside the agency.

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[3] Statement of work for the NASA Institute for Advanced Concepts, Attachment A of Contract NAS5-03110, Amendment of Solicitation/Modification No. 7, issued by NASA for the Universities Space Research Association, dated July 11, 2003, pp. 1-2; reprinted in Appendix D.

As discussed previously, NIAC was formed to solicit advanced concepts from outside NASA. It was established as an organization outside NASA, with no direct NASA involvement in its operations, to reinforce the message that it was an independent source of new ideas to affect NASA's long-range planning. The committee supports this purpose for NIAC and, therefore, recommends that NIAC's managerial independence be maintained. The committee also recognizes that there were some negative consequences of this independence, and addresses them below.

RECOMMENDED CHANGES TO IMPROVE THE EFFECTIVENESS OF NIAC

In an effort to better align prospective NIAC2 advanced concept innovations with future NASA missions and improve success in infusing advanced concepts into future NASA missions, the committee recommends some changes to the recommended future NIAC2 entity. These changes address the following problems encountered by the original NIAC that limited its impact or detracted from its reputation:

1. NIAC's focus only on truly "revolutionary" advanced concepts had the effect of distancing it from NASA's future planning because it did not allow for significant "evolutionary" advanced concepts that might build on or improve mission concepts already identified in NASA's future plans.
2. NIAC's focus only on concepts that were 10 to 40 years in the future made it difficult to judge the success of the NIAC grants from year to year and added to this "distancing" problem.
3. The existence of NIAC may have helped to justify a reduction in internal NASA funding for advanced concepts even though NASA personnel were excluded from submitting proposals to NIAC. This led to a reduction in innovation opportunities within NASA and did not facilitate good relationships between NASA and NIAC innovators.
4. The 6-month period of performance for NIAC Phase I awards was not well coordinated with the annual academic or business year cycle, and the initial award amounts were not increased with inflation in the decade after the original NIAC was established.
5. Many NIAC projects have yet to demonstrate a significant impact on NASA's future plans. Additionally, many NIAC investigators expressed frustration at a lack of access to NASA management to facilitate the infusion of their ideas.
6. The management of the intellectual property resulting from NIAC projects was a concern to some investigators.

Each of these issues is discussed below in some detail and is addressed by the following specific recommendations.

Recommendation 3.5(a): The key selection requirement for NIAC2 proposal opportunities should be that the concept is scientifically and/or technically innovative and has the potential to provide major benefit to a future NASA mission in 10 years and beyond.

The emphasis of the original NIAC on funding only those concepts that are new and not already identified in NASA's future mission planning should be maintained. However, the committee found that NIAC's focus only on concepts that were *revolutionary* was too restrictive. There is a spectrum of advances, ranging from incremental or evolutionary improvements in individual components through innovative combinations of existing technologies to produce new results, to concepts that are truly revolutionary because they replace existing capabilities with something very different or enable new missions not previously possible.

By emphasizing revolutionary concepts, the original NIAC contributed to a sense that it was often "too far out" to be relevant to NASA's more immediate and pressing needs (for example, the lunar exploration architecture). The committee recommends that NIAC2 adopt a standard of "technically innovative" rather than "revolutionary" to help to address this issue. The committee further recommends that NIAC2 focus on concepts 10 years in the future and beyond. The committee strongly endorses the primary standard of the original NIAC, i.e., only those concepts that are new and not already identified in NASA's future mission needs should be funded; however, to qualify for NIAC2 support, concepts should have the potential to provide a major benefit to a future NASA mission or system.

Recommendation 3.5(b): Over the long term, the ultimate criterion for NIAC2 success is the number of funded projects that eventually make their way into the relevant NASA mission directorate decadal survey, strategic plan, or mission stream. Because most NIAC2 projects will bear fruit only over the long term, in addition to the annual performance and feedback reviews, a major review of NIAC2 grants should occur every 5 years to ensure continuous infusion opportunities into NASA missions and planning.

The annual reports produced by NIAC are an excellent source of information on its activities and on the progress and status of its projects. These types of reports should be maintained and continued in NIAC2, and NIAC2 should be accountable to the public for its performance every year through similar types of annual reports. However, the committee thinks that a substantive review of the success of NIAC2 grants, for the purpose of determining fit and potential infusion into NASA missions and planning, should be performed every 5 years. The prospective NIAC2 should provide a forum every 5 years for NIAC2 grantees, past and present, to present their concepts to NASA mission directors to facilitate infusion of worthy concepts into NASA missions and strategic planning. Such a forum would reinforce the intention of NASA to invest in the NIAC2 process for the long term and would enable the NIAC2 leadership to plan for a stable and durable institution. Such an approach also implies a long-term, stable funding commitment from NASA.

Recommendation 3.5(c): NIAC2 proposal opportunities should be open to principal investigators or teams both internal and external to NASA.

One of the problems suffered by NIAC was that its products were viewed by many at NASA as foreign to NASA's mission directorates. This was an unintended consequence of the formation of NIAC as an external institution, and it was exacerbated by the fact that NASA employees were not allowed to submit proposals to it and were not invited to participate in its programs and forums. This connectivity weakness was cited by an NRC committee in 2003.[4] While NIAC was formed specifically to solicit concepts from outside NASA, the committee found no compelling reason to maintain this restriction in NIAC2. Freedom to select the best proposals for funding, regardless of their source, should be assured.

Recommendation 3.5(d): NIAC2 proposal opportunities should be defined as follows: Phase I, up to $100,000 each for 1 year; Phase II, up to $500,000 each for 2 years.

The committee heard from a variety of investigators funded by NIAC. The committee's recommendation to increase the maximum duration of a Phase I award from 6 months to 1 year was made in response to the comments of a number of successful NIAC investigators that the original 6-month duration was too short. A 1-year period would also better align NIAC2 activities with annual government, business, and academic cycles. The recommended $100,000 maximum Phase I award amount represents a $25,000 increase over NIAC's 1998 guideline that was set over a decade ago. This does not represent a real increase in buying power. For Phase II awards, the committee does not recommend any change in the 2-year duration for Phase II awards and recommends a modest increase in the maximum award from $400,000 to $500,000 for the same reasons given for the Phase I awards.

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[4] National Research Council, *Review of NASA's Aerospace Technology Enterprise: An Assessment of NASA's Pioneering Revolutionary Technology Program*, The National Academies Press, Washington, D.C., 2003.

Recommendation 3.5(e): NIAC2 proposal opportunities should include the potential selection of a small number of Phase III "proof-of-concept" awards for up to $5 million each for 4 years to demonstrate and resolve fundamental feasibility issues, and such awards should be selected jointly by NIAC2 and NASA management.

This recommendation is intended to address the difficulty of technology infusion into NASA's long-term plans that has been identified by NIAC-funded investigators. It establishes an obligation on the part of NASA to review the successful Phase II projects for their applicability and relevance to NASA's long-term mission and system plans; a specific mechanism to support further development and refinement of the most promising concepts to a "proof of concept" level; and a mechanism for the transfer of these projects from NIAC2 to a NASA mission directorate.

The committee recommends that NASA provide NIAC2 with the funding to implement Phase III awards as an initial step in transferring the NIAC2 product into a NASA mission directorate. As Phase II projects mature, NIAC2 would assess them. As one aspect of its responsibility to infuse the results of its activities into NASA's long-range plans, NIAC2 would identify an appropriate NASA organization to adopt the project and would work with representatives of that organization to establish and fund the Phase III activity. The transition of the project from NIAC2 to NASA would occur as part of the Phase III development, and NASA would be responsible for assessing the final Phase III performance.

Recommendation 3.5(f): NASA, through NIAC2, should allow awardees to retain rights to data and associated intellectual property developed under NIAC2 awards. NIAC2 should also be proactive in coaching the awardees in protection of intellectual property.

The committee heard from some NIAC awardees, particularly small businesses, that were uncomfortable with what they understood to be their rights to intellectual property developed under a NIAC award. NIAC awardees expressed uncertainties about the status of intellectual property for proposals submitted to NIAC and the status of intellectual property rights for work developed under NIAC support. The committee recommends that NIAC2 develop and document a policy allowing awardees rights to data and associated intellectual property to address these issues before soliciting any proposals.

As an organization with a focus on the development of new concepts and technologies, NIAC was in an ideal position to foster an innovative program of intellectual property management and train its innovators in how to manage intellectual property and their rights in compliance with the law and government policy.

Recommendation 3.5(g): Efforts should be made to disseminate announcements and solicitations to the widest possible audience in order to reach the largest possible number of researchers, including those from small disadvantaged businesses and minority institutions.

NIAC2 should ensure that its calls for proposals are widely distributed to ensure that all organizations, including minority-serving academic institutions and small disadvantaged businesses, are aware of the opportunity to submit proposals.

Recommendation 3.5(h): Efforts should be made to encourage the widest possible demographics of reviewers, including gender, age, and ethnicity, while ensuring that breadth of experience and technical competence are paramount considerations in reviewer selection.

NIAC2 should select technically qualified reviewers that encompass the range of disciplines required by the advanced concept proposals received. When possible, NIAC2 should also strive to include a broad range of reviewers with consideration given to years of experience, gender, and ethnicity.

4

Infusion of Advanced Concepts into NASA

Committee to Review the NASA Institute for Advanced Concepts Statement of Task, Objective 4—

Make recommendations as to how the federal government in general and NASA in particular should solicit and infuse advanced concepts into its future systems.

In this chapter, the committee recommends modifications in organization and approach for a reintroduction of the NASA Institute for Advanced Concepts (NIAC) as NIAC2. The intent is to improve the probability of providing a sustained flow of contributions of value to NASA by a NIAC2 entity. The desired contributions involve infusion of both long-term and, on a trial basis, shorter-term advanced concepts into NASA's mission directorate programs. As a consequence, other non-governmental U.S. space entities would also benefit. The committee assumes continuation of existing major NASA objectives and programs.

The committee determined that successful infusion of advanced concepts into government systems is generally situational and depends critically on the histories, structures, requirements, and constraints of specific government entities. The scope of the committee's effort was, therefore, limited to considerations of NIAC2 functions within NASA. The committee also found that successful infusion of advanced concepts into government systems is highly dependent on an agency's charter, strategic plan, and management approach.

NASA's current organizational structure is illustrated in Figure 4-1. At the time of its termination in 2007, NIAC was located within the Exploration Systems Mission Directorate. From its inception through 2004, NIAC reported to NASA's chief technologist, who also served as associate administrator for the Office of Aerospace Technology. Location within the chief technologist's office provided NIAC with both high-level exposure and advocacy within NASA. This led to natural pathways for accessing NASA's mission directorates for infusion of advanced concepts into technology maturations and mission planning. An example of this approach was coordination of relevant themes for NIAC studies from across the agency's mission directorates.[1] Inputs from past and present NASA managers have indicated that the closure of NIAC was consistent with a long-term trend within NASA to increase focus on near-term missions, with corresponding reductions in support of longer-term advanced mission concepts and technologies. Examples of such dissolutions are the Office of Aeronautics and Space Technology, the Office of Advanced Concepts and Technology, the Office of Space Access and Technology, and the Office of Aerospace Technology, in 1992, 1994, 1996, and 2004, respectively. The schedule and budget requirements of NASA's new strategic focus on the Vision for Space Exploration served to deepen the cultural mismatch between the goals and timelines of NIAC and the agency's major efforts.

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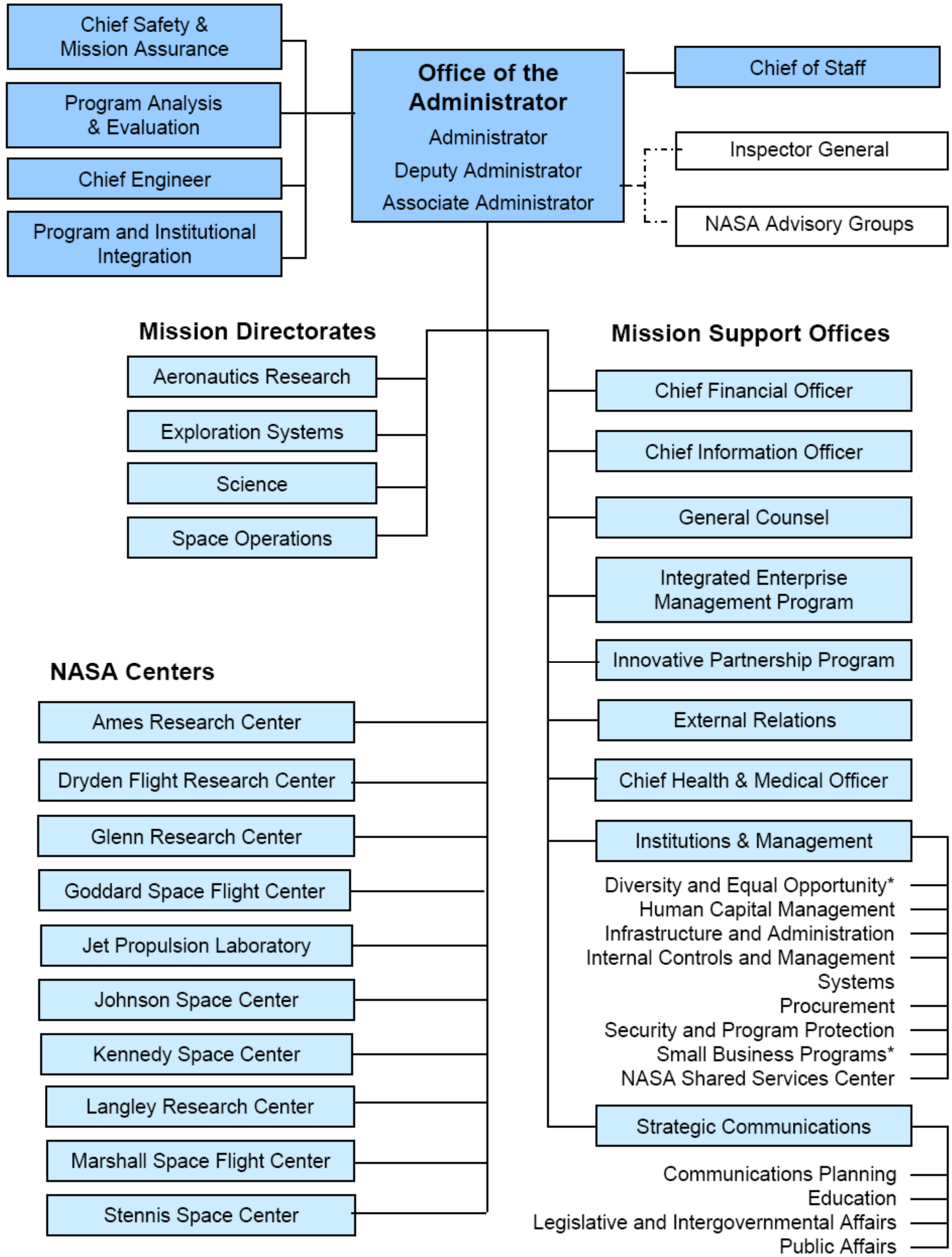
[1] NASA, *Visionary Challenges of NASA Strategic Enterprises for the NASA Institute for Advanced Concepts for 2004,* Office of Space Flight Visionary Challenges, Washington, D.C., January 9, 2004, available at http://www.niac.usra.edu/files/library/misc/Enterprise_Visionary_Challenges.pdf.



* In accordance with law, the offices of Diversity and Equal Opportunity and Small and Disadvantaged Business Utilization maintain reporting relationships to the Deputy Administrator and Administrator.

FIGURE 4-1 NASA organization. SOURCE: Courtesy of NASA, available at http://www.nasa.gov/about/org_index.html.

Finding 4.1: NASA is now an agency oriented toward flight-system development and operations. Priorities have thus diminished within NASA for long-range research and development efforts. At present, there is no NASA organization responsible for solicitation and evaluation of advanced concepts (defined as technology readiness level 1 or 2) and subsequent infusion of worthy candidates into NASA planning and development activities.

NASA's four mission directorates conduct, as appropriate to their specific objectives, a variety of technology development programs. One example is Research Opportunities in Space and Earth Sciences within the Science Directorate. Reviews of development programs, with the help of NASA inputs, indicated that most development efforts generally support defined and/or approved missions. Therefore, there is a concentration on requirements-driven, high-technology-readiness-level (TRL) efforts. NIAC, with its long-range and agency-wide perspective, was not a natural fit to the objectives and timelines of the mission directorates

NASA does, however, currently support long-term, agency-wide technology activities in for TRL 3 to 6 within the Innovative Partnership Program (IPP) which is located outside of the mission directorates with direct reporting to the Office of the Administrator. The IPP has three elements—Technology Infusion, Innovation Incubator, and Partnership Development—funded at about $147 million in fiscal year 2008. The IPP has offices at all 10 NASA centers in order to enhance the effectiveness of outreach and infusion. There was essentially no overlap between IPP and NIAC because IPP did not, and does not, support projects at very low TRL levels (1 or 2), which was NIAC's focus.

NIAC successfully infused concepts into multiple U.S. space sectors. However, transfers into NASA were found difficult, which, may have been partially due to the exclusion of NASA technical participation in NIAC projects. Input from NASA personnel to the committee indicated that adoption, maturation, and infusion of advanced concepts into NASA's principal activities require the strong collaborative participation of NASA center personnel. Such participation was lacking in the previous NASA implementation approach for NIAC. NASA and NIAC2 approaches that could facilitate participation of NASA field centers and access to agency-wide projects should materially improve the chances for infusion of NIAC outputs into NASA programs.

To achieve the original NASA intent of independence, NIAC was managed and operated external to NASA by the Universities Space Research Association (USRA). USRA is a non-profit organization that provided institutional benefits such as procurement procedures and access to and formal liaison with NASA management through the NIAC director and the NASA contracting officer's technical representative (COTR). NIAC evolved a "virtual institute" approach that used the Internet for nearly all communication functions. That concept allowed rapid completion of major functions, including solicitation, procurement, contract management, reporting, and important outreach and public relations functions to be accomplished with a permanent staff of less than six persons. Other examples of the global efficiency of the NIAC approach were the high fraction of total resources placed on contract (>75 percent), the short time from solicitation to award, and the wide media attention given to supported efforts.

Objective 3 of this report recommended modest changes to the resource levels for NIAC2 Phase I and Phase II efforts, and the establishment of a small number of Phase III efforts. Implementation of those recommendations would require an increase in the NASA resources specified for NIAC.

Finding 4.2: Any expectations of a NIAC2 will depend on the management approach provided by the agency. Management with senior, NASA-wide perspectives and resources outside the near-term focus of the NASA mission directorates should, based on successful Innovative Partnership Program experiences, materially increase the probability for sustained value from a NIAC2 program.

Recommendation 4.1: To improve the manner in which advanced concepts are infused into its future systems, the committee recommends that NASA consider reestablishing an aeronautics and

space systems technology development enterprise. Its purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies. NASA's consideration should include implications for the agency's strategic plan, organizations, resource distributions, field center foci, and mission selection process.

Recommendation 4.2: To allow for successful, sustained implementation of NIAC2 infusion objectives, NIAC2 should report directly to the Office of the Administrator, be outside mission directorates, and be chartered to address NASA-wide mission and technology needs. It is worth noting that this organizational structure was in place during the formation and initial operation of NIAC. To increase NIAC2's relevance, NASA mission directorates should contribute thematic areas for consideration. The Innovative Partnership Program (IPP) offers characteristics compatible with effective and healthy, long- and short-term advanced concepts projects. The agency should consider adding a new element to the existing IPP to house the (internal management of) NIAC2, with its focus on technology readiness level 1 and 2 and higher concept studies.

Recommendation 4.3: Identification of center technical champions and provision for technical participation of NASA field center personnel in NIAC2 efforts—participation that can be expected to increase as NIAC2 projects mature—is recommended. Increased participation of NASA field center personnel, beyond review and management functions, may significantly enhance advanced concept maturation and infusion into NASA mission planning. As appropriate, Phase II and Phase III NIAC2 projects should include realistic transition plans to the appropriate NASA enterprises.

5

Concluding Remarks

> NASA is an investment in America's future. As explorers, pioneers, and innovators, we boldly expand frontiers in air and space to inspire and serve America and to benefit the quality of life on Earth.[1]

VALUE TO NASA AND THE NATION

The committee found that the NASA Institute for Advanced Concepts (NIAC) program met its mission and accomplished its stated goals. Funded at approximately $4 million per year, NIAC received a total of $36.2 million in NASA funding and expended more than 75 percent of these funds directly for its grants. At present, there is no NASA organization responsible for solicitation and evaluation of advanced concepts (defined as technology readiness level 1 or 2) and subsequent infusion of worthy candidates into NASA planning and development activities. Testimony from several sectors confirmed that NASA and the nation must maintain some mechanism to investigate visionary, far-reaching advanced concepts in order to achieve NASA's mission. As such, the committee recommends that NASA should reestablish a NIAC-like entity (NIAC2) to seek out visionary, far-reaching advanced concepts relevant to NASA's charter and to begin the process of maturing these advanced concepts for infusion into NASA's missions.

The committee found that NIAC was most successful when it was sponsored at the highest level of the agency, enjoying a cross-cutting applicability to NASA enterprises and missions. To allow for sustained implementation of NIAC2 infusion objectives, the committee recommends that NIAC2 should report directly to the Office of the Administrator, be outside the mission directorates, and be chartered to address NASA-wide mission and technology needs. To increase NIAC2's relevance, NASA mission directorates should contribute thematic areas for consideration. The committee also recommends that NIAC2 should be funded and administered separately from the NASA development programs, mission directorates, and institutional constraints. Future NIAC proposal opportunities should continue to be managed and peer-reviewed outside the agency.

While the NIAC Internet-based, technical review and management processes were found to be effective and should be continued in NIAC2, the committee found a few NIAC practices that may have had unintended negative consequences for NIAC. Key among these was (1) the complete focus on revolutionary advanced concepts and (2) the exclusion of NASA participants from NIAC awards or research teams. The committee recommends that NIAC2 alter its scope to focus on concepts that are scientifically and/or technically innovative and have the potential to provide major benefits to a future NASA mission in 10 years and beyond. The committee also recommends that future NIAC2 proposal opportunities be open to principal investigators or teams that are both internal and external to NASA.

One important NIAC performance metric assessed by the committee was achievement of 5 to 10 percent infusion of NIAC-developed advanced concepts into NASA's long-term plans. One way to measure this infusion is by studying post-NIAC funding from NASA for the continued development of

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[1] National Aeronautics and Space Administration, *NASA Strategic Plan: 1998 Policy Directive (NPD)-1000.1*, Washington, D.C., 1998. Available at http://www.hq.nasa.gov/office/nsp/.

the advanced concept. Initially funded by NIAC at a level of $7 million, 14 of the NIAC Phase I and Phase II advanced concepts garnered at least $23.8 million in additional support from NASA, other agencies, or the private sector, proving their value. Over the long term, the ultimate criterion for NIAC success is the number of funded projects that eventually make their way into the relevant NASA mission directorate decadal survey, strategic plan, or mission stream. Three NIAC efforts (7 percent of the Phase II awards) appear to have had an impact on NASA's long-term plans, and two of these efforts either have already been incorporated or are presently under consideration by the National Research Council's Astronomy and Astrophysics Decadal Survey as future NASA missions. Given the 40-year planning horizon of NIAC activities, coupled with the 9-year existence of NIAC, the committee considers it likely that the number of NIAC Phase II projects considered for NASA missions will continue to increase over time.

A persistent challenge has been the lack of a NASA interface to facilitate transition of promising NIAC projects. The committee recommends identification of NASA field center technical champions and a provision for the technical participation of center personnel in NIAC2 efforts. The degree of participation of NASA personnel may be expected to increase as NIAC2 projects mature. In addition, the committee recommends that future NIAC proposal opportunities include the potential selection of a small number of Phase III proof-of-concept awards for up to $5 million/4 years to demonstrate support and resolve fundamental feasibility issues, and that their selection be made jointly by NIAC and NASA management.

The termination of NIAC in 2007 reflects a larger issue within NASA related to the demise of programs throughout the agency for advanced concepts and technology development. To effectively infuse advanced concepts into its future systems, NASA needs to become an organization that values and nurtures the creation and maturation of advanced aeronautics and space concepts. Working for NASA, NIAC helped for almost 10 years to serve NASA's need for advanced concepts, and NIAC demonstrated its success in creating a community of innovators focused on advanced concepts that might impact future NASA missions. A NIAC2 can look out for advanced concepts beyond the current development programs. It can work on the edges where requirements are not yet known, focused on what program managers would want if they knew that they needed it. However, an independent organization that nurtures technology "push" must also be balanced by a meaningful program of technology "pull" from the mission directorates—running in parallel and focused on nearer-term phased activities. Toward this objective, the committee recommends that NASA consider reestablishing an aeronautics and space systems technology development enterprise. Its purpose would be to provide maturation opportunities and agency expertise for visionary, far-reaching concepts and technologies. NASA's considerations should include implications for the agency's strategic plan, organizations, resource distribution, field center foci, and mission selection process. The technology development approaches used by other federal agencies can serve as a benchmark in this examination.

Appendixes

A

Statement of Task

An ad hoc committee operating under the auspices of the Aeronautics and Space Engineering Board will conduct a review to evaluate how well the NASA Institute for Advanced Concepts (NIAC) developed revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its mission. NASA funding for NIAC ended in 2007, and Congress has directed the NRC [National Research Council] to review NIAC performance. The review will help guide NASA in assessing NIAC's processes and results and in shaping future efforts in this area.

The objectives of the review are to:

1. Evaluate NIAC's effectiveness in meeting its mission, including a review of the grants made by the Institute, their results, and the likelihood that they will contribute to the Institute's stated goals.
2. Evaluate the method by which grantees were selected and recommend changes, if needed.
3. Make recommendations on whether NIAC or a successor entity should be funded by the federal government and, if so, what changes, if any, should be made to NIAC's original mission, goals, operations, or other matters
4. Make recommendations as to how the federal government in general and NASA in particular should solicit and infuse advanced concepts into its future systems.

NIAC generated advanced concepts as its sole focus. NIAC especially pursued revolutionary systems and architectures from external sources of innovation. According to a review of NIAC's accomplishments published by USRA [Universities Space Research Association], NIAC studies were aimed at having a major impact on NASA missions and activities 10 to 40 years in the future.

In evaluating NIAC's performance, the committee will address the following questions:

- To what extent were the NIAC-sponsored advanced concept studies innovative and technically competent?
- How effective was NIAC in infusing advanced concepts into NASA's strategic vision, future mission plans, and technology development programs?
- How relevant were these studies to the aerospace sector at large?
- How well did NIAC leverage potential partnerships or cost-sharing arrangements?
- What potential approaches could NASA pursue in the future to generate advanced concepts either internally or from external sources of innovation?

A committee of approximately 12 members will meet twice, with additional discussion and writing via telecon or electronic communications. A prepublication version of the report will be delivered to the sponsor within 10 months after the NRC receives funding and authority to proceed, followed by a 6-month period for printing and dissemination activities.

B

Committee Member Biographies

ROBERT D. BRAUN is the David and Andrew Lewis Associate Professor of Space Technology in the Daniel Guggenheim School of Aerospace Engineering at the Georgia Institute of Technology. He is also director of Georgia Tech's Space Systems Design Laboratory, where he leads a research program focused on the design of advanced flight systems and technologies for planetary exploration. He is responsible for undergraduate- and graduate-level instruction in the areas of space systems design, astrodynamics, and planetary entry. Prior to Georgia Tech, he served on the technical staff of the NASA Langley Research Center for 16 years where he contributed to the design, development, test, and operation of several robotic spaceflight systems. He has worked extensively in the areas of entry system design, planetary atmospheric flight, and mission architecture development. Dr. Braun is a fellow of the American Institute of Aeronautics and Astronautics (AIAA) and is the principal author or co-author of more than 150 technical publications in the fields of planetary exploration, atmospheric entry, multidisciplinary design optimization, and systems engineering. He has a B.S. in aerospace engineering from Pennsylvania State University, an M.S. in astronautics from George Washington University, and a Ph.D. in aeronautics and astronautics from Stanford University. He previously served as a member of the National Research Council (NRC) New Opportunities in Solar System Exploration Committee.

DIANNE S. WILEY is a technical fellow at Boeing Phantom Works. In addition to managing proposal strategy and execution for the enterprise, she also serves as the enterprise liaison to the Boeing Technical Fellowship Program to facilitate technology maturation and technology transition to the space exploration systems business area. Previously, Dr. Wiley was assigned to the Missile Defense National Team, responsible for international missile defense activities. In her prior assignment with Boeing Phantom Works, she was the program manager for airframe technology on the NASA Space Launch Initiative Program. Previously, she was with Northrop Grumman for 20 years where she was manager of Airframe Technology. Dr. Wiley was responsible for developing and implementing innovative structural solutions to ensure the structural integrity of the B-2 aircraft. Dr. Wiley's 25 years of technical experience have involved durability and damage tolerance, advanced composites (organic and ceramic), high-temperature structures, smart structures, low-observable structures, concurrent engineering, and rapid prototyping. Dr. Wiley has taught senior and graduate mechanical engineering at the University of California, Los Angeles (UCLA). Dr. Wiley holds a Ph.D. in applied mechanics from the UCLA School of Engineering and Applied Science. She has attended Defense Systems Management College (1996) and she is a graduate of the Center for Creative Leadership (1995), Leadership California Class of 1998, and the Boeing Leadership Center (2002).

HENRY W. BRANDHORST, JR., is the director of the Space Research Institute at Auburn University. His interests include technology development and transfer to commercial use of power technologies for space and terrestrial applications. His areas of research include photovoltaics, lightweight space solar arrays, electrochemical energy storage, dynamic power systems, power management and distribution, free piston Stirling power systems, environmental durability, hypervelocity impact studies, high-power spacecraft concepts, and management of technology development programs. Within the government, he has had responsibility for various technology development projects. He demonstrated the first integrated solar dynamic power system (2 kW) for space use and tested it in a vacuum environment. He initiated and led the Auburn student-faculty team that designed and built a solar-powered house, winning third place in the first Department of Energy (DOE)-sponsored Solar Decathlon. Dr. Brandhorst helped to develop the ENTECH concentrator solar array used in the 1992 Deep Space 1 mission to a comet. He has served as the chief of the Power Technology Division at the NASA Lewis Research Center. He has received the NASA Exceptional Engineering Achievement Medal (photovoltaics; 1984), the IEEE William R. Cherry Award (photovoltaics; 1984), and the NASA Outstanding Leadership Medal (space power; 1996). Dr. Brandhorst received a Ph.D. in nuclear chemistry from Purdue University.

DAVID C. BYERS is a consultant in the areas of spacecraft propulsion and power systems. He was manager of the spacecraft propulsion line of business for the TRW Space and Electronics Group from 1995 to 1998. Previously, Mr. Byers was chief of the On-Board Propulsion Branch at NASA's Lewis (now Glenn) Research Center, agent for electric propulsion for the Ballistic Missile Defense Organization (BMDO), manager of research and technology for NASA's Office of Aeronautics and Space Technology, and section head and engineer in electric propulsion at NASA's Lewis Research Center. Mr. Byers' extensive expertise includes micropropulsion, electric propulsion (resistojets, arcjets, ion and Hall accelerators, and advanced concepts), and chemical propulsion (bi-propellants, advanced mono-propellants, and H/O RCS). He received the AIAA Wyld Propulsion Award in 1989 and the NASA Outstanding Leadership Award in 1990 and was named an AIAA fellow in 1998.

DAVID L. CHENETTE is the director of the space sciences and instrumentation section of the Lockheed Martin Advanced Technology Center, with responsibility for the Solar and Astrophysics Laboratory and the Space Physics Laboratory. Following a postdoctoral appointment in the Space Radiation Laboratory of the California Institute of Technology, Dr. Chenette joined the Space Sciences Laboratory of the Aerospace Corporation, where he continued research on the magnetospheres of the outer planets as well as the energetic particle environments near Earth and its magnetosphere. He contributed to both theoretical and laboratory work on cosmic ray effects on microelectronics, including solar energetic particle effects. Dr. Chenette joined the Space Physics Department of the Lockheed Palo Alto Research Laboratory in 1987 and led the development of the department's energetic particle and auroral x-ray spectrometers, which were launched in 1991 aboard the NASA Upper Atmosphere Research Satellite. He was named space physics department manager in 1998 and manager of the Solar and Astrophysics Laboratory in 2000. In 1999 he led the development of the Earth Polychromatic Imaging Camera that Lockheed Martin, which was developed for the Triana mission. In 2004 he was promoted to his current position. Dr. Chenette earned all three of his degrees in physics at the University of Chicago.

INDERJIT CHOPRA is the Alfred Gessow Professor of Aerospace Engineering and director of the Alfred Gessow Rotorcraft Center at the University of Maryland. His studies include work on various fundamental problems related to aeromechanics of helicopters, including aeromechanical stability, active vibration control, modeling of composite blades, rotor head health monitoring, aeroelastic optimization, smart structures, micro air vehicles, and comprehensive aeromechanics analyses of bearingless, tilt-rotor, servo-flap, compound, teetering, and circulation control rotors. Prior to teaching, Dr. Chopra spent more than 4 years at NASA Ames Research Center/Stanford University Joint Institute of Aeronautics and Acoustics working on the development of aeroelastic analyses and testing of advanced helicopter rotor systems. Dr. Chopra served on the NRC Panel C: Structures and Materials of the Committee on Decadal Survey of Civil Aeronautics, and he is a member of the Aeronautics and Space Engineering Board.

FRANK D. DRAKE is the director of the SETI Institute's Carl Sagan Center for the Study of Life in the Universe. He started his professional career as an electronics officer in the U.S. Navy. He was then associated with the Agassiz Station Radio Astronomy project at Harvard University, where he received the Ph.D. degree in astronomy. He then conducted planetary research and cosmic radio source studies at the National Radio Astronomy Observatory at Green Bank, West Virginia, where he shared in the discovery of the radiation belts of Jupiter and conducted Project OZMA—the first organized search for extraterrestrial intelligence. Following an appointment as chief of lunar and planetary sciences at the Jet Propulsion Laboratory, he joined Cornell University in 1964 where he became chair of the Astronomy Department, director of the National Astronomy and Ionosphere Center, and the Goldwin Smith Professor of Astronomy. Dr. Drake moved to the University of California, Santa Cruz, in 1984 as professor of astronomy and astrophysics; he served as dean of the Natural Sciences Division from 1984 to 1988. He founded and presided over the SETI Institute in 1984 where he is presently chairman emeritus of the board of trustees and director of the Carl Sagan Center for the Study of Life in the Universe. Dr. Drake was elected to the National Academy of Sciences in 1972 and is a fellow of the American Association for the Advancement of Science, the American Academy of Arts and Sciences, and the British Interplanetary Society. He was awarded the 2001 Education Prize by the American Astronomical Society. Dr. Drake has been a member of three NRC astronomy survey committees and chaired both the U.S. National Committee for the International Astronomical Union and the NRC Board on Physics and Astronomy.

OLIVIA A. GRAEVE is an associate professor of materials science and engineering at Alfred University and is head of the Nanomaterials Processing Laboratory. Previously she was an assistant professor at the University of Nevada, Reno. Her area of research is broadly described as the synthesis and processing of nanostructured materials, including ceramic and metallic nanomaterials, and amorphous/nanocrystalline composites. She has received research grants and/or contracts from the National Science Foundation (NSF), the Department of Defense, NASA, and the DOE, as well as from industrial partners and has published more than 30 refereed journal articles. Dr. Graeve has contributed to the development of human resources as a research advisor and as an instructor, including the development of three new courses for the materials science and engineering program at the University of Nevada, Reno. She has served on numerous committees and in many different capacities for her primary societies (the American Ceramic Society, the Materials Research Society, the Society of Hispanic Professional Engineers, and Sociedad Mexicana de Materials, A.C.). Dr. Graeve has been involved in the recruitment and retention of women and Hispanic students in science and engineering and has received several prestigious awards, including the NSF CAREER award and the 2006 Hispanic Educator of the Year award by the Society of Hispanic Professional Engineers.

MARSHALL G. JONES is a Coolidge Fellow at GE Corporate Research and Development. He joined GE Global Research in 1974 as a mechanical engineer after receiving his M.S. and Ph.D. degrees from the University of Massachusetts. He received his B.S. from the University of Michigan. He worked for 4 years at Brookhaven National Laboratory after his undergraduate studies. Dr. Jones has performed research and development work for all the industrial business segments of GE. He has spent most of his GE career addressing laser material processing, laser device development, and fiber optics, which has afforded him 49 U.S. patents and over 45 publications. Dr. Jones is a GE-Global Research Coolidge fellow and is member of the National Academy of Engineering, a fellow of the American Society of Mechanical Engineers, and a fellow of the Laser Institute of America (LIA). He serves or has served on both local and national boards, including the Engineering Directorate for NSF and the LIA.

ROBERT A. MOORE is a consultant at DST, Inc. His early career was in the aerodynamic design and development of tactical aircraft and high-speed cruise missiles at McDonnell Aircraft. With the beginning of the human spaceflight program, he worked on the reentry thermal protection problem for Mercury and then electric propulsion for space travel. He then moved to the inter-continental ballistic missile program where he assisted the Air Force and the Navy in the management of reentry physics, penetration aids, and reentry vehicle technology programs. He then joined the Defense Advanced Research Projects Agency (DARPA) and managed advanced technology programs for future strategic offensive and defensive systems. He became director of the Tactical Technology Office at DARPA and directed programs in air vehicle technology and observables, stealth aircraft, armored vehicle and anti-armor technology, undersea warfare technology, and sensor systems. Later he was deputy director of

DARPA. During the Carter administration he was appointed to the executive position of deputy undersecretary of defense for tactical warfare programs, and was responsible for planning and oversight of acquisition of all defense systems for land, sea, and air warfare. He returned to industry and became director of Black Programs at the Lockheed Corporation “Skunk Works.” Next, he established a consulting company, DST, Inc., in which he continues to be active, providing advice to major aerospace and defense companies in the areas of systems analysis and engineering, systems management, research and technology, program development, and proposal preparation. He serves on government and military advisory panels and is a member of the Army Science Board. He was a charter member of the Senior Executive Service (SES), and he received the SES Presidential Rank Award and the Secretary of Defense Meritorious Civilian Service Medal. Mr. Moore received B.S. and M.S. degrees in mechanical engineering.

E. PHILLIP MUNTZ is the A.B. Freeman Professor of Engineering in the Department of Aerospace and Mechanical Engineering at the University of Southern California, where he has served as co-chair and chair of the department. Dr. Muntz received his B.S., M.S., and Ph.D. degrees in aeronautical engineering and aerophysics from the University of Toronto, Canada. He then took a position with the General Electric Missile and Space Division, Space Sciences Laboratory in Valley Forge, Pennsylvania. In 1969, he joined the University of Southern California. His research interests have included rarefied gas dynamics, medical imaging, isotope separation, nondestructive testing, and transient energy release micromachining; he holds patents in many of these areas. His industrial experience, in addition to his early career at General Electric, has been as director of the Division of Medical Sciences at Xonics, Inc., and as vice president and senior scientist at Rapid Analysis and Development Corp., both in southern California. Dr. Muntz has been recognized for his scientific achievements by election as a member of the National Academy of Engineering and as a fellow of the AIAA and the American Physical Society. He received the Aerospace Contribution to Society Award from the AIAA in 1987. Dr. Muntz was a pilot with the Royal Canadian Air Force from 1955 to 1960.

LAURENCE R. YOUNG is the Apollo Program Professor of Astronautics and professor of health sciences and technology (HST) at the Massachusetts Institute of Technology (MIT). He was the founding director (1997-2001) of the National Space Biomedical Research Institute. He directs the HST Ph.D. program in bioastronautics. Dr. Young was elected to the National Academy of Engineering and the Institute of Medicine and is a full member of the International Academy of Astronautics. He received an A.B. from Amherst College; a Certificate in Applied Mathematics from the Sorbonne, Paris; and S.B. and S.M. degrees in electrical engineering and a Sc.D. degree in instrumentation from MIT. He joined the MIT faculty in 1962. He co-founded MIT’s Man-Vehicle Laboratory, which does research on the visual and vestibular systems, visual-vestibular interaction, flight simulation, space motion sickness, and manual control and displays. In 1991 Dr. Young was selected as a payload specialist for Spacelab Life Sciences 2. He has been active on many professional and government committees, including the Air Force Scientific Advisory Board, the NRC Committee on Space Biology and Medicine, NASA’s Life Science Advisory Committee, and the National Institutes of Health Training Committee on Biomedical Engineering. He has served on several NASA advisory panels relating to life sciences and the space station. He is a fellow of the Institute of Electrical and Electronics Engineers, the Biomedical Engineering Society, the American Institute of Medical and Biological Engineering, and the Explorers Club. In 1998, for his contributions to neuroscience he received the prestigious Koetser Foundation Prize in Zurich.

C

List of Presenters to the Committee

Marc Allen, Assistant Associate Administrator for Strategy, Policy and International, Science Mission Directorate, NASA Headquarters
Dennis Bushnell, Chief Scientist, NASA Langley Research Center
Robert Cassanova, former Director, NIAC
A.C. Charania, President, SpaceWorks Commercial, NIAC grantee
Ray Colladay, Chair, Aeronautics and Space Engineering Board, NRC; formerly Director of the Defense Advanced Research Projects Agency, Associate Administrator of NASA, and President of Lockheed Astronautics
Murray Hirschbein, NASA (retired)
Robert Hoyt, Tethers, Inc., NIAC grantee
Christopher Moore, Program Executive, Exploration Systems Mission Directorate, NASA Headquarters
Dava Newman, Professor, Massachusetts Institute of Technology, NIAC grantee
Dick Obermann, Staff Director, House Subcommittee on Space and Aeronautics
Eric Rice, CEO and Chair, Orbitec, NIAC grantee
Robert Whitehead, former Associate Administrator for Aeronautics and Space Transportation Technology, NASA, former member of NIAC Science Council
Robert Winglee, University of Washington, NIAC grantee

D

NIAC Statement of Work

The statement of work for the NASA Institute for Advanced Concepts (Attachment A of Contract NAS5-03110, Amendment of Solicitation/Modification No. 7, issued by NASA for the Universities Space Research Association, dated July 11, 2003) is reprinted below.

1. INTRODUCTION

This Statement of Work (SOW) is for a NASA Institute for Advanced Concepts (NIAC). The purpose of the NIAC is to provide an independent, open forum for the external analysis and definition of space and aeronautics advanced concepts to complement the advanced concepts activities conducted within the NASA Enterprises. It shall focus on revolutionary concepts, specifically systems and architectures that can have a major impact on future missions of the NASA Enterprises.

2. BACKGROUND

NASA's overall program, as outlined in the agency's Strategic Plan, is comprised of five Strategic Enterprises. Each enterprise covers a major area of the agency's research and development efforts. The NASA Enterprises are: Aerospace Technology, Biological and Physical Research, Earth Science, Human Exploration and Development of Space, and Space Science (see the NASA Home Page at http://www.nasa.gov/enterprises.html for more information about each NASA Enterprise).

The area of domain of the NIAC shall be limited to the National Space Policy and the NASA Strategic Plan. The NIAC shall create an additional channel for advanced concepts to respond to NASA Enterprise challenges for the 10-40 year timeframe and to augment NASA Enterprise Strategic Objectives. It shall generate ideas for how the current long-term NASA Agenda can be done better; it shall expand our vision of future possibilities. Ideally, the successful development of these advanced concepts will result in changes to NASA's future policies and plans.

The NIAC will be functionally independent of NASA, and the concepts it selects for NASA support will be the result of an external review by respected technical experts. NASA intends that the best products of the institute will be fused into NASA's future programs, keeping in mind our budget realities. During the first century of human aerospace endeavor, cost has been our primary constraint; this constraint will remain for the foreseeable future. The intellectual challenge of how to do exciting missions much more inexpensively in the future must be engaged.

3. GOALS

One goal of the NIAC shall be to sustain public interest in revolutionary concepts of alternative aerospace futures. The NIAC shall attract revolutionary ideas from a broad community to catalyze NASA's imagination and stimulate a dynamic interchange of competing future options. As such, this NIAC shall provide a nationally prestigious and visible support to NASA in developing aerospace advanced concepts for our Nation's future. Participation shall be limited only by the quality of proposers' ideas. To the maximum extent possible, these ideas shall be broadcast for public scrutiny via the Internet.

A second goal is to provide a positive inspiration to the nation's youth to study technical subjects so that they conceive their exciting role in the future and persevere in making their vision a reality.

Another significant goal for the NIAC is a balanced distribution of effort and resources between NASA Enterprises, a record of 5-10% infusion of NIAC-developed advanced concepts into NASA's long-term plans.

4. DEFINITION OF ADVANCED CONCEPTS

The term "advanced concepts" has many meanings. Establishing the meaning and scope of the kind of "advanced concepts" to be solicited by the NIAC is fundamental in meeting the goals of this SOW. The following are a number of tests that the contractor shall apply to a specific concept to determine if it meets the requirements and intent of this SOW. Generally, the NIAC is seeking advanced concepts that could come into fruition in the 10-40 year timeframe.

A. The concepts shall be revolutionary rather than evolutionary. ***Evolutionary*** means the next progressive step in development and/or a similar type of research to the research currently being conducted. ***Revolutionary*** often includes a new paradigm. It entails a leap ahead in technological advances and is generally a totally new way of doing something. The advanced concept may have been explored before, but in order for another exploration of the advanced concept to be revolutionary, it must be a new approach. This difference is illustrated in the following example: An improved rocket that would enhance human's ability to explore space would be *evolutionary*. A totally different and new type of transportation into space would be *revolutionary* and might include a space tether, a space elevator, or a mini magnetospheric plasma propulsion system, three concepts previously studied under past NIAC funded studies.

B. The concepts shall be consistent with the National Space Policy and the NASA Strategic Plan (see http://www.hq.nasa.gov/office/codez/new/policy/pddnstc8.htm and http://www.hq.nasa.gov/office/codez/plans.html).

C. The concepts shall have a "new" aspect. They shall not repeat or duplicate concepts previously studied or currently being studied by NASA unless they have a new approach as stated in 4.A. above.

D. The concepts shall involve major systems and architectures and potentially have a major impact on how future Enterprise missions are accomplished. ***Systems*** include the physical embodiment of the overall plan to accomplish a goal and/or a suite of equipment, software and operations methods capable of accomplishing an operational objective. ***Architectures*** include an overall plan to accomplish a goal and/or a suite of physical embodiments of the overall plan and their operational methods of meeting an overall mission or program objective.

E. The concepts shall not solely be a specific advanced technology or new design approach such as a new solar cell or a new spectrometer. The concepts must be put into a mission application context.

F. The concepts shall expand the number of approaches or choices rather than increase the depth of analysis of known concepts.

G. An advanced concept shall include both a technical description (the physics, chemistry and technology) as well as the quantification of potential benefits.

5. DESCRIPTION OF THE NIAC

The contractor shall manage the NIAC. The contractor shall be responsible for selecting the appropriate staff and the operation of the NIAC. The contractor shall establish the NIAC in a manner precluding any perceived or actual conflicts of interest pertaining to future business proposals or to future mission participation. The credibility of the NIAC is an essential element of the proposal selection process.

The NIAC shall proactively advocate and stimulate interest and participation in the generation of advanced concepts with both aerospace and non-aerospace communities.

The NIAC shall be as independent from NASA as possible, guided as much as possible by external review. The NIAC shall have advanced aerospace concepts as its sole focus. It shall not perform research itself or have research facilities. Elements of the contractor not associated with the NIAC will be eligible to propose to the NIAC; however, the contractor shall be responsible for avoiding any actual or perceived conflicts of interest. The Principal Investigators (PIs) who are selected as a result of the advanced concepts solicitation will be the advanced concept study subcontractors/grantees. The contractor shall be responsible for assuring no actual or perceived conflict of interest in the performance of the external proposal review by them or by the reviewers. The NIAC shall utilize the Internet and advanced communications technology to communicate with the PIs and with the public, thus creating a "virtual institute."*

6. NASA'S ROLE

A. NASA personnel (including JPL personnel) will neither participate in, nor submit research proposals under, this program. However, NASA personnel will support the contractor to facilitate understanding of NASA's mission and NASA's current and past funded advanced concepts. Also, NASA will support the review of proposals when it is the only expert source for the advanced concept development.

B. The actions of the NIAC are to be as independent from NASA as possible. Although NASA will not provide direct oversight of any specific NIAC activity or research subcontract/grant award, NASA must have insight into all the activities of the NIAC to fulfill its fiduciary responsibilities.

C. NASA will assist the contractor to assure that proposals to the NIAC do not represent work previously accomplished (or rejected on a sound technical basis), that proposals are not duplicative of work currently funded elsewhere, and that the scope of the proposals are consistent with the Agency's overall mission and Enterprise long-range strategic goals. NASA will do this by attending briefings at NASA Headquarters to be given by the contractor prior to their proposed award selections so that NASA can provide the above stated feedback to the contractor concerning these elements of the proposals.

D. If requested by the contractor, NASA Goddard Space Flight Center will provide coordination of possible NASA systems engineering analysis of the advanced concepts studies and will also facilitate any other NASA-unique technical assistance needed by the advanced concepts studies to the extent practical and in the best interest of NASA.

7. CONTRACTOR RESPONSIBILITIES

The contractor shall:

A. Provide an additional source of technical leadership and advocacy for the analysis and definition of space and aeronautics advanced concepts. This advocacy requires an understanding of the National Space Policy, the NASA Strategic Plan and the NASA Enterprise Strategies. It also requires an understanding of aerospace technology state of the art and a general understanding of advanced aerospace concepts, to support the above directives. The NIAC shall initiate major outreach activities to stimulate and support participation by aerospace and non-aerospace communities in the definition and analysis of aeronautics and space advanced concepts. It is not necessary or required that such activities result in formulation of a written outreach plan.

B. The primary function of the NIAC is to provide NASA with an additional source of innovative aeronautics and space advanced concepts. This shall include issuing an annual solicitation for advanced concepts proposals, conducting an evaluation process of the proposals by an independent external review by respected technical experts, selecting the best candidate proposals based upon standards imposed by the contract, awarding, and administering subcontracts/grants to selected investigators. Note that proposals received by the NIAC from foreign entities constitute a special case. If the NIAC selects such a proposal for award consideration, it must submit the proposal to NASA for a final decision to accept, or not accept, the proposal for award.

The NIAC shall also oversee the progress of the concept studies.

C. Research Proposal Process

Each year, the contractor shall solicit new proposals for funding. Solicitations shall constitute two separate groupings:

- Completely new concepts (Phase I Awards) and
- Continued funding of currently funded new concepts that show the most promise (Phase II Awards).

Phase I Awards:

Key components are:

- May be awarded as subcontracts or grants
- Maximum dollar amount is $75K
- Period of performance shall be up to 6 months.
- Phase I shall validate the viability of the concept and define the major feasibility issues.
- At the end of Phase I, these items shall be documented in a final report that shall be the basis for Phase II selection.
- It is estimated that about 10-15 Phase I awards will be made annually.

Phase II Awards:

Phase II proposals shall be solicited from Phase I investigators. Key components are:

- May be awarded only as subcontracts
- Maximum dollar amount is $500K
- Period of performance shall be up to 2 years.
- Phase II shall study the major feasibility issues associated with the concept cost, performance and development time; identify key technology issues that require more detailed study and development; and generally provide a sound basis for a NASA program manager to consider the concept for a future mission.
- At the end of Phase II, these items shall be documented in the final Phase II report.
- It is estimated that 4-6 Phase II awards will be made each year.

The purpose of this phased approach is to allow a greater range of concepts to be considered initially during any solicitation cycle with a down selection for Phase II funding, based on an external review of the most promising Phase I concepts. Past successful offerors may propose again for the next solicitation but they must submit a new concept.

In addition, with prior written COTR approval, the contractor may allocate additional funds to transition the most successful Phase II awards into mainstream technology or research programs. The purpose of transition is to assist the infusion of the NIAC-developed advanced concept into other mainstream NASA programs for receipt of sustained NASA funding. Post-Phase II funding will require a clear pathway for the concept to receive subsequent funding from NASA directly. The criteria for NIAC providing additional funds for this transition are as follows:

- NIAC must be in receipt of the final Phase II report.
- The advanced concept study must continue to be relevant to NASA's needs and in the best interest of NASA.
- The Phase II study must have demonstrated reasonable probability of success with future development and be of significant interest to NASA Strategic Enterprises.

The kinds of advanced concepts requested in the solicitation shall be characterized in terms of the seven tests discussed in the Scope of Advanced Concepts section. The solicitation will also include a set of challenges annually developed by the contractor based upon the contractor's analysis of input the contractor has solicited from the NASA Enterprise Associate Administrators. Although these challenges shall serve to focus the attention of the proposers, ideas outside the venues of the challenges shall also be accepted. Concept studies are to be selected for technical merit, innovation and economic benefit.

NASA, including JPL, is not eligible to participate and submit research proposals, and all proposals awarded shall support United States leadership in space activities and related technology transfer.

D. Based upon input solicited by the contractor from NASA's Enterprises, establish a set of challenges that could potentially have a revolutionary impact on how the NASA Enterprises perform future programs.

E. Present potential selected advanced concepts studies to the NASA Enterprise Associate Administrators and the NASA Chief Technologist to assure that the studies have not previously been accomplished (or rejected on a sound technical basis), are not duplicative of work currently funded elsewhere, and are consistent with NASA's charter and strategy.

F. Provide NASA with status reviews of the progress on funded investigations.

G. Accept and organize evaluations of unsolicited proposals that may be submitted to the NIAC.

H. Provide options for the potential fusion of NIAC-developed advanced concepts into NASA future missions.

I. Prepare an annual report to the NASA Chief Technologist, which shall include but is not limited to, the state of the NIAC and the status of the funded investigations.

J. Organize and lead an Annual Conference on Advanced Concepts. This would include selecting an annual theme for the conference, overseeing the conference logistics, developing the agenda and serving as conference master of ceremonies. At this meeting, current NIAC Phase II study subcontractors shall brief their research and results. Attendance at this meeting shall be open to the public. Additionally, a second annual meeting shall be held for the NIAC Phase I study subcontractors/grantees to brief their research and results. The attendance at this second annual meeting shall also be open to the public.

K. Manage subcontractor/grantee costs consistent with established NASA financial management principles.

L. The NIAC shall use an Internet based electronic management system for the administration of the program.

* Any web development shall be in compliance with **Section 508 of the Rehabilitation Act: Electronic and Information Technology Accessibility Standards, 36 CFR Section 1194.22** as follows:

§ 1194.22 Web-based intranet and Internet information and applications.

(a) A text equivalent for every non-text element shall be provided (e.g., via "alt," "longdesc," or in element content).

(b) Equivalent alternatives for any multimedia presentation shall be synchronized with the presentation.

(c) Web pages shall be designed so that all information conveyed with color is also available without color, for example from context or markup.

(d) Documents shall be organized so they are readable without requiring an associated style sheet.

(e) Redundant text links shall be provided for each active region of a server-side image map.

(f) Client-side image maps shall be provided instead of server-side image maps except where the regions cannot be defined with an available geometric shape.

(g) Row and column headers shall be identified for data tables.

(h) Markup shall be used to associate data cells and header cells for data tables that have two or more logical levels of row or column headers.

(i) Frames shall be titled with text that facilitates frame identification and navigation.

(j) Pages shall be designed to avoid causing the screen to flicker with a frequency greater than 2 Hz and lower than 55 Hz.

(k) A text-only page, with equivalent information or functionality, shall be provided to make a web site comply with the provisions of this part, when compliance cannot be accomplished in any other way. The content of the text-only page shall be updated whenever the primary page changes.

(l) When pages utilize scripting languages to display content, or to create interface elements, the information provided by the script shall be identified with functional text that can be read by assistive technology.

(m) When a web page requires that an applet, plug-in or other application be present on the client system to interpret page content, the page must provide a link to a plug-in or applet that complies with §1194.21(a) through (l).

(n) When electronic forms are designed to be completed on-line, the form shall allow people using assistive technology to access the information, field elements, and functionality required for completion and submission of the form, including all directions and cues.

(o) A method shall be provided that permits users to skip repetitive navigation links.

(p) When a timed response is required, the user shall be alerted and given sufficient time to indicate more time is required.

E

List and Statistical Analysis of NIAC Grants

LIST OF NIAC GRANTS

The NASA Institute for Advanced Concepts (NIAC) awards are categorized according to the NASA directorate (Aeronautics Research, Exploration Systems, Science, and Space Operations) which appeared to be most closely associated with the ultimate application of the work. A statistical analysis of the origin of each proposal is also presented.

Aeronautics Research

An Advanced Counter-Rotating Disk Wing Aircraft Concept
Artificial Neural Membrane Flapping Wing
Environmentally-Neutral Aircraft Propulsion Using Low-Temperature Plasmas
Solid State Aircraft

Exploration Systems

A Contamination-Free Ultrahigh Precision Formation Flight Method Based on Intracavity Photon Thrusters and Tethers
A Realistic Interstellar Explorer
A System of Mesoscale Biomimetic Roboswimmers for Exploration and Search of Life on Europa
Advanced Solar- and Laser-pushed Lightsail Concepts
Advanced System Concept for Total ISRU-Based Propulsion and Power Systems for Unmanned and Manned Mars Exploration
An Architecture of Modular Spacecraft with Integrated Structural Electrodynamic Propulsion (ISEP)
Antimatter Driven Sail for Deep Space Missions
Antiproton-Driven, Magnetically Insulated Inertial Fusion (MICF) Propulsion System
Architectures and Algorithms for Self-Healing Autonomous Spacecraft
Autonomous Self-Extending Machines for Accelerating Space Exploration
Bio-electric Space Exploration
Cislunar Tether Transport System
Cyclical Visits to Mars Via Astronaut Hotels
Development of Lunar Ice Recovery System Architecture
Directed Application of Nanobiotechnology for the Development of Autonomous Biobots
Electromagnetic Formation Flight
Enabling Exploration of Deep Space: High Density Storage of Antimatter
Europa Sample Return Mission Utilizing High Specific Impulse Refueled with Indigenous Resources

Extreme Expeditionary Architecture (EXP-Arch): Mobile, Adaptable Systems for Space and Earth Exploration
Formation Flying with Shepherd Satellites
High-Speed Interplanetary Tug/Cocoon Vehicles (HITVs)
High-Acceleration Micro-Scale Laser Sails for Interstellar Propulsion
Hypersonic Airplane Space Tether Orbital Launch System
Lorentz-Actuated Orbits: Electrodynamic Propulsion Without a Tether
Low Cost Space Transportation Using Electron Spiral Toroid (EST) Propulsion
Lunar Space Elevators for Cislunar Space Development
Magnetized Beamed Plasma Propulsion (MagBeam)
Micro Asteroid Prospector Powered by Energetic Radioisotopes: MAPPER
Microbots for Large-Scale Planetary Surface and Subsurface Exploration
Mini-Magnetospheric Plasma Propulsion, M2P2
Modular Laser Launch Architecture: Analysis and Beam Module Design
Modular Spacecraft with Integrated Structural Electrodynamic Propulsion
Multi-Mice: A Network of Interactive Nuclear Cryoprobes to Explore Ice Sheets on Mars and Europa
Optimal Navigation in a Plasma Medium
Planetary Exploration Using Biomimetics
Positron Propelled and Powered Space Transport Vehicle for Planetary Missions
Primary Propulsion for Piloted Deep Space Exploration
Propellantless Control of Spacecraft Swarms Using Coulomb Forces
Pulsed Plasma Power Generation
Rapid Manned Mars Mission with a Propagating Magnetic Wave Plasma Accelerator
Sailing the Planets: Science from Directed Aerial Robot Explorers
Scalable Flat-Panel Nano-Particle MEMS/NEMS Propulsion Technology for Space Exploration in the 21st Century
Self-Organized Navigation Control for Manned and Unmanned Vehicles in Space Colonies
Self-Transforming Robotic Planetary Explorers
Space Transport Development Using Orbital Debris
Spacecraft Propulsion Utilizing Ponderomotive Forces
System Architecture Development for a Self-Sustaining Lunar Colony
The Black Light Rocket Engine
The Magnetic Sail
The Mesicopter: A Meso-Scale Flight Vehicle
The Plasma Magnet
The Space Elevator
Ultrafast Laser-Driven Plasma for Space Propulsion
Ultralight Solar Sails for Interstellar Travel

Science

3D Viewing of Images on the Basis of 2D Images
A Deep Field Infrared Observatory near the Lunar Pole
A Self-Sustaining Boundary-Layer-Adapted System for Terrain Exploration and Environmental Sampling
Adaptive Observation Strategies for Advanced Weather Prediction
Assessment of the Feasibility of Extremely Large, Structureless Optical Telescopes and Arrays
An Ultra-High-Throughput X-Ray Astronomy Observatory with a New Mission Architecture
Architecture of Intelligent Earth Observation Satellite for Common Users in 2010-2050
Autonomous VTOL Scalable Logistics Architecture
Controlling the Global Weather

Efficient Direct Conversion of Sunlight to Coherent Light at High Average Power in Space
Exploration of Jovian Atmosphere Using Nuclear Ramjet Flyer
Extraction of Antiparticles Concentrated in Planetary Magnetic Fields
Extremely Large Swarm Array of Picosats for Microwave/RF Earth Sensing, Radiometry and Mapping
Feasibility of Communications Using Quantum Entanglement
Global Constellation of Stratospheric Scientific Platforms
Global Environmental MEMS Sensors: A Revolutionary Observing System for the 21st Century
Global Observations and Alerts from Lagrange-Point, Pole-Sitter, and Geosynchronous Orbits (GOAL&GO)
High Resolution Structureless Telescope
Inherently Adaptive Structural Systems
Intelligent Satellite Teams for Space Systems
Investigation of the Feasibility of Laser Trapped Mirrors in Space
Large Telescope Using Holographically Corrected Membranes
Large Ultra-Lightweight Photonic Muscle Telescope
Large-Product General-Purpose Design and Manufacturing Using Nanoscale Modules
New Architecture for Space Solar Power Systems: Fabrication of Silicon Solar Cells Using In-Situ Resources
New Worlds Imager
Planetary Circumnavigation: A Concept for Surface Exploration of the Inner Planets
Planetary-Scale Astronomical Bench
Practicality of a Solar Shield in Space to Counter Global Warming
Primary Objective Grating Astronomical Telescope
Protein Based Nano-Machines for Space Applications
Reduction of Trapped Energetic Particle Fluxes in Earth & Jovian Radiation Belts
Scientific Exploration and Human Utilization of Subsurface Extraterrestrial Environments: A Feasibility Assessment of Strategies, Technologies and Test Beds
Self-Assembly of Optical Structures in Space
SHIELD—A Comprehensive Earth Protection System
The Hematopoietic Stem Cell Therapy for Exploration of Space
The League of Extraordinary Machines: A Rapid and Scalable Approach to Planetary Defense Against Asteroid Impactors
Ultra-High Resolution Fourier Transform X-Ray Interferometer
Ultrahigh Resolution X-Ray Astronomy Using Steerable Occulting Satellites
Very Large Optics for the Study of Extrasolar Terrestrial Planets
X-Ray Interferometry: Ultimate Astronomical Imaging

Space Operations

A Chameleon Suit to Liberate Human Exploration of Space Environments
A Flexible Architecture for Plant Functional Geonomics in Space Environments
A Modular Robotic System for Surface Operations of Human Mars Exploration
A Novel Information Management Architecture for Maintaining Long Duration Space Crews
A Novel Interface System for Seamlessly Integrating Human-Robot Cooperative Activities in Space
Achieving Comprehensive Mission Robustness
An Architecture for Unmanned Self-Replicating Lunar Factories
Analysis of a Lunar Base Electrostatic Radiation Shield Concept
Antimatter Harvesting in Space
Astronaut Bio-Suit System for Exploration Class Missions
Biologically Inspired Legged Robots for Space Operations

Customizable, Reprogrammable, Food Preparation, Production and Invention System
Development of a Single-Fluid Consumable Infrastructure for Life Support, Power, Propulsion, and Thermal Control
Development of Plant Genetic Assessment and Control System for Space Environments
Development of Self-Sustaining Mars Colonies Utilizing the North Polar Cap and the Martian Atmosphere
Electric Toroid Rotor Technology Development
In-Orbit Assembly of Modular Space Systems with Non-Contacting, Flux-Pinned Interfaces
Magnetically Inflated Cable (MIC) System for Space Applications
Mars Atmosphere Resources Recovery System (MARRS)
Methodology for the Study of Autonomous VTOL Scalable Logistics Architecture
Modeling Kinematic Cellular Automata: An Approach to Self-Replication
Networks of the Edge of Forever: Meteor Burst Communication Networks on Mars
Plasma Magnetic Shield for Crew Protection
Programmable Plants: Development of an In Planta System for the Remote Monitoring and Control of Plant Function for Life Support
Redesigning Living Organisms to Survive on Mars
Robotic Lunar Ecopoiesis Test Bed
Self-Deployed Space or Planetary Habitats and Extremely Large Structures
System Feasibility Demonstrations of Caves and Subsurface Constructs for Mars Habitation and Scientific Exploration
Tailored Force Fields for Space-Based Construction
Use of Superconducting Magnet Technology for Astronaut Radiation Protection
Wide Bandwidth Deep Space Quantum Communication

STATISTICAL ANALYSIS

As noted in Chapter 2 section on the diversity of grantees, over the 9 years of NIAC's existence, a total of 1,066 Phase I proposals and 129 Phase II proposals were received at NIAC and evaluated for possible funding. Tables E-1 through E-4 (and corresponding Figures E-1 through E-4) provide a breakdown of submissions for the entire history of NIAC, excluding the proposals that were submitted during the CP 07-01 solicitation, which were returned without review due to the closure of NIAC.

TABLE E-1 Number of Phase I Proposals Submitted to and Evaluated by NIAC

Category	CP 98-01[a]	CP 98-02[b]	CP 99-03[c]	CP 00-02[d]	CP 01-02[e]	CP 02-02[f]	CP 04-01[g]	CP 05-01[h]	CP 06-01[i]	Total
Universities	58	15	33	62	34	17	35	56	45	355
Small Disadvantaged Businesses	7	5	8	3	9	0	12	12	15	71
Small Businesses	47	39	50	87	59	37	64	86	97	566
Historically Black Colleges and Minority-Serving Institutions	0	1	2	2	1	1	0	0	2	9
Large Businesses	5	3	11	8	11	1	1	3	7	50
National Laboratories	2	1	0	10	0	0	1	1	0	15
Total	119	64	104	172	114	56	113	158	166	1,066

[a] NASA Institute for Advanced Concepts, *NIAC 2nd (1999) Annual Report*, Atlanta, Ga., 2000. Discrepancies in the numbers from one annual report to the next were found. When this was encountered, the most recent report was used.

[b] Ibid.

[c] NASA Institute for Advanced Concepts, *Annual Report* (3rd; 2000-2001), Atlanta, Ga., 2001.

[d] NASA Institute for Advanced Concepts, *Annual Report* (4th; 2001-2002), Atlanta, Ga., 2002.

[e] NASA Institute for Advanced Concepts, *5th Annual Report* (2002-2003), Atlanta, Ga., 2003.

[f] NASA Institute for Advanced Concepts, *Annual Report* (6th; 2003-2004), Atlanta, Ga., 2004.

[g] NASA Institute for Advanced Concepts, *7th Annual Report* (2004-2005), Atlanta, Ga., 2005.

[h] Ibid.

[i] NASA Institute for Advanced Concepts, *9th Annual and Final Report* (2006-2007), Atlanta, Ga., 2007.

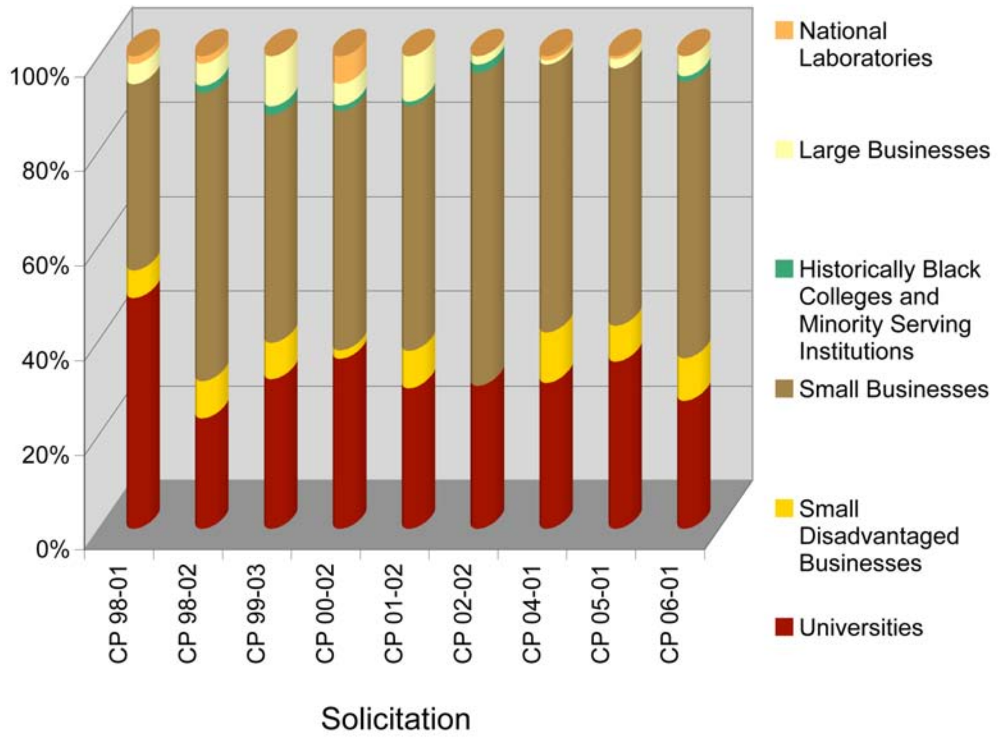

FIGURE E-1 Percentage of evaluated proposals by submission category for all Phase I solicitations during the life of NIAC.

TABLE E-2 Number of Phase I Proposals Awarded

Category	CP 98-01[a]	CP 98-02[b]	CP 99-03[c]	CP 00-02[d]	CP 01-02[e]	CP 02-02[f]	CP 04-01[g]	CP 05-01[h]	CP 06-01[i]	Total
Universities	8	3	1	10	9	4	7	3	4	49
Small Disadvantaged Businesses	0	0	0	0	1	0	1	3	1	6
Small Businesses	6	10	13	5	4	6	4	6	6	60
Historically Black Colleges and Minority-Serving Institutions	0	0	1	1	1	0	0	0	0	3
Large Businesses	0	1	1	2	1	1	0	0	0	6
National Laboratories	2	0	0	0	0	0	0	0	0	2
Total	16	14	16	18	16	11	12	12	11	126

[a] NASA Institute for Advanced Concepts, *Annual Report* (2nd; 1999-2000), Atlanta, Ga., 2000.
[b] Ibid.
[c] NASA Institute for Advanced Concepts, *Annual Report* (3rd; 2000-2001), Atlanta, Ga., 2001.
[d] Ibid.
[e] NASA Institute for Advanced Concepts, *5th Annual Report* (2002-2003), Atlanta, Ga., 2003.
[f] NASA Institute for Advanced Concepts, *Annual Report* (6th; 2003-2004), Atlanta, Ga., 2004.
[g] NASA Institute for Advanced Concepts, *7th Annual Report* (2004-2005), Atlanta, Ga., 2005.
[h] Ibid.
[i] NASA Institute for Advanced Concepts, *9th Annual and Final Report* (2006-2007), Atlanta, Ga., 2007.

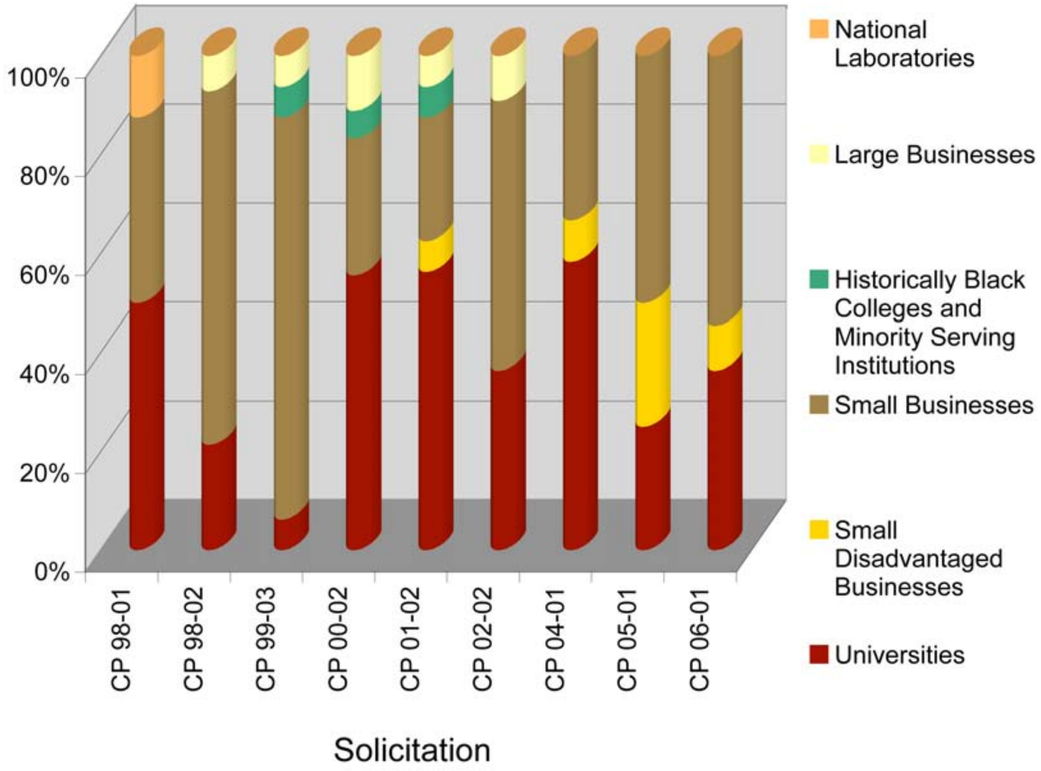

FIGURE E-2 Percentage of awarded proposals by submission category for all Phase I solicitations during the life of NIAC.

TABLE E-3 Number of Phase II Proposals Submitted to and Evaluated by NIAC

Category	CP 99-01[a]	CP 99-02[b]	CP 00-01[c]	CP 01-01[d]	CP 02-01[e]	CP 03-01[f]	CP 05-02[g]	CP 06-02[h]	Total
Universities	8	5	1	9	11	7	10	4	55
Small Disadvantaged Businesses	0	0	1	1	1	0	2	1	6
Small Businesses	6	9	16	6	6	6	2	8	59
Historically Black Colleges and Minority-Serving Institutions	0	0	0	0	0	0	0	0	0
Large Businesses	0	1	1	2	1	1	1	0	7
National Laboratories	2	0	0	0	0	0	0	0	2
Total	16	15	19	18	19	14	15	13	129

[a] NASA Institute for Advanced Concepts, *Annual Report* (2nd; 1999-2000), Atlanta, Ga., 2000.

[b] NASA Institute for Advanced Concepts, *Annual Report* (3rd; 2000-2001), Atlanta, Ga., 2001.

[c] Ibid.

[d] NASA Institute for Advanced Concepts, *Annual Report* (4th; 2001-2002) Atlanta, Ga., 2002.

[e] NASA Institute for Advanced Concepts, *Annual Report* (6th; 2003-2004), Atlanta, Ga., 2004.

[f] Ibid, and NASA Institute for Advanced Concepts, *7th Annual Report* (2004-2005), Atlanta, Ga., 2005.

[g] Ibid (7th Annual).

[h] NASA Institute for Advanced Concepts, *9th Annual and Final Report* (2006-2007), Atlanta, Ga., 2007.

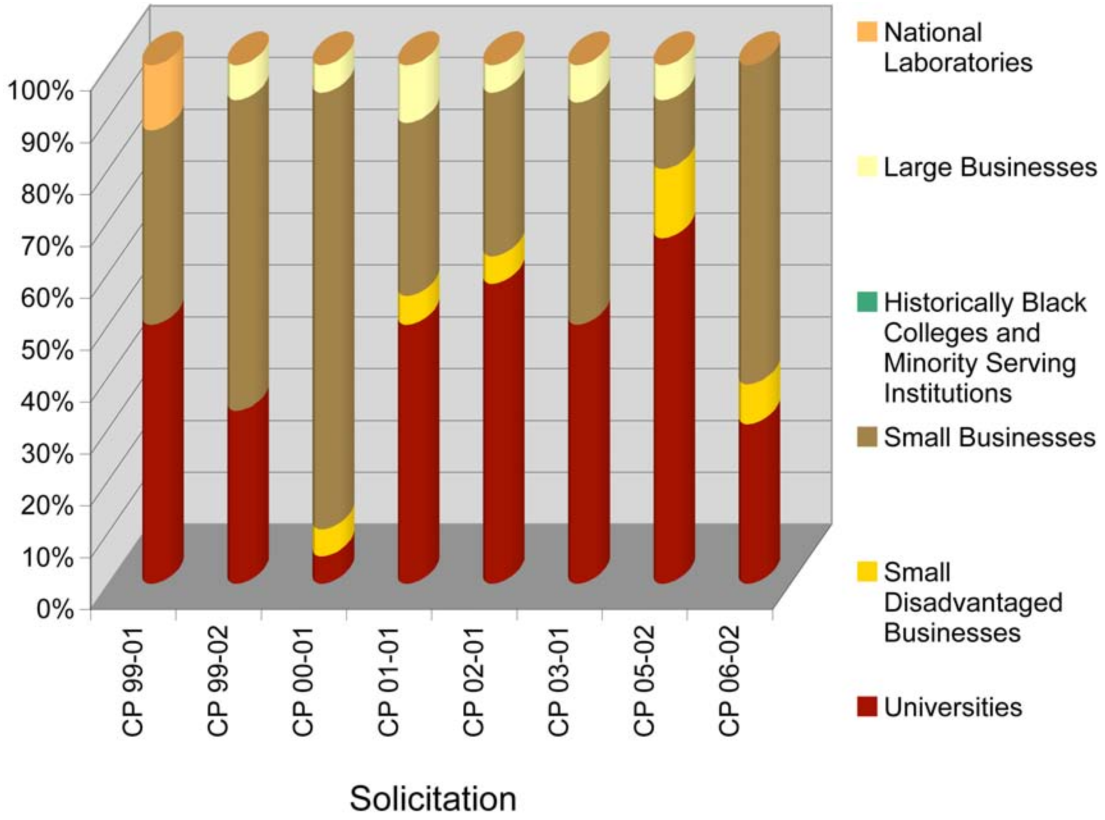

FIGURE E-3 Percentage of evaluated proposals by submission category for all Phase II solicitations during the life of NIAC.

TABLE E-4 Number of Phase II Proposals Awarded

Category	CP 99-01[a]	CP 99-02[b]	CP 00-01[c]	CP 01-01[d]	CP 02-01[e]	CP 03-01[f]	CP 05-02[g]	CP 06-02[h]	Total
Universities	4	2	0	2	3	3	5	2	21
Small Disadvantaged Businesses	0	0	0	0	1	0	0	1	2
Small Businesses	1	2	4	2	2	2	0	1	14
Historically Black Colleges and Minority-Serving Institutions	0	0	0	0	0	0	0	0	0
Large Businesses	0	1	1	1	0	0	0	1	4
National Laboratories	1	0	0	0	0	0	0	0	1
Total	6	5	5	5	6	5	5	5	42

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[a] NASA Institute for Advanced Concepts, *Annual Report* (2nd; 1999-2000), Atlanta, Ga., 2000.
[b] NASA Institute for Advanced Concepts *Annual Report* (3rd; 2000-2001), Atlanta, Ga., 2001.
[c] Ibid.
[d] NASA Institute for Advanced Concepts, *5th Annual Report* (2002-2003), Atlanta, Ga., 2003.
[e] NASA Institute for Advanced Concepts, *Annual Report* (6th; 2003-2004), Atlanta, Ga., 2004.
[f] Ibid, and NASA Institute for Advanced Concepts, *7th Annual Report* (2004-2005), Atlanta, Ga., 2005.
[g] NASA Institute for Advanced Concepts, *7th Annual Report* (2004-2005), Atlanta, Ga., 2005.
[h] NASA Institute for Advanced Concepts, *9th Annual and Final Report* (2006-2007) Atlanta, Ga., 2007.

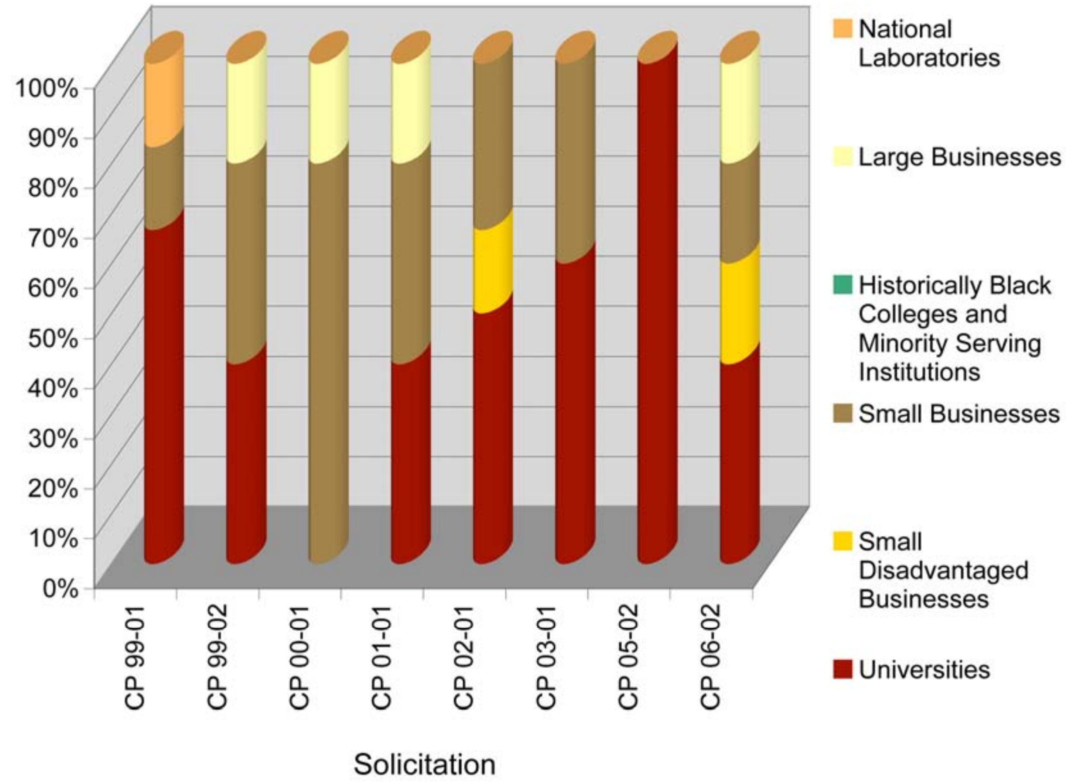

FIGURE E-4 Percentage of awarded proposals by submission category for all Phase II solicitations during the life of NIAC.

F

Three NIAC Phase II Projects Infused into NASA’s Long-Term Plans

MINI-MAGNETOSPHERIC PLASMA PROPULSION

Project of Robert M. Winglee, University of Washington

The Mini-Magnetospheric Plasma Propulsion (M2P2) system, proposed by Robert Winglee and John Slough of the University of Washington, was funded in 1998 as a Phase I effort followed by a Phase II effort in 1999 (Figure F-1). M2P2 is a revolutionary means for spacecraft propulsion that efficiently utilized the energy from space plasmas to accelerate payloads to much higher speeds than can be attained by present chemical oxidizing propulsion systems.[1,2] The system utilized an innovative configuration of existing technology based on well-established principles of plasma physics. It offered the potential of feasibly providing cheap, fast propulsion that could power an Interstellar Probe, as well as powering large payloads that may be required for a crewed mission to Mars.

The M2P2 system utilized low-energy plasma to transport or inflate a magnetic field beyond the typical scale lengths that can be supported by a standard solenoid magnetic field coil. In space, the inflated magnetic field would be used to reflect high-speed (400 to 1000 km/s) solar wind particles, thereby attaining an unprecedented acceleration for a power input of only a few kilowatts. Initial estimates were made for a minimum system that would provide a thrust of about 3 Newton continuous (0.6 MW continuous) power at a specific impulse of 10^4 to 10^5 s, producing an increase in speed of about 30 km/s in a period of 3 months. As part of the NASA Institute for Advanced Concepts (NIAC) Phase I effort, several laboratory-scale models were developed and tested to

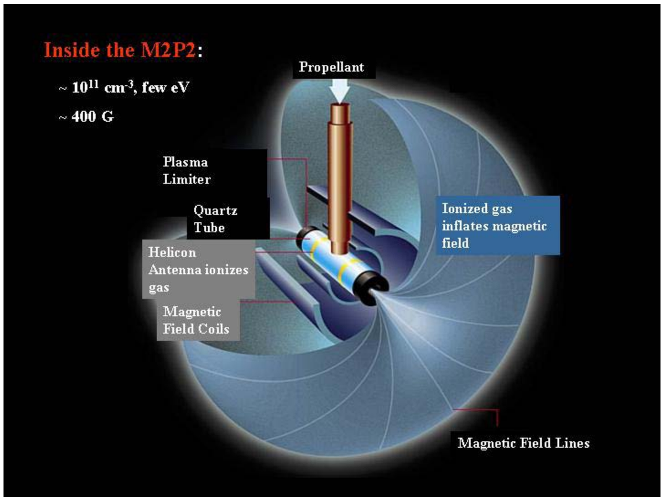

FIGURE F-1 Mini-Magnetospheric Plasma Propulsion concept. SOURCE : Courtesy of Robert M. Winglee, University of Washington.

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[1] R. Winglee, J. Slough, T. Ziemba, and A. Goodson, Mini-magnetospheric plasma propulsion: Tapping the energy of the solar wind for spacecraft propulsion, *Journal of Geophysical Research* 105(20):833, 2000.

[2] R.M. Winglee, J. Slough, T. Ziemba, and A. Goodson, Mini-magnetospheric plasma propulsion: High speed propulsion sailing the solar wind, p. 962 in *2000 Space Technology and Applications International Forum,* M.S. El-Genk, ed. CP504. American Institute of Physics, College Park, Md., 2000.

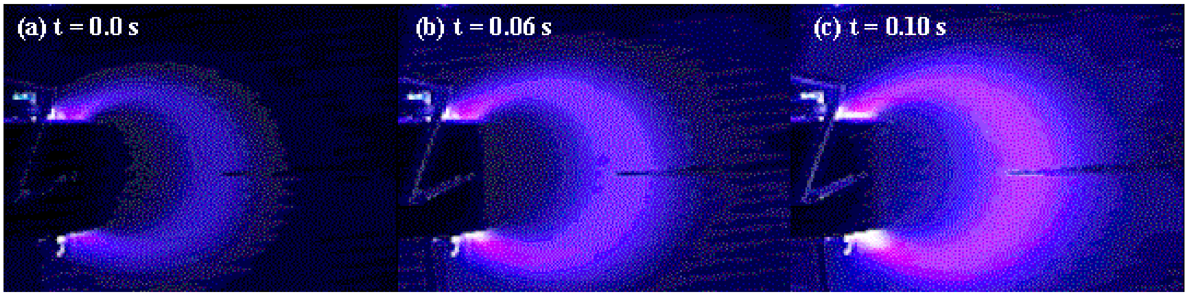

FIGURE F-2 Optical emissions from an injected neutral puff into the plasma. SOURCE: Courtesy of Robert M. Winglee, University of Washington.

improve understanding of the proposed magnetic inflation process and to confirm models of the effect.[3,4] These tests included that measurements of the plasma parameters at the helicon source and at the magnetic equator and perturbations in the magnetic field caused by plasma injection along dipole field lines. The tests demonstrated plasma confinement by the M2P2 followed classical linear scaling up to the point where wall effects became important, and the tests demonstrated plasma inflation. This finding was instrumental in leading to NASA evaluation and testing in a much larger chamber.

The Phase I effort developed extensive models for the effect. This modeling was based on the fluid equations for plasmas, but the equations for conservation of mass and energy were combined in a multifluid treatment. This is more complex than traditional MHD modeling, which combines the equations into a single-fluid treatment. The multifluid approach required that the dynamics of the electrons and the different ions species be kept separate. The modeling was detailed and led to the amount of solar wind deflection with dipole tilt and the total force imparted onto the M2P2. On the basis of these detailed calculations and the development of a laboratory prototype, a Phase II award was made.

As part of the NIAC Phase II project, a simulation model[5,6] was developed where the magnetic field was represented by either a point dipole or a finite width solenoid and studies were performed to resolve processes occurring in close proximity to the magnet. The modeling was complicated by the physics of wall interactions, observed in the test program, that cause mirror currents, sputtering, and plasma sheaths. These effects were not incorporated into the model due to computational limitations. Despite those limitations, both the modeling and the tests in a 1-m-diameter chamber gave evidence that the M2P2 prototype had proven transport of magnetic flux. Figure F-2 shows quenching of the plasma initially followed by expansion of the closed field lines. The emission extends both downward and further into the chamber as the models predict.

These initial NIAC Phase II tests led to further testing at MSFC in an 18 ft x 32 ft vertical vacuum chamber and used a plasma source from the SEPAC program for comparisons with the M2P2

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[3] R.M. Winglee, T. Ziemba, J. Slough, P. Euripides, and D. Gallagher, Laboratory testing of Mini-Magnetospheric Plasma Propulsion prototype, p. 407 in *2001 Space Technology and Applications International Forum*, M.S. El-Genk, ed., CP552, American Institute of Physics, College Park, Md., 2001.

[4] T. Ziemba, R.M. Winglee, and P. Euripides, Parameterization of the laboratory performance of the Mini-Magnetospheric Plasma Propulsion (M2P2) prototype, 27th International Electric Propulsion Conference, October 15-19, 2001.

[5] R. Winglee, T. Ziemba, P. Euripides, and J. Slough, Computer modeling of the laboratory testing of Mini-Magnetospheric Plasma Propulsion (M2P2), *International Electric Propulsion Conference Proceedings*, October 14-19, 2001.

[6] R. Winglee, T. Ziemba, P. Euripides, and J. Slough, Computer modeling of the laboratory testing of Mini-Magnetospheric Plasma Propulsion (M2P2), *International Electric Propulsion Conference Proceedings*, October 14-19, 2001.

helicon source.[7] Figure F-3 shows density contours when the SEPAC is operated by itself and when the M2P2 operates in conjunction with SEPAC. The plasma plume is substantially thickened both horizontally as well as vertically. Most surprisingly, the plasma plume is affected all the way in to close proximity of the plasma source. Modeling confirmed that this deflection of the external plasma is associated with the inflation of the mini-magnetosphere.

Additional tests and modeling confirmed that M2P2 led to expansion of the magnetic field to several tens of magnetic radii. The tests also showed the existence of a plasma depletion layer between the SEPAC and M2P2 plasmas. This gap is analogous to the magnetopause of Earth where there is deflection of solar wind by the terrestrial magnetosphere. Its persistence in the experiment indicates that the mini-magnetosphere is stable over long periods. Other data confirmed that the plasma within the mini-magnetosphere was well confined and that continued plasma production leads to an increasing buildup of the mini-magnetosphere.

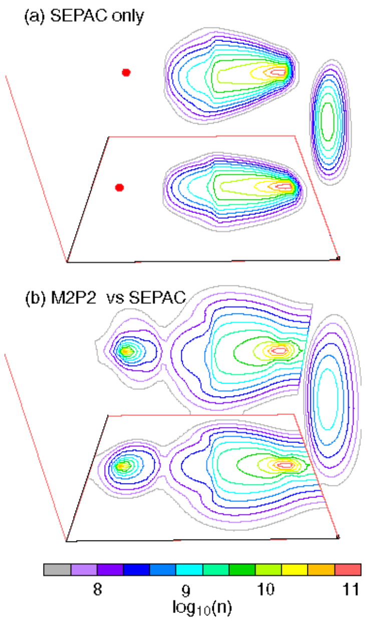

FIGURE F-3 Density contours showing inflation with the M2P2. SOURCE: Courtesy of Robert M. Winglee, University of Washington.

These experiments were able to quantify the performance of the prototype through comparative studies of the laboratory test results with the simulation results. The results showed that the transport of flux within the mini-magnetosphere had a very distinctive signature, where the flux inside the magnetosphere declined and the flux outside the initial closed region of the vacuum dipole increased. As flux was transported outward, both the simulations and the observations showed a pileup of the terrestrial magnetic field. The perturbations observed were small at only ~1 G, but this change in magnetic field was sufficient to drive the field lines into the walls of the laboratory chambers that are available. In addition, both the simulations and the experimental results showed that this same type of magnetic field perturbation was able to deflect plasma at large distances and produce observable effects all the way into the throat of an external plasma source. These results were all strong indicators that the inflation of a mini-magnetosphere was achieved and that the closed magnetic field geometry of M2P2 provides an efficient means for deflecting external plasma winds at much greater distances than could be accomplished by a magnet alone. Inflation and deflection are the key tenants of the M2P2 system, and the experimental confirmation of the simulation results in the laboratory provided strong evidence that the high thrust levels (1-3 N) reported in the original description should be achievable for low energy input (~500 kW) and low propellant consumption (<1 kg/day). Further testing to measure the thrust levels attainable by the prototype, however, did not confirm measurable thrust.

In the 2001 to 2002 time frame, the M2P2 concept was considered as a viable, emerging technology by the NASA Decadal Planning Team and the NASA Exploration Team. Within NASA, these teams were created to generate and assess innovative concepts for NASA senior leadership that allowed new approaches to human and robotic space exploration. Specifically, these teams were chartered to develop options that could achieve major scientific goals over the subsequent 20 years using advanced technologies and could take advantage of the capabilities that astronauts made available on site. External to NIAC, the M2P2 was funded by various NASA organizations to continue experiments confirming computer models as noted above. Continued development of a high-powered helicon component and collaboration between the JSC VASIMR program and the M2P2 program was

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[7] R.M. Winglee, T. Ziemba, J. Slough, P. Euripides, D. Gallagher, P. Craven, W. Tomlinson, J. Cravens, and J. Burch, Large scale laboratory testing of Mini-Magnetospheric Plasma Propulsion (M2P2)—Enabling technology for planetary exploration, *12th Annual Advanced Space Propulsion Workshop Proceedings,* April 3-5, 2001.

established. Through peer review, the M2P2 effort was deemed highly innovative and technically competent. This research effort created considerable interest within and external to NASA. The NIAC Phase II implementation was professional and the M2P2 team was focused on demonstrating the feasibility of this advanced concept to NASA. In 2002, a review panel that included plasma experts concluded there were additional unresolved technical issues that centered around magnet field strengths, mass, and power requirements. While partially addressed by the M2P2 team,[8] this work came to a stop due to changing priorities within the agency.

MICRO-ARCSECOND X-RAY IMAGING MISSION

Project of Webster Cash, University of Colorado, Boulder

In 1999, University of Colorado Professor Webster Cash was awarded a NIAC Phase I award for his proposal entitled “X-Ray Interferometry: Ultimate Astronomical Imaging.” The proposed concept was for an array of grazing-incidence x-ray mirrors on free-flying spacecraft, coordinated to focus the x rays on a set of beam-combining and detector spacecraft. The Phase I work validated the basic concept and suggested a method to test the predicted performance in the laboratory. Initial tests of a prototype x-ray interferometer were performed with additional NASA support at the Marshall Space Flight Center and demonstrated an angular resolution of 100 milli-arcseconds, a factor-of-5 improvement over the best previous results. In 2000 Cash’s “X-ray Interferometry” proposal was selected by NIAC for Phase II funding. Cash and his colleagues published their x-ray interferometry test results in a September 2000, issue of *Nature*.[9] Also that year NASA incorporated this concept into its strategic plans. Dubbed MAXIM, the Micro Arcsecond X-ray Imaging Mission, this concept appeared in the National Research Council’s (NRC’s) Decadal Review of Astronomy and Astrophysics released in 2000,[10] which identified x-ray interferometry for $60 million in funding over the following 10 years.

The technique of interferometric imaging, combining light from a dispersed array of collector optics onto a single focal plane (see Figure F-4), has been exploited at RF wavelengths (e.g., the Very Large Array and Very Long Baseline Array for radio astronomy) and is being implemented for optical telescopes (e.g., the European Southern Observatory Very Large Telescope). Properly implemented, the technique yields angular resolution inversely proportional to the distance between the collectors, so that extremely high resolution can be obtained by placing the collectors very far apart.

Cash’s NIAC Phase II x-ray interferometry proposal was an extension of this concept to x-ray wavelengths. By choosing extremely bright x-ray objects to image, he identified an ideal combination of subject and scientific motivation: to image the event horizon of a black hole. The technical credibility of the concept was clear, but the technical implementation remains extremely challenging, in part because of the difficulty of maintaining path length control to a small fraction of the very small x-ray wavelength. However, the fact that the laboratory demonstration of this capability was published in *Nature* testifies to the significance of this accomplishment.

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[8] R.M. Winglee, P. Euripides, T. Ziemba, J. Slough, and L. Giersch, Simulation of Mini-Magnetospheric Plasma Production (M2P2) interacting with an external plasma wind, AIAA Paper No. 2003-5224, July 2003.

[9] W. Cash, A. Shipley, S. Osterman, and M. Joy, Laboratory detection of x-ray fringes with a grazing-incidence interferometer, *Nature* 407:160-162, doi:10.1038/35025009Letter.

[10] National Research Council, *Astronomy and Astrophysics in the New Millennium*, National Academy Press, Washington, D.C., 2001.

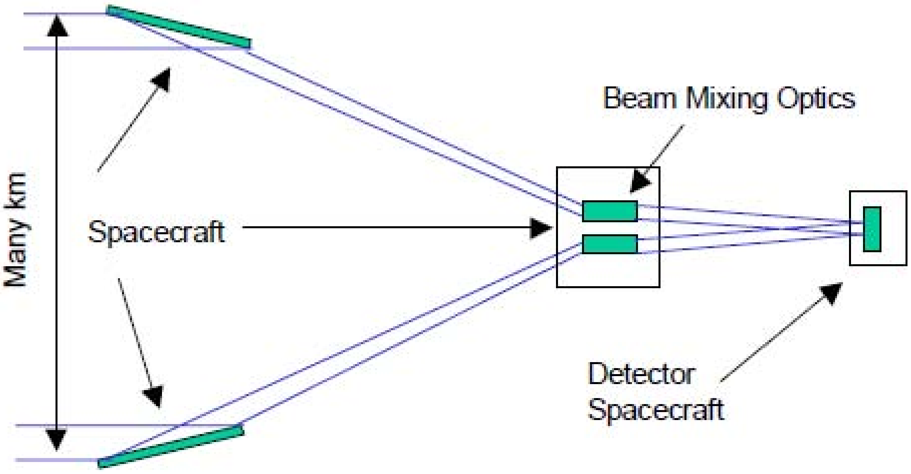

FIGURE F-4 The x-ray interferometry imaging mission concept successfully proposed in 1999 by Webster Cash for a Phase I NIAC study. SOURCE: NASA Institute for Advanced Concepts, *Annual Report* (2nd; 1999-2000), Atlanta, Ga., 2000, p. 23. Courtesy of Webster Cash, University of Colorado.

FIGURE F-5 The x-ray interferometry approach to imaging the event horizon of a black hole is one of the methods being pursued by NASA for its Black Hole Imager mission. SOURCE: NASA Institute for Advanced Concepts, *5th Annual Report* (2002-2003), Atlanta, Ga., 2003, p. 7. Courtesy of Webster Cash, University of Colorado.

NASA has continued support to further define and develop high-resolution x-ray imaging missions, and Cash's interferometry concept has remained among the leading contenders.[11] The MAXIM Pathfinder mission was the subject of a NASA-supported "Integrated Mission Design Center" study in 2002. In 2004, MAXIM was selected as one of the NASA Vision Mission studies for advanced definition. Today, the technology of x-ray interferometry that was the subject of the initial NIAC study is the first (see Figure F-5) of three competing methods that NASA is pursuing under its Black Hole Imager (BHI) mission. The BHI team presented a white paper to the NRC's Astro2010: The Astronomy and Astrophysics Decadal Survey of the NRC and expects the BHI to be identified as one of the compelling astrophysics missions for NASA to pursue in the near future.

NEW WORLDS OBSERVER

Project of Webster Cash, University of Colorado, Boulder

In 2004 University of Colorado Professor Webster Cash submitted a proposal for a NIAC Phase I study of a concept called the New Worlds Imager (Figure F-6); its objective was to study a variety of pinhole camera and occulting mask designs to enable imaging of planetary systems around other stars. As documented in the final Phase I study report, dated March 31, 2005, Cash and his collaborators realized that occulting masks had significant performance advantages, and they identified an occulter design that could meet the contrast requirements of the exoplanet exploration missions under active consideration by NASA as the Terrestrial Planet Finder and by ESA as Darwin.

The basic concept is an occulting mask (to first order, an opaque disk) with an edge shaped like petals of a flower (see Figure F-5), but precisely designed to cancel the diffraction effects that famously result in a local intensity maximum along the axis of the occulter at the center of the expected shadow, the Arago Spot.

Following the completion of the Phase I effort, in May 2005, NIAC selected a proposal for Phase II, now called the New Worlds Imager. The ultimate implementation envisioned was for a five-spacecraft constellation consisting of two sets of starshade and telescope combinations, plus a fifth spacecraft carrying a beam combiner/interferometer. This NIAC-funded work was described in an article featured on the cover of the July 6, 2006, issue of *Nature*.[12] During Phase II, Cash and his collaborators demonstrated suppression performance $<10^{-7}$ in a laboratory test of a miniature, 16-petal occulter. Both the *Nature* publication and the laboratory demonstration testify to the significance and technical competence of the basic concept and the research supported by NIAC.

With the completion of the NIAC Phase II study, NASA has provided significant additional support for Cash's occulter concept, and it is now one of the competitive concepts for the Terrestrial Planet Finder program. In addition, both Ball Aerospace Corporation and Northrop Grumman Corporation have made internal investments to further develop the concept in conjunction with Cash and the rest of his team. According to NIAC, "In February 2006, NASA/GSFC [Goddard Space Flight Center] announced its intent to issue a sole-source request for proposal to Northrop Grumman Corp. and Ball Aerospace Corp. for the further development of the New Worlds Imager (NWI)."[13] NASA/GSFC continues to support this concept with funding. More than 40 papers have been published between 2004 and 2008 by Cash and his colleagues on this technique and its applications.

In February 2008, NASA announced that a team led by Cash had been awarded $1 million for the New Worlds Observer as one of its Astrophysics Strategic Missions Concept Studies (ASMCS). The

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[11] See http://maxim.gsfc.nasa.gov.

[12] W. Cash, Detection of Earth-like planets around nearby stars using a petal-shaped occulter, *Nature* 442:6, 2006.

[13] NASA Institute for Advanced Concepts, *Annual Report* (8th; 2005-2006), Atlanta, Ga., 2006, p. 23.

FIGURE F-6 An artist's rendering of the New Worlds Observer concept for imaging a distant planetary system. Light from the central star is blocked by a large external occulting disk that is shaped to control diffraction of the starlight around the occulter. A telescope placed in the right location can image the surrounding planetary system without glare from the central star. SOURCE: Webster Cash, *The New Worlds Imager, Final Report to the NASA Institute for Advanced Concepts for Phase I Study,* NIAC Phase I study report, 2005. Courtesy of Webster Cash, University of Colorado.

study now has been completed and the final report is available.[14] The results of this study will be used to prepare the New Worlds Observer mission concept for the NRC's Astronomy and Astrophysics Decadal Survey. In conjunction with the ASMCS study, NASA convened a Technical Assessment Review (TAR) panel for the New Worlds Observer mission concept. The NASA TAR report is part of the ASMCS document package. The TAR recommendations are being used to motivate further NASA investment and to prepare the technologies necessary for a successful New Worlds Observer mission.

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[14] Webster Cash, principal investigator, *Final Report, Astrophysics Strategic Mission Concept Study, The New Worlds Observer,* April 24, 2009.

G

The DARPA Model for Advanced Concepts Development

The most frequently referenced model of success for advanced concept development is the Defense Advanced Research Projects Agency (DARPA). DARPA is the central research and development organization for the U.S. Department of Defense (DOD). DARPA's mission is to maintain the technological superiority of the U.S. military and prevent technological surprise from harming our national security. DARPA is not tied to a particular operational mission. Near-term needs and requirements generally drive the Services to focus on those needs at the expense of longer-term changes. Consequently, a large organization like DOD needs a place like DARPA whose *only* charter is radical innovation.

DARPA's approach is to imagine what capabilities a *future* military commander might need and accelerate those capabilities into being through technology demonstrations. Since the very beginning, DARPA has been the place for people with ideas too far out and too risky for most development organizations.

DARPA's business processes reflect its singular focus on radical innovation for national security in a straightforward way: bring in expert, entrepreneurial program managers; empower them; protect them from red tape; and quickly make decisions about starting, continuing, or stopping research projects. The time horizon for DARPA programs is heavily driven by its staffing philosophy. Program managers must possess technical excellence, as well as management and leadership skills, and are selected for their entrepreneurial ideas and program vision. Program managers have intentionally short tenures (4-6 years typically), which ensure that they return to the mainstream as transition advocates and champions of their programs. Another unique feature of DARPA is that the agency has very limited overhead and no laboratories or facilities.

DARPA invests about 97 percent of its funds at organizations outside DARPA. It funds researchers in industry, universities, government laboratories, and elsewhere to conduct high-risk, high-reward research and development projects that span basic, fundamental scientific investigations to full-scale prototypes of military systems. DARPA programs usually start as seedling studies in response to a Broad Agency Announcement for new ideas and concepts that fit the mission and objectives and that will lead to larger, focused programs in the future. If the seedling phase is successful, then a solicitation is formally issued for development and demonstration, with funding levels to hundreds of millions of dollars for full system prototypes.

When a DARPA research program is completed, the technology is available to the Military Services and defense contractors for use in military systems. Getting DARPA's scientific and technological achievements into the hands of the users is an exceptional challenge, because its focus is on high-risk, revolutionary technologies and systems, which may have no clear home in a Service, are Joint, or threaten to displace current equipment or doctrine. DARPA has several strategies to assist with technology transition. For example, to build potential Service customers for DARPA technology, DARPA deliberately engages a Service organization to serve as DARPA's agent, signing the contracts with the research performers and monitoring the day-to-day technical work. This investment creates a cadre of technical champions inside a Service who are familiar with a DARPA technology, who can vouch for it, and who can shepherd it into a Service acquisition program. DARPA tries to ensure transition of system prototypes by negotiating a memorandum of agreement (MOA) with the Service adopting the system. In general, for its Advanced Technology Development programs, DARPA requires that an MOA or a transition strategy be negotiated with a Service at some predetermined point during its development in order to proceed to its later stages. DARPA also makes use of an extensive network of transition liaisons to ensure successful technology transition to services:

- *Special Assistant for Technology Transition*—A permanent full-time person assigned to the Director's Office and focused on promoting technology transition.
- *Operational Liaisons*—Personnel from each military Service assigned to the Director's Office to maintain DARPA's connection to real-life problems while helping transition DAPRA technology to the Services. Operational liaisons are usually very senior both in rank and in experience, come with a great set of contacts, and help reinforce the day-to-day links between DARPA's research programs and the needs and opportunities of the DOD special assistant to the director for technology transition.
- *Service Chiefs Program*—Interns from the Services who rotate through DARPA on a 2- to 3-month basis for in-depth looks at DARPA programs. As these young officers progress through their careers, their exposure to DARPA at an early stage should make them more receptive to new technology and its potential value for U.S. national security.
- *United States Special Operations Command liaison*—DARPA representative posted to USSOCOM to maximize the flow of new technology to Special Forces.

Questions posed to or by the Committee to Review the NASA Institute for Advanced Concepts included how the federal government in general and NASA in particular should solicit and infuse advanced concepts into its future systems, and how other similar federal agencies such as DARPA accomplish this task. DARPA is the primary focus of this appendix, but the military departments in the DOD are also included.

First, it is important to understand that DARPA is not monolithic in terms of how it solicits and selects projects nor in how the results of its programs are infused or transitioned so that the those results benefit the Military Services and other organizations in DOD.

DARPA comprises five independent offices: two system offices, two technology offices, and one that does both. The Defense Sciences Office and the Microsystems Technology Office focus on new capabilities and component technologies that might have significant national security applications. The Tactical Technology Office (TTO) and the Strategic Technology Office are system offices focused on solutions to military problems and technology programs leading to specific military advanced concepts and products, such as strike aircraft. The Information Processing Techniques Office covers the continuum from research to prototyping of military systems.

The activity and budget categories of these offices include 6.1, Basic Research; 6.2, Exploratory Research; and 6.3, Advanced Development. Each office has a well-defined mission set, goals, strategy, and programmatic thrusts. An example—for the TTO—follows:

- Mission

  —High-risk, high-payoff advanced technology development of military systems, emphasizing the "system" and "subsystem" approach to the development of aerospace systems and tactical multipliers.

- Goals

  —Highly capable systems that enable "order-of-magnitude" improvement in military capabilities.
  —Avoidance technological surprise in areas of TTO emphasis.
  —Efficient management and transition existing programs.

- Strategy

—Understand and address *critical deficiencies* in *crucial mission areas.*

—Develop, demonstrate, and *transition* advanced technologies and concepts for effective, survivable, and affordable military systems.

—Institute modern materials, design, and manufacturing techniques that enable *low-cost production* of military systems.

- Thrust Areas

—Directed Energy Systems
—Precision Strike
—Space Operations
—Uncrewed Systems
—Air/Space/Land/Sea Platforms

Now 50 years after it was established, DARPA has changed significantly. The constants in the DARPA programs are the continuing focus on major challenges with high payoff to military capability, and the focus on transition of programs and technologies to the military departments so that the improved capability can be fielded as soon as possible.

In its early period DARPA was assigned single, major missions by the President or the Secretary of Defense. The first mission was space, and that was later transferred to NASA and the Air Force. The second was ballistic missile defense, which was executed and culminated in large-scale demonstrations and test. The program was transferred to the Army and became the Army Ballistic Missile Defense Agency. After that DARPA took on multiple missions and became more diversified in its goals and program activities.

While DARPA does not develop systems ready for production, it does develop prototypes and carry out major system-level demonstrations, normally in a four-phase program. DARPA seeks to *transfer* or *transition* programs and concepts to the military departments or other DOD agencies for system development by a Program Executive Office or a Program Management Office that requires a technology readiness level of 6 or more. DARPA takes responsibility for the failure of a program if transition does not occur.

The DARPA TTO and NIAC advanced concept development programs are not comparable. Funding for advanced technology programs at DARPA TTO is two to three orders of magnitude higher than it was at NIAC. A more reasonable comparison would be to compare NIAC to Small Business Innovation Research (SBIR) programs or “seed” projects sponsored by the DARPA system offices, but even there, transition is planned for in Phase 3 of an SBIR project.

Over the decades DARPA has evolved some proven processes for transitioning its programs:

- Maintain highly qualified staff with direct technical management of all programs.
- Maintain a continuing relationship with operational forces to ensure understanding of military needs and requirements.
- Stay abreast of technical intelligence on adversary capabilities.
- Develop a well-prepared plan for transition early in the technology program.
- Set up teaming arrangements with the military organization; make it a joint effort where possible.
- Sustain adequate funding to provide for successful demonstration of sufficient technical maturity.
- Establish the need for the technology by showing where it will enhance mission accomplishment.
- Recognize “windows of opportunity” where technology can be inserted into military systems.

The DARPA processes for establishing programs and solicitation of proposals include:

- Assignment by SECDEF or USD AT&L;
- Ideas for new programs from DARPA staff, SETA contractors, advisory boards, unsolicited proposals, and white papers;
- Solicitations conducted through broad agency announcement, request for proposal, request for information, and sources sought;
- A standing BAA at each DARPA Office is updated annually;
- New programs usually starting as “seedlings” at a low funding level;
- Following success in the seedling phase, formal solicitation issued for development and demonstration;
- Solicitation and awards that can be executed by DARPA, a military department command, a project management office or laboratory, or another federal agency; and
- Award instruments that include grants, cooperative agreements, procurement contracts, technology investment agreements, and other transaction-for-prototype agreements.

Criteria for investment in a new program have varied over time, but one set of guidelines still in use in parts of DARPA are those developed by a previous director, George Heilmeier:

- What are you trying to do?
- How is it done today?
- What is new in your approach?
- If you are successful, what difference will it make?
- What are the risks and payoffs?
- How much will it cost? How long will it take?
- What are the midterm and final “exams” to check for success?

The time window of interest is a huge difference between DARPA programs and NIAC programs. NIAC’s objective was advanced concepts of interest between 10 and 40 years in the future. At DARPA the term for programs is 3 to 10 years with a few exceptions. Programs are normally finished and transitioned by then or they are terminated for one of the following reasons:

- Failed mid-term exam;
- Cost, schedule, and technical problems;
- Champion(s) left; or
- Transition prospects low.

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Definition of Technology Readiness Levels

Definitions of technology readiness levels (TRLs) from NASA's *Definition of Technology Readiness Levels* are given below.[1]

TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of-concept: Proof-of-concept validation. Active research and development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

TRL 4 Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.

TRL 5 System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.

TRL 6 System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space): Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.

TRL 7 System prototyping demonstration in an operational environment (ground or space): System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.

TRL 8 Actual system completed and "mission qualified" through test and demonstration in an operational environment (ground or space): End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and

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[1] National Aeronautics and Space Administration, *Definition of Technology Readiness Levels*, Washington, D.C., 2005. Available at http://esto.nasa.gov/files/TRL_definitions.pdf.

maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.

TRL 9 Actual system "mission proven" through successful mission operations (ground or space): Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.